IOWA DEPARTMENT OF TRANSPORTATION
AUTOMATED TRUCK MEASURING SYSTEM

FINAL REPORT

MAY 1991

IOWA STATE UNIVERSITY

CPR E 482
EE 462

Iowa State University
Department of Electrical and
Computer Engineering

May 10, 1991

Bill McCall
Director, Transportation Planning and Research Division
Iowa Department of Transportation
Ames, IA 50010

Dear Mr. McCall:

Enclosed is the Iowa State University truck measurement design team final report. This report summarizes the work done by the ISU team including research and testing from September 1990 to May 1991.

At the time of this report, there is a prototype system in operation at a weigh station south of Ames. Because of budget constraints, this system only has the basic elements necessary to determine the feasibility of an automated measurement system.

The designing and building of a permanent installation and implementation of the rest of the system will be left to the DOT. This report will be useful in designing a permanent system for future weigh stations.

We have enjoyed working with the DOT on this project and have gained valuable experience. We anticipate seeing the final system in operation in the near future. If you have and questions, please contact any one of us through Dr. E. C. Jones, 240 Engineering Annex, 294 - 4962.

Sincerely,

William Grupp
ISU DOT Design Team

enclosure: Report (1 copy)

PURPOSE

This document contains a proposal for an automated truck measuring system designed for the Iowa Department of transportation. It includes information on the problem description, research, design, and testing of a possible system by a student design team at Iowa State University.

EXECUTIVE SUMMARY

The Department of Transportation has been working to develop a dynamic weigh station and this EE 462/CPR E 482 design team was given the opportunity to design a system to measure the height and width of the trucks while in motion. This report will contain a brief description of our accomplishments, and a detailed description can be found in the appendices.

We decided that using an ultrasound system was the best method of measurement. The prototype that uses this system, was set up at the northbound weigh station on Interstate 35 south of Ames. A system of three ISU 1000 transducers, purchased from Contaq Incorporated, was constructed for testing purposes. They were arranged in the configuration of one transducer directly above the road to measure the height and one transducer on each side of the road to measure the width of the vehicles.

During the last month, we have devoted most of the time spent on this project to testing the prototype system at the weigh station. The results that we have collected to this point have had a high degree of accuracy, taking the weather effects of wind and rain and the human effects of not being able to measure the trucks at their appropriate highest and widest spots into account.

Taking an estimation of the cost so far, it is approximately $4100. This price is including the initial cost of the old system and the fractional, additional cost of the ISU 1000 system, after exchanging the old system for the ISU 1000 system. Since it is just a prototype system, the final cost is still not known. A few additional costs that remain are the permanent overhead structure, more transducers for better accuracy, and the labor for installation.

Since the prototype system is working within a good degree of accuracy, we agree that using transducers will work for measuring trucks. We recommend that seven transducers should be incorporated into the final system, because all different shapes of trucks could be covered.

Why 7? Why not 9 or 10?

If in the future truck lengths data is deemed necessary a system of axle detectors could be used.

EXPLAIN FURTHER

TABLE OF CONTENTS

LIST OF APPENDIXES

1. INTRODUCTION

In August of 1990, this EE461/CPR E 481 design team undertook the continuance of a two year design project for the Iowa Department of Transportation under the auspices of Bill McCall, Director of the Transportation Planning and Research Division. The intent of this report is to describe the events that transpired from September 1990 to May 1991 and to explain further procedures required for implementation of the final product.

In an effort to alleviate problems with static measurement methods, the DOT is working towards creating a completely dynamic station. We are playing an active role in developing such a weigh station. Dynamic scales already exist; however, a means for measuring the height and width of a vehicle in motion does not yet exist. Last year's team was approached with the problem of developing a method to do this. The following criteria were given:

1. The system must be able to measure the height and width of a vehicle while it is moving.

2. The system must be accurate to within one inch.

3. The system must be able to withstand and perform in adverse weather conditions.

4. The system must be able to record the dimensions of the highest and widest part of the vehicle.

5. The system must cost less than $5000.

The design that we developed involves the use of seven transducers purchased from Contaq at a cost of $498 per transducer. The total cost amounts to $4100 which includes the wire, the power supply, the transducers, and the interface. This does not include the cost of items supplied or work done by the DOT.

The preliminary testing with the prototype system that was installed at the northbound weigh station on I-35, has proven to produce results with a high degree of accuracy. This report will briefly describe the prototype design, the testing results, recommendations for the final system, and a breakdown of the cost for this system. A more detailed description of the components and the actual test results are found in the appendices C and E, respectively..

2. PROTOTYPE SYSTEM DESCRIPTION

The team has decided that in order to achieve an accurate assessment of the greatest height and width of a truck, we require a minimum of 20 measurements from each transducer per second. The ISU system produced by Contaq will be used to achieve this goal. Other companies produce better equipment than the ISU system; however the ISU is the most cost effective. The prototype system used consisted of three ISU transducers. They were connected to a temporary structure located at the northbound weigh station on I-35 south of Ames. One transducer was located on top and one on each side of the structure. The transducers were controlled by a Toshiba 1200 laptop computer, which was located at the weigh station building about 500 feet away from the structure.

2.1 Operation

With the ISU system, three ISU 1000 transducers are positioned on an overhead structure in the configuration previously described. An RS-485 cable links the transducers to the computer. Simultaneous operation allows each transducer to operate at 20 hertz or 20 measurements per second. These measurement are then read individually by the computer,which then processes the data to determine the truck's maximum height and width.

2.2 Computer Control

The operation of the above mentioned system is controlled by the Toshiba 1200. The program to control the system was written in Quick Basic to provide a fast enough response. This program has different functions including: 1) setting calibrations, 2) displaying current settings, 3) setting limits on the systems, and 4) measuring trucks. A copy of the program is in appendix D.

The transducer located at the top of the structure is used to determine the speed of sound which in turn is used to calibrate the measurements from the transducers. This will provide greater accuracy when the temperature and humidity changes, because of the effect both have on the speed of sound.

The normalized height and width of the structure relative to the temperature and humidity, can be set by the operator of the computer. The maximum allowable height and width of a truck according to the law can also be set.

The main part of the program deals with sending a signal to and receiving a measurement from the ISU transducers. The computer sends a signal to the transducers to retrieve the current measurement. The results are sent back to the computer through the serial port. This is done while the transducers continuously take measurements.

When calculating the height of the truck, the overhead transducer is used. Each measurement is first multiplied by the calibration factor, and then the smallest number is chosen and subtracted from the normalized frame height to give the maximum height of the truck.

The width measurement is a little more complicated. The measurements from the two transducers on the sides are first multiplied by the calibration factor. Then the results from the two transducers are added together, and the minimum value is subtracted from the width of the structure. This value is the maximum width of the truck.

The measurements of the maximum calculated height and width are displayed on the screen. Currently these results are not permanently stored, but the final program will store the maximum height and width of each truck in a data base.

3.0 SYSTEM TESTING RESULTS

A multitude of height and width measurements was collected under various weather conditions. Due to the limited time available to collect this data, not all of the weather conditions typical to Iowa were encountered during testing. The conditions that were encountered were rain, high winds, and temperatures ranging from 40 to 80 degrees.

3.1 Measurement Statistics

The following table shows an analysis of the data taken on each truck. The types of trucks were dump, van, tanker, flatbed, and livestock. There were not enough measurements to make an analysis of the prototype system's performance on grain or pick-up trucks.

3.1.1 Table of Measurement Statistics

DUMP	TRUCKS MEASURED		
HEIGHT	35	AVERAGE DIFFERENCE	7.74"
		AVERAGE PERCENT ERROR	8.82%
		STANDARD DEVIATION	9.40%
WIDTH	49	AVERAGE DIFFERENCE	3.30"
		AVERAGE PERCENT ERROR	7.45%
		STANDARD DEVIATION	9.95%
VAN	TRUCKS MEASURED		
HEIGHT	138	AVERAGE DIFFERENCE	1.66"
		AVERAGE PERCENT ERROR	1.37%
		STANDARD DEVIATION	1.35%
WIDTH	143	AVERAGE DIFFERENCE	0.67"
		AVERAGE PERCENT ERROR	2.69%
		STANDARD DEVIATION	2.03%
TANK	TRUCKS MEASURED		
HEIGHT	36	AVERAGE DIFFERENCE	5.81"
		AVERAGE PERCENT ERROR	5.54%
		STANDARD DEVIATION	6.86%
WIDTH	40	AVERAGE DIFFERENCE	5.95"
		AVERAGE PERCENT ERROR	9.28%
		STANDARD DEVIATION	10.39%
LIVESTOCK	TRUCKS MEASURED		
HEIGHT	6	AVERAGE DIFFERENCE	1.50"
		AVERAGE PERCENT ERROR	0.93%
		STANDARD DEVIATION	1.02%
WIDTH	6	AVERAGE DIFFERENCE	0.63"
		AVERAGE PERCENT ERROR	1.53%
		STANDARD DEVIATION	1.45%
FLAT BED	TRUCKS MEASURED		
HEIGHT	39	AVERAGE DIFFERENCE	7.10"
		AVERAGE PERCENT ERROR	6.06%
		STANDARD DEVIATION	9.95%
WIDTH	48	AVERAGE DIFFERENCE	0.93"
		AVERAGE PERCENT ERROR	6.10%
		STANDARD DEVIATION	6.39%

3.2 Result Interpretation

The table of measurement statistics was interpreted to determine the accuracy of the prototype system for each style of truck. The interpretation includes errors from several sources. These are wind effects, sensor position, odd surfaces of the trucks, and static measurement techniques.

3.2.1 Height Measurement Observations The system performance on height measurements had an average percent error of 4.5 %. The amount of error was less on trucks that were square in shape. Trucks with rounded or irregular surfaces did not measure as accurately. This may be due to a few reasons. The most likely source of error on irregular shaped trucks was the position of the truck as it passed beneath the overhead sensor. With only one overhead sensor, it was impossible to ensure the highest part of the truck would be measured by the system. It was also not possible to determine if the static measurements were taken at the highest (and widest) part of the truck. Overall the system was not within the required one inch, but did perform well enough to record measurements within five percent.

3.2.2 Width Measurement Observations The system performance on width measurements had an average percent error of 5.4 %. Again, the system performed better on trucks that were square in shape. Tank style trucks had the highest amount of measurement error. The high amount of error on these trucks is most likely due to the position of the sensors and the number of sensors used to measure the vehicles width. The overall system performance on width measurements was not within the required one inch and not as good as the height results, but was, for all trucks, within 10 percent.

3.3 Weather Conditions

The effects of rain and temperature change had little to no noticeable effect on the accuracy of the height and width measurements. The wind had the most detrimental effect due to the positioning of the top transducer on a wire over the road.

3.3.1 Wind Effects The effects of the wind on the prototype system were mainly caused by the temporary nature of the support structure. The movement of this structure in high wind made it difficult to obtain accurate measurements under those conditions. The reason for this is the angle of reflection of the sound is too great when the transducer is tilted by the wind.

How do we know this?

4.0 COST ANALYSIS

The hardware costs of the ISU 1000 system are outlined below.

ISU TRANSDUCERS	$469.00 ea.
RATE INCREASE	$29.00
TRANSDUCER TOTAL	$498.00 ea.
	3
TRANSDUCERS (3)	$1,494.00
1000' CABLE	$250.00
MISCELLANEOUS	$150.00
TOTAL COST	$1,794.00

This cost only includes the cost associated with the hardware of the actual system. Other costs such as the cost of erecting the rigid structure, burying the cable, and the cost of the DOT's labor were not included.

5.0 IMPLEMENTATION RECOMMENDATIONS

In order for this prototype system to become a fully functioning truck measurement system, several improvements and changes need to be made. These changes include: 1) the use of at least 7 transducers, 2) a permanent rigid structure, 3) a different computer, and 4) a change in the power supply. These changes will make the system more accurate, reliable, and easier to operate.

5.1 Seven Transducers

The original design called for the use of seven transducers to accurately measure the entire height and width of the truck. This would still be necessary for the final system, in order to completely cover all size vehicles. Each transducer has a spread angle of 12 degrees, so that covers approximately a circle of three feet in diameter on the side or top of the truck. With seven transducers, the system would be able to cover a nine foot section across the top and a six foot section in the vertical direction on each side. Additional sensors would be required if a larger area was to be covered. This should be sufficient to produce an accurate measurement of the truck.

5.2 Permanent Structure

The permanent structure must be able to rigidly support the transducers. The structure must also be able to support three transducers across the top directly perpendicular to the road. The other four transducers must be set up directly parallel to each other and the road. This arrangement should reduce many of the inaccuracies that have been noticed in the prototype system. In particular the detrimental effect of high winds on the system will be significantly reduced if not entirely eliminated with the rigid structure.

5.3 Alternate Computer

The present Toshiba 1200 computer has been sufficient for the purposes of testing the prototype system; however, the final system will require a more capable computer. Expansion slots for the purpose of using a RS-485 interface card is a required capability. This card will allow the computer to directly control the transducers. The Toshiba 1200 does contain this feature.

5.4 Power Supply and Selection of Computer Cable

The power supplied to the transducers should be supplied directly at the structure This will eliminate the need to run the power out to the structure with the data signals. The problem with this is the small computer cable creates too great of a voltage drop over 500 feet of wire. The computer cable used will then be two conductor cable. This cable should be suitable for underground operation.

6.0 CONCLUSION

This design team has been working with the Department of Transportation to develop a dynamic system to measure the height and width of a moving truck. A prototype system was designed and tested to achieve this goal. The test results show that the prototype system achieves a high degree of accuracy although not meeting the goal, to be accurate to within one inch, given by the DOT.

Recommendations have been presented on how to increase the accuracy for a final system. These recommendations are as follows, the use of seven transducers, a rigid permanent structure, a computer with expansion slots for the use of a RS-485 interface card, and power supplied at the structure.

With these changes to the prototype system we conclude that this system can become a functional working system that can be used either to gather statistical information about heights and width of trucks or to locate oversized vehicles.

APPENDIX A

PROBLEM WITH LAST YEAR'S DESIGN

When the old system was put together, a problem of cycling time was discovered. From the DOT specifications, it was determined that 20 complete cycle measurements per truck is the minimum sampling rate to produce an accurate representation of each truck. For this design, it means being capable of recording 20 measurements per second. This figure was determined using an average speed of 30 mph and an average length of 60 feet per truck. At this length and velocity, a truck will be in the view of the transducers for 1.5 seconds.

