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POTENTIAL MEANS OF COST REDUCTION IN GRADE CROSSING AUTOMATIC GATE SYSTEMS

Volume II: Improved Gate Arm Concepts for Railroad/Highway Grade Crossings

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16. Abstract

This report, Volume II of a two-volume study, examines the potential for reduction of the cost of installing and maintaining automatic gates at railroad-highway grade crossings. It includes a review of current practices, equipment, and standards; consideration of modification of existing specifications to permit use of alternative technologies: generation of design concepts for new gate systems or subsystems intended to offer significant economic benefits; analysis and comparative evaluation of the more promising concepts; and conclusions concerning further design, development, and test activities. Concepts found to be particularly promising include a pneumatic gate-drive mechanism and a swing-away, gravity-resetting arm support intended to reduce the incidence of gate breakage; and a gate arm utilizing new materials to obtain resistance to breakage.

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PREFACE

The work described in this report was carried out under the direction of the Transportation Systems Center to provide a technical basis for improvement of railroad-highway grade crossing safety. The program was sponsored by the Federal Railroad Administration, Office of Research and Development.

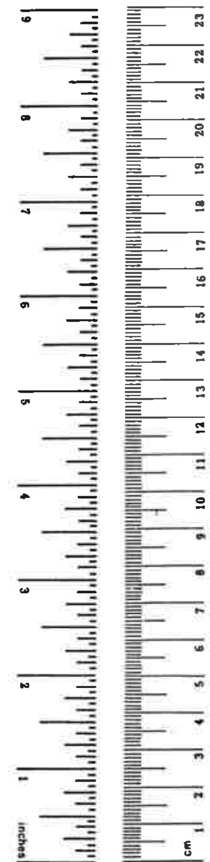
The overall project was based upon two contractor studies, one of which is reported here; the other, accompanied by an overview prepared by TSC, can be found in Volume I of this report.

Appreciation is expressed to the many individuals, both in government and industry who have contributed in great measure to the program effort.

METRIC CONVERSION FACTORS

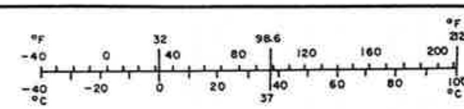
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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LIST OF ILLUSTRATIONS

ABBREVIATIONS

AAR	Association of American Railroads
AASHTO	American Association of State Highway Officials
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
MUTCD	Manual on Uniform Traffic Control Devices
RS&I	Rules, Standards, and Instructions for Railroad Signal Systems

EXECUTIVE SUMMARY

The purpose of this study was to synthesize new concepts for automatic gate systems, used at railroad grade crossings, which have the effect of lowering total costs. The specific goal was to achieve a cost reduction potential of at least 30% when compared to the total costs for the present gate systems.

The automatic gate system components which were specifically addressed in this study were the gate arm and the drive mechanism which raises and lowers the gate arm. Train detection, the control logic, and the flashing lights have not specifically been a part of this study although due to their relation to the gate mechanism they have been touched upon in a cursory manner.

Existing Grade Crossing Barrier Specification

A survey of all the agencies which determine the existing specifications for automatic gate systems resulted in the conclusion that all specifications are based largely upon the specifications set forth in the AAR Signal Manual. The most useful information is found in the Signal Manual Part 194 and in the AAR Bulletin No. 7, Railroad-Highway Grade Crossing Warning Systems - Recommended Practices.

Changes to the Existing Specifications

Two areas of the existing specifications were investigated with regard to possible changes which may result in a cost savings. First was the requirements that all electrical apparatuses in the signal system must have 3,000 volt insulation. The second area investigated was the present maintenance procedures outlined in the AAR Signal Manual Part 150.

The 3,000 volt insulation requirement is a consequence of the type of surge suppression devices that are currently employed to protect the electrical equipment from power surges. These surges are due mainly to lightning. Since most industrial type equipment is not available with 3,000 volt insulation, all the electrical equipment is specially manufactured at higher costs. It is felt that if economical and highly reliable surge protectors could be developed to protect railroad signal systems, this 3,000 volt insulation requirement could be lowered so as to effect a cost savings.

The maintenance requirements in Part 150 were found to be somewhat vague. Although this vagueness may be partially deliberate so as to allow railroads to determine their specific maintenance requirements, it may have caused the railroads to place strict and excessive maintenance requirements upon themselves to provide protection in case of liability suits. It is recommended that maintenance procedures be developed that would clearly define what should be inspected and how often that inspection should take place.

New Concepts

Two new concepts are fully delineated in this report. They are the Overhead Hinged Arm and the Rotating Arm.

With the Overhead Hinged Arm design the arm is lowered to the down position from a cantilever over the roadway. It is pneumatically powered and features a compliant arm arrangement which will "swingaway" on impact. The swingaway arm feature should reduce arm breakage costs and possibly result in a lifetime savings of as much as $6,000. The total costs (initial plus recurring costs) were estimated to effect a cost savings of 12% to 22% when compared to the existing gate mechanisms.

The Rotating Arm arrangement also features the use of a pneumatic (optional) drive system and a swingaway arm. However, in this design the mechanism is installed at the side of roadway in a manner that is similar to the present system. The difference lies in the fact that the drive shaft, to which the gate arm is mounted, is installed at angles of 45° to both the vertical and horizontal planes. This arrangement permits the arm to move both up and away from impacting vehicles thereby reducing arm breakages and arm replacement costs. The estimated lifetime cost savings for this concept would range between 30% and 40%. If it is deemed desirable to use overhead flashing lights, mounted on a cantilever, these savings would be about 10% less.

Conclusions

From a technical standpoint, the Rotating Arm, as opposed to the Overhead Hinged Arm, is considered to be the more promising device. It is sturdier, less susceptible to secondary damage due to impacts, and it is easier to install and maintain. Economically, once again it is the Rotating Arm which shows the greatest potential for cost reductions. Therefore, the Rotating Arm is the concept which is recommended to be the subject of further development. A development and testing program will yield more exact estimates for cost and also provide for a better evaluation of the safety and functional reliability of this device under actual operating conditions.

1. INTRODUCTION

Of the nearly 220,000 public grade crossings in the United States, only about 50,000 are protected with active warning devices (i.e., a device which indicates the presence of a train). However, there are only about 9,000 of these crossings which are protected by automatic gates. A number of studies have shown that automatic gates provide the most effective warning so that one might ask why so few crossings have this type of a device. Consideration of this question yields three apparent reasons. First, it has been the custom of the railroads to install flashing lights at single track crossings and flashing lights with automatic gates at multiple track crossings. Since there are more single than multiple track crossings, this policy has resulted in there being a greater number of flashing light crossings. The use of gates at multiple track crossings was, and still is, considered the best method of preventing a "scissors" type accident from occurring. A scissors accident is one in which the motorist has proceeded across the crossing, immediately after the passage of a train, thinking that it is safe but unaware that a second train is approaching on the adjacent tracks from the opposite direction than that of the first train. The use of gates prevents the motorist from proceeding until it is completely safe.

The second reason for fewer automatic gates being installed is due to the somewhat higher cost for automatic gate devices. The average cost for installing gates at a crossing is nearly $35,000. The cost of maintaining these gates for their expected lifetime will equal those initial costs.

The third reason is that the greater effectiveness of automatic gates has been realized only recently and has not yet been universally accepted.

Recently, state and federal governments have been funding up to 90% of the initial costs for installing active protection at crossings. A number of states reimburse the railroads for portions of the maintenance expense, but in most instances it is the railroads who end up paying for most or all of the maintenance. With the financial problems of the railroads continually growing worse, they are heavily burdened by the added expense of maintaining more crossings. On the other hand, the public cannot afford to put up with the risk of inadequately protected grade crossings. There is a legitimate public desire for the best crossing protection available. Governmental agencies, along with the railroads, have the desire and responsibility to achieve that type of crossing protection which results in the greatest cost effectiveness. Gates that cost less to install and maintain, but provide the desired protection of the current gate mechanisms, could greatly increase the use of gates, and reduce costs in cases where gates are already used.

In response to this need, this report will investigate the possibility of synthesizing new or modified concepts that show promise of providing a significant cost reduction. It is hoped that by reducing the installation, original equipment, and/or maintenance costs, more crossings will warrant the expense of automatic gates which, in turn, will lead to fewer grade crossing accidents. This report delineates several concepts which might meet the aforementioned needs. Based on a detailed analysis and preliminary design, the concept showing the greatest promise is recommended for further development.

2. GRADE CROSSING BARRIER SPECIFICATIONS

2.1 Existing Grade Crossing Barrier Specifications

The purpose of this part of the study was to assemble a single, comprehensive specification describing the characteristics on which the current gate mechanisms are based. However, the plurality of agencies which have developed recommended practices for gate mechanisms makes this a difficult task. The Federal Highway Administration (FHWA), the Association of American Railroads (AAR), the Federal Railroad Administration (FRA), state governments, and the railroads themselves, have all developed recommendations or regulations which govern the installation, operation or maintenance of grade crossing barriers. Each agency deals with grade crossings systems in its own particular manner. Any attempt to assemble all the different requisites into a single and coherent specification appears to be nearly impossible. However, after surveying these various agencies, there appears to be mutual agreement that the basis for most requirements is contained in the AAR Signal Manual and the FRA Rules, Standards, and Instructions for Railroad Signal Systems, even though there are no specific requirements for grade crossing signals mentioned in the latter document. Therefore, the starting point for a single specification should be these two documents, along with any pertinent requirements established by any of the other agencies.

2.2 The AAR Signal Manual

The AAR Signal Manual is voluminous. It contains all the recommended requisites or specifications for the installation of all types of railroad signals. It was first issued by the AAR in 1912 with the intent of promoting uniformity in railroad signalling practices. Each year new additions and revisions are made in order to keep it abreast of technological developments.

A large part of the manual deals with the recommended installation practices for railroad-highway grade crossing signals. Nearly every part of the crossing signal is covered by a set of specifications in the manual. In order to make this information more concise and meaningful, the AAR has published another document entitled Railroad-Highway Grade Crossing Warning Systems - Recommended Practices - (BULLETIN NO. 7). It is upon this booklet or its earlier editions that most states and railroads base their guidelines for the installation of grade crossing warning devices.

2.3 The FRA Rules, Standards, and Instructions for Railroad Signal Systems (RS&I)

The RS&I provides uniform signal system regulations, administered by the FRA, to which the railroads must adhere. Although the RS&I does not specifically mention grade crossing signal systems, the common carrier railroads that were surveyed use the RS&I, in addition to the AAR Signal Manual, as a guideline for the installation, inspection, maintenance and repair of grade crossing signal systems. Relevance of the RS&I to grade crossings arises through the interconnection of crossing track circuits with the block signal track circuits. The principles, technology, and importance to safety are the same for both systems. Therefore, it is only reasonable that the railroads should inspect and maintain both signal systems using the same standards.

2.4 Manual on Uniform Traffic Control Devices (MUTCD)

The Manual on Uniform Traffic Control Devices is prepared by the National Advisory Committe on Uniform Traffic Control Devices and adopted by the Federal Highway Administration for use as a national standard on all highways and roads. This manual is referred to in AAR Bulletin No. 7. Its main application to grade crossings is the governing of the placement of advance warning signs near the grade crossing. The MUTCD contains no regulations which govern the installation or maintenance of grade crossing signals.

2.5 State Regulations

Most states also have regulations as to the installation of protective warning devices at grade crossings. The regulations vary from state to state, but generally they all refer to the AAR Bulletin No. 7 or to one of its earlier editions. Three states, Pennsylvania, Florida, and Texas, were contacted to obtain their regulations.

In Pennsylvania, the Public Utility Commission (PUC) determines the regulations which govern the installation of crossing signals. All proposed or existing protection must conform with the standards recommended by the AAR subject to modifications by the PUC.

Florida also installs grade crossing protection systems in compliance with AAR specifications. They have also established procedures for reimbursing 50% of the maintenance costs to the railroads.

Texas, like Florida and Pennsylvania, must approve all new installations. All systems conform to AAR standards. Texas also has a maintenance reimbursement program in which they allocate $100 per year for single track crossings and $150 per year for multiple track crossings.

2.6 Railroad Installation and Maintenance Requirements

Three railroads were visited to determine their installation and maintenance requirements for crossing protection. The summary of the information obtained from these railroads is contained in Table I. Much of the information may be reflective of the opinion of the particular signal engineer interviewed and should therfore only be considered as merely indicative of a general concensus.

TABLE 1

INFORMATION ON THE GRADE CROSSING SIGNAL PRACTICES OF THREE EASTERN RAILROADS

	RAILROAD A	RAILROAD B	RAILROAD C
Installs Own Mechanism	Yes	Yes	Yes
Cost for Automatic Gates (Total)	NA	$25,000-$35,000	$40,000-$50,000
(Installation Costs)[1]	50%	25% to 30%	50%
Competitive Bidding	No	No	Yes
Able to Purchase Prewired Equipment	Yes	No	No
Type of Gate Arm	Aluminum	Aluminum or Fiberglass	Wood
Estimated No. of Crossings Protected by Gates	NA	300	1,000
Gate Arms Broken Per Crossing	Less Than One	.5	.3
Maintenance Costs Per Crossing	½ of Real Total Costs	$750 (1972) Per Year	$1,700 Per Year
Man-Hours/Month for Maintaining Each Crossing	Approximately 8	Approximately 4	Approximately 4
Frequency of Inspection	One Per Week	One Per Month	One Per Week
Lightning a Serious Problem	Yes	Yes	Yes
Vandalism a Significant Problem	Yes	Yes	Yes

Legend:

NA - Not Available

[1] Installation costs refer to all those initial costs not included in the cost of the original equipment.

2.7 Industry Grade Crossing Barrier Specifications

Information concerning automatic gates was received from three of the five leading manufacturers of railroad signal equipment. It was learned that all systems manufactured by all five are in compliance with AAR standards and therefore most of the systems are designed and operated very similarly.

2.8 The Functional, Electrical, Mechanical and Environmental Characteristics of the Present Gate Mechanism

The purpose of Task I is assembly of a single, coherent specification for grade crossing signal systems. Investigation of the roles of the various agencies have shown that the only body of information upon which all the different agencies base their regulations is the AAR Signal Manual. However, the RS&I is used by railroads to govern maintenance procedures and therefore should also be taken into account in preparing any specification.

The following specification describes the functional, electrical, mechanical, and environmental characteristics of crossing gates, based primarily upon the AAR Signal Manual and the RS&I as qualified in Paragraph 1.2.

(A) Functional Characteristics

The purpose of using flashing signals at a grade crossing is to adequately warn the approaching motorist of the presence of a train at or near the crossing. The gate arm serves to enhance the warning by placing a clearly visible barrier horizontally across the highway. It cannot physically restrain a motor vehicle from proceeding over the crossing when the system is activated. The automatic gate arm is most often used at crossings with multiple tracks where there is a possibility that multiple train movements may occur simultaneously. Multiple train movements present the hazard of an occurrence of a scissors accident which has been described earlier in this report. They are increasingly being used at single track crossings to obtain the superior protection afforded by gates.

List of functional characteristics:

1. The gate, when in the raised position, shall not interfere with traffic.

2. The gate must operate in conjunction with the crossing signal. The light at the tip of the gate arm shall burn steadily when the signal is activated with the other two lights on the arm flashing alternately in unison with the signal lights.

3. The gate must begin its descent not less than 3 seconds after the signal lights have been activated.

4. The gate arm shall reach the horizontal position before any train reaches the crossing. It shall remain in the horizontal position until the last car of the train has cleared the crossing.