From the specifications sheet of the Distance Measurement Instrument, the design team last year concluded that the cycle rate of 13 measurements per second was the complete cycle time for all seven sensors, which would have been close to what was needed. This was a misinterpretation of the data sheet. Instead, this refers to only one sensor. This was discovered after the system was tested in the lab. The resulting rate was about 1 or 2 measurements for the time it takes a truck to pass through the system, far less than the 20-30 measurements that are needed. It was, therefore, necessary to modify the design to correct this problem.

APPENDIX B

ALTERNATE SOLUTIONS TO LAST YEAR'S DESIGN

1. Alternate Solutions

Correcting the problem required a revision of the old design. This could have been done a number of different ways. We researched three different ways of improving the design, each of them are based on the original design. The three other options that were considered were: 1) Increase the rate at which the DMI board operates. 2) A system based on Contaq's Remote Measurement Unit (RMU) could be developed. 3) A system based on Contaq's Intelligent Sensor Unit (ISU) could be developed.

Included in this appendix are copies of the letters of correspondence between the design team, Bill McCall and Contaq. The first letter was our proposal to Contaq. The second letter deals with our proposal to Bill McCall, which contains the response from Contaq. The final letter was written to Bill McCall and contains the estimated additional cost of the system using the ISU transducers.

1.1 Increase DMI Board Rate

After consulting with Contaq, the manufacturer of the DMI board, we found that the rate of the board can be increased. The standard product can handle as much as 13 measurements per second. This can be increased to as high as 60 measurements per second; however, a trade off exists between the response time and the maximum range. If we increased the rate to 20 measurements per second the range would be about 17 ft. This would be a sufficient range to reach any object within the structure. The cost for such an adjustment is $50.00. The advantage with this system is that it is an inexpensive upgrade. The disadvantage with this alternative is that all of the transducers have to be multiplexed into the DMI which decreases the cycle time. With seven transducers, this method could complete almost three cycles per second. This is far less than the 20 cycles per second that are required.

1.2 Develop RMU Based System

A second option was to return the old system, (The DMI system), and purchase the Remote Measurement Unit (RMU) system. This system would consist of 6 Polaroid transducers, 3 RMU-200 units, a multiplexer and the Toshiba T1200 computer. This system would be very similar to the original system. The main difference is that the 3 RMU units would replace the DMI board. Each RMU unit would interface with 2 transducers. The RMU units would then interface with the computer through a multiplexer. The advantage of this system is that it will have a measuring rate fast enough to complete 9 cycles per second. This is a big improvement over the DMI system. The disadvantages are: 1) The increased measurement rate is still much slower than the 20 measurement cycles per second that would be required to obtain the maximum height and width of a truck. Therefore this system would still have to be updated to actually work for the DOT. 2) This system would cost about $2000 , $1485 for the 3 RMU units and approximately $500 for a new multiplexer. The increased rate is not great enough to justify the cost of the system.

1.3 Develop ISU Based System

The third option to increase the speed of the system is to develop a system based on Contaq's Intelligent Sensor Unit. This device is an ultrasonic sensor and measurement board contained in an environmental housing. This system again consists of 7 transducers, located on an overhead structure. These, however, use a RS-485 multi-drop interface that does not require a multiplexer. With a modification, these transducers can be made to operate at 20 readings per second.

Because there is no longer a need to multiplex the signals to the transducers, and each transducer has its own measurement board, the entire system will be able to operate at 20 cycles per second. The cost of this option is $4200.00 for the 7 ISU transducers.

$4200

Brian S. Law
2919 Oakland
Ames, Ia. 50010
(515)292-9641

November 16, 1990

Mr. Paul Orellana
Contaq Technologies Corporation
15 Main Street
Bristol, Vermont 05443

The purpose of this letter is to propose a preliminary return and purchase agreement.

On April 1, 1990, a purchase order, identical to the enclosed copy, was mailed to you. The Iowa State University senior design team purchased this equipment, through the Iowa Department of Transportation, believing that the response time of the equipment would be fast enough to meet the requirements of the design project. Upon further study of the equipment specifications, it was determined that the system would not respond fast enough, even if it was modified to increase the response time.

Our desire is to return this equipment for credit on an Intelligent Sensor Unit system. We would like to return the sections of coaxial cable, the serial port instrument, the seven channel multiplexer, the power supply, and the enclosure. These items are highlited on the enclosed purchase order copy. The total price of these components is $1786, and we would like to apply this to the cost of seven ISU 1000 transducers.

Upon completion of this project, the Iowa Department of Transportation will be implementing this system at the busier weigh stations in the state. This system is expected to gain national exposure with many different state transportation departments.

I will be contacting you by phone within the week for your response. Your approval of this proposal would be greatly appreciated. Thank you.

Sincerely,

Brian S. Law

Brian S. Law

Department of Electrical
and Computer Engineering
Iowa State University
December 4, 1990

Bill McCall
Director, Transportation Planning
and Research Division
Iowa Department of Transportation
Ames, Ia. 50010

Dear Mr. McCall:

On November 16,1990 I sent a proposal to Paul Orellana requesting a return of our equipment for the purchase of an Intelligent Sensor Unit system. A copy of the proposal and response are attached to the back of this memo.

As you can see, Contaq is willing to give us credit for the returned equipment upon receipt of an order for seven ISU transducers. They have agreed to credit our account for $1786 minus a 10% restocking fee. The net amount will be $1607.40.

Our team had proposed purchasing the Remote Measurement Unit as alternative to the ISU: however, after further consideration, we have decided that this is not an acceptable option. The response time of the RMU would not be quite fast enough to receive an accurate measurement. As a result, we recommend purchasing seven ISU transducers and returning the equipment that was previously purchased. The cost of this option is as follows:

ISU TRANSDUCERS	$469.00	Ea.
RATE INCREASE CONVERSION	29.00	Ea.
PRICE PER TRANSDUCER	$498.00	
	7	
THE PRICE OF SEVEN	$3,486.00	
	$0.98	
LESS 2% DISCOUNT	$3,416.28	
LESS CREDIT	$1,607.40	
REQUIRED ADDITIONAL AMOUNT	$1,808.88	

In order to purchase the ISU system, we would need an additional $1,808.88 after deduction the credited account. In order to save time, we would like to send in the order and the equipment before the end of this semester on December 21,1990.

Sincerely,

Brian S. Law

Brian S. Law
ISU DOT Design Team

Department of Electrical
and Computer Engineering
Iowa State University
December 4, 1990

Bill McCall (Sam Sermet)
Director, Transportation Planning
and Research Division
Iowa Department of Transportation
Ames, Ia. 50010

Dear Mr. McCall:

I talked with Paul Orellana at Contaq in regards to the accuracy of the ISU transducer. He assured me that if the transducer was calibrated for temperature and humidity that the accuracy would be 0.007". The program that we have written does this automatically when there is no target in view; therefore, the accuracy of the system should not be a problem.

The figures that you requested are listed below. The final amount includes everything that we will require.

ISU TRANSDUCERS	$469.00	Ea.
RATE INCREASE CONVERSION	29.00	Ea.
PRICE PER TRANSDUCER	$498.00	
	7	
THE PRICE OF SEVEN	$3,486.00	
	$0.98	
LESS 2% DISCOUNT	$3,416.28	
LESS CREDIT	$1,607.40	
AMOUNT OWED TO CONTAQ	$1,808.88	
12V POWER SUPPLY	- $85.00	
8 CONNECTORS WITH HOODS	$54.00	
COMPUTER CABLE 1000 FT.	$500.00	
REQUIRED ADDITIONAL AMOUNT	$2,447.88	

Please inform me or one of the other team members on the status of this situation. If you need the Contaq catalog for ordering information myself or Mike Dolan can get that to you.

Sincerely,

Brian D. Law

Brian Law

APPENDIX C

PROTOTYPE SYSTEM COMPONENTS

2. Components

The prototype consists of the following components 1) three ISU transducers, 2) Toshiba laptop computer, 3) RS-232 to RS-485 interface, and 4) connecting cable.

2.1 The Transducer

This prototype system uses three ISU 1000 transducer produced by Contaq. These transducers contain both a measurement board and an RS-485. The measurement board and transducer are then both housed in a weather-proof enclosure. Each transducer works independently from the others. They each take approximately 20 measurements per second and are able to measure up to a distance of 24 feet. The sound wave radiates away from the transducer at a 12 degree angle.

2.1.1 RS-485 interface The RS-485 is a multi-drop interface. This allows the multiple transducers to be connected to the computer without the use of a multiplexer. The transducers are each assigned an address which can then be selected by the computer. Each transducer can then be called to send its current measurement. Using this interface allows the 7 transducers to take measurements simultaneously to increase the speed of the system. The RS-485 has a maximum cable length of 4000 feet. This will allow the placement of the structure to be anywhere within a 4000 foot radius of the weigh station.

2.1.2 Operating ranges Contaq guarantees the ISU sensors to operate between 0° and 70°C; however the sales representative at Contaq claims that it will operate at colder temperatures because of the weatherproof housing. The system is also guaranteed to operate in humidity in the range of 5% to 95%. On the few days of the year when the humidity is greater than 95% the sensor may be used, but the sensor may not be accurate to within one percent.

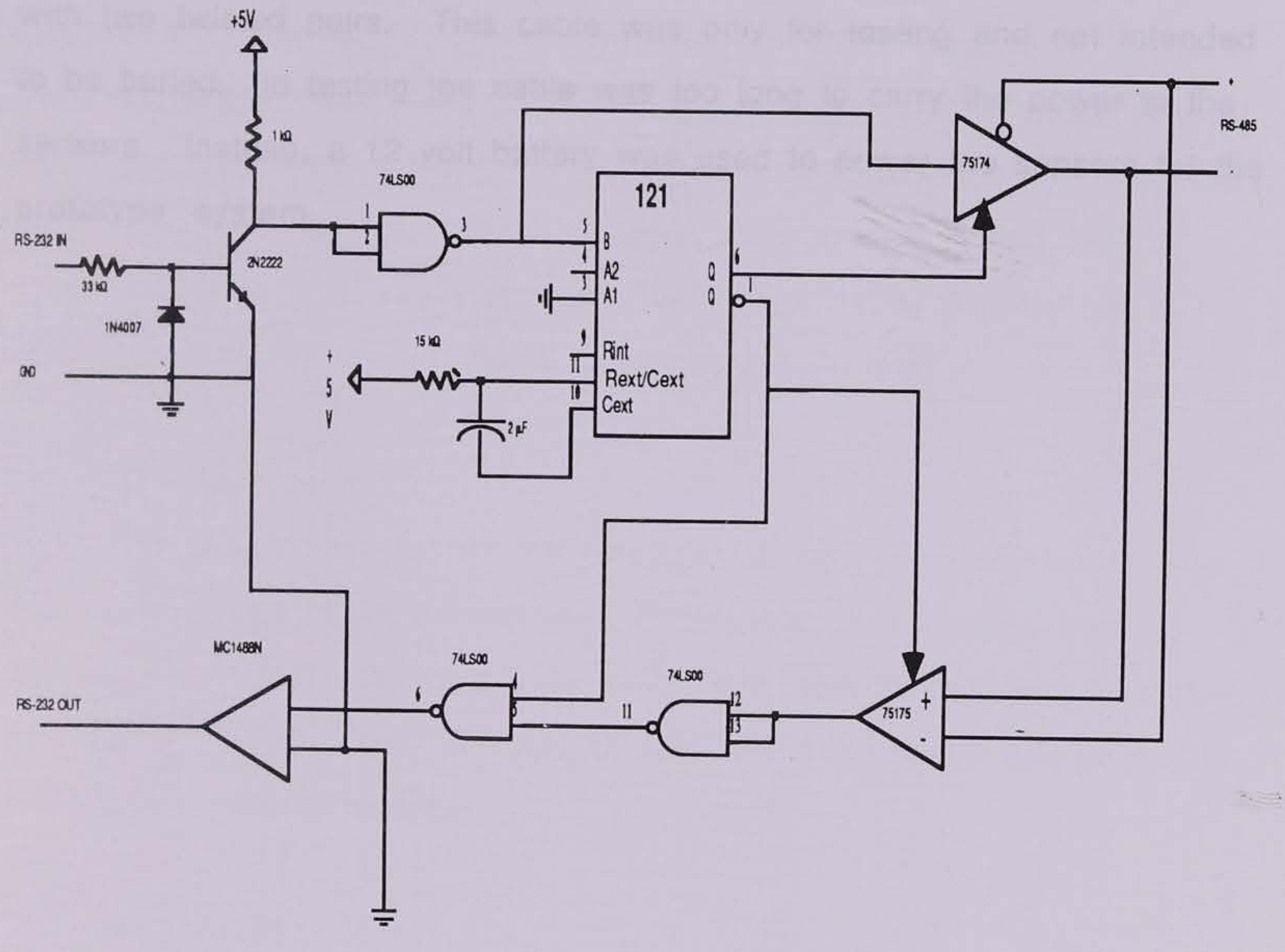
2.2 Toshiba Laptop Computer

The ISU - 1000 transducers are controlled by a PC compatible computer. The computer that the DOT provided is a Toshiba 1200 laptop computer. The Toshiba 1200 has a built in RS-232 serial port that can be used to communicate with other devices. A program was written for the laptop computer to control the operation of the sensors and record and interpret the information. The computer did not have any expansion slots to receive additional interface boards.

2.3 RS-232 to RS-485 Interface

Because the Toshiba computer was not able to accept an interface board to connect to the sensors, it was necessary to use an interface external to the computer. There are commercially available converters that would work for this system but they were out of the price range for the project. For this reason, a converter to adapt RS-232 signals to RS-485 signals was developed by our team. Using information from Contaq about the specific operation of their ISU-1000 transducers, a device was developed that would control the flow of information from the transducers to the computer. This device was constructed using parts supplied by Iowa State with a total cost of under $50.00. The device was then tested in a lab at Iowa State. The circuit for the interface is shown below.

2.3.1 Converter Diagram



2.4 Connecting Cable

A cable to connect the sensors to the computer was necessary. The sensors were located approximately 500 feet from the computer. This cable needed to be able to carry both the data signals and power to the sensors. A 1000 foot reel of cable was purchased from the Newark cable catalog. The cable chosen was a four conductor, 22 AWG shielded cable with two twisted pairs. This cable was only for testing and not intended to be buried. In testing the cable was too long to carry the power to the sensors. Instead, a 12 volt battery was used to power the sensors for the prototype system.

APPENDIX D

COMPUTER PROGRAM

3. Computer Programs Used

The two programs used to run the prototype design system are included in this appendix. They were written in Quick Basic and run on the Toshiba 1200 computer. The first program was used to make sure all the transducers were working and the second one calculated the height and width of a moving truck. These program were written to test the operation of the prototype system and were intended to be used as building blocks for an automated measurement system.

3.1 First Program

This program instructed the computer to take a measurement reading from one of the transducers. It converted this reading into a distance value and displayed it on the screen. This process was repeated for each the transducers. A value of zero would indicate if one of the transducers wasn't working.

3.1.1 DOT3.BAS

```
5 ' DOT TRUCK PROJECT
6 ' ver 3  William Grupp
7 ' NOTES: VER 1.2 Is set up to drive three ISU sensors, one on each
8 ' side of the truck.
9 ' USE TO DETERMINE IF SENSORS ARE WORKING.  GIVES MEASUREMENTS OF EACH

11 ' SENSOR NUMBERS
12 ' S(1) = LEFT
```

```
13 ' S(2) = TOP
14 ' S(3) = RIGHT
15 DIM S(10), SENID$(3)
17 SENID$(1) = "Z1284:U"
18 SENID$(2) = "Z1285:U"
19 SENID$(3) = "Z1286:U"
20 CLS
30 PRINT " IOWA DOT TRUCK PROJECT "
40 PRINT " IOWA STATE UNIVERSITY "
50 PRINT " VERSION 1.2.3 "
60 PRINT : PRINT : PRINT

10000 ' MEASURE TRUCKS
10005 OPEN "COM1:9600,N,8,2,CS,DS,CD" FOR RANDOM AS #1 LEN = 256
10010 '
10015 LOCATE 1, 1
10020 PRINT : PRINT : PRINT : PRINT : PRINT
10030 PRINT " MEASURING TRUCKS -- PRESS 'E' EXIT "
10040 ZZ$ = INKEY$: IF ZZ$ = "E" OR ZZ$ = "e" THEN CLOSE #1: END

10050 'MEASUREMENT LOOP
10060 'GET READINGS FROM EACH SENSOR
10080 FOR SENNUM = 1 TO 3
10090 GOSUB 30000
10100 NEXT SENNUM

10250 ' PRINT MEASUREMENTS
10260 PRINT SENID$(1), S(1)
10265 PRINT SENID$(2), S(2)
10270 PRINT SENID$(3), S(3)
15000 GOTO 10015

30000 'THIS SUBROUTINE WILL RECEIVE A READING FROM THE TRANSDUCER
30010 'DELAY MAY BE NEEDED
30020 FOR WW = 1 TO 8: NEXT WW
30030 PRINT #1, SENID$(SENNUM)
530040 A$ = INPUT$(LOC(1), #1)
30050 S(SENNUM) = VAL(A$) * .007324218#
30100 RETURN
```

3.2 Second Program

The second program was used to run the prototype system. It calculated the height and with of a moving truck. To determine the height measurement, the reading received by the computer from the overhead sensor was subtracted from the frame height. This height was stored if it was greater than the current maximum height for that truck. The same procedure was used to determine the width except the distance from each side sensor was subtracted from the frame width. This width was then stored if it was greater than the current maximum width. To determine when a truck has passed the structure, a count of the number of zero height readings were kept. A total of 15 consecutive zero height measurements signaled the program to print the current maximum height and width. There are several options the user can use. The options are: set calibration (inputting height and width of the structure), display current height and width settings, set regulatory limits, and measure trucks. These options are listed in the program below.

3.2.1 DOT6P.BAS

```
5  ' DOT TRUCK PROJECT
6  ' ver 6P  William Grupp
7  ' NOTES: VER 1.2 Is set up to drive three ISU sensors, one on each
8  ' side of the truck.

11 ' SENSOR NUMBERS
12 ' S(1) = LEFT
13 ' S(2) = TOP
14 ' S(3) = RIGHT
15 DIM S(10), SENID$(3)
17 SENID$(1) = "Z1284:U"
18 SENID$(2) = "Z1285:U"
19 SENID$(3) = "Z1286:U"
20 CLS

25 'INIT
27 GOSUB 16000

30 PRINT " IOWA DOT TRUCK PROJECT "
40 PRINT " IOWA STATE UNIVERSITY "
50 PRINT " VERSION 1.2.6P "
60 PRINT : PRINT : PRINT
70 ' MENU
80 PRINT " MAIN MENU "
90 PRINT : PRINT " SELECT FROM THE FOLLOWING:"
100 PRINT " C - SET CALIBRATION  "
105 PRINT " D - DISPLAY CURRENT SETTINGS "
110 PRINT " L - SET LIMITS        "
```

```
120 PRINT " M - MEASURE TRUCKS   "
130 PRINT " Q - QUIT "
200 PRINT : PRINT
210 PRINT " SELECT ONE (C,D,L,M,Q)"
220 A$ = INKEY$: IF A$ = "" GOTO 220
230 IF A$ = "C" OR A$ = "c" THEN GOSUB 3000
235 IF A$ = "D" OR A$ = "d" THEN GOSUB 6000
240 IF A$ = "L" OR A$ = "l" THEN GOSUB 4000
250 IF A$ = "M" OR A$ = "m" THEN GOSUB 10000
260 IF A$ = "Q" OR A$ = "q" THEN END
300 GOTO 20
3000 ' SET CALIBRATION MEASUREMENTS
3010 CLS : PRINT : PRINT : PRINT
3020 PRINT " THIS SELECTION SETS THE CURRENT FRAME MEASUREMENTS "
3030 PRINT " DO YOU WANT TO CONTINUE (Y/N) ";
3040 INPUT ZZ$
3050 IF ZZ$ = "N" OR ZZ$ = "n" THEN RETURN
3060 PRINT : PRINT : PRINT
3070 PRINT " ENTER THE HEIGHT TO "
3080 PRINT " THE SENSORS IN INCHES ";
3090 INPUT FRHEIGHT
3100 PRINT : PRINT
3110 PRINT " ENTER THE WIDTH BETWEEN "
3120 PRINT " THE SENSORS IN INCHES ";
3130 INPUT FRWIDTH
3140 PRINT : PRINT
3150 PRINT " THE FRAME HEIGHT IS "; FRHEIGHT; " INCHES "
3160 PRINT " THE FRAME WIDTH IS "; FRWIDTH; " INCHES "
3170 PRINT
3180 PRINT " IS THIS CORRECT (Y/N) ";
3190 INPUT ZZ$
3200 IF ZZ$ = "N" OR ZZ$ = "n" THEN GOTO 3060
3210 RETURN
4000 ' SET ALLOWABLE LIMITS
4010 CLS
4020 PRINT : PRINT
4030 PRINT " THIS SECTION SETS THE MAXIMUM ALLOWABLE TRUCK SIZE "
4040 PRINT " DO YOU WANT TO CONTINUE (Y/N) ";
4050 INPUT ZZ$
4060 IF ZZ$ = "N" OR ZZ$ = "n" THEN RETURN
4070 PRINT : PRINT : PRINT
4080 PRINT " ENTER THE MAXIMUM ALLOWABLE HEIGHT IN INCHES ";
4090 INPUT MAXH
4100 PRINT : PRINT
4110 PRINT " ENTER THE MAXIMUM ALLOWABLE WIDTH IN INCHES ";
4120 INPUT MAXW
4130 PRINT : PRINT
4140 PRINT " THE MAXIMUM HEIGHT IS "; MAXH; "INCHES"
4150 PRINT " THE MAXIMUM WIDTH IS "; MAXW; "INCHES"
4160 PRINT : PRINT
4170 PRINT " IS THIS CORRECT (Y/N)";
4180 INPUT ZZ$
4190 IF ZZ$ = "N" OR ZZ$ = "n" THEN GOTO 4070
4200 RETURN
```

```
6000 ' DISPLAY CURRENT SETTINGS
6010 CLS
6020 PRINT : PRINT : PRINT
6030 PRINT " THE CURRENT SETTINGS ARE:"
6040 PRINT : PRINT
6050 PRINT " FRAME HEIGHT = "; FRHEIGHT; "INCHES "
6060 PRINT " FRAME WIDTH  = "; FRWIDTH; "INCHES "
6070 PRINT
6080 PRINT " MAXIMUM ALLOWABLE HEIGHT = "; MAXH; " INCHES "
6090 PRINT " MAXIMUM ALLOWABLE WIDTH  = "; MAXW; " INCHES "
6100 PRINT : PRINT : PRINT
6110 PRINT " PRESS ANY KEY TO CONTINUE "
6120 ZZ$ = INKEY$: IF ZZ$ = "" GOTO 6120
6130 RETURN

10000 ' MEASURE TRUCKS
10005 OPEN "COM1:9600,N,8,2,CS,DS,CD" FOR RANDOM AS #1 LEN = 256
10010 CLS
10015 LOCATE 1, 1
10020 PRINT : PRINT : PRINT : PRINT : PRINT
10030 PRINT " MEASURING TRUCKS -- PRESS 'E' EXIT "
10040 ZZ$ = INKEY$: IF ZZ$ = "E" OR ZZ$ = "e" THEN CLOSE #1: RETURN

10050 'MEASUREMENT LOOP
10060 'GET READINGS FROM EACH SENSOR
10080 FOR SENNUM = 1 TO 3
10090 GOSUB 30000
10100 NEXT SENNUM

10220 ' CONVERT FROM DISTANCE-TO-TRUCK TO HEIGHT/WIDTH-OF-TRUCK
10224 TRHEIGHT = FRHEIGHT - S(2)
10227 TRWIDTH = FRWIDTH - S(1) - S(3)

10228 IF TRWIDTH > 120 THEN TRWIDTH = 0

10229 ' FILTER OUT ANY MEANINGLESS MEASUREMENTS
10230 IF (S(3) < 10) OR (S(3) > 240) THEN TRWIDTH = 0
10233 IF (S(1) < 10) OR (S(1) > 240) THEN TRWIDTH = 0
10240 IF (TRHEIGHT < 10) OR (TRHEIGHT > 200) THEN TRHEIGHT = 0
10242 IF (TRHEIGHT = 0) THEN TRWIDTH = 0

10244 ' FIND MAX DIMENSIONS
10247 GOSUB 20000

10250 ' PRINT TRUCK DIMENSIONS
10260 IF (FLAG = 1) AND (MAXHEIGHT > 0) THEN LPRINT " HEIGHT = "; INT(MAXHEIGHT / 12);
INT(MAXHEIGHT - (INT(MAXHEIGHT / 12) * 12)), READINGS
10270 IF (FLAG = 1) AND (MAXHEIGHT > 0) THEN LPRINT " WIDTH = "; MAXWIDTH: LPRINT

10280 ' STORE DATA TO DISK
10600 ' CHECK FOR OVERSIZE TRUCKS
10610 'IF (FLAG = 1) AND (MAXHEIGHT > MAXH) THEN LPRINT " TRUCK TOO TALL"
10620 'IF (FLAG = 1) AND (MAXWIDTH > MAXW) THEN LPRINT " TRUCK TOO WIDE "
```

```
15000 GOTO 10040

16000 ' INIT
16010 FLAG = 0
16020 MAXHEIGHT = 0
16030 MAXWIDTH = 0
16040 CAL = 1
16050 READINGS = 0
16999 RETURN

18000 ' CALIBRATION
18010 ' CALIBRATE WHEN HEIGHT READING IS  APPROX ZERO
18020 CAL = FRHEIGHT / S2

20000 ' FIND MAXIMUM HEIGHT AND WIDTH OF A TRUCK
20010 ' THIS SUBROUTINE WILL DETERMINE WHEN A TRUCK HAS ENTERED
20020 ' THE MEASURING DEVICE AND RECORD THE MAXIMUM HEIGHT AND
20030 ' WIDTH OVER THE LENGTH.
20040 ' THE ROUTINE WILL CONSIDER A SERIES OF 10 ZERO MEASUREMENTS
20050 ' TO MEAN THE TRUCK HAS PASSED
20060 ' TRHEIGHT AND TRWIDTH ARE PASSED IN BUT NOT MODIFIED
20070 ' IF FLAG IS 1 THE TRUCK AS PASSED

20100 IF TRHEIGHT = 0 THEN NUMZERO = NUMZERO + 1
20105 IF NUMZERO > 15 THEN FLAG = 1: NUMZERO = 0:  RETURN

20106 IF TRHEIGHT > 0 THEN NUMZERO = 0: READINGS = READINGS + 1

20107 IF FLAG = 1 THEN FLAG = 0: MAXHEIGHT = 0: MAXWIDTH = 0: READINGS = 0

20110 IF TRHEIGHT > MAXHEIGHT THEN MAXHEIGHT = TRHEIGHT
20120 IF TRWIDTH > MAXWIDTH THEN MAXWIDTH = TRWIDTH
20130 RETURN

30000 'THIS SUBROUTINE WILL RECEIVE A READING FROM THE TRANSDUCER
30010 'DELAY MAY BE NEEDED
30020 FOR WW = 1 TO 9: NEXT WW
30030 PRINT #1, SENID$(SENNUM)
30040 A$ = INPUT$(LOC(1), #1)
30050 S(SENNUM) = VAL(A$) * .007324218#
30100 RETURN
```