5. In the event of failure to any part of the warning system, the hold clear device will release allowing the gate arm to descend by gravity to the horizontal position.

6. The gate shall descend smoothly from the clear to the horizontal position in 10 to 15 seconds.

7. The gate arm shall complete all movements smoothly and evenly without rebounding. It shall be securely held in the clear position until the gate is required to lower.

8. The arm shall promptly reverse its direction to reflect any changes in track occupancy.

9. The gate arm will stop when it strikes an object and upon removal of the object it will assume a position in correspondence with the control apparatus.

10. The mechanism shall operate by power to assist gravity in initial movement of the gate arm from the clear position. After initial power assisted movement, the gate arm shall descend by gravity alone to the horizontal position.

11. The gate arm shall clear from the horizontal position in no longer than 12 seconds.

(B) Electrical & Mechanical Characteristics

Due to the many electrical and mechanical specifications contained in the AAR Signal Manual, only a listing of the pertinent manual parts will be presented. The only complete specification for these two areas of the crossing gate is the AAR Signal Manual itself. Therefore, with this in mind, the following is a listing of the parts of the AAR Signal Manual which contain the electrical and mechanical specifications of the present gate mechanisms.

1. Railroad-highway crossing signals shall conform to Figures 4, 5 and 6 of Bulletin No. 7 with variations in design and mounting permissable.

2. Light units on signal shall conform to Signal Manual, Part 166. (See Figure 1)

3. Gate mechanism shall be in accordance with Signal Manual, Part 194. (See Figure 2)

4. Lights on gate arm shall be in accordance with Signal Manual, Part 263.

5. Painting shall be in accordance with Signal Manual, Part 110.

6. The gate may be mounted either on the signal mast or on a separate structure between the track and the signal.

(C) Environmental Characteristics

The following environmental requisites have been taken from AAR Signal Manual, Part 194:

1. Metal parts shall be protected against corrosion except where such protection will interfere with the proper functioning of that part.

2. Material used for protection against corrosion shall neither soften nor flake under atmospheric conditions between temperatures of -40°F and 185°F.

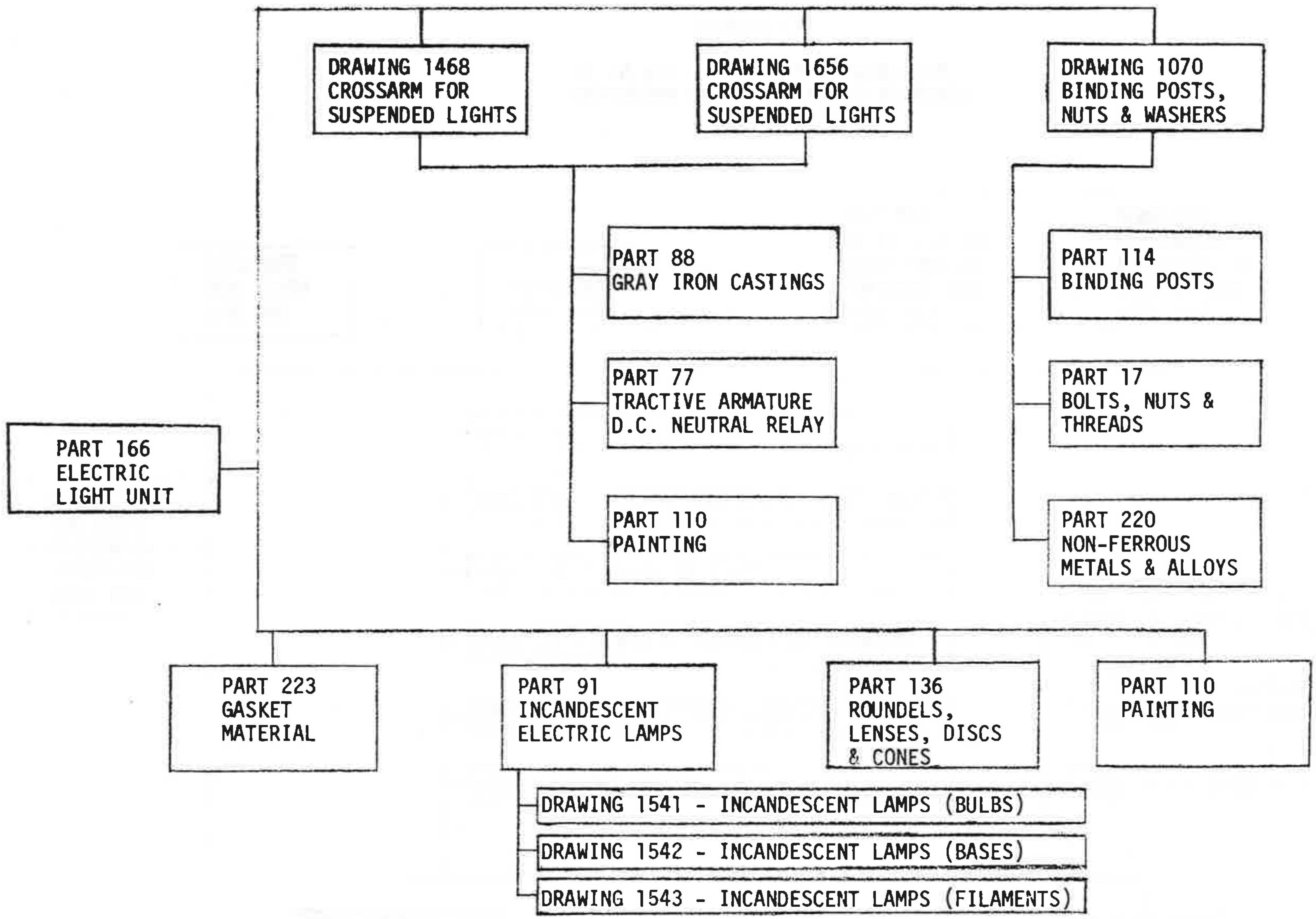
3. Electrical apparatus assembled shall withstand for one minute an insulation test of 3,000 volts ac between all parts of electric circuits and other metallic parts insulated therefrom.

4. At 20°C (68°F), the variation in the resistance of individual coils shall not exceed plus or minus 10%.

5. Coils shall be wound with insulated wire and treated so as not to be injuriously affected by atmospheric conditions or by changes in the temperature between -40°F and 180°F.

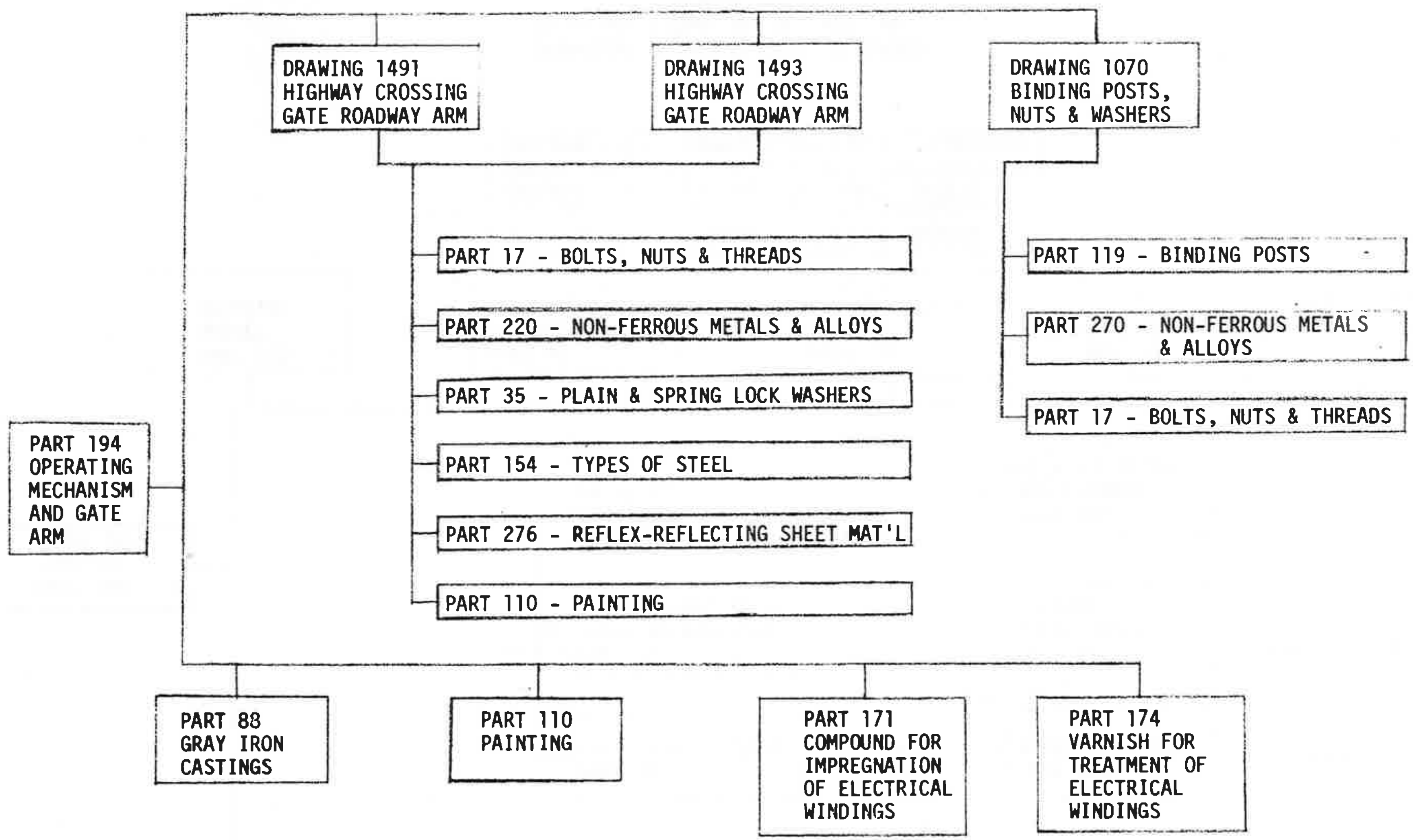
6. Bearing assemblies shall be so constructed as to prevent entrance of water.

7. Mechanism case shall be waterproof.



BREAKDOWN OF MANUAL PARTS REFERRED
TO IN AAR SIGNAL MANUAL PART 166

FIGURE 1 -



BREAKDOWN OF MANUAL PARTS REFERRED TO IN AAR SIGNAL MANUAL PART 194

FIGURE 2

(D) Installation

Installation of crossing signals and devices shall be in accordance with Signal Manual, Part 149 and AAR Bulletin No. 7. Most states set construction priorities even though the actual construction is done by the railroads. On state roads, approval for installing crosssing protection must be obtained from the state. Likewise, when Federal funds are involved, approval of the FHWA is required.

2.9 Existing Specification Summary

It should be noted that the AAR specifications in themselves are not absolute standards--they are merely recommendations. However, after surveying several states, it was found that most states require the installation of crossing protection to conform to AAR standards. Also, all crossing equipment is manufactured according to AAR specifications and likewise the railroads will only purchase AAR approved equipment. Hence, despite the fact that the AAR did not necessarily intend the Signal Manual to become an absolute standard, it has become one through state regulations and industry and railroad practices.

The description of the characteristics of the present crossing gates that has been outlined is general in nature and should not be considered the complete specification. A complete specification would include the applicable sections of the AAR Signal Manual, the RS&I instructions as applied by the railroads, the MUTCD, AAR Bulletin No. 7, and each of the 50 states' specific regulations governing crossing protection. Only a summary of those aspects which were considered to be most important to the grade crossing gate has been presented here.

3. CHANGES TO PRESENT SPECIFICATION

3.1 Introduction

The specifications contained in the AAR Signal Manual outline the maintenance, installation and operational requirements for the entire grade crossing signal system. They do not contain any macroscopic requirements for the overall system. Rather, they aim at the individual components in a specialized manner. To examine each and every specification, of which there are many, would be of doubtful benefit. Any change to the specifications would most likely be a minor change and probably do little to lower the cost of the entire system. It should also be noted that the AAR reviews these specifications annually and often makes revisions and additions. Therefore, only those areas which may significantly affect costs will be examined.

It is recommended that the following requirements be added to the List of Functional Characteristics of the preceeding section. This new list should then be considered the complete specification for gate devices.

1. The entire system shall be protected with surge suppressors which will limit electrical surges to a maximum of 500 volts.

2. All equipment shall be readily servicable.

3. The mechanism shall operate properly within temperature extremes of -40°C to 85°C nor shall it be adversely affected by normal environmental conditions such as rain, wind, sleet or snow.

4. All electrical apparatuses shall be insulated for 600 volts.

5. The driving mechanism shall be designed for minimal power consumption without adversely affecting overall operation.

6. If the mechanism uses 115 VAC commercial power, means must be provided for the storage of emergency power that will allow for normal gate operation for a period of up to 24 hours should this commercial power source be interrupted.

7. Means shall be provided to prevent damage to the mechanism for varying load conditions due to weather when the gate is descending or by the counter-balancing device driving it to the clear position in the event of a broken arm.

8. Installation shall be in accordance with AAR Bulletin No. 7.

Since scheduled maintenance and repair costs represent about 1/2 of the real total costs, this was considered an important area to investigate for possible changes which may result in a cost savings. Another specification which appeared to warrant investigation was the 3,000 volt insulation requirement. Presumably, other areas exist which could be modified so as to effect a reduction in costs, but these savings would be likely to be small and do little to effect an overall savings. This study has thus be limited to two areas which contribute significantly to the costs.

3.2 3,000 Volt Insulation Requirement

Relays, motors and other railroad electrical equipment must meet a 3,000 volt insulation requirement. The reason for this requirement is that lightning often causes large electrical surges to enter the system's circuits which can in turn cause severe damage to all the electrical equipment contained in the system. The 3,000 volt insulation alone is not sufficient protection against these electrical surges. Air gap arrestors are employed as surge suppression devices to protect the electrical equipment.

The basic premise of a gap arrestor is to break down at a certain voltage and to shunt the surge to ground. For railroad equipment, the gap arrestor is usually designed to break down at 1,000 volts or less. Two drawbacks of the gap arrestor are that it is slow and the firing point is high. For these reasons the equipment requires heavy insulation in order to protect it from the high voltage present in the system before the arrestor can fire. For the same reasons, the gap arrestor is not suitable for protecting solid state devices.

Generally, solid state equipment cannot withstand voltages greater than 30 to 300 volts. Unlike conventional relays, which have large inductances and mass that permit them to absorb energy until the surge has subsided, the mass of the solid state device is small so that it only takes a few micro-seconds to destroy it.

To protect sensitive solid state equipment from surges, complex and expensive equipment is needed. In addition to the gap arrestor, other devices such as surge inductors and Zener diodes are used. This results in a faster suppression device which fires at lower voltages.

The use of solid state train detection equipment (most notably the Audio Frequency Overlay) is becoming widespread. Conceivably, all of the present equipment may be eventually replaced by solid state devices. If this is true, the need for the 3,000 volt insulation would certainly seem excessive since the solid state devices would need to be protected by sophisticated surge protection equipment, which would fire sooner and at a much lower voltage than the gap arrestors that are presently being used. Surges present in the system would have to be kept to a minimum before the suppressor shunts the surge to ground.

It appears then, that the need for the 3,000 volt insulation should only continue so long as the present form of surge protection is used. In essence, the degree of insulation needed is determined by the type of surge protection that is used to protect the control equipment. One should not misconstrue this to mean that if sophisticated surge protection were to be installed in all crossing equipment it would result in an overall cost reduction since the insulation requirement could be lowered. On the contrary, solid state surge protection devices are expensive and often failure prone. It may well be that the 3,000 volt insulation used in conjunction with the conventional gap arrestor is both cheaper and less prone to failure than the solid state suppressors. The point is that if solid state equipment is going to replace all of the conventional equipment, by its very nature, it needs extra surge protection. So if one is going to use surge protection that fires rapidly and at a low voltage, there is no apparent need to increase the costs by also requiring 3,000 volt insulation.