APPENDIX E

TEST DATA

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	VEHICLE	AXLES	DESCRIPTION	MEASURED				RECORDED						
2	NUMBER			HEIGHT		INCHES	WIDTH	HEIGHT		INCHES	WIDTH	READINGS	CALIBRATION HEIGHT	WIDTH
3	57					0		6	8	80	83.6	7	229.7	441
4	155					0		5	8	68	15.5	2	232.3	445
5	176					0		4	0	48		4	232.3	445
6	421					0	86			0			227.3	442
7	503	2				0	94.5	6	2	74		14	227.3	442
8	30	2	BOOM	8	11	107	89.5	9	5	113	86	5	230.1	443.75
9	6	3	DUMP	9	2.5	110.5	94.25	8	11	107	117	6	230.1	443.75
10	17	3-2	DUMP			#VALUE!		8	9	105	87.5	16	230.1	443.75
11	18	2	DUMP			0	92.5	7	10	94	89	6	230.1	443.75
12	21	3-2	DUMP	9	8	116	95.5	9	7	115	92.6	15	230.1	443.75
13	55	3-2	DUMP	9	8.5	116.5	95	9	8	116	146.5	14	229.7	441
14	63	5	DUMP	9	1	109	95.5	8	9	105	99.5	10	229.7	441
15	68	5	DUMP	9	2	110	95.5	9	3	111	87.1	21	229.7	441
16	70	3	DUMP	9	1.5	109.5	95	9	3	111	91	8	229.7	441
17	71	3-2	DUMP	9	7.5	115.5	95.5	9	5	113	91.1	221	229.7	441
18	137	3-2	DUMP	9	7	115	96	9	7	115	90.2	11	232.3	445
19	139	3-2	DUMP	9	7	115	96	9	7	115	90.1	11	232.3	445
20	142	3	DUMP	9	4	112	95.5	9	5	113	80	8	232.3	445
21	153	2	DUMP	9	0	108	89.5	7	4	88	89.6	6	232.3	445
22	157	3-2	DUMP	9	11	119	96	9	8	116	88.2	13	232.3	445
23	158	3-2	DUMP	9	10	118	96	9	4	112	88.7	14	232.3	445
24	161	3-2	DUMP	9	11	119	95.5	8	8	104	88.5	11	232.3	445
25	178	5	DUMP	9	5	113	95.5	9	6	114		10	232.3	445
26	179	5	DUMP	9	4	112	95.5	8	9	105	56.6	8	232.3	445
27	197	3	DUMP			0	96			0	90	9		444
28	205	3-2	DUMP			0	96.5			0	90.7	11		444
29	208	3-2	DUMP			0	97			0	91.4	17		444
30	211	3-2	DUMP			0	96			0	90.1	7		444
31	213	3-2	DUMP			0	97			0	92.2	13		444
32	230	3	DUMP			0	96			0	90.6	6		444
33	243	3	DUMP			0	96			0	90.7	7		444
34	255	3	DUMP			0	96			0				444
35	263	3	DUMP			0	97			0	93.2	6		447
36	273	3	DUMP			0	97			0	95.2	7		447
37	275	3	DUMP			0	96			0	94.5	5		447
38	278	4	DUMP			0	96			0	89.7	8		447
39	284	3	DUMP			0	96			0	94.4	8		447
40	291	3-2	DUMP			0	96			0	94.6	13		447
41	292	3-2	DUMP			0	98			0	95.4	16		447
42	294	3-2	DUMP			0	96			0	116.1	23		447
43	318	3	DUMP	9	4	112	95	8	9	105		2	227.3	442
44	319	3	DUMP	9	7	115	95	8	8	104	94.2	5	227.3	442
45	320	3	DUMP	9	11	118.5	95	8	8	104	93.9	9	227.3	442
46	324	3	DUMP	9	7	115	96	8	10	106	91.5	6	227.3	442
47	329	5	DUMP	10	3	123	95.5			0			227.3	442
48	334	5	DUMP	9	1	109	96	8	8	104	84.1	5	227.3	442
49	336	5	DUMP	9	2	110	95.5			0			227.3	442
50	373	3	DUMP	9	7	115	95.5	9	0	108	95.3	3	227.3	442
51	384	3-2	DUMP	9	11	119	95.5	8	8	104	95.4	11	227.3	442
52	385	3-2	DUMP	9	11	119	95.5	8	7	103	95.7	15	227.3	442
53	387	6	DUMP	9	10	118	94.5	8	6	102	89	6	227.3	442
54	392	3-2	DUMP	9	7	115	95.5	8	7	103	96.4	7	227.3	442
55	393	3	DUMP	9	8	116	96	9	0	108	95.2	6	227.3	442
56	399	3-2	DUMP	9	6	114	95.5			0			227.3	442
57	400	3-2	DUMP	9	7.5	115.5	95.5	9	4	112	96.6	5	227.3	442
58	401	3-2	DUMP	9	11	119	95.5	8	9	105	96.4	7	227.3	442
59	402	3-2	DUMP	9	9	117	95.5	9	4	112	96.5	7	227.3	442
60	403	3-2	DUMP	9	9	117	95.5	8	7	103	91.2	8	227.3	442
61	409	3-2	DUMP	9	8	116	95.5	9	5	113	95.1	13	227.3	442
62	414	3-2	DUMP	9	11	119	95	9	7	115	96.2	29	227.3	442
63	416	3	DUMP	10	3	123	95.5	10	0	120	96.3	7	227.3	442
64	420	3	DUMP	9	4	112	95.5			0			227.3	442
65	425	3	DUMP	10	0	120	95.5	13	6	162	103.1		227.3	442
66	430	3	DUMP	9	1	109	95	8	8	104	87.5	7	227.3	442
67	431	3-2	DUMP	10	3	123	95	4	4	52		1	227.3	442
68	457	3	DUMP	9	1	109	94	8	11	107	73.4	8	227.3	442
69	465	5	DUMP	9	5	113	95.5	8	11	107	94.9	9	227.3	442
70	471	3-2	DUMP	9	8	116	95.5	9	6	114	97	46	227.3	442
71	473	3	DUMP	10	4	124	95.5	9	8	116	96.7	6	227.3	442
72	486	3	DUMP	9	6	114	94	8	10	106	97.5	20	227.3	442
73	490	3-2	DUMP	10	0	120	95.5	9	6	114	96.5	11	227.3	442
74	497	5	DUMP	10	9	129	96	9	3	111	97.3	28	227.3	442
75	2	3-2	DUNP	9	4	112		9	1	109		15	230.1	443.75
76	12	5	FLAT	12	9	153	95	12	8	152	92	24	230.1	443.75
77	25	5	FLAT	12	7.5	151.5	94	12	10	154	92.9	13	230.1	443.75
78	28	5	FLAT	13	1	157	95	13	2	158	102	15	230.1	443.75
79	29	5	FLAT	13	0	156	95.5	13	2	158	132	22	230.1	443.75

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
80	58	5	FLAT	10	2.5	122.5	95.5	9	3	111	214.4	19	229.7	441
81	60	5	FLAT	9	11	119	100			0			229.7	441
82	61	3	FLAT	12	11	155	96	13	5	161	92.2	6	229.7	441
83	67	5	FLAT	9	7.5	115.5	95	9	11	119	115.9		229.7	441
84	69	5	FLAT	9	12	119.5	95.5	10	1	121	158.5	20	229.7	441
85	83	5	FLAT	11	7.5	139.5	101.5	11	9	141	86.6	24	229.7	441
86	92	5	FLAT	10	8.5	128.5	110	10	4	124	97.5	36	229.7	441
87	93	5	FLAT	9	6	114	94.5	9	7	115	97.2	18	229.7	441
88	102	5	FLAT	9	5	113	93	9	4	112	90.4	25	229.7	441
89	103	5	FLAT	9	10	118	95	9	9	117	91.6	25	229.7	441
90	110	2	FLAT	9	8.5	116.5	96	7	10	94	90.9	7	229.7	441
91	113	5	FLAT	9	8	116	95	9	11	119	96.3	21	229.7	441
92	114	5	FLAT	9	2.5	110.5	95.5	9	4	112	92	19	229.7	441
93	115	5	FLAT	11	7.5	139.5	96	8	10	106	89	24	229.7	441
94	124	3	FLAT	13	2	158	102	12	11	155	96.9	14	229.7	441
95	144	5	FLAT	9	3	111	95.5	9	5	113	89.2	21	232.3	445
96	149	2	FLAT	8	4.5	100.5	100	8	8	104	86.8	10	232.3	445
97	167	4	FLAT	13	5	161	96	13	3	159		6	232.3	445
98	189	7	FLAT	8	9	105	94	8	10	106	85.6	36	232.3	445
99	195	5	FLAT			0	97			0	91	16		444
100	199	5	FLAT			0	96			0	106.3	27		444
101	216	5	FLAT			0	96			0	103.5	18		444
102	219	5	FLAT			0	101.5			0	94.8	21		444
103	232	2	FLAT			0	96			0	111	7		444
104	240	5	FLAT			0	95.5			0	93.8	15		444
105	256	5	FLAT			0	132			0	119	31		447
106	265	5	FLAT			0	96.5			0	107.8	14		447
107	266	2	FLAT			0	95			0	95.6	3		447
108	274	2	FLAT			0				0		5		447
109	302	5	FLAT			0	92.5			0	92.1	10		447
110	308	5	FLAT	9	6	114	101.5	9	4	112	102.8	23	227.3	447
111	310	5	FLAT	11	9	141	95.5	11	9	141	98.7	23	227.3	447
112	313	5	FLAT	11	1	133	102	11	3	135	103.3	25	227.3	447
113	327	5	FLAT	12	10	154	101.5	12	0	144	115.9	16	227.3	442
114	333	5	FLAT	9	11	119	95.5	9	7	115	92.3	16	227.3	442
115	341	5	FLAT	9	0	108	94	9	0	108	119.8	15	227.3	442
116	343	5	FLAT	9	3	111	96	9	3	111	93.5	16	227.3	442
117	349	5	FLAT	13	4	160	102	9	4	112	101	27	227.3	442
118	355	5	FLAT	13	1	157	96	13	2	158	96.3	23	227.3	442
119	362	5	FLAT	11	9	141	95.5	9	4	112	92.4	41	227.3	442
120	364	5	FLAT	11	0	132	93	10	11	131	95	34	227.3	442
121	366	9	FLAT	13	6	162	114			0			227.3	442
122	374	5	FLAT	12	5	149	96	12	6	150	95.8	12	227.3	442
123	377	5	FLAT	11	8	140	102	11	6	138	114.8	17	227.3	442
124	388	5	FLAT	12	10	154	95.5	12	9	153	94	19	227.3	442
125	390	2	FLAT			0	93.5	7	3	87	119.1	4	227.3	442
126	411		FLAT	13	4	160	134	13	0	156	113.6	34	227.3	442
127	415	5	FLAT	9	6	114	95.5	9	6	114	93.7	20	227.3	442
128	423	5	FLAT	13	0	156	94	13	4	160	98.5		227.3	442
129	427	5	FLAT	12	10	154		12	6	150	102.7		227.3	442
130	440	5	FLAT	9	11	119	96	9	6	114	93	10	227.3	442
131	456	5	FLAT	13	6	162	96	13	3	159	94.8	20	227.3	442
132	464	5	FLAT	13	5	161	95.5	8	9	105	92.7	12	227.3	442
133	466	5	FLAT	11	2	134	92.5	9	9	117	94.7	10	227.3	442
134	487	5	FLAT	9	7	115	94	9	9	117	96.2	21	227.3	442
135	488	5	FLAT	9	7	115	101.5	9	10	118	105	23	227.3	442
136	489	5	FLAT	11	4	136	93.5	11	9	141	109.6	23	227.3	442
137	496	2	FLAT	9	2	110	79	9	4	112	80.6	21	227.3	442
138	498	3-2	FLAT	9	10	118	95	9	8	116	97.1	50	227.3	442
139	502	5	FLAT	12	9	153	95	8	0	96	98	16	227.3	442
140	11	2	GLASS	10	5.5	125.5	92.5	8	0	96	85	7	230.1	443.75
141	14	5	GRAIN	10	4	124	96.25	10	1	121	93	6	230.1	443.75
142	91	2	GRAIN	10	7	127	94.5	10	10	130	89.4	6	229.7	441
143	101	5	GRAIN	10	4	124	96	11	0	132	91.3	11	229.7	441
144	182	6	GRAIN	9	9	117	94.5	8	8	104	113.7	21	232.3	445
145	217	5	GRAIN			0	96			0	90.8	4		444
146	224	5	GRAIN			0	96			0	116.3	8		444
147	231	5	GRAIN			0	97			0	64.7	9		444
148	241	5	GRAIN			0	96.5			0	115.3	11		444
149	250	5	GRAIN			0	96			0	75.5	10		444
150	262	4	GRAIN			0	99			0	95.7	11		447
151	279	5	GRAIN			0	96			0	94.9	11		447
152	289	6	GRAIN			0	94.5			0	118	12		447
153	296	5	GRAIN			0	93			0	93.4	18		447
154	299	5	GRAIN			0	96			0	111.8	16		447
155	169	5	LIVE	13	5	161	95	13	9	165	93	18	232.3	445
156	185	5	LIVE	13	4	160	96	13	7	163	92.1	21	232.3	445
157	321	5	LIVE	13	5	161	95.5	13	6	162	95.6	20	227.3	442
158	338	5	LIVE			0				0			227.3	442