It is realized that this does not address the question of whether a 1,500 volt surge standard, in itself, would significantly increase the vulnerability of the motor to lightning damage. This question cannot be confidently answered with the data now available. Only if several test installations, equipped with motors insulated for 1,500 volts, were to be put into service for several years, would there be sufficient data with which to make a judgment. However, due to the motor's large mass and inductance, it is qualitatively reasoned that, motors insulated for 1,500 volts should be able to withstand most electrical surges.

Since a detailed investigation of the electrical components of the signal system was not an intended part of this study, the benefit of using a completely solid state signal system which has expensive surge protection, as opposed to the conventional equipment, cannot be easily determined. The problem of insulation is dependent upon the nature of the equipment which is used. Therefore, any recommended changes to the 3,000 volt insulation requirement should be part of a detailed study investigating the benefits of using a 100% solid state control system. Presently, however, there appears to be no justification for lowering the insulation requirement so long as conventional control circuitry is being employed.

3.3 Maintenance and Test Requirements

The recommended practice for the maintenance of automatic highway grade crossing protective systems is set forth in AAR Signal Manual, Part 150. Part 150 outlines all the recommended maintenance and tests for all parts of the system. One possible shortcoming is that it makes no reference as to how often these tests should be made, or how they should be made. Most statements are vague. For example:

> "In case of severe storm, inspection, as instructed, must be made as soon as possible, to insure equipment is functioning as intended."[1]

The phrase "as instructed" has significant importance. According to a footnote in Part 150, "as instructed" refers to the individual railroad instructions. This phrase is used in almost every section of Part 150. It is understood that due to the varying conditions under which the crossing signals must operate, the needed maintenance for those signals may vary from one installation to another. However, a specification that is overly vague may lead to misunderstandings and irregular practices. As Part 150 now reads, the railroads are left free to determine how often and in what manner the signals must be inspected. It is possible that in some instances this has resulted in over-maintenance rather than under-maintenance. In a possible effort to protect themselves in legal battles, the railroads may have unnecessarily burdened themselves with excessive and costly maintenance procedures.

What appears to be needed is a complete, more rigorous, and specific determination of inspection and maintenance requirements for grade crossing signals. Part 150, as it now reads, allows for varying interpretations which has forced the railroads to place strict and possibly excessive maintenance requirements upon themselves. The AAR Signal Manual, Part 150, should be amended to include more exact standards with regard to frequency of inspection and as to how the systems should be checked.

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[1] AAR Signal Manual, Part 150, Section 7

Perhaps a lower frequency rate of inspection of the crossing would be sufficient. The maintainer could quickly check the battery water level, replace burned out lamps, and run a quick functional check of the system. A complete test of the system could be conducted every one or two years. This test would include an inspection of the relays and cables as instructed in the RS&I, Sections 236.101, 236.102, 236.106, 236.107, 236.108, and 236.59.

Maintenance checks could be further reduced if remote monitoring of the system could be established. Many specific items could be monitored, such as the gate being down longer than a preset time, bulb burnouts, battery water level, etc. One way of achieving this would be to incorporate something similar to a radio call box into the system. For example, a major traffic signal supplier currently manufactures a radio call box that is self-monitoring. It transmits a signal once a day to report that it is properly functioning. It will also transmit an appropriate signal if the system has been tampered with by vandals. This signal can be sent by radio or it can be coded onto existing signals on pole lines.

It is considered feasible to incorporate such a monitoring device into the grade crossing signal system. At some predetermined time, probably early in the morning, the device would activate the crossing. If the system was properly functioning, the monitor would transmit a signal to inform a dispatch station that everything was working properly. If anything had failed, the station operator would be notified and would then dispatch a maintainer to the crossing with the malfunction. Of course, the maintainer would have to inspect the crossing periodically to make sure lights are properly aligned and the mechanism lubricated, but this inspection might be considerably less frequent than the present inspections.

This system is not without its drawbacks. There is a problem of transmitting the error signal. Interfacing to existing pole lines may become very complex if all cross talk is avoided. It is also impractical to have failure sensors on every function. The problem becomes very burdensom when there are monitors on the monitors. However, it is felt that most of these problems could be overcome with some effort. Since it is not within the scope of this study to thoroughly investigate such a system, it is not possible to determine whether the advantages of such a system outweigh the disadvantages. What does appear to be warranted is an in-depth study of the possible applications of a radio call box monitor to grade crossing systems.

4. NEW CONCEPTS

4.1 Introduction

Four new preliminary concepts will be delineated. In addition, a modular polycarbonate resin gate arm[1], will also be presented. It is considered that this gate arm may be applied to any of the four concepts.

4.2 The Folding Gate Arm

The Folding Gate Arm concept is illustrated in Figure 3. In this design the arm is raised and lowered by the two actuating cables. When in the raised position, the arm folds in half thereby requiring less overhead space. Due to the cable coming from the split mast, the arm will always fall by gravity toward the bottom of the arc. Any lateral displacement of the arm will result in one of the cables applying a force opposite to the direction of displacement. Hence, upon impact the arm will move both up and away and then return to the horizontal position. The gate arm support acts as a large universal joint allowing the arm to move in any direction. The option of a protective housing mounted between the two masts adds extra protection from wind and ice.

This concept has several shortcomings. The first is the complexity of the design would probably result in higher costs than the present mechanisms. Secondly, the cables may be subject to vandalism, especially when the arm is in the lowered position. Further, when in the raised position due to the gate arm folding, the end of the arm is within easy access to any vandals.

The disadvantages mentioned were felt to outweigh the advantages of this design. The complexity of the device would be likely to make it much too expensive to warrant development. For these reasons the Folding Gate Arm concept was eliminated as a possible choice for further consideration.

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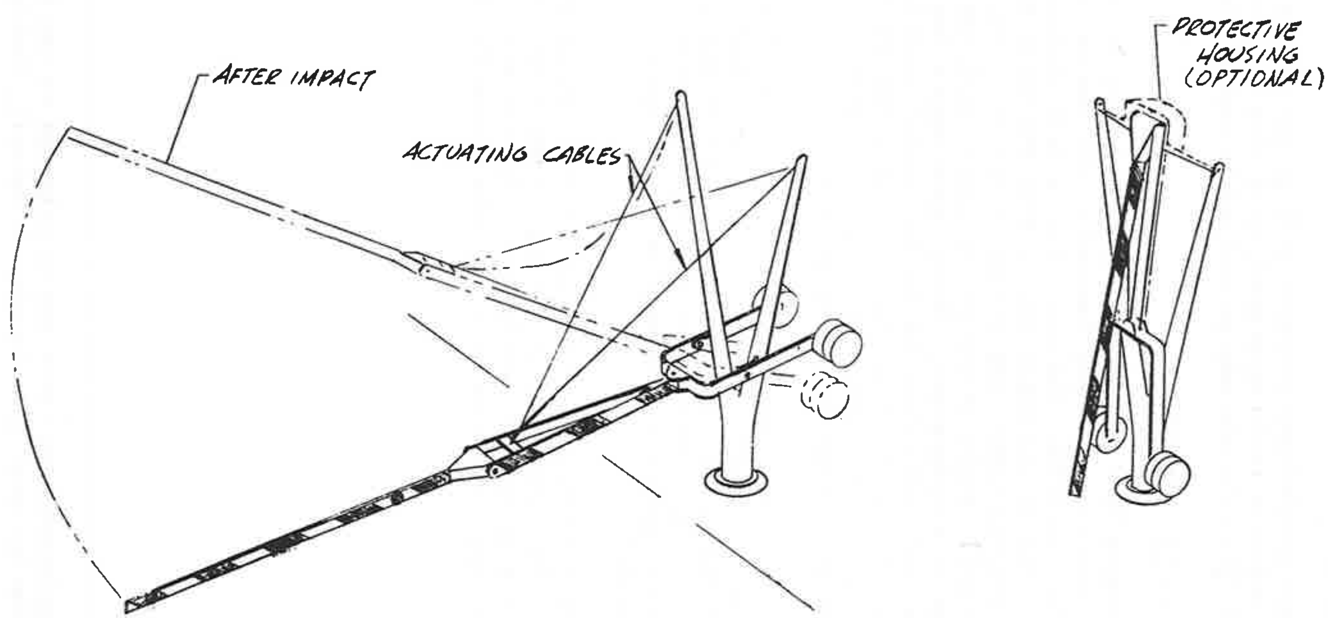
[1] The modular polycarbonate resin arm is patented by the Railroad Reflectors Division of the National Sand Foundry in Detroit, Michigan.



FOLDING GATE ARM

FIGURE 3

4.3 The Overhead Cable

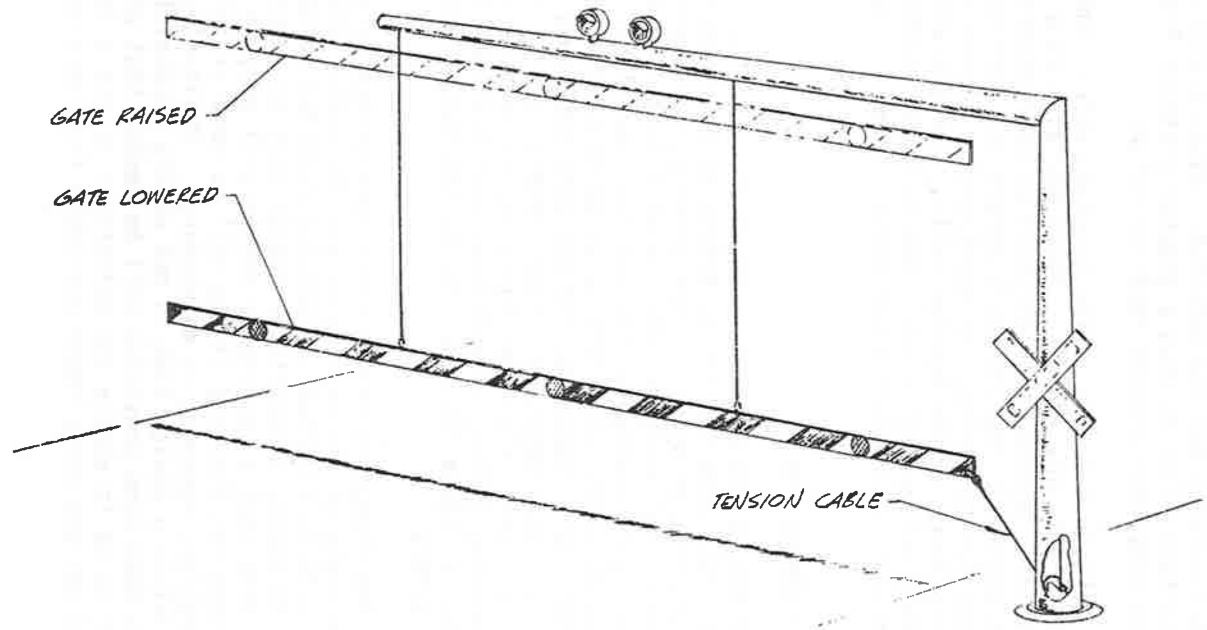
The Overhead Cable concept is shown in Figure 4. Here, the arm is raised and lowered by two cables driven by an electric drive motor and pulley arrangement. The tension cable is added to restrain the arm from oscillating during windy conditions. The arm, when impacted by a car, will "swingaway" and then assume the activated position after impact. The cantilever also allows for mounting of the flashing lights above the roadway to provide a better warning for the motorist. Also, a cantilever design allows the structure to be located a greater distance from the edge of the roadway thereby providing greater roadside safety.

One problem with this design is the tension cable. The tension cable is easily accessible to any vandals. There may also be a problem of ice forming on the cables. Another problem would be maintenance. To make maintenance easier, a desirable feature would permit the span to be rotated to the side of the road for servicing. An additional disadvantage is that despite the restraining force of the tension cables, the arm will probably still oscillate slightly during high winds. Due to these shortcomings, it was felt that this concept lacked sufficient merit to warrant further investigation.

4.4 The Overhead Hinged Arm

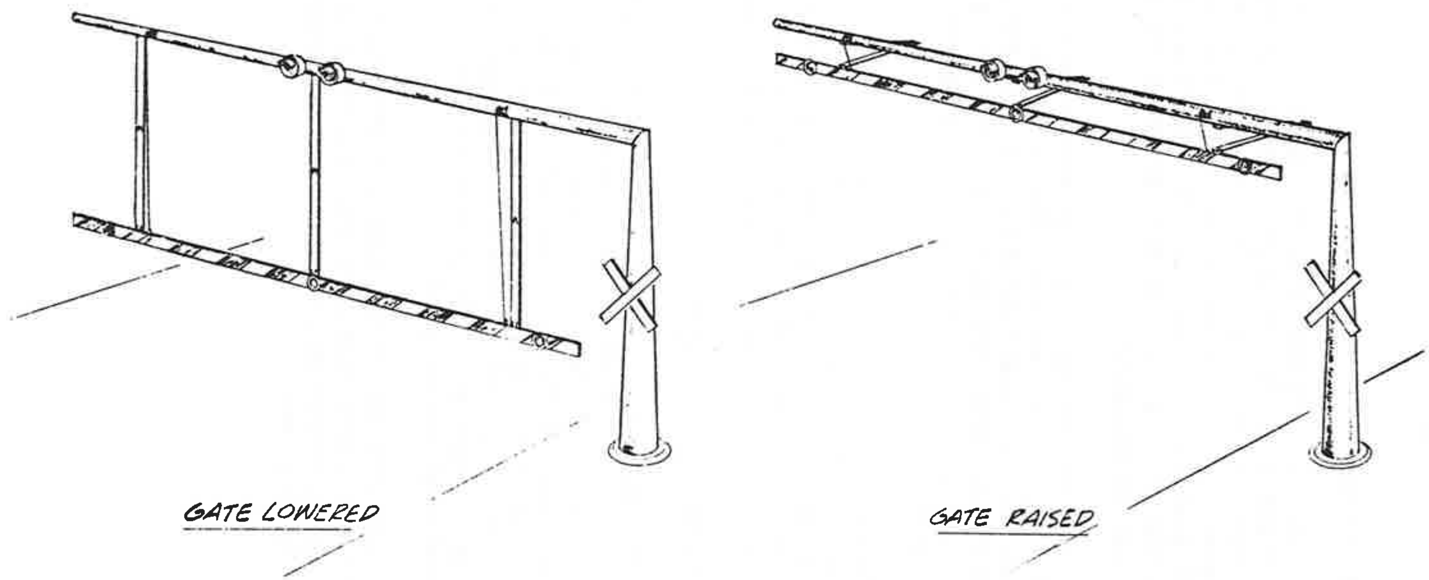
The Overhead Hinged Arm concept is shown in Figure 5. This, like the Overhead Cable concept, uses two cables driven by an electric drive motor and pulley arrangement or by some other means to raise and lower the gate arm. When in the raised position, the arm will fold in under the span. This will protect the lights mounted on the arm from vandalism. The vertical arm supports will provide sufficient rigidity so as to prevent the arm from oscillating in the wind. When impacted, the arm will move away allowing the motor vehicle to pass underneath it. After impact it will resume the activated position. As before, flashing lights may be mounted on the span to provide a better warning. Also, a cantilever design allows the structure to be located a greater distance from the edge of the roadway to provide for greater roadside safety.