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
159	398	5	LIVE	13	5	161	96	13	6	162	95.6	17	227.3	442
160	429	5	LIVE	13	5	161	95	13	5	161	95.8		227.3	442
161	483	5	LIVE	13	6	162	96.5	13	6	162	98.1	30	227.3	442
162	72	4	PU			0	96	5	10	70	92.2		229.7	441
163	75	2	PU			0	95	7	4	88	88.8	6	229.7	441
164	133	4	PU	9	7	115	81	9	11	119	75.3	8	232.3	445
165	165	4	PU	10	10	130	96	8	3	99	48.6	9	232.3	445
166	174	2	PU	8	11	107		8	9	105		2	232.3	445
167	226	2	PU			0				0				444
168	290	4	PU			0	86			0	74	10		447
169	297	2	PU			0				0		1		447
170	305	2	PU			0	88	5	5	65	93.3	3	227.3	447
171	380	2	PU	8	2	98	6	5	9	69		3	227.3	442
172	412	2	PU	9	0	108	90.5	6	3	75	92.3	9	227.3	442
173	422	2	PU			0		7	1	85			227.3	442
174	499	5	PU	9	7	115	95.5	10	0	120	96.7	9	227.3	442
175	5	5	TANK	11	2.8	134.75	95.5	11	1	133	72	9	230.1	443.75
176	8	5	TANK	10	9.5	129.5	95.5	11	5	137	92	14	230.1	443.75
177	20	5	TANK	11	8	140	95.5	9	5	113	92.2	8	230.1	443.75
178	26	5	TANK	10	1	121	96.5	10	1	121	76.5	15	230.1	443.75
179	59	5	TANK	9	12	119.5	93	9	9	117	92.1	16	229.7	441
180	90	5	TANK	9	6	114	95.5	9	7	115	90.7	15	229.7	441
181	95	5	TANK			0	95.5	10	10	130	81	22	229.7	441
182	122	5	TANK	10	0	120	96.5	10	7	127	91.3	19	229.7	441
183	127	5	TANK	10	0	120	95.5	10	0	120	90.3	92	229.7	441
184	128	5	TANK	10	0	120	95	9	2	110	72.3	4	229.7	441
185	163	5	TANK	11	0	132	95	11	4	136	79.7	9	232.3	445
186	168	3	TANK	10	11	131	95	11	3	135	88	7	232.3	445
187	170	5	TANK	11	9.5	141.5	96	9	1	109	90.1	8	232.3	445
188	181	5	TANK	10	4	124	97	10	4	124	76	15	232.3	445
189	186	5	TANK	9	9	117	94	9	8	116	90.1	11	232.3	445
190	187	5	TANK	10	4	124	94.5	10	4	124		8	232.3	445
191	198	5	TANK			0	96			0	77.7	10		444
192	203	5	TANK			0	97			0	89.6	19		444
193	206	5	TANK			0	96			0	90.6	11		444
194	233	5	TANK			0	95			0	116.1	8		444
195	251	5	TANK			0	96			0	88.6	23		444
196	259	5	TANK			0	95.5			0	87	4		447
197	285	5	TANK			0	96			0	77.7	6		447
198	304	5	TANK			0	97.5			0	91.7	16		447
199	326	5	TANK	10	2	122	95.5	9	11	119	94.8	19	227.3	442
200	328	5	TANK	10	7.5	127.5	96	10	11	131	91	26	227.3	442
201	332	5	TANK	12	1	145	95	12	5	149		15	227.3	442
202	337	5	TANK	10	11	131	95.5			0			227.3	442
203	339	5	TANK	10	10	130	93	10	1	121	89.5	7	227.3	442
204	360	5	TANK	12	9	153	95	12	9	153		14	227.3	442
205	361	5	TANK	12	4	148	94	12	9	153	92.4	41	227.3	442
206	365	5	TANK	10	4	124	96	9	0	108	89.3	14	227.3	442
207	372	5	TANK	11	8	140	93	11	0	132	84.2	7	227.3	442
208	378	5	TANK	11	1	133	96	9	1	109	93.8	4	227.3	442
209	382	5	TANK	11	5	137	95.5	11	3	135	95.8	15	227.3	442
210	418	5	TANK	11	6	138	95.5	11	1	133	88.4	12	227.3	442
211	426	5	TANK	11	10	142	95	8	11	107	96.5		227.3	442
212	438	5	TANK	13	0	156	95.5	12	6	150	95	11	227.3	442
213	446	5	TANK	11	4	136	94	11	6	138	93.2	19	227.3	442
214	449	5	TANK	11	5	137	95.5	11	0	132	95.3	3	227.3	442
215	450	5	TANK	11	7	139	95	11	0	132	38.9	8	227.3	442
216	452	5	TANK	11	6	138	95.5	11	2	134	82.8	13	227.3	442
217	463	5	TANK	10	10	130	95.5	10	6	126	97.7	9	227.3	442
218	468	5	TANK	11	6	138	95	11	4	136	82.4	21	227.3	442
219	469	5	TANK	11	4	136	95.5	10	11	131	83.7	18	227.3	442
220	474	5	TANK	12	3	147	93	11	8	140	79.4	10	227.3	442
221	477	5	TANK	12	5	149	95.5	9	2	110	82.4	2	227.3	442
222	478	5	TANK	12	3	147	97	12	2	146	91.4	12	227.3	442
223	491	5	TANK	10	4	124	94	9	7	115	95.6	7	227.3	442
224	492	5	TANK	10	0	120	94	9	6	114	95.7	10	227.3	442
225	495	5	TANK	11	7	139	94.5	11	7	139	90.4	33	227.3	442
226	501	2	TANK	9	5	113	94.5	9	7	115	96	11	227.3	442
227	146	4	TOW	12	4	148	94	9	4	112		10	232.3	445
228	254	2	TOW			0	97			0	92.6	50		444
229	330	2	TOW	8	0	96		6	1	73		7	227.3	442
230	154	3	TRACTOR	12	5	149	94.5	9	10	118	88.7	6	232.3	445
231	381	3	TRACTOR	9	0	108	95	6	2	74	46.4	2	227.3	442
232	1	5	VAN	13	4	160		13	7	163		13	230.1	443.75
233	3	5	VAN	12	8.8	152.75		13	0	156		28	230.1	443.75
234	4	2	VAN	10	0	120		10	2	122		8	230.1	443.75
235	7	5	VAN	13	5.5	161.5	102	13	8	164	101	15	230.1	443.75
236	9	5	VAN	13	4.5	160.5	102	13	6	162	99	11	230.1	443.75
237	10	5	VAN	13	4.5	160.5	103.5	13	6	162	100	18	230.1	443.75

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
238	13	2	VAN	10	4	124	95.75	10	6	126	93	6	230.1	443.75
239	15	5	VAN	13	4.5	160.5	102	13	7	163	101.4	15	230.1	443.75
240	16	5	VAN	13	3	159	95.5	13	5	161	94.4	17	230.1	443.75
241	19	5	VAN	13	4	160	102	13	5	161	100.3	27	230.1	443.75
242	22	3-2	VAN	13	3.5	159.5	101	13	6	162	100.1	17	230.1	443.75
243	23	5	VAN	13	4.5	160.5	102	13	7	163	100	37	230.1	443.75
244	24	5	VAN	13	4	160	102	13	6	162	100	18	230.1	443.75
245	27	5	VAN	13	3	159	102	13	5	161	100.4	28	230.1	443.75
246	31	5	VAN	13	5.5	161.5	102.2	13	9	165	127	32	230.1	443.75
247	32	5	VAN	13	5.5	161.5	86	13	6	162	94	21	230.1	443.75
248	53	5	VAN	13	1.5	157.5	96	13	4	160	93	18	229.7	441
249	54	5	VAN	13	6	162	102.5	13	8	164	115.4	18	229.7	441
250	56	3-2	VAN	10	11	130.5	94.5	11	1	133	126.7	11	229.7	441
251	62	5	VAN	13	3.5	159.5	102.5	13	5	161	105.9	22	229.7	441
252	64	5	VAN	13	5	161	102	13	7	163	98.8	25	229.7	441
253	65	5	VAN	13	2.5	158.5	102	13	6	162	178.9	34	229.7	441
254	66	2	VAN	10	0.5	120.5	94			#VALUE!		44	229.7	441
255	73	5	VAN	13	5	161	96	13	4	160	87.5	2	229.7	441
256	74	2	VAN	11	4	136	94	12	0	144	91.7	6	229.7	441
257	76	3	VAN	8	12	107.5	96	9	1	109	145.9	23	229.7	441
258	77	5	VAN	13	2	158	102	13	5	161	99.4	30	229.7	441
259	78	5	VAN	13	3.5	159.5	102			0			229.7	441
260	79	5	VAN	13	3	159	102	13	6	162	99.6	17	229.7	441
261	80	5	VAN	12	11	155	95.5	11	7	139	92.6	14	229.7	441
262	81	3	VAN	11	2	134	96			0			229.7	441
263	82	5	VAN	13	5	161	102	13	7	163	144.3	30	229.7	441
264	84	5	VAN	13	6	162	102	13	7	163	195.5	65	229.7	441
265	85	5	VAN	13	2.5	158.5	102	13	6	162	192	67	229.7	441
266	86	5	VAN	13	3	159	101.5			0			229.7	441
267	87	5	VAN	13	3.5	159.5	96	13	5	161	92.3	10	229.7	441
268	88	5	VAN	13	2.5	158.5	101.5	13	6	162	98.5	20	229.7	441
269	89	5	VAN	13	5.5	161.5	102	13	7	163	98.4	26	229.7	441
270	94	2	VAN	9	9	117	95.5	10	1	121	90.5	10	229.7	441
271	96	5	VAN			0		13	6	162	109.7	36	229.7	441
272	97	5	VAN			0		13	6	162	98.6	36	229.7	441
273	98	5	VAN			0		13	7	163	98.3	45	229.7	441
274	99	5	VAN	13	2	158	102	13	5	161	98.8	21	229.7	441
275	100	2	VAN	12	0	144	96	12	3	147	91.8	10	229.7	441
276	104	5	VAN	13	3.5	159.5	102	13	5	161	98.2	23	229.7	441
277	105	5	VAN	13	5	161	102	13	6	162	97.7	43	229.7	441
278	106	5	VAN	13	8	164	102	13	2	158	98.4	10	229.7	441
279	107	4	VAN	13	4	160	96	13	6	162	91.8	42	229.7	441
280	108	5	VAN	13	7	163	102	13	8	164	98.4	20	229.7	441
281	109	5	VAN	13	0	156	102	13	4	160	99.6	23	229.7	441
282	111	3-2	VAN	13	2.5	158.5	100	13	6	162	97.3	26	229.7	441
283	112	5	VAN	13	6	162	102	13	9	165	107.8	25	229.7	441
284	116	5	VAN	13	4	160	102	13	7	163	98.6	18	229.7	441
285	117	3-2	VAN	13	1	157	100.5	13	5	161	97.8	32	229.7	441
286	118	5	VAN	13	5.5	161.5	100	13	7	163	98.7	11	229.7	441
287	119	3-2	VAN	13	3	159	100.5	13	5	161	97.6	19	229.7	441
288	120	3-2	VAN	13	1	157	94.5	13	6	162	97.8	22	229.7	441
289	121	5	VAN	13	5	161	102	13	6	162	99.5	15	229.7	441
290	123	3	VAN	12	11	155	102	13	3	159	98.2	11	229.7	441
291	125	5	VAN	13	5	161	101.5	13	8	164	94.5	37	229.7	441
292	126	5	VAN	12	11	154.5	95.5	13	1	157	110.1	72	229.7	441
293	134	3	VAN	13	4	160	102	13	9	165	96.9	13	232.3	445
294	135	5	VAN	13	7	163	102	13	11	167	96.8	27	232.3	445
295	136	5	VAN	13	2	158	102	13	8	164	98.1	16	232.3	445
296	138	5	VAN	12	12	155.5	101.5	13	8	164	98.1	15	232.3	445
297	140	3-2	VAN	13	0	156	94.5	13	8	164	96.8	16	232.3	445
298	141	3-2	VAN	13	2	158	101	13	6	162	96	16	232.3	445
299	143	3-2	VAN	13	3	159	101.5	13	7	163	96.6	22	232.3	445
300	145	3-2	VAN	13	2	158	101.5	13	8	164	96.9	25	232.3	445
301	147	5	VAN	13	2	158	103.5	13	6	162	98.1	130	232.3	445
302	148	4	VAN	13	6	162	96	13	10	166	92.3	112	232.3	445
303	150	3	VAN	12	9	153	97	13	0	156	90.1	12	232.3	445
304	151	3-2	VAN	12	10	154	101	13	7	163	96.2	18	232.3	445
305	152	5	VAN	13	1.5	157.5	96	13	4	160	90.7	16	232.3	445
306	156	5	VAN	13	5	161	102	13	8	164	96.5	29	232.3	445
307	159	5	VAN	13	4	160	95.5	13	9	165	91.7	20	232.3	445
308	160	5	VAN	12	11	155		13	2	158	119.3	16	232.3	445
309	162	5	VAN	13	4	160	102	13	7	163	97.1	13	232.3	445
310	164	5	VAN	13	4.5	160.5	112	13	8	164	97.5	18	232.3	445
311	166	4	VAN	13	5	161	96	13	10	166	91.5	13	232.3	445
312	173	5	VAN	9	11	119	96	10	5	125	90.6	11	232.3	445
313	175	2	VAN	10	0	120	96	10	6	126	90.5	6	232.3	445
314	177	2	VAN	12	5	149	95.5	12	8	152	90.4	9	232.3	445
315	180	5	VAN	13	1.5	157.5	102	13	8	164	97.6	29	232.3	445
316	183	5	VAN	13	3	159	103	13	8	164	97.2	14	232.3	445

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
317	184	3-2	VAN	13	3	159	101.5	13	8	164	98.4	14	232.3	445
318	188	5	VAN	9	8	116	95.5	9	6	114	90.5	1	232.3	445
319	193	2	VAN			0	96			0	91.9	7		444
320	194	5	VAN			0	102			0	99.2	23		444
321	196	5	VAN			0	96			0	91.9	9		444
322	200	5	VAN			0	102			0	99.7	38		444
323	201	5	VAN			0	103			0	97.9	15		444
324	202	5	VAN			0	102.5			0	98.4	20		444
325	204	5	VAN			0	97			0	92.4	22		444
326	207	5	VAN			0	102			0	98.8	25		444
327	209	5	VAN			0	103			0	98.8	26		444
328	210	5	VAN			0	96.5			0	91.9	21		444
329	212	5	VAN			0	102.5			0	98.8	17		444
330	214	5	VAN			0	103			0	99	23		444
331	215	5	VAN			0	98			0	93.1	23		444
332	218	5	VAN			0	96			0	100.5	18		444
333	220	5	VAN			0	102.5			0	97.9	16		444
334	221	5	VAN			0	102.5			0	99	22		444
335	222	5	VAN			0	96			0	93	24		444
336	223	5	VAN			0	102.5			0	98.5	22		444
337	225	5	VAN			0	102.5			0	99.4	12		444
338	227	5	VAN			0	96			0	93.1	18		444
339	228	5	VAN			0	97			0	93	21		444
340	229	2	VAN			0	96			0	90.2	5		444
341	234	5	VAN			0	102			0	99.5	22		444
342	235	5	VAN			0	102			0	99.9	19		444
343	236	5	VAN			0	97			0	93.1	18		444
344	237	4	VAN			0	96.5			0	92.6	9		444
345	238	5	VAN			0	102.5			0	100	25		444
346	239	5	VAN			0	103			0	98.6	22		444
347	242	5	VAN			0	99.5			0	93.2	25		444
348	244	5	VAN			0	102.5			0	101.7	15		444
349	245	5	VAN			0	102.5			0	98.8	15		444
350	246	2	VAN			0	96.5			0	92.6	4		444
351	247	5	VAN			0	102.5			0	99.6	18		444
352	248	5	VAN			0	102			0	100.2	15		444
353	249	5	VAN			0	96			0	92.8	8		444
354	252	5	VAN			0	102			0	100.3	31		444
355	253	5	VAN			0	102.5			0	119.1	33		444
356	258	5	VAN			0	96			0	112.2	16		447
357	260	5	VAN			0	102.5			0	102.2	15		447
358	261	3-2	VAN			0	101			0	101.8	27		447
359	264	3-2	VAN			0	102			0	102.3	8		447
360	267	5	VAN			0	98			0	96.8	28		447
361	267	5	VAN			0	96.5			0	97.4	17		447
362	268	5	VAN			0	97			0	97.6	23		447
363	269	5	VAN			0	96			0	96.2	19		447
364	270	5	VAN			0	98			0	96.1	20		447
365	271	5	VAN			0	97			0	96.1	15		447
366	272	5	VAN			0	102			0	102.8	20		447
367	276	2	VAN			0	95.5			0	96.3	8		447
368	277	5	VAN			0	102			0	102.1	12		447
369	280	3	VAN			0	94			0	92	4		447
370	281	2	VAN			0	96			0	96	8		447
371	282	5	VAN			0	97			0	97.5	14		447
372	283	5	VAN			0	97			0	96.6	15		447
373	286	5	VAN			0	102.5			0	103.1	25		447
374	288	5	VAN			0	102.5			0	102.3	20		447
375	293	5	VAN			0	102.5			0	103.3	24		447
376	295	5	VAN			0	102			0	102.9	17		447
377	298	5	VAN			0	96.7			0	96.7	12		447
378	300	5	VAN			0	96.6			0	96.6	12		447
379	301	5	VAN			0	96			0	96.5	19		447
380	303	3-2	VAN			0	101			0	102.3	17		447
381	306	5	VAN	13	6.5	162.5	101.5	13	6	162	107.1	18	227.3	447
382	307	5	VAN	13	5	161	101	13	6	162	107.1	19	227.3	447
383	309	5	VAN	13	3.5	159.5	102	13	4	160	107.2	13	227.3	447
384	311	5	VAN	13	5	161	101.5	13	5	161	106.9	18	227.3	447
385	312	5	VAN	13	2	158	103	13	2	158	107.2	17	227.3	447
386	314	5	VAN	13	4	160	96	13	4	160	100.8	40	227.3	447
387	315	5	VAN	12	2	146	95.5	12	4	148	101.5	42	227.3	447
388	316	5	VAN	13	0	156	102	13	1	157	107	187	227.3	447
389	317	5	VAN	13	5	161	102	13	5	161	119.4	4	227.3	442
390	322	5	VAN	13	1	157	102	13	2	158	102.3	29	227.3	442
391	323	5	VAN	13	4.5	160.5	95.5	13	5	161	96.1	13	227.3	442
392	325	5	VAN	13	2	158	95.5	13	4	160	96.3	20	227.3	442
393	331	5	VAN	13	2.5	158.5	102	13	3	159	102.2	18	227.3	442
394	335	2	VAN	12	12	156	96	12	5	149	96.3	13	227.3	442
395	340	2	VAN	9	8	116	95.5	9	11	119	96.2	3	227.3	442