There are a few drawbacks when a cantilever design is used. One problem is the higher costs of the cantilever and its installation. However, with recent efforts directed at removing roadside obstacles, it may become necessary to employ a cantilever design just to support flashing lights. Also, it is felt that a cantilever design will provide better warning protection since the flashing lights will be more visible to the motorist. Another problem, however, is maintenance. Obviously, it is more difficult to maintain a device that is not easily accessible. Therefore, it appears that some provision will be needed that allows rotating the span 90° so as to enable the maintainer to use a ladder to reach the span. Such designs are already available from some suppliers.



OVERHEAD CABLE

FIGURE 4



HINGED ARM

FIGURE 5

The desirable features of a cantilever design, along with the "swingaway" advantage, makes this concept one which merits further consideration. A more detailed analysis of the concept will be presented in Section 5.

4.5 The Rotating Arm Concept

The Rotating Arm concept is illustrated in Figure 6. In this particular design, the gate arm shaft has been installed at unique angles. The angles are such that when the shaft is rotated, the tip of the arm describes an arc. The angles can be adjusted to determine the horizontal and vertical components of position that are desired, see Figure 7. In other words, by adjusting the shaft angle, the rate at which the arm moves vertically or horizontally can be adjusted.

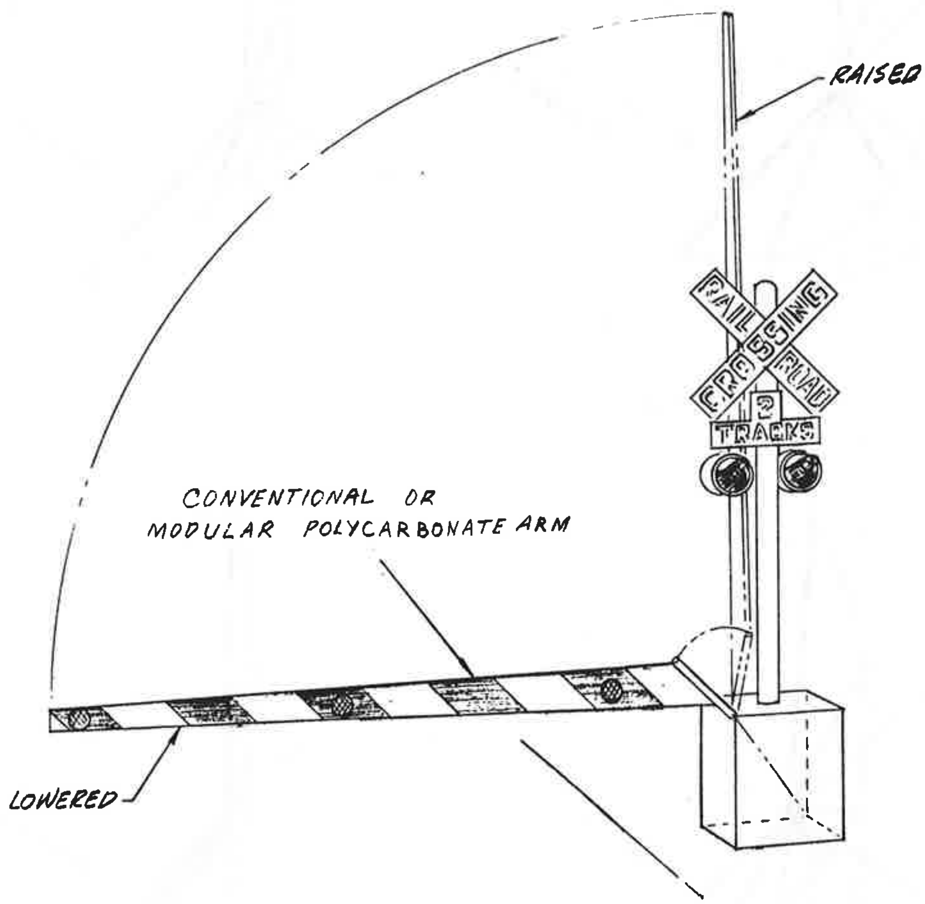
When required to descend, the gate will be driven to a predetermined angle (similar to the present systems) and then be allowed to drop by gravity until it reaches the horizontal position. Now if the arm is struck by a vehicle, it will move both vertically and longitudinally away from the vehicle. After impact, the gate will once again return by gravity to its normal lowered position.

The driving mechanism in this device will be very similar to that of the present system, except that the drive shaft is installed as a different angle. Allowing the arm to "swingaway" and then return after impact should result in reduced repair costs. Due to these advantages it is considered that this design also warrants further investigation.

4.6 The Modular Polycarbonate Resin Arm

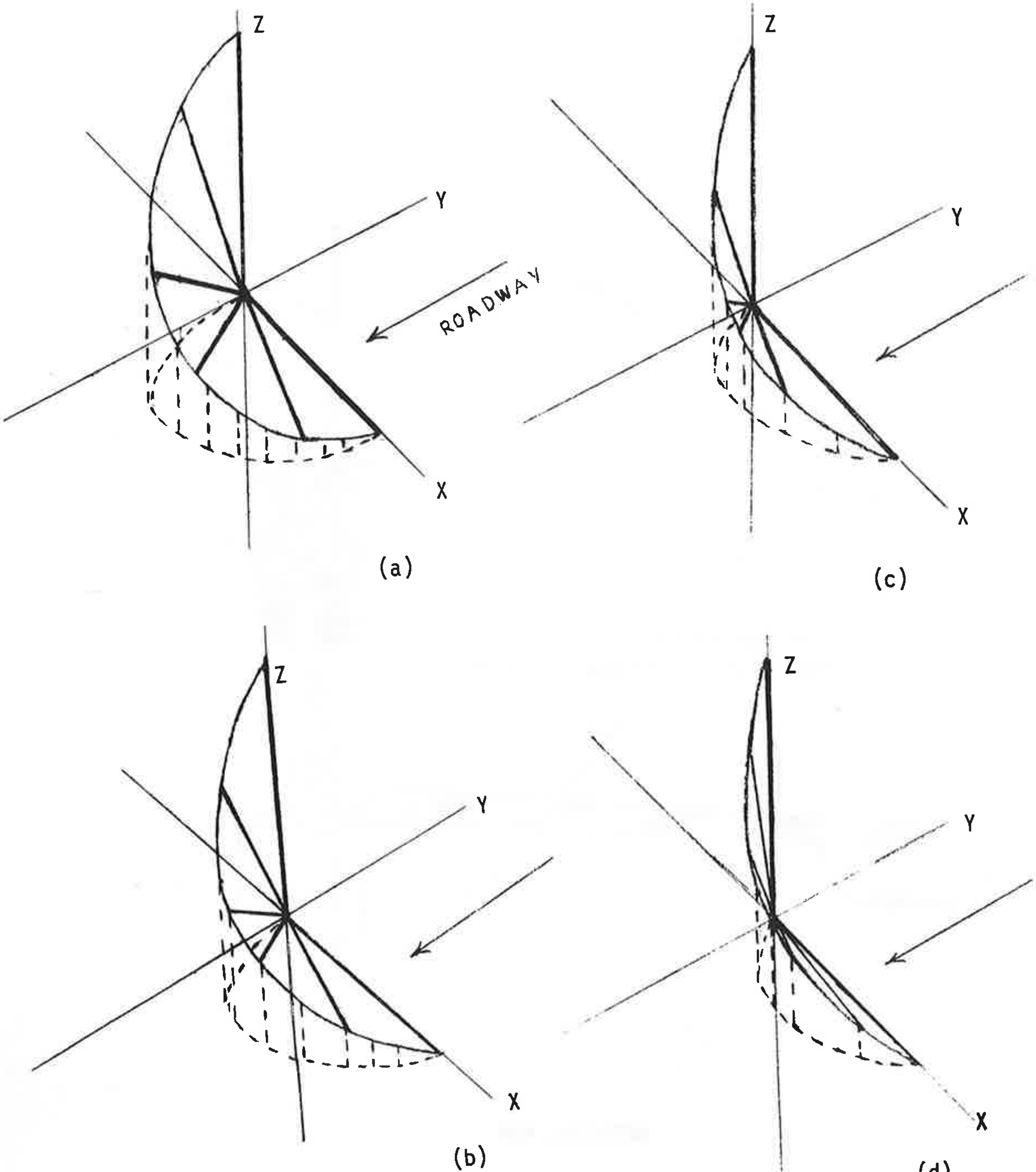
The Modular Polycarbonate Resin Arm is shown in Figure 8. It consists of 18-inch molded sections which can be assembled to any length. Since the arm is sectionalized, installation and repair are made easily. A damaged arm can be easily repaired by quick replacement of damaged sections. This also eliminates the need for establishing a large inventory of different sized arms. The use of hollow sections also can allow for internal lighting of the entire gate arm. Polycarbonate also can withstand greater impacts than conventional arm materials.

This arm can be used with any of the concepts that have been presented. In fact, it is considered necessary that the arm used for a swingaway design must be strong enough to absorb the initial impact, and polycarbonate should satisfy this need.



ROTATING ARM

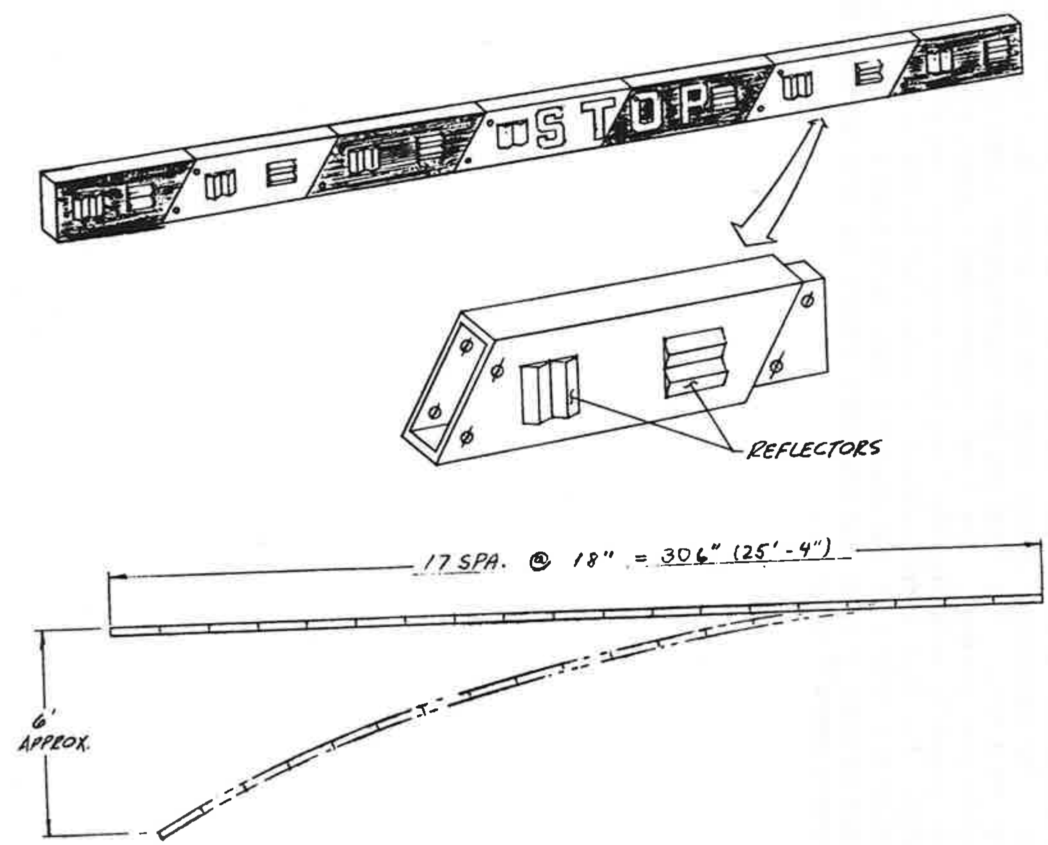
FIGURE 6



Figures (a) thru (d) Demonstrate Progressively Smaller Lateral Deflections and Progressively Faster Rising Actions

AREAS SWEPT BY ROTATING ARM

FIGURE 7



POLYCARBONATE RESIN ARM

FIGURE 8

4.7 Recommended Concepts

Two concepts, the Rotating Arm and the Hinged Arm, will be further analyzed. An engineering and economic analysis will be performed for each. The concept that shows the greatest potential for cost reduction will become the recommended concept.

It should be noted, however, that these are two different and distinct concepts. Both concepts have unique features that make them appear promising. The cantilever design provides the better warning and roadside safety but at a cost. The Rotating Arm incorporates simplicity of operation and probable cost savings. The final recommended concept will be chosen only after properly weighing the long term advantages and disadvantages of each design. For cost effectiveness, a reduction in the original equipment costs should not result in the need for more maintenance. The final recommended concept will be the one that offers the best warning protection at the lowest overall costs.

5. ENGINEERING AND ECONOMIC ANALYSIS

In order to determine which concept (the Rotating Arm or the Overhead Hinged Arm) appears to show the greatest promise, the criteria for judgment will be cost effectiveness. This judgment or evaluation will determine which concept allows for the largest cost reduction without a loss in reliability or safety. Hence, each of the above concepts will now be subjected to an economic and technical evaluation. This evaluation or analysis will be based upon the preliminary design of both concepts.

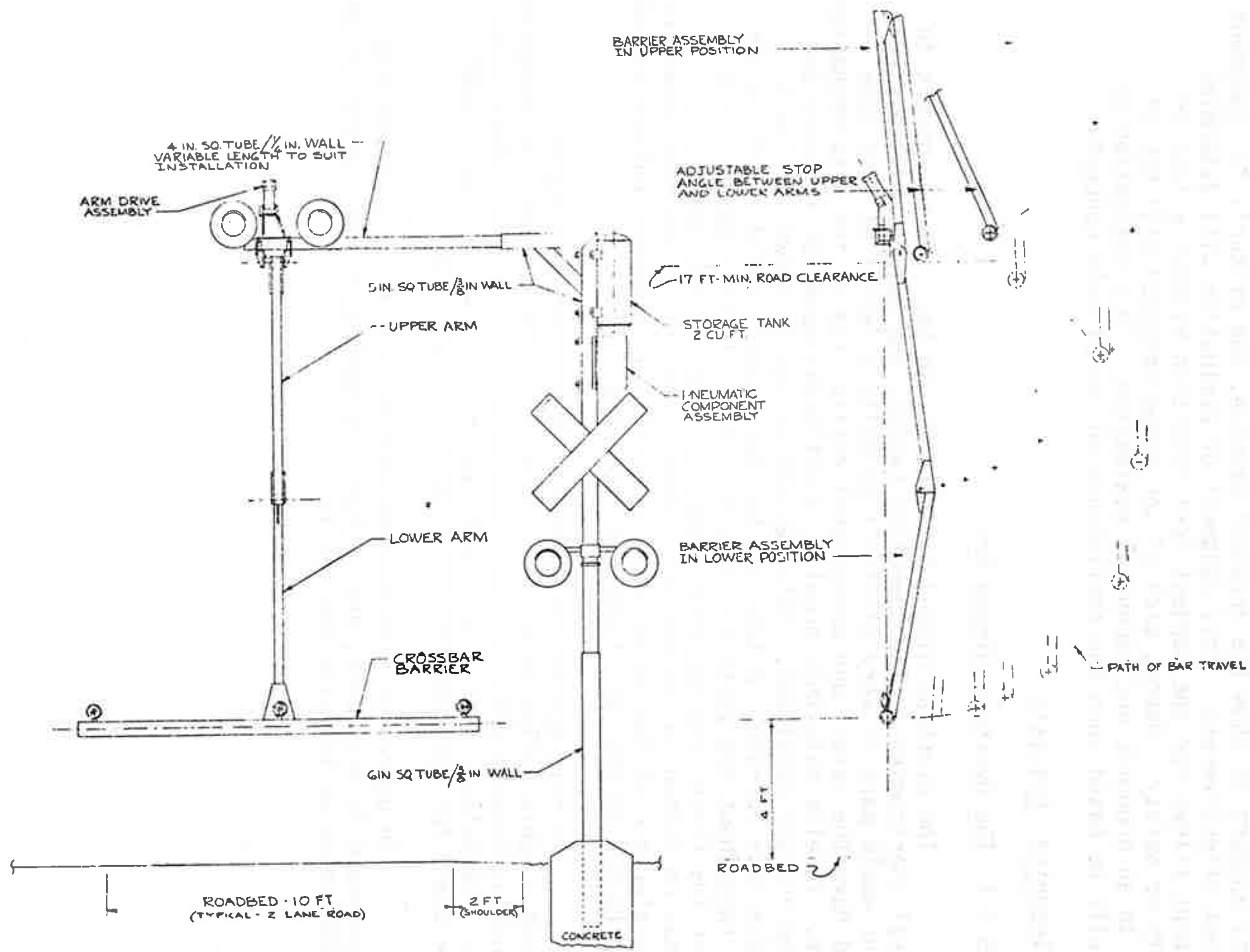
5.1 Technical Analysis

5.1.1 The Overhead Hinged Arm

The Overhead Hinged Arm concept, in basic form, appears to have several shortcomings. The operating cables, the pulley and the hinge arrangement would make it very difficult to build a device of this type that would have the safety and operational reliability of the gate mechanisms now in use. To eliminate this problem, a different means of lowering and raising the arm was developed. This revised design is shown in Figure 9 for a single-lane barrier. A two-lane barrier support would require a six inch tube throughout the vertical support. This will be reduced to five inches over the first lane and four inches over the second lane. The sections can be joined to one another either by bolting or welding depending upon the preference of the installer. An additional actuator and arm assembly would be attached to the cantilever over the second lane.

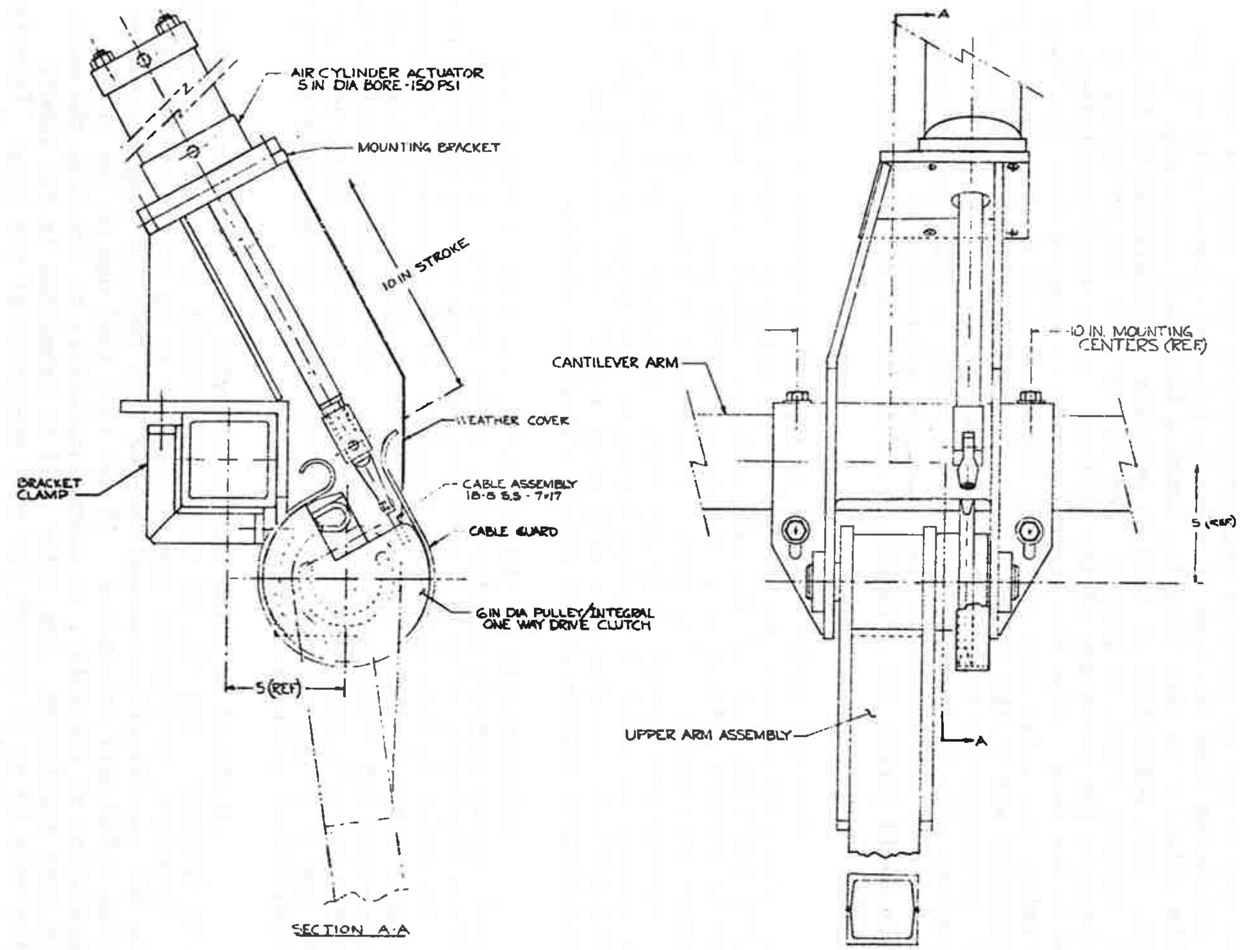
In this system the upper bar is powered by a pneumatic actuator and a cable/pulley drive (see Figure 10). The actuator is connected to the mounting bracket with the rod joined to one end of a stainless steel wire rope. The pulley, over which the latter functions, contains a wedge type cable clamp for securing the other end of the wire rope.

In operation, the barrier is normally in the down position. When air pressure is available, and a signal is applied to the control valve, the actuator operates to raise the barrier.



OVERHEAD HINGED ARM

FIGURE 9



ARM DRIVE ASSEMBLY FOR OVERHEAD HINGED ARM

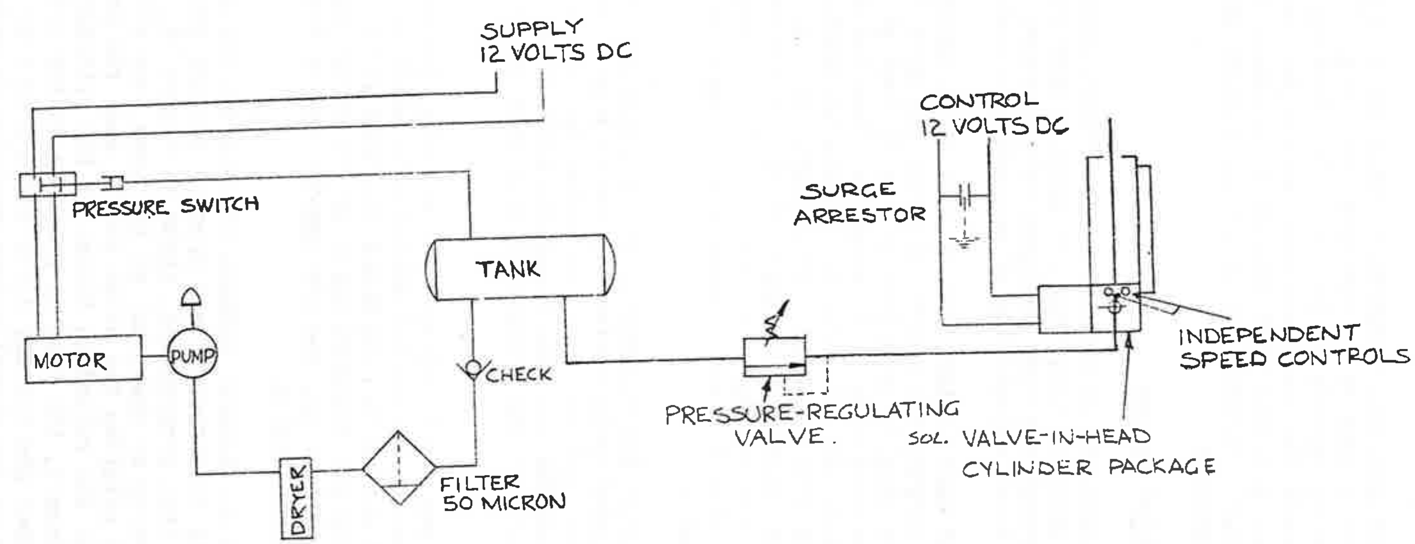
FIGURE 10

The pneumatic component assembly is shown in Figure 11. A power supply will be connected to the pump drive motor through a pressure switch. This pressure switch will read tank pressure and will regulate between 50 and 75 psi by starting and stopping the pump motor at these limits. Discharge from the tank is normally blocked (signal off) at the valve. The actuator is then floating because both ends are vented to atmosphere. This means that so long as pressure is maintained in the tank and a D.C. control signal is present, the barrier will remain in the up position becuase the drive end of the cylinder, under these conditions, is connected to the tank. When the control signal is removed from the 3-way solenoid valve, the valve will return to the float position and the pressure in the operating end of the cylinder will start to decrease. The rate of decay will be controlled by the size of the orifice in the port. The lowering motion will begin when the decaying force is equal to the gravity imbalance force of the retracted arm. A slight alteration of this arrangement would permit the actuator to drive the arm down if this is deemed desirable.

When the control signal is applied to raise the barrier, the 3-way valve will connect the rod end of the actuator to the tank. The orifice will limit the rate of pressure rise, but when it reaches a level sufficient to produce a force equal to the unbalanced gravity vector arm, motion upward will commence. As pressure continues to rise, the arm will reach the maximum (horizontal) load position. Acceleration will continue beyond this position until it reaches the maximum velocity governed by the size of the orifice. Deceleration will occur rapidly when the actuator reaches the dynamic cushion at the end of the upward stroke.

Vulnerability of the pneumatic system to corrosion and freezing will be very nearly eliminated by drying the air. A dessicant dryer, with a disposable silca gel cartridge, will remove the moisture from the air. Air dried in this unit has a constant -40°F atmospheric dew point. The disposable slica gel cartridge can be replaced cheaply and quickly without disconnecting the dryer from the air line. For a typical installation, the frequency of replacement for the cartridge is estimated to be once per year. The use of chrome plated components and copper tubing for air piping provides additional protection from corrosion.

It should be noted that this device, like the conventional devices, is failsafe. Any loss of signal will result in the barrier being lowered. Therefore, this device does not appear to be in violation with any of the AAR specifications except for the fact that the pump motor does not have the 3,000 volt insulation. It was felt that due to the intermittent operation of the motor, it seemed unecessary to insulate the motor with 3,000 volt insulation. The motor will be connected to its supply circuit for only 20 to 30 seconds for each operation of the gate. Therefore, if a gate is normally lowered 10 times a day, the motor is only vulnerable for a total of 4 or 5 minutes a day or about .4% of the time. This means that the probability of lightning striking the system while the motor is operating is extremely small.



PNEUMATIC SYSTEM DIAGRAM

FIGURE 11

Another possible weakness in this design is that the two bar linkage may be easily damaged by torsional twisting. This twisting may be produced either by vandals or by a vehicle striking the very end of the arm. Also, should the arm catch upon some object protruding from the vehicle, it is very possible that considerable damage to the cantilever arm and mast would occur. Careful design of the linkage and arm, however, should minimize this problem.

5.1.2 The Rotating Arm

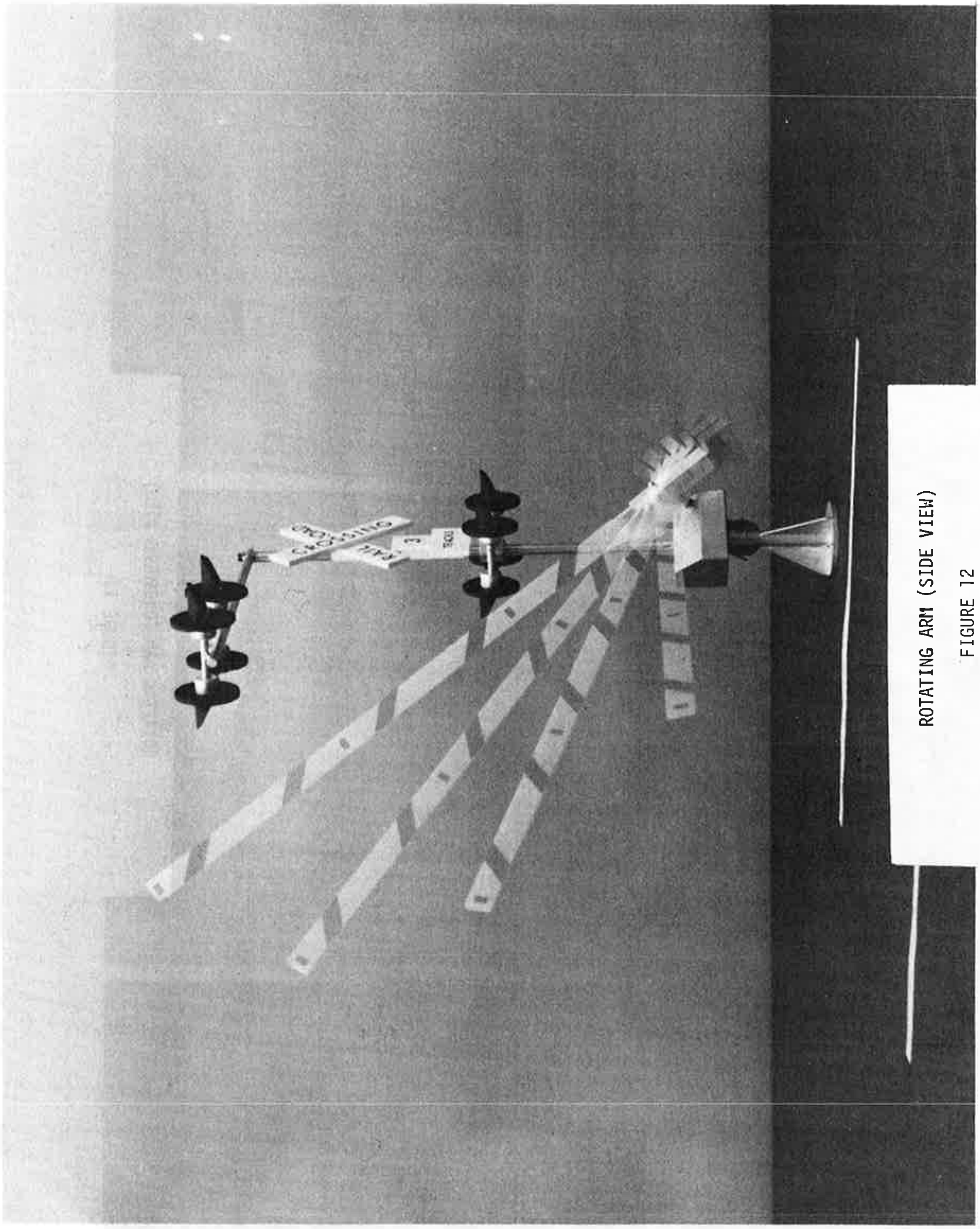
This concept, as previously described, also incorporates the idea of the gate swinging sway from the vehicle upon impact. A mechanism for realizing this concept has been designed which appears to achieve both the safety and operational reliability of present gate mechanisms.