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
396	342	5	VAN	13	4	160	101.5	13	5	161	102.8	21	227.3	442
397	344	3	VAN	13	2	158	96	13	2	158	96.6	15	227.3	442
398	345	3	VAN	13	3	159	102.5	13	4	160	102	11	227.3	442
399	346	5	VAN	13	1	157	96	13	3	159	96	22	227.3	442
400	347	5	VAN	13	6	162	102	13	6	162	102.3	21	227.3	442
401	348	5	VAN	13	7.5	163.5	101.5	13	8	164	102.2	25	227.3	442
402	350	2	VAN	11	9.5	141.5	95	12	1	145	95.8	16	227.3	442
403	351	2	VAN	12	3	147	102	12	4	148	107	20	227.3	442
404	352	5	VAN	13	4	160	102	13	5	161	102.7	29	227.3	442
405	353	2	VAN	12	1	145	95	12	3	147	95.9	9	227.3	442
406	354	2	VAN	9	9	117	95.5	9	10	118	95.2	9	227.3	442
407	356	5	VAN	13	3	159	102	13	4	160	102.6	25	227.3	442
408	357	5	VAN	9	5	113	95.5	9	11	119	94.7	11	227.3	442
409	358	2	VAN	12	5.5	149.5	96	12	6	150	96.3	7	227.3	442
410	359	5	VAN	13	2	158	96	13	3	159	95.5	15	227.3	442
411	363	3	VAN	13	0	156	96	13	0	156	96.3	28	227.3	442
412	367	5	VAN	13	6.5	162.5	102	13	7	163	103.3	18	227.3	442
413	368	3	VAN	13	5.5	161.5	102	13	6	162	102.2	13	227.3	442
414	369	5	VAN	13	3	159	96	13	3	159	96.4	25	227.3	442
415	370	5	VAN	13	5	161	96.5	13	5	161	96.9	32	227.3	442
416	371	5	VAN	13	3	159	102	13	6	162	102.7	13	227.3	442
417	375	5	VAN	12	3	147	96	12	4	148	97.3	18	227.3	442
418	376	5	VAN	13	0	156	96	13	0	156	96.3	14	227.3	442
419	379	2	VAN	9	10	118	95.5	9	10	118	96.3	7	227.3	442
420	383	5	VAN	13	4.5	160.5	102	13	4	160	102.6	23	227.3	442
421	386	5	VAN	13	6	162	96	13	6	162	97.1	31	227.3	442
422	389	5	VAN	13	5	161	102			0			227.3	442
423	391	3-2	VAN	13	0	156	101	13	3	159	102.1	18	227.3	442
424	394	5	VAN	13	4	160	96	13	6	162	97.8	25	227.3	442
425	395	5	VAN	13	4	160	102.5	13	4	160	103.9	20	227.3	442
426	396	5	VAN	13	4.5	160.5	96	13	3	159	119.8	31	227.3	442
427	397	5	VAN	13	4	160	102	13	4	160	102.9	16	227.3	442
428	404	5	VAN	12	9	153	96	12	10	154	97.6	22	227.3	442
429	405	5	VAN	13	3	159	101.5	13	5	161	103	21	227.3	442
430	406	5	VAN	13	3	159	102	13	5	161	104	24	227.3	442
431	407	5	VAN	13	0	156	96	13	0	156	96	28	227.3	442
432	408	5	VAN	13	3	159	96	13	4	160	97	30	227.3	442
433	410	5	VAN	13	7	163	96	13	7	163	97.3	44	227.3	442
434	413	5	VAN	10	5	125	97	10	4	124	97.7	17	227.3	442
435	417	2	VAN	9	10	118	95.5	10	1	121	97.8	8	227.3	442
436	419	2	VAN	9	7	115	92	9	9	117	93.5	7	227.3	442
437	424	5	VAN	13	6	162	102.5	13	2	158	96.7		227.3	442
438	428	5	VAN	13	0	156	97	13	1	157	99.3		227.3	442
439	432	5	VAN	13	2	158	102	13	3	159	103.5	14	227.3	442
440	433	5	VAN	13	5	161	102	13	5	161	104.7	17	227.3	442
441	434	2	VAN			0	96	8	8	104	96.6	5	227.3	442
442	435	5	VAN			#VALUE!	96	13	5	161	100.1	11	227.3	442
443	436	3	VAN	13	5	161	102	13	5	161	103.3	19	227.3	442
444	437	5	VAN	13	4.5	160.5	102	13	4	160	103.5	19	227.3	442
445	439	2	VAN	9	7	115	94	9	10	118	95.4	4	227.3	442
446	441	5	VAN	12	12	155.5	95.5	13	0	156	97.5	15	227.3	442
447	442	5	VAN	13	4	160	102	13	5	161	103.8	22	227.3	442
448	443	5	VAN	13	4	160	95.5	13	5	161	98.1	24	227.3	442
449	444	5	VAN	13	5	161	95.5	13	6	162	96.5	20	227.3	442
450	445	5	VAN	13	3	159	102	13	4	160	103.8	26	227.3	442
451	447	5	VAN	13	3	159	102.5	13	3	159	113.1	60	227.3	442
452	448	3-2	VAN	13	5	161	102	13	6	162	102.4	17	227.3	442
453	451	5	VAN	13	7.5	163.5	102	13	7	163	105	26	227.3	442
454	453	5	VAN	13	3.5	159.5	101.5	13	4	160	103.2	14	227.3	442
455	454	2	VAN	10	3	123	94	10	2	122	94.9	8	227.3	442
456	455	5	VAN	13	9	165	102	13	9	165	104.1	21	227.3	442
457	458	5	VAN	13	4	160	102	13	5	161	104.4	19	227.3	442
458	459	3-2	VAN	13	2	158	101	13	6	162	104	25	227.3	442
459	460	5	VAN	10	4	124	96	10	4	124	97.7	8	227.3	442
460	461	5	VAN	12	10	154	96	12	11	155	97.7	19	227.3	442
461	462	5	VAN	13	4	160	102	13	5	161	104.8	15	227.3	442
462	467	5	VAN	10	2	122	95.5	9	11	119	97.3	9	227.3	442
463	470	2	VAN	11	7	139	95	11	10	142	98.7	18	227.3	442
464	472	5	VAN	13	4	160	102.5	13	5	161	104.4	42	227.3	442
465	475	5	VAN	13	4	160	103	13	5	161	103.6	40	227.3	442
466	476	5	VAN	13	5	161	102	13	6	162	104.8	17	227.3	442
467	479	5	VAN	13	4	160	101.5	13	5	161	103.5	17	227.3	442
468	480	5	VAN	13	1	157	101.5	13	3	159	102.7	17	227.3	442
469	481	5	VAN	13	2	158	101.5	13	5	161	104.5	19	227.3	442
470	482	2	VAN	10	4	124	91	10	5	125	93.8	8	227.3	442
471	484	5	VAN	13	6	162	102	13	7	163	105	29	227.3	442
472	485	5	VAN	13	2	158	102	13	4	160	104.5	46	227.3	442
473	493	5	VAN	13	4	160	102	13	5	161	105.1	23	227.3	442
474	494	5	VAN	13	1	157	102	13	2	158	103.4	26	227.3	442

APPENDIX F

LAST YEAR'S REPORT

EE 462

1989/1990
ISU DOT TRUCK MONITOR
DESIGN TEAM FINAL REPORT

AUTOMATIC VEHICLE
MEASUREMENT SYSTEM

APRIL 27, 1990

Department of Electrical
and Computer Engineering
Iowa State University
May 11, 1990

Bill McCall
Director, Transportation Planning
and Research Division
Iowa Department of Transportation
Ames, IA 50010

Dear Mr. McCall:

We are enclosing the ISU DOT Truck Monitor Design Team final report, *Automatic Vehicle Measurement System*. This system will be implemented at the new weigh station on I-80 near Des Moines. The report summarizes the work done by the ISU Truck Monitor Design Team from September 1989 to May 1990.

At the time of this report, the parts for the prototype system are on order. We have developed some software and have discussed the set-up of the prototype system at the I-35 southbound weigh station south of Ames. Once this system is built and tested, only minor changes will be needed to implement a permanent system at new weigh stations.

The building and testing of the prototype system and the final system will be done by a future design team or by the DOT. The enclosed report discusses the ultrasonic sensors, the measurement system, the prototype system, and our conclusions. The report will prove useful for further work which will be done on the project.

We have enjoyed working on this project for the DOT and would like to see the final system in operation some day. If you have any questions, contact any one of us through Dr. E. C. Jones, 240 Engineering Annex, 294-4962.

Sincerely,

ISU DOT Design Team

Enclosed: Report (1 copy)

AUTOMATIC VEHICLE MEASUREMENT SYSTEM

ISU - EE 461-462

DOT TRUCK MONITOR

DESIGN TEAM FINAL REPORT

April 27, 1990

Alan Eichmann
Ali Ismail
Michael Meyer
Paul Seppa

Paul Fritz
John Leick
Brian Riesberg
Dan Wagner

ABSTRACT

A comprehensive report detailing the research and decisions made by the Department of Transportation Truck Measurement Design Team has been made. In August of 1989, the team was asked to design a system to measure height width and length of a truck on a weigh station off-ramp. The designed system was limited to a total cost of $5000, and was to measure to an accuracy of ±1 inch. Numerous measuring technologies were explored including radar, lasers, electromagnetics, image processing, infra red, ultrasonics, and piezoelectric road sensors.

The design team concluded that the ultrasonic technology was best to measure height and width of trucks. The team also completed a detailed design of a length measuring scheme. A final design was made to mount ultrasonic sensors on the sides and over the road surface. In addition, designs of interfaces used to obtain measurement information from the sensors and pass it on to the DOT's computer were made. Since installation of this system at a permanent site will not be possible before the end of this school year, plans for a portable test system and instructions for final installation have been drawn.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDIXES

INTRODUCTION

This is the year end report of the Iowa State EE 462 DOT design team. In the fall of 1989, the team was given the problem of electronically measuring the size of vehicles as they move through a weigh station. Bill McCall, Director of Planning and Research at the DOT, initiated the project. Dr. E. C. Jones was the Iowa State faculty advisor for the project. The design team consisted of eight senior electrical engineering students. (They are listed in *Appendix J: Authors.*)

The DOT wants to design a measurement system for two reasons: first, to detect any oversized vehicles, and second, to gather statistical data on the sizes of vehicles using the interstate system. The measurement system will eventually be implemented at a new weigh station on I-80 near Des Moines, Ia. The accuracy of the system should be such that it can measure maximum dimensions of the vehicle to within one inch. The original task was to measure length, width, and height. The budget for such a system was limited to $5000.

The team began by investigating a variety of measurement techniques. To answer some questions about weigh stations, members of the team visited one. This report can be found in *Appendix A: Weigh Station Trip Report.* All the alternate solutions examined are discussed in detail in *Appendix B: Alternate Solutions.* The team narrowed the design of the system down to one method. This method uses Polaroid Ultrasonic Transducers and a control unit made by Contaq. A Polaroid transducer kit was purchased. Experiments performed with the kit can be found in *Appendix D: Tests on Polaroid Experiment Kit.* It was determined that length could not be measured given the specifications. A novel idea of measuring length can be found in *Appendix C: Length Measurement Using Axle Detectors.* Our proposed system measures the maximum width and maximum height of the vehicle.

This report deals mainly with the proposed system, for which parts are currently on order. The report will discuss: I. Ultrasonic Theory, II. System Set Up, III. Companies Involved, IV. A Prototype System and finally, V. Hardware of the System . The report concludes with how the project will continue.

I. ULTRASONIC SENSOR THEORY

There are many ways to electronically measure distance, such as, optics, sensors, or electrostatics. After careful consideration, our design team has adopted ultrasonic sensors as a tool for taking measurements of the vehicles at I-80 weigh station.

The time delay between the emission of a sound burst and the reception of its echo by the ultrasonic sensor is measured and used to calculate the distance that the sound has traveled. To compute an accurate distance, the speed of sound in air must be known. Sound travels approximately 1 ft/ms in air; however, the actual speed is dependent upon the air temperature and humidity. The distance measurements can be compensated for temperature and humidity conditions by calibrating sensors that measure unknown distances with a sensor that measures a known fixed distance.