As had been stated, the various areas swept out by the arm could be adjusted by varying the angles at which the gate is installed. Since the mechanism is usually installed within 15 feet of the center line of the tracks, the arm must rise fast enough to allow for adequate clearances. However, if the arm does not allow for sufficient horizontal motion, the arm will most likely break when impacted. It appears that the optimum condition exists when the arm is mounted at an angle of 45° to the vertical and also at an angle of 45° to the roadway. Figure Nos. 12, 13, and 14 demonstrate the various positions that the arm assumes when being lowered or raised at these installation angles.

No matter how the mechanism is installed, however, a fast moving vehicle will undoubtedly strike the arm with an impact hard enough to break it. But since most arms are now broken by slow moving vehicles attempting to go around the arm, the foregoing arrangement will absorb, by displacement alone, most of the vehicle impacts that would otherwise fracture the arm.

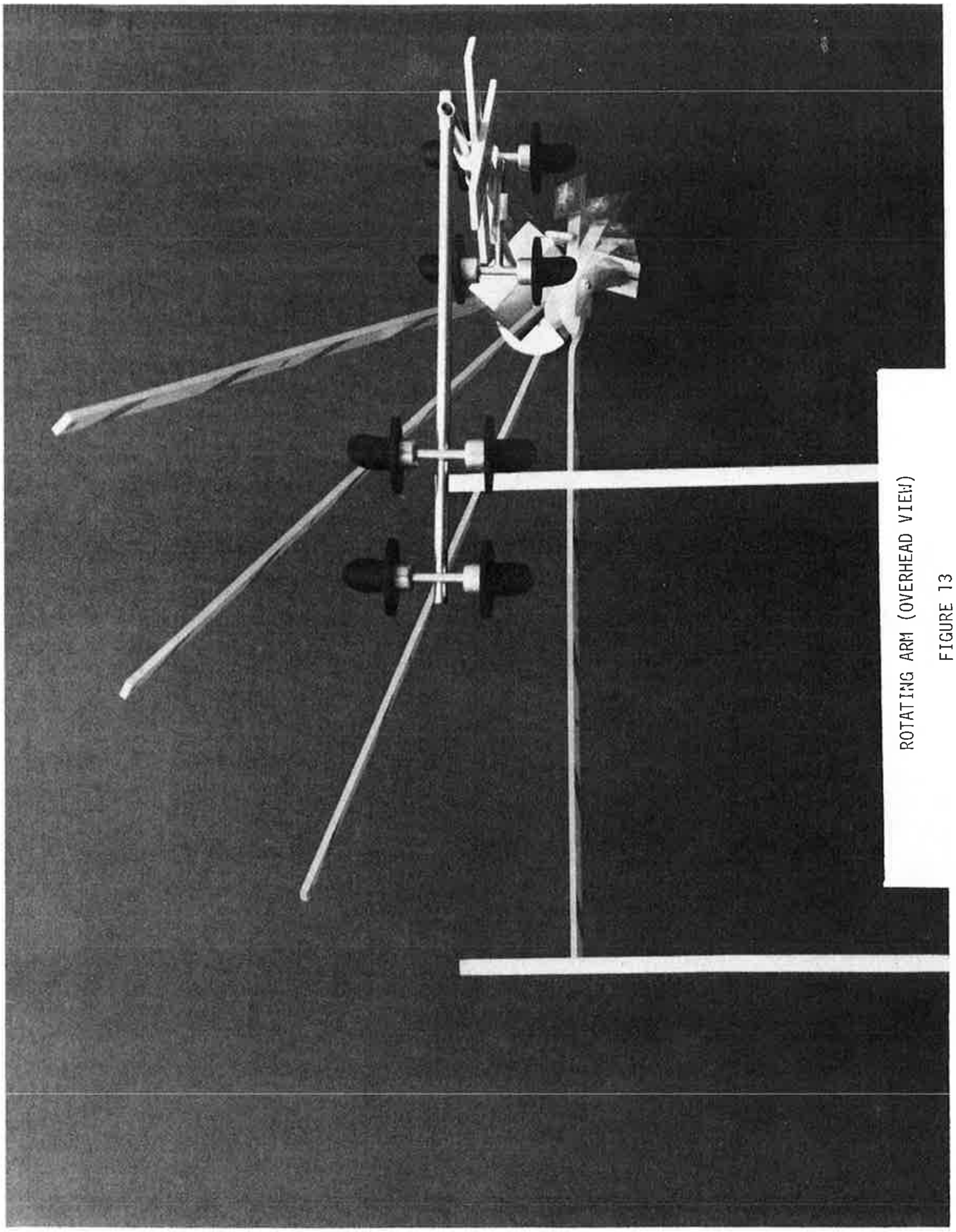
When the arm is struck by a vehicle, the arm swings both forward and upward, having horizontal motion with which it retreats from the vehicle, and vertical motion to rise above the hood of the vehicle. On the vehicle backing up, the arm descends again to its normal lowered position. If the vehicle does not back up, the arm remains in its displaced position until it is raised automatically.

There are several methods of allowing the arm to swing freely on impact. One way is to incoprorate a special key and keyway arrangement on the drive shaft. This arrangement, shown in Figure 15, would permit the shaft to drive the arm up or down, but at the same time allow the arm to swing freely, without rotating the drive shaft, when the arm is impacted. Another method reduces the retarding forces of the cylinder by the use of a relief valve. Upon impact, the rise in pressure in the cylinder would cause the relief valve to open and thereby allow the arm to rise. In either case, the return of the arm to its normally down position is snubbed by the use of cushioned stops.



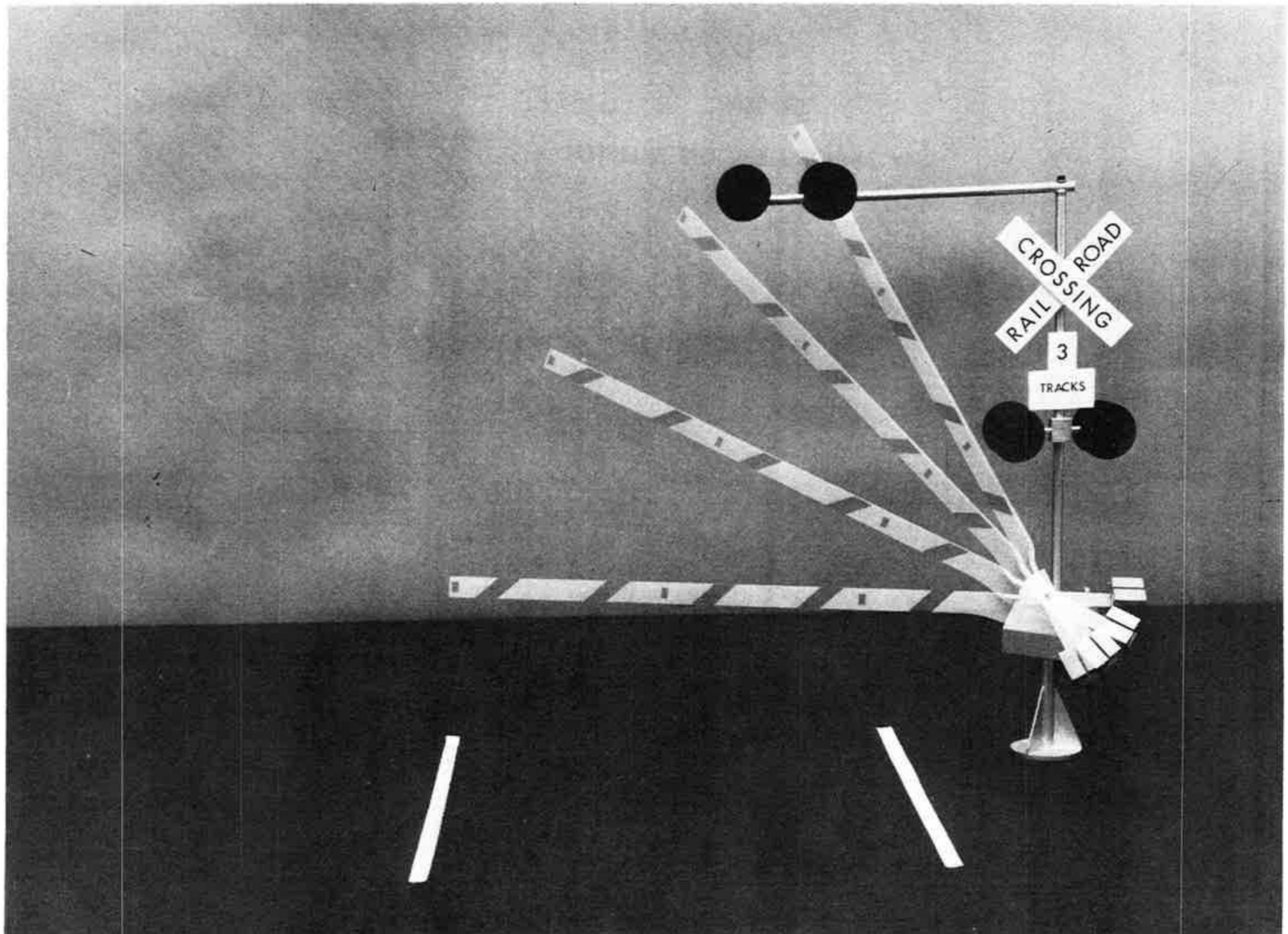
ROTATING ARM (SIDE VIEW)

FIGURE 12



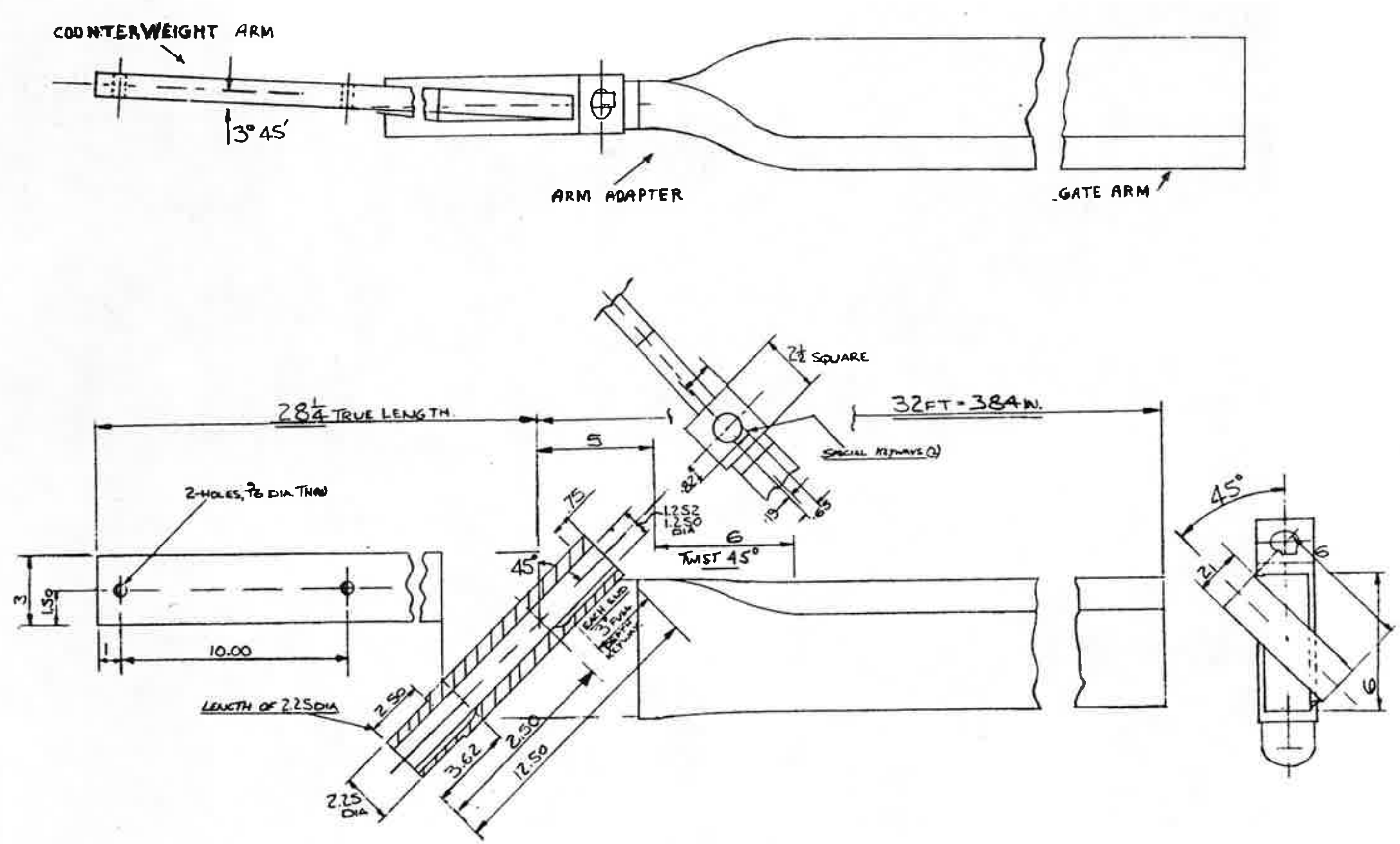
ROTATING ARM (OVERHEAD VIEW)

FIGURE 13



ROTATING ARM (FRONT VIEW)

FIGURE 14



MOUNTING BRACKET FOR GATE ARM

FIGURE 15

The preliminary design of the Rotating Arm is shown in Figures 16 and 17. As can be seen, the movement of the arm is constrained at the upper and lower positions by stops. These are provided so as to locate the arm in its correct respective positions. The counterweight is adjustable to provide proper torque for the length of the gate arm that is being used.

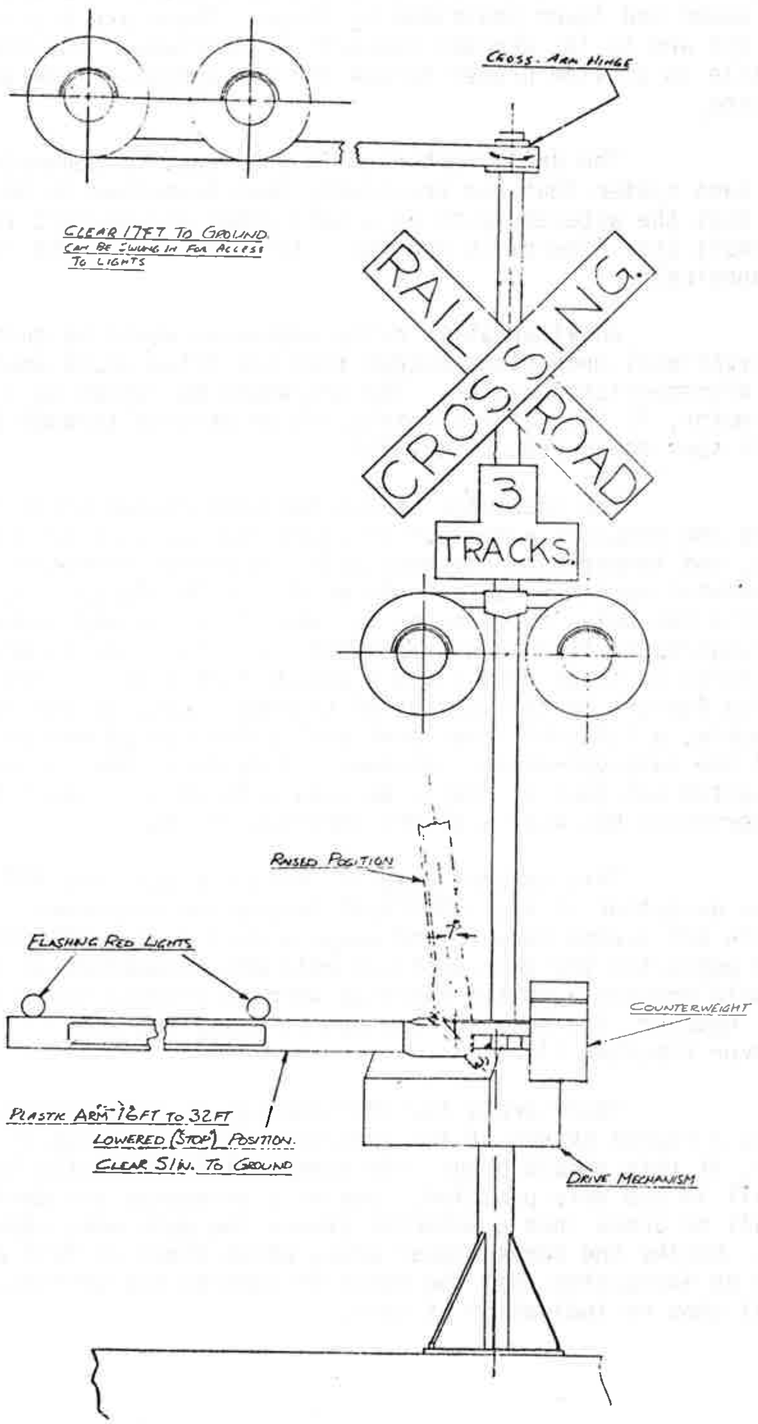
The drive mechanism is once again a pneumatic system. It is the same system that has previously been described in Section 5.1.1 except that the actuator acts as a bell crank arrangement to rotate the drive shaft (see Figures 18 and 19). This driving method is both simple and economical.

An alternative drive mechanism would be quite similar to the conventional mechanisms except that the drive shaft would be installed at the aforementioned angles. The arm would be raised by a low speed, high torque motor, 12 VDC, approximately 1/6 HP driving through 3 ratios of standard spur gears (see Figure 20).

The pneumatic system has been chosen since it is self-snubbing and requires a minimum of electrical contact controls. It is also oilless, and temperature extremes will not affect operation. Additionally, the pneumatic system requires only an OFF or ON signal. It is not necessary to reverse the polarity of motor currents to raise and lower the arm. Nor is it required to include cam operated limit switches to provide snubbing. This results in fewer relays and a concomitant cost savings. Another promising feature is the storage of standby energy in the storage tank. For example, a 2.2 cubic foot tank will allow for 20 normal gate operations without the pump operating. However, if desired, the conventional mechanical drive system can just as easily be used without any change to the functional characteristics but with a slight increase in costs.

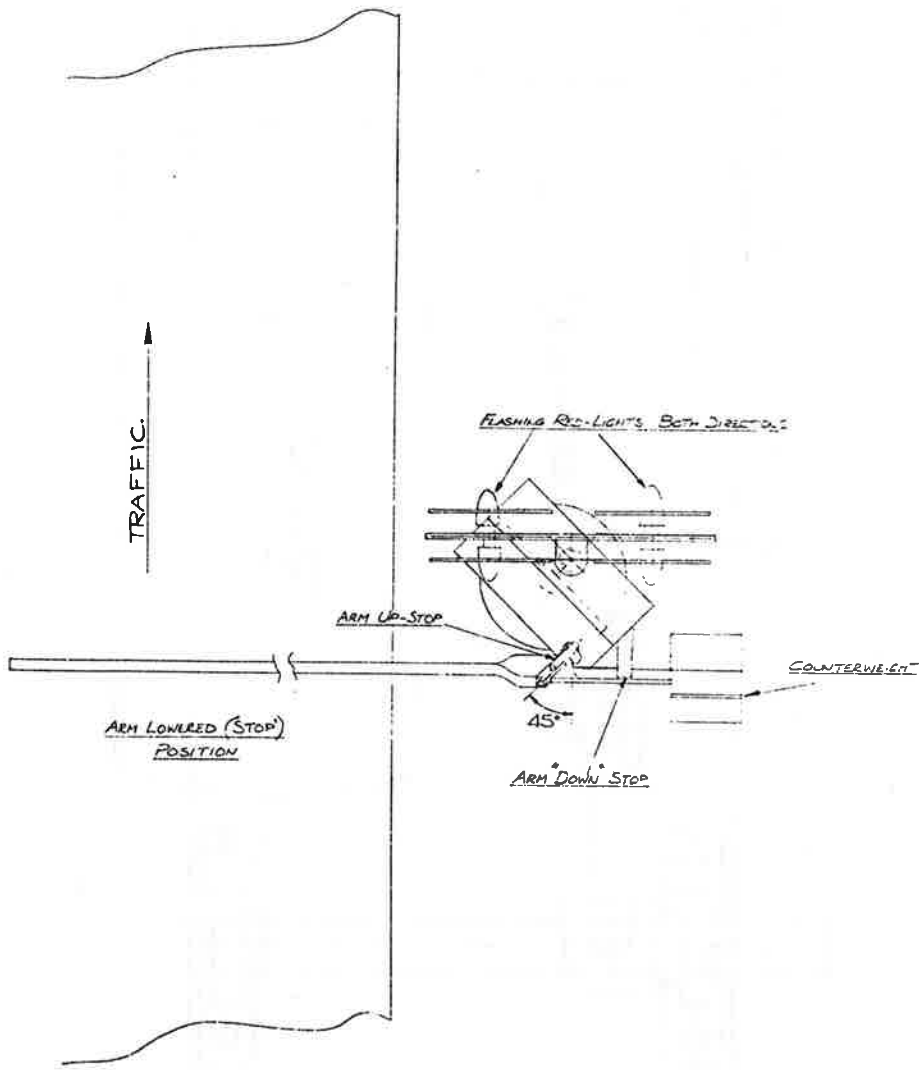
This concept complies with the existing AAR specifications, with the exception of the 3,000 volt insulation requirement for the motor. Since the arm sweeps forward and away, a cantilever with flashing lights can be used employing the same vertical pole and foundation as the mechanism. This would provide a better motorist warning without significantly increasing costs. However, the Rotating Arm can be installed with or without the cantilever flashing lights.

There are a few shortcomings in this device. As before, there is a remote chance of the pump motor being damaged by lightning. However, if this should occur, the system will eventually lose pressure and then fail in the safe position. Use of a swingaway arm design may make it difficult to prove that a motorist struck the gate arm, should litigation result. Unlike the conventional arms, which break or fall away upon impact to give an indication that the motorist ignored the warning, the swingaway arm will show no indication of this.



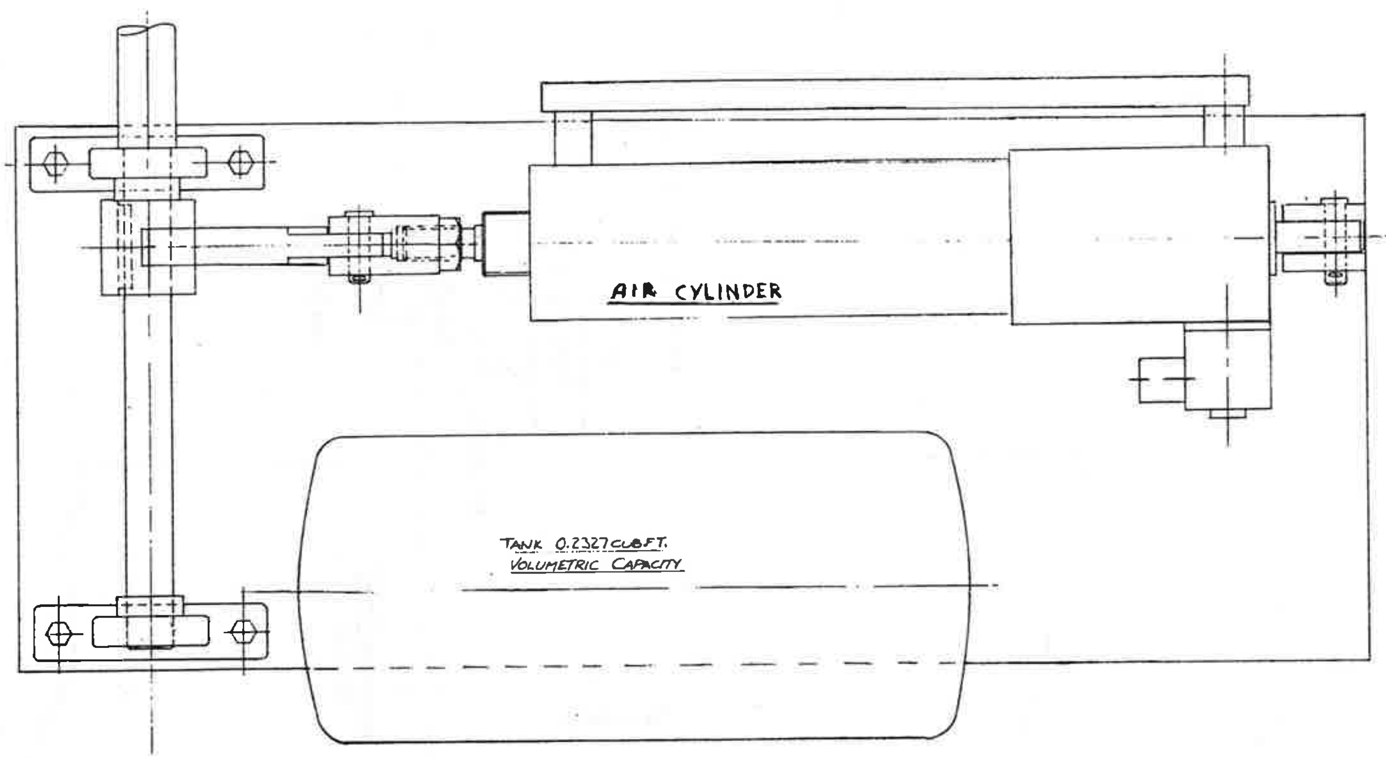
ROTATING ARM DESIGN (SIDE VIEW)

FIGURE 16



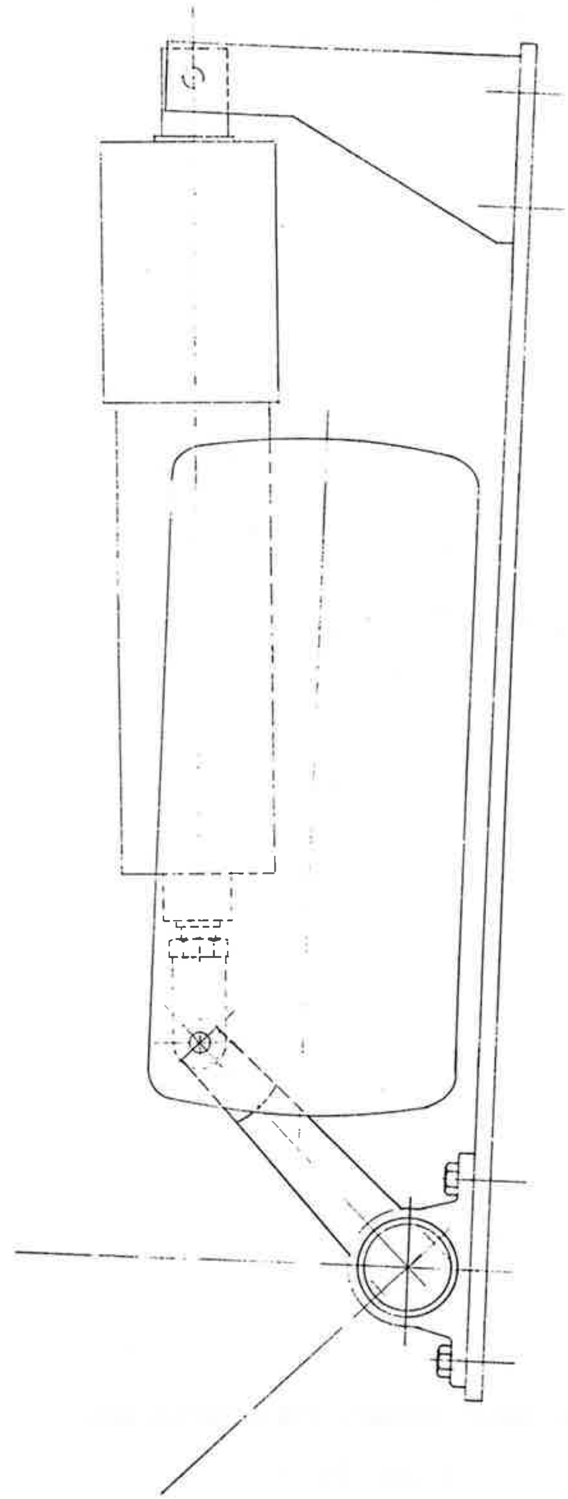
ROTATING ARM DESIGN (OVERHEAD VIEW)

FIGURE 17



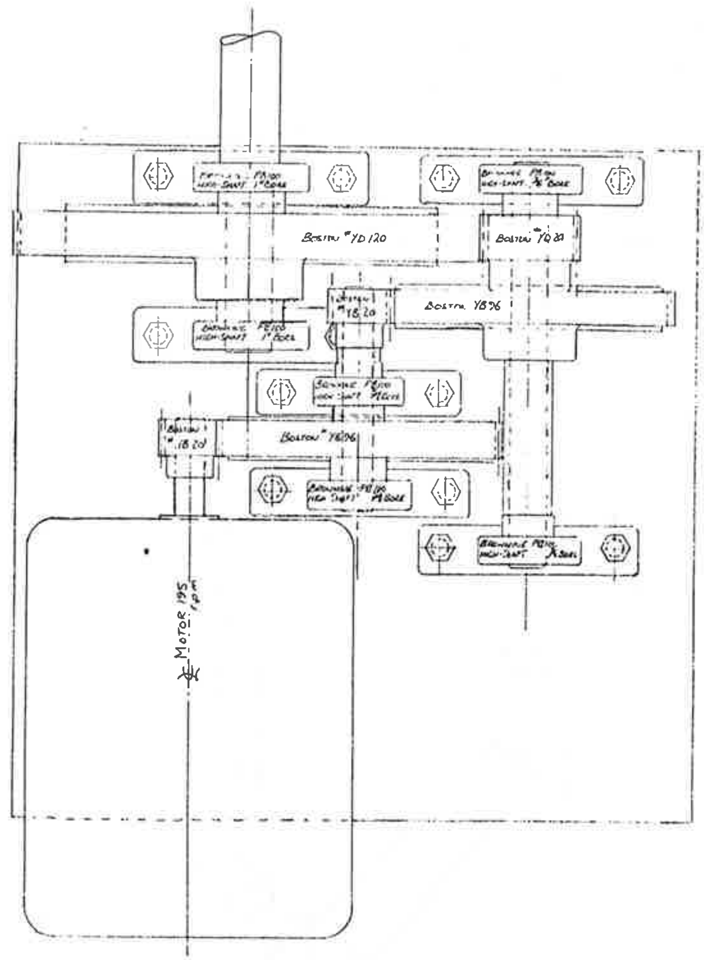
PNEUMATIC DRIVE ASSEMBLY FOR ROTATION ARM (OVERHEAD VIEW)

FIGURE 18



PNEUMATIC DRIVE ASSEMBLY FOR ROTATING ARM (SIDE VIEW)

FIGURE 19



MECHANICAL DRIVE ASSEMBLY FOR ROTATING ARM

FIGURE 20

5.1.3 Technical Analysis Summary

Both the Overhead Hinged Arm and the Rotating Arm designs provide for the arm to swingaway on impact and then return to its normal position. Both systems are driven by a pneumatic drive system and both can use cantilever lights to provide for a better warning. However, technical evaluation of differences between the two concepts permits choice of the device which shows greater promise.