Our basic idea about using Ultrasonic sensors is to have them continually transmit sound bursts. The sound burst is emitted by the transducer, travels towards the target and is then echoed back towards the receiver. The time it takes between transmitting the burst and receiving the echo is proportional to the distance. From this fact, the distance can be calculated. The sensors that are used in this system will have the capability of behaving as transmitter and receiver. This practice offers obvious economies and avoids the problem of mismatch between transmitter and receiver. The sound dispersion angle of the transducer is generally about ten degrees. Almost anything that lies within this beam will reflect the signal.

II. SYSTEM SET UP

After reviewing all the alternate solutions, ultrasonics were found to be best suited for the system's needs. Several problems had to be resolved with the ultrasonic system before a proposal could be submitted to the DOT. This section will describe work done on the following problems: 1) the transducer to computer interface 2) the structure and system design 3) the performance of transducers and electronics in adverse weather conditions and 4) the system's budget. Also there is a section included especially to help the next design team; which includes important facts that should be known .

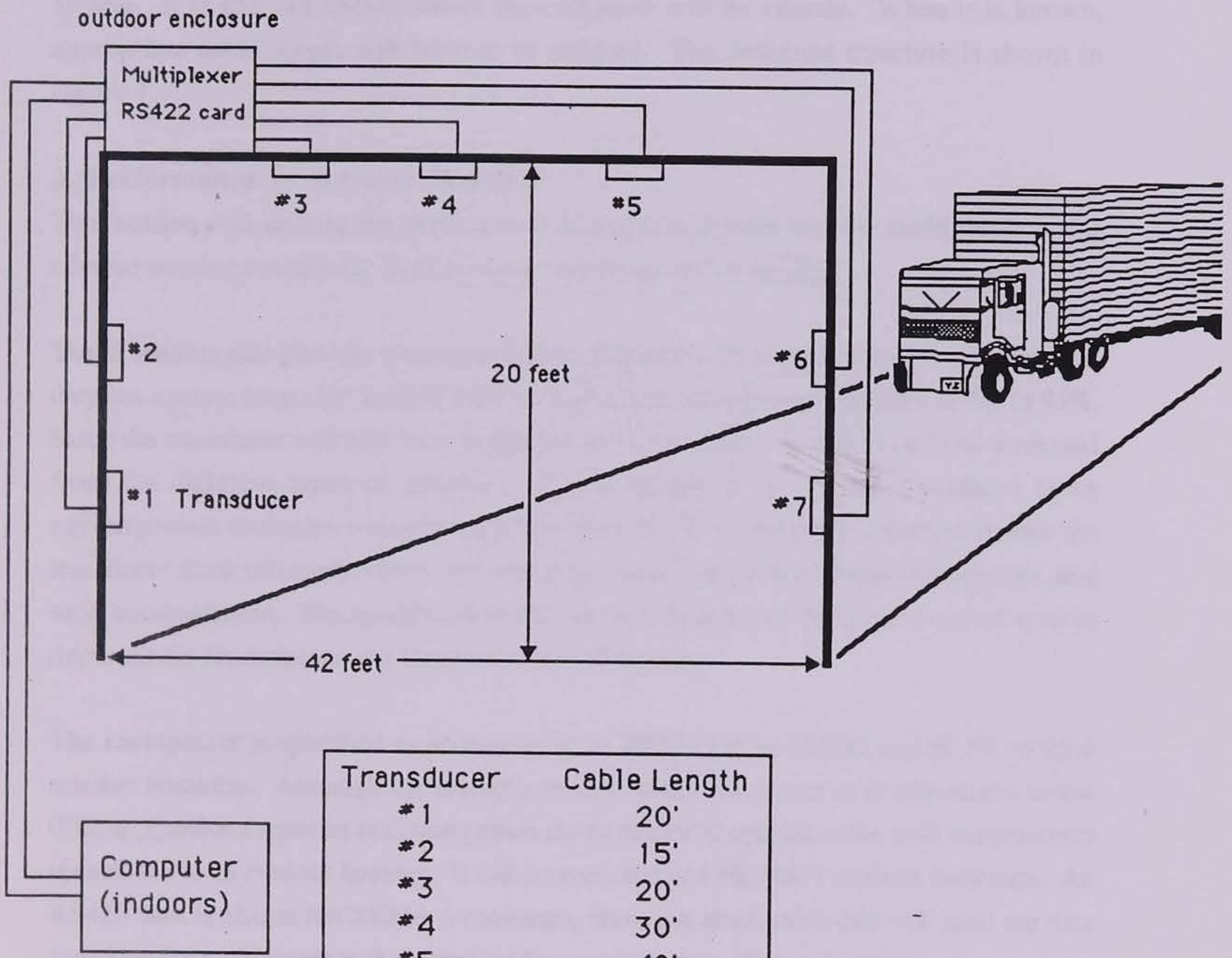
1. Computer Interface

Control of the transducers is to be handled by a computer. To interface the transducers and computer, a line of IBM compatible ultrasonic distance measurement cards was proposed. These cards are manufactured by a company called Contaq and use ultrasonic transducers made by Polaroid. The Polaroid transducers are available through Contaq; however, Contaq alters the transducers to fit their own applications such as enclosing them in a protective housing when they are to be used in adverse environments, or covering the transducers with a thin layer of material to make them more durable. But Contaq's cost increase on the transducers is more than twice as much as Polaroid's direct cost, and Polaroid's transducers and enclosures are capable of suiting our needs, so transducers and enclosures were purchased directly from Polaroid.

Contaq also produces a 7-channel multiplexer that can be driven by the IBM compatible card. This multiplexer receives data from up to seven transducers and sends it to a computer. The exact output of the signals or code to the computer are not known at this time, but once it is known the information can be used in programs to calculate the height and width of a vehicle.

2. Structure And System Design

The system is limited to a maximum of seven transducers by the multiplexer. The most accurate design devised under the seven transducer constraint is to have two transducers on each side of the structure and three on the top (See Fig. 1). One or all of the top transducers will be used for temperature compensation. When no vehicle is present, they can measure the known distance to the ground. From this measurement, a compensation factor can be found.



Transducer	Cable Length
#1	20'
#2	15'
#3	20'
#4	30'
#5	40'
#6	55'
#7	60'

Figure 1. Measurement System Layout

When the initial proposal was made, it was not known where the computer would be located or exactly what type of structure would be used. A preliminary sketch of the proposed system is at the end of *Appendix E: Proposed Height and Width Measurement System.* It is still not known where the computer will be exactly. When it is known, appropriate cable length will have to be ordered. The designed structure is shown in figure 1.

3. Performance In Adverse Weather

This section will discuss the performance of the transducers and the multiplexer under adverse weather conditions. Both of these will be located outdoors.

The brochures that give the specifications for Polaroid's ultrasonic transducers claim that they can operate from -30° to 70°C (-20° to 160°F) and at a relative humidity of 5% to 95%. Since the transducer will also have to operate in rain and snow it will have to be protected from the different types of moisture. It was proposed to put the transducer in an environmental enclosure which is made by Polaroid. The enclosure claims to protect the transducer from salt spray, shock and vibration, water immersion, chemical exposure, and sand bombardment. The specifications for the transducers and enclosures can be seen in *Appendix G: Transducers and Electronics Specifications.*

The multiplexer is specified to operate at 0° to 70°C (32° to 158°F) and at 5% to 95% relative humidity. Although the multiplexer has never been tested at temperatures below 0°C, application engineers at Contaq claim the system will operate at the cold temperatures if enclosed in an outdoor housing. It will be enclosed in a NEMA 4 outdoor enclosure. An RS422 card is also in the NEMA 4 enclosure, these are electronics that will send the data found by the multiplexer to the computer for manipulation. The multiplexer unit contains a small power supply that is operated on 120 V ac. This can help generate some heat near the electronics on very cold days. The specifications for the equipment made by Contaq are also in *Appendix G: Transducers and Electronics Specifications.*

4. The System's Budget

A proposed system was submitted to the DOT on December 13, 1989. It can be seen in *Appendix E: Proposed Height and Width Measurement System.* The cost of the initial proposal was $3000. In *Appendix H: Parts Ordered*, a list of all the equipment for the final design is shown along with their prices, this total came to $2374.

All of the equipment ordered can be used in the test system. In the final design, longer cables will be needed to connect the multiplexer to the computer. Also shown in the list is a RS422 to RS232 adapter which will be needed to alter the signal from the RS422 electronics to be used by the RS232 port on the Toshiba T-1200 computer that is to be used. The adapter to be used will cost between $100 to $200, but has not been purchased with the order.

Information For Project Continuation

Although the exact design and operation specifications are not down on paper, a general idea of how the system operates is given in this report. Since we did not have a complete understanding of how Contaq's software works at the time this paper was written, we could not design software to run the system. A portion of this task will be up to the next design team.

A sketch of the system is shown in Figure 1. This system differs from the one in the proposal in that the unit containing the multiplexer is not on the ground anymore. It is now located at the top corner of the structure because the lengths of the cables to the transducers from the multiplexer were to be kept under 60 feet. If the cables are longer than 60 feet, the signal will be lost to noise.

The original proposal used a measurement card that was IBM compatible to drive the system. The DOT wanted us to use a Toshiba T-1200 computer, which the DOT already owns. The Toshiba T-1200, however, is a laptop and does not have a standard IBM bus slot that will accommodate this card. Another device, a Distance Measurement Instrument (DMI), was found that could send information to the computer through the serial port. The multiplexer would then be driven with the computer's parallel port. This device was also available through Contaq. Since in the final design the distance from the computer to the multiplexer may be greater than 1000 feet, an RS422 type signal was proposed. This type of signal is less susceptible to noise than the RS232 and will be stronger after traveling long distances. An RS422 version of the DMI is available. An RS422 port does not exist on the Toshiba T-1200, but an RS422 to RS232 adapter can be purchased commercially. A problem that may arise is that the Toshiba T-1200 may not be powerful enough to drive a signal over 1000 feet. If this is true, a line driver circuit can be built to help the computer. If problems occur in building a circuit, Paul Orellana at Contaq has informed us that he knows what types of chips to use.

All of the research has been done and the design team believes that the system will work. The next design team can fine tune the system and make it efficient. Problems such as what order in which to fire the transducers, how to format and store the output , and how to work out all of the noise in the system will have to be resolved by the next design team for the system to work.

III. PRINCIPAL COMPANIES INVOLVED IN THE SYSTEM

Two companies are supplying the equipment for the system. They are Polaroid and Contaq. Both of the companies products were discovered through the vendor catalogs in ISU's library. The purpose of this section is to specify what role each company plays in the final system. The exact parts that were ordered can be seen in *Appendix H: Parts Ordered.*

Polaroid

The ultrasonic transducers and their housings were purchased from Polaroid. These are the same types of transducers used in the Polaroid SX-70 and Pronto Sonar Camera for automatic focusing. They work on the same principle that was mentioned in the ultrasonic theory section. Although only seven transducers are used in the design, ten transducers and housings were ordered to satisfy Polaroids minimum order requirement.

Contaq

The multiplexer, the RS422 version of the DMI, and all necessary cables were purchased from Contaq. Contaq also will make all the proper internal connections and enclosed the multiplexer and the DMI in an outdoor enclosure. By having these components in the NEMA 4 (outdoor safe) enclosure they can safely be located at the structure and operate in all weather conditions. Contaq produces components to be used with Polaroid's transducers to make them more applicable to industrial and commercial needs.

IV. PROTOTYPE SYSTEM

A prototype system will be built at the southbound I-35 weigh station, five miles south of Ames. This system is to be built by the next design team. Figure 2 shows the approximate dimensions of station area. The following paragraphs will (1) describe the system, (2) explain possible problems, and (3) explain shortcuts that will be used in the prototype system.

1. System Description

The prototype system will be very similar to the final system. To measure width, two transducers will be mounted: one on the light pole and one on the building. Three transducers will be mounted on an overhead structure for the height measurement. The multiplexer will be mounted on the top west corner of the overhead structure, similar to that of the final system shown in Figure 1. The cable connecting the multiplexer and the computer can be run through the window of the building. An outlet is available in the building to power the computer.

2. Possible Problems

Two problems will have to be solved before the prototype system can be tested. The major obstacle, which the DOT has agreed to manage, will be the construction of a structure over the roadway. The structure is needed for mounting the height transducers and also for carrying the transducer cables across the roadway. A second problem involves the path the vehicles take through the sensor area. The vehicles may need to be routed through the center of the roadway to obtain measurements similar to those that will be taken in the final system.

3. Shortcuts Used in the Prototype System

The prototype system will be simplified by the use of three major shortcuts. First, the output from the computer for each vehicle will be shown on the screen and will be placed in a data file. In the final system design, the output will be sent to the main computer for storage in a data file. The second simplification will be the length of the cable from the multiplexer to the computer. In the prototype system the length will be approximately 50 feet, whereas the cable may be up to 1500 to 2000 feet long for the final system. Third, the prototype system will be manually triggered to begin and end taking measurements for each vehicle. The final system will have to trigger automatically for each vehicle.