1. It is believed that with the Overhead Hinged Arm there is greater chance that the arm will be caught on a vehicle. This would result in more broken gate arms and greater secondary damage to the support structure.

2. The Rotating Arm is a much sturdier device than the Overhead Hinged Arm.

3. The Overhead Hinged Arm would be more difficult to maintain and install than the Rotating Arm due to the fact that the drive mechanism would be difficult to service when located high above the roadway.

Based upon these facts, it would appear from a technical standpoint that the Rotating Arm shows greater promise than the Overhead Hinged Arm.

5.2 Economic Analysis

The objective of this part of the study is comparison of cost reduction potential for the Overhead Hinged Arm and the Rotating Arm. The goal of this study is generation of a concept that has original equipment, installation and maintenance costs that, in total, are less than those currently applicable for existing gate designs without important loss of function or reliability.

A problem arises, however, when trying to determine costs for the current gate mechanism. There is very little reliable information available from which to obtain cost estimates. It is especially difficult to obtain the cost breakdown for the installation and maintenance of these devices. Therefore, the following cost analysis should be viewed as approximate. It is believed, however, that they provide a reasonable basis for cost comparison between the two new concepts and the current gate mechanism.

For this analysis the following assumptions have been made:

1. The cost comparison is for the installation of a gate at a crossing which (1) does not presently have a gate, or (2) the present mechanism requires replacement.

2. Amoritization rates, discount rates, and accounting philosphy are assumed to be the same regardless of the gate design used. Consequently, these will not affect the ratio of cost-effectiveness when comparing different devices.

3. Cost comparisons are based on 1974 dollars.

5.2.1 The Current Gate Mechanism

Obtained from the various agencies mentioned earlier in this report, the typical overall system costs were:

Initial Cost of Gates and Flashing Lights..................$35,000

Yearly Recurring Costs of Gates and Flashing Lights........$ 1,500

To obtain the original equipment costs for the present gate mechanisms alone, three leading manufacturers of these devices were contacted. It was found that the average cost for one gate mechanism was $1,800. Added to this is the cost for the arm ($300 for a typical aluminum gate arm). The average original equipment cost for one gate mechanism and arm then becomes $2,100. Since there are usually two or more gate mechanisms per crossing, the cost is then $4,200.

There are virtually no reliable cost estimates for the installation of the gate mechanism alone. It is therefore necessary to make qualitative judgments concerning these costs. From other reports, the installation costs for the whole system were found to equal between 40% and 50% of the total initial costs. The burying of cables, the installation of insulated joints, and the wiring of the control logic would presumably represent the bulk of the installation costs. Therefore, a reasonable estimate of the installation costs that are attributable to the gate mechanism alone would be about 20% of the total installation costs, or about $3,000. The $3,000 for gate installation costs is probably conservative. But, it is desirable to be conservative in estimating this cost since an under-estimate will lead to an over-estimate for the potential cost reductions of each concept.

Using $4,200 as the original equipment costs and $3,000 as the cost for installation, the total initial costs are $7,200 for conventional gate mechanisms.

To estimate the maintenance costs due to the gate mechanism and arm, a report by Alan M. Voorhees & Associates, Inc.[1] was used. This report outlines the average maintenance costs for typical installations in 1968 dollars.

Flashing Lights @ Multiple Track Crossing..............$ 880

Flashing Lights and Automatic Gates @ Multiple Track Crossing..............................$1,250

It is assumed that the difference ($370) between these costs was attributable to the gate arm and mechanism only. Then, the percentage of the maintenance costs due to the gate arm and mechanism is 29%.

From the preceeding it was learned that $1,500 is the present (1974) estimated maintenance cost for a typical crossing protected with flashing lights and automatic gates, taking 29% of $1,500 yields $435 as the maintenance costs attributable to the present gate and arm mechanism.

The generally accepted value for the lifetime of a typical installation is 30 years. Therefore, the total maintenance costs due to the gate arm and mechanism is

30 x $435 = $13,050

The total cost due to the gate arm and mechanism equals the sum of the initial and maintenance costs.

$7,200 + $13,050 = $20,250

5.2.2 Gate Arm Breakage Costs

Since both concepts feature swingaway designs, it becomes necessary to estimate the resultant savings attributable to this feature. To do this, the present costs due to gate arm breakage must be determined, and the expected costs due to arm breakage for the new-concept designs must be estimated.

From other sources of information, (viz. TSC and the railroad signal engineers that were interviewed), arm breakages occur on the average at an approximate rate of one every one or two years per crossing. An assumed arm breakage rate of .75 per year per crossing is used for estimation purposes.

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[1] "A Program Definition Study for Rail-Highway Grade Crossing Improvement", FRA-RP-70-2, FRA, 1969

The cost of an aluminum or fiberglass gate arm is approximately $300. The estimated cost to install that arm is about $100, implying a total arm replacement cost of about $400. For a 30 year expected lifetime of a typical installation and .75 as the rate of arm breakage, the total cost for broken arms is $9,000.

It can be reasonably expected that the rate of arm breakage is reduced by about 2/3 due to the swingaway feature that is exhibited by both concepts. This yields an expected arm breakage rate of about .25 arms per year. This estimate is really only an educated guess. It is the estimated rate of arm breakage based upon the assumption that most of the present arms are broken by slow moving vehicles which attempt to go around the end of the gate arm.

Using .25 arms per year for the reduced arm breakage rate, the expected total costs attributed to the replacement of broken arms is $3,000, if the assumed replacement costs for a broken arm is $400 each. This results in a savings of $6,000 when compared to the conventional gate systems.

5.2.3 The Overhead Hinged Arm

The following is a breakdown for the estimated equipment costs for the Overhead Hinged Arm based on a quantity of 500.

Motor-Compressor	$ 75.00
Actuator	195.00
Pressure Switch	4.00
Dryer, Dessicant	24.00
Pressure Regulating Valve	10.00
Filter, 50 micron	8.00
Check Valve	2.00
Copper Tube	20.00
Miscellaneous Fittings	40.00
Cable Assembly	7.00
Tank	50.00
Control Box	75.00
Clevis End	8.00
Pulley/Cable Anchor	18.00
Clutch (1-way)	35.00
Arms and Crossbar Assembly	105.00
Drive Mounting Bracket	85.00
Arm Assembly (Parts and Labor)	50.00
Box Assembly (Parts and Labor)	35.00
Cantilever Support	725.00
TOTAL COSTS	$1,571.00

Using a 50% mark-up, the selling price becomes $2,355 each, or $4,710 per crossing. The installation costs are estimated at $4,000. The reason that this cost is higher than that of the conventional devices ($3,000) is the extra work that is needed to install the cantilever structure. Therefore, the total initial cost is $8,710 per crossing.

To estimate the maintenance costs for the Overhead Hinged Arm more assumptions must be made. It has been estimated that of the $13,050 for the maintenance of the conventional mechanism, $9,000 is due to gate arm breakage. Therefore, $4,050 is left for all other maintenance for the gate mechanisms. It will be assumed that the use of a cantilever structure will raise these other maintenance costs to $5,000 due to the extra equipment, time and effort that will be needed to service it. Since the concept uses a swingaway arm, the cost of arm breakage will be assumed to be $3,000. Hence, the total estimated maintenance costs will be $8,000.

Based upon the above assumptions, the total estimated cost for the Overhead Hinged Arm is $16,710. This is a cost reduction of about 17% when compared to the present gate arm and mechanism. It should be noted, however, that these estimated costs do not take into account the possible costs due to secondary damage to the cantilever and mechanism when the gate arm is broken by a vehicle. Therefore, the actual cost reduction is probably somewhat less than 17%. Without actual field testing of this device, it is impossible to estimate these secondary damage costs and any other unforeseen costs.

5.2.4 The Rotating Arm

The following is a breakdown for the estimated equipment costs for the Rotating Arm based on a quantity of 500.

Motor-Compressor	$ 75.00
Actuator	140.00
Pressure Switch	4.00
Pressure Regulating Valve	10.00
Filter, 50 micron	8.00
Check Valve	2.00
Copper Tube	20.00
Miscellaneous Fittings	40.00
Surge Arrestor	4.00
Crank Lever	10.00
Drive Shaft and Bearings	30.00
Tank	50.00
Mounting Bracket for Arm	50.00
Control Box	250.00
Clevis End	8.00
Arm	200.00
Pole	100.00
Dryer, Dessicant	24.00
TOTAL COSTS without Cantilever	$1,025.00
Cantilever Support	725.00
Pole	(100.00)
TOTAL COSTS with Cantilever	$1,650.00

Using 50% as the mark-up, the selling price for the Rotating Arm, without the cantilever, becomes $1,537 each or $3,075 per crossing. Also, using $3,000 as the installation costs, the total initial costs are $6,075. The maintenance costs will equal the $4,050 due to regular maintenance plus the $3,000[1] attributable to gate arm breakage or a total maintenance cost of $7,050. Therefore, the total cost equals $13,125. This represents a cost reduction of about 35% when compared to conventional devices.

If the cantilever support is to be considered, the initial costs become $8,150 (an extra $200 installation cost). Keeping maintenance costs constant, the total costs become $15,200. In this instance, there is an estimated 25% reduction in costs.

5.2.5 Economic Analysis Summary

Table 2 shows a cost summary for the conventional, the Overhead Hinged Arm, and the Rotating Arm concepts.

TABLE 2

COST SUMMARY

Device	Initial Costs	Maintenance Costs	Total Costs	Estimated Cost Reduction
Conventional	$ 7,200	$ 13,050	$20,250	--
Overhead Hinged Arm	8,710	8,000	16,710	17%
Rotating Arm (with Cantilever)	8,150	7,050	15,200	25%
Rotating Arm (without Cantilever)	6,075	7,050	13,125	35%

[1] It should be noted that this cost was determined for replacing an aluminum arm. The arm that is recommended for this devices is the sectionalized polycarbonate arm which would further lower the gate arm breakage costs.

It can be seen that the Rotating Arm has the apparent lowest total costs and also the largest reduction potential. However, these cost figures are only estimates based upon preliminary design and analysis. There are many areas of possible error: profit margins, installation costs, and the maintenance costs attributable to the gate mechanisms. What these figures do suggest is the relative cost of each concept when compared to each other.

The reliability of these cost figures would be greatly increased if a larger and more extensive sampling of the railroads were undertaken. Actual development and field testing of the new concepts would yield a more accurate estimate for the equipment and recurring costs.

6. CONCLUSIONS AND RECOMMENDATIONS

From the previous sections, it is obvious that the Rotating Arm is both technically and economically the more promising of the two concepts. The Rotating Arm is sturdier and allows for easier installation and maintenance when compared to the Overhead Hinged Arm. Also, it should effect a greater reduction in costs with respect to equipment and recurring costs. Due to these characteristics, it is the Rotating Arm that has been chosen as the recommended concept.

The Rotating Arm differs with the conventional devices in two respects. It is pneumatically powered and features a swingaway arm that will yield on impact. It is impossible to determine the exact effects these will have on safety and costs without actually field testing this device at several crossings. It appears that neither feature should adversely affect safety, but the analysis described here suggests that both will effect a cost savings. For example, the Rotating Arm should reduce total costs significantly through reduced arm breakage and the fact that all parts are commercially available at competitive prices.

The economic analysis performed for this concept showed an estimated cost reduction potential of about 25%, with an even greater cost reduction (35%) if the Rotating Arm is used without the overhead cantilever lights. (Since the overhead lights apparently provide a better warning for the motorist, it is recommended that they be a part of the device.) There are, however, certain unpredictable factors that were not taken into account during the economic analysis which could easily make these percentages vary considerably. Thus, it would be more reasonable to use an estimated range for the cost reduction potential. Arbitrarily, it is estimated that the actual cost savings probably vary ± 5% from the predicted cost savings. Therefore, the probable cost reduction potential of the Rotating Arm is 20% to 30% when compared to conventional mechanisms.

Besides the standard cost savings that have been shown, there exist other areas in which this concept promises to show cost reductions. When the replacement costs for broken arms was estimated, the costs were based on those for an aluminum arm. With use of a sectionalized polycarbonate arm, these replacement costs could be lower, since only one or two sections will need to be replaced. Damage to the drive shaft can be avoided by using a different grade of polycarbonate for the arm section closest to the shaft. This section would be brittle which would cause it to break before any damaging impacts could be transmitted to the drive shaft.

Technically, this concept should be realizable within AAR standards, with the possible exception of the 3,000 volt insulation on the motor. As stated earlier, it is felt that the risk of the motor being damaged by a power surge is sufficiently small so as to allow for the utilization of standard insulation. A motor using the 3,000 volt insulation could be used but the increase in the initial equipment costs would lower the potential for cost savings.

The pneumatic system should not be objectionable to the railroads since the air brakes used on trains and many track switches are already pneumatic devices. It is obvious that the railroads have already exhibited a confidence in pneumatic devices.

Based upon the preceeding, it appears that the Rotating Arm (preferably used with cantilever lights) warrants development since a 20% to 30% reduction in total costs is projected without loss of safety or function. A development and testing program should provide many answers with respect to costs of equipment, installation, maintenance and arm breakage. The testing of the device should include impact testing to show speeds and angles of approach that the device can withstand without the arm breaking. Life cycle tests and tests to determine the environmental characteristics of the device would also be useful in estimating recurring costs. This testing would allow for a more accurate comparison with the conventional mechanisms.

During the course of this study, several areas not formally a part of the gate mechanism were investigated briefly. One example of this was the remote monitoring of the crossing using a device similar to the present radio call box (see Section 3.3). Other areas included the use of solid state relay logic, alternative detection techniques and improved forms of surge suppression. These specific areas were investigated by the Eagle Signal Division. It is recommended that a study be conducted that would investigate the feasibility of using remote monitoring techniques. The use of solid state relays and improved surge suppression techniques also should be the subjects of further study. The application of such technology to railroad crossing signals may do much to provide lower cost warning systems, thereby enhancing overall safety.

In conclusion, the Rotating Arm appears to satisfy the objective of this study. It is innovative in the sense that it utilizes a pneumatic drive system and the arm can withstand slow speed impacts without being damaged. The true extent of the potential it offers in cost reduction can only be realized through a development and testing program and finally actual usage at grade crossings. Potential cost savings may well be sufficient to permit use of gates at many more crossings than at present, with consequent improvement of grade crossing safety.

APPENDIX A

GLOSSARY

Active Protection	Refers to flashing light signals or automatic gates. Provides a warning indication to the motorist when a train or other railroad movement approaches or occupies the crossing.
Failsafe	A failure of any part in the warning system will result in the activation of the warning signals.
Passive Protection	Crossbuck signs or similar fixed signs without flashing light signals or gates. It merely designates the location of the crossing, sometimes with appropriate supplemental information on the number of tracks or other significant facts.
Reliability	The ability of a device to function as intended. Degree of consistent dependability.

APPENDIX B

REPORT OF INVENTIONS

The objective of the contract reported in this document was the generation and evaluation of innovative gate concepts. A number of novel unusual ideas resulted in the course of the project. Both teams found the concept of a rotating swing-away arm attractive, and several alternatives for arm materials and drive mechanisms were presented. All promising concepts are described in the two report volumes.

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