I-35 WEIGH STATION
SOUTHBOUND
5 MILES SOUTH OF AMES

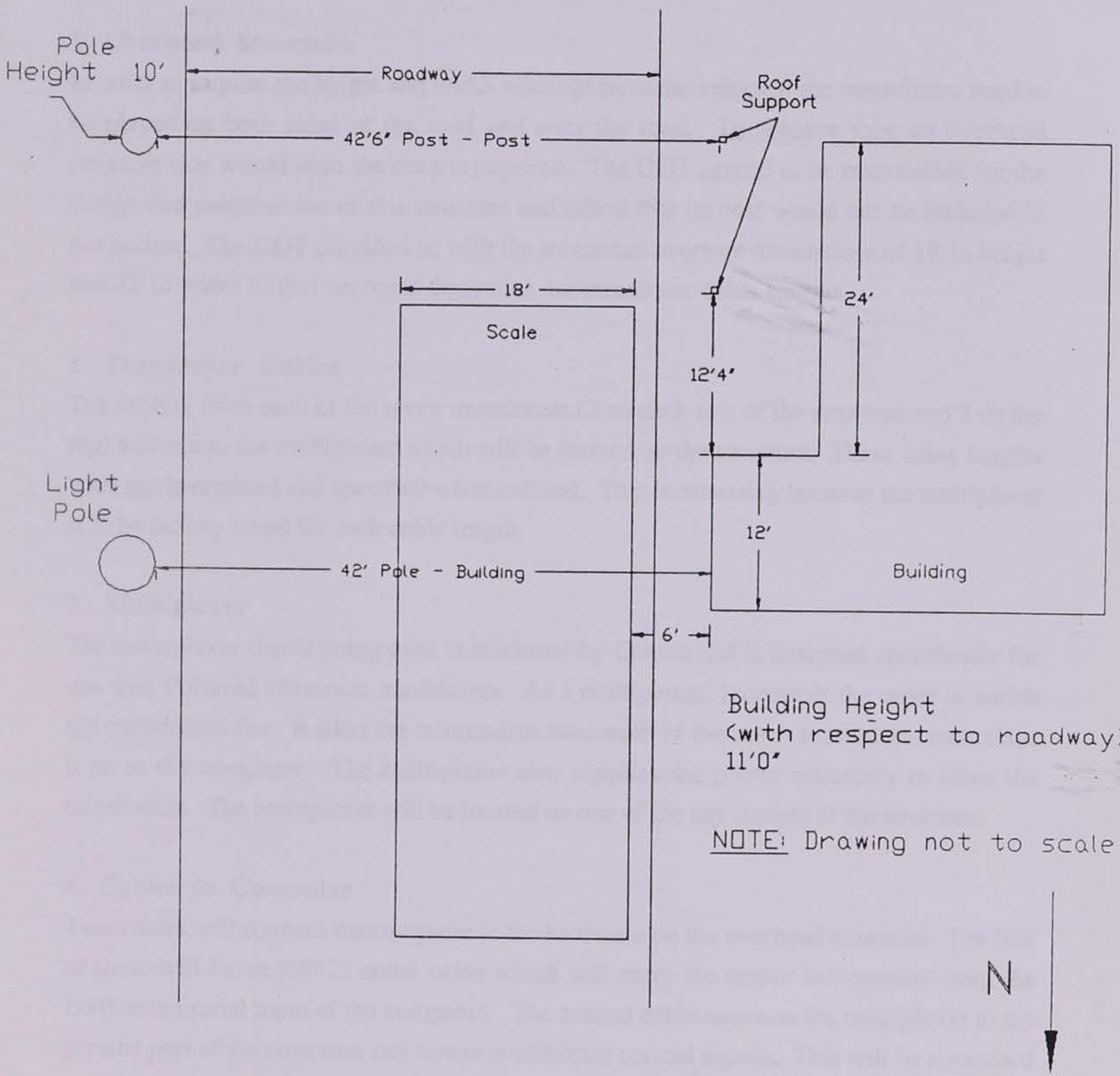


Figure 2. Weigh Station Layout

V. HARDWARE OF THE PROPOSED SYSTEM

This section will discuss the designed system from a hardware standpoint. The major hardware components of this system include; 1) an overhead structure, 2) transducer cables, 3) a multiplexer, 4) cabling to the computer, and 5) the computer.

1. Overhead Structure

In order to acquire the height and width readings from the vehicles, the transducers need to be placed on both sides of the road and over the road. To achieve this, an overhead structure that would span the road is required. The DOT agreed to be responsible for the design and construction of this structure and added that its cost would not be included in our budget. The DOT provided us with the minimum structure dimensions of 18' in height and 42' in width so that we could determine our transducer cable lengths.

2. Transducer Cables

The cabling from each of the seven transducers (2 on each side of the structure and 3 on the top) will run to the multiplexer which will be located on the structure. These cable lengths were predetermined and specified when ordered. This is necessary because the multiplexer is to be factory tuned for each cable length.

3. Multiplexer

The multiplexer that is being used is marketed by Contaq and is designed specifically for use with Polaroid ultrasonic transducers. As a multiplexer, it controls the order in which the transducers fire. It takes the information from each of the seven transducers and relays it on to the computer. The multiplexer also supplies the power necessary to drive the transducers. The multiplexer will be located on one of the top corners of the structure.

4. Cables to Computer

Two cables will connect the computer to the hardware on the overhead structure. The first of these will be an RS422 serial cable which will carry the sensor information from the DMI to the serial input of the computer. The second cable connects the multiplexer to the parallel port of the computer and carries multiplexer control signals. This will be a standard parallel cable for the prototype system, but may need either line drivers or conversion to RS422 to compensate for the large cable length.

5. Computer

The computer for our task will be a Toshiba T-1200. It was supplied to us by the DOT. The system control software is being written by the design team in QuickBASIC and will be installed on the hard drive of the Toshiba T-1200. All of the information from the sensors will come in on the Toshiba's serial RS232 port. It will also use its parallel controller port to control the multiplexer. The computer will be located indoors at the weigh station more than 1000' from the structure.

CONCLUSION

Our design team dealt with the concept on how a system to measure height and width would work. A design was made on the basis of research and parts were ordered. The principal companies involved are Polaroid and Contaq. When parts arrive in May of 1990, the prototype system can be built.

If technology or costs change, some of our alternate solutions may become viable. That is why we chose to include a brief description of them in Appendix B, *Alternate Solutions*.

Little more will be done on this project by us because parts will come in only a week before we graduate. This need not be the end of the project, however. A new design team, perhaps another EE461-462 class, could pick up where we left off. We estimate that the project may require 6-10 months for completion.

We brainstormed over possible problems and solutions a design team might have upon implementation of our system. Since we did not have any of the components of the system, we were unable to test anything out. Many unforeseen problems are sure to emerge once system erection commences. The software for the system is one area that will need a lot of work once the hardware arrives. Also, little idea on how the sensors can be mounted is currently available.

We have designed a practical solution. With some work, it can become a reliable system.

APPENDIX A

WEIGH STATION TRIP REPORT

by Dan Wagner
November 8, 1989

This report will list and explain data obtained at the eastbound weigh station on Interstate 80, north of Des Moines, IA. Bill McCall, Sam Sermet, Paul Seppa, and I visited the station from 3:00 to 5:00 P.M., on October 25, 1989. Sam made a video tape of the station in operation, while Bill, Paul, and I made velocity measurements and other observations.

Velocity Measurements

We set seven cones at thirty foot intervals at the entrance to the station as shown in the diagram below.

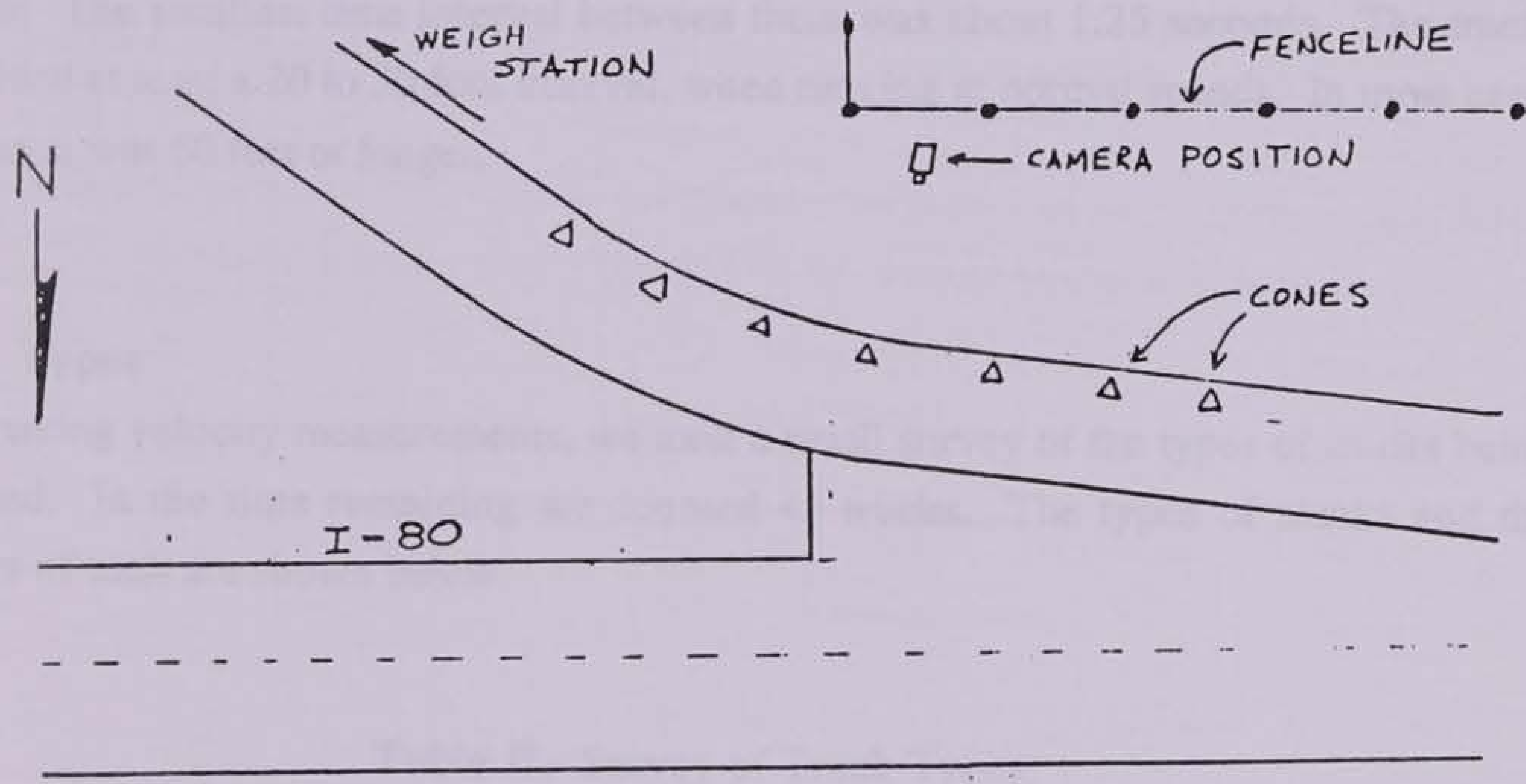


FIG A-1. DIAGRAM OF WEIGH STATION ENTRANCE.

We made nineteen time measurements over the 180 foot interval. The data obtained for normal operating conditions (no traffic back-ups) is listed in Table I.

Table I. Average velocities (mph).

12.27	26.85	34.09
16.13	28.74	34.38
18.97	29.08	35.99
20.36	31.23	37.53
21.09	31.39	38.96
23.92	32.04	41.32
	25.10	

Average: 28.41 Maximum: 41.32 Minimum: 12.27

We discontinued measurements when trucks began to slow to a stop. At one point, eighteen to twenty trucks were at a standstill. At that time the station operator turned on the station's "CLOSED" sign.

Intervals Between Trucks

We approximated the time intervals and the distances between trucks traveling closely together. The smallest time interval between them was about 1.25 seconds. The trucks maintained at least a 20 to 30 foot interval, when moving at normal speeds. In most cases the interval was 60 feet or longer.

Truck Types

After making velocity measurements, we took a small survey of the types of trucks being measured. In the time remaining we counted 45 trucks. The types of trucks and the numbers of each are shown below.

Table II. Survey of Truck Types.

Type	Number	% of Total
Standard Box	35	78.0
Short Box	3	6.6
Flat Bed	3	6.6
Tanker	3	6.6
Car Carrier	1	2.2

Notes

1. Although acceleration values were not measured at the time, a general idea of these values might be obtained by reviewing the video tape.

2. The interstate speed limit was 55 mph

3. Velocities close to the station ranged from 0 to 25 mph

4. An unloaded trailer had a maximum height of 2 or 3 feet.

5. Paul and I checked the area between the interstate and the weigh station lane as a possible location for a range finder. It appeared that we would be able to place the range finder, so that an unobstructed distance measurement to the rear of the trucks could be made.

6. The station was run manually and all trucks had to come to a full stop to be weighed.

7. The station processed the trucks at approximately three per minute.

8. Under the proposed weigh station, the trucks would be "weighed in motion" (WIM) and fewer trucks would actually stop. Therefore, the process rate would increase.

APPENDIX B

ALTERNATE SOLUTIONS

Several methods were considered and developed to measure the height, width and length of trucks moving through a weigh station. Methods for height and width tended to be complementary, meaning height and width were often thought of as being measured using a similar technique. Methods for measuring length tended to be more involved because a constant velocity or acceleration could not be assumed.

This appendix will discus the different solutions which were considered for the measurement of truck dimensions and include an explanation of why they were or were not chosen. Also included is the decision matrix which was used to determine the group's preferred method of solution of truck dimensions.

HEIGHT and WIDTH

The four Height/Width solution technologies considered were; 1) Ultrasound, 2) Photoelectric, 3) Image Processing, and 4) Laser Triangulation.

1. Ultrasound. The design team's best solution to the Height/Width problem came from using ultrasonic distant measuring sensors. These sensors are much like the sensors used in Polaroid Auto-focus cameras. For a detailed description of this system, refer to the main body of this paper under II. System Set Up.

2. Photoelectric. A technology considered for the measurement of Height/Width was the use of photoelectric sensors. These sensors would use infrared frequencies such as those used in security systems. Many narrow-dispersion beams would be placed along the height and width of an over-the-road structure. Depending on the reception of transmitted signals, a measurement of the dimensions could be found. The height and width would be determined by computing which of the sensors did not receive a signal. (If a signal was not received, the truck could be assumed to be in the signal's path.) This solution's accuracy was limited by the number of sensor/receiver pairs that were used and the spacing between those sensors. It was also prone to problems associated with alignment of path of signal and obstructions in the signal path, such as butterflies.

3. Image Processing. Image processing was considered for a possible solution to the entire dimension problem. This solution required the use of a television camera to take a snapshot of the truck as it passed. The image would then be digitized and processed by a computer to find height, width, and length. The major drawback of this alternative was the expense of the television cameras and the computer used to process the mass of data collected.

4. Laser Triangulation. The technology of lasers was examined to measure height and width. Two lasers and an array of receivers would be placed along the roadside. One would be on top of the traffic lane, and the other would be along the side. Each would shoot a laser beam at the truck at some angle relative to the motion of the truck. The beams would be reflected by the truck towards the receiver arrays. Depending on which receivers the beam hit, a dimension could be derived by using Snell's equation, angle of incidence equals the angle of reflection. Major concerns about the cost of quality laser products and lane position of the trucks were the reasons that this method was not pursued further.

Decision Matrix

The following is the decision matrix that was used to determine the best overall method to measure height and width. Each criteria was assigned an appropriate weight and each method was ranked according to how it performed in each category. (1 = bad, 5 = great)

Technology	Accuracy	Reliability	Cost	Feasibility	Maintenance	Acceptance	Total
	20%	20%	20%	20%	15%	5%	100%
Ultrasound	5	4	5	5	4	3	455
Photoelectric	3	4	2	3	3.5	4	312.5
Image Processing	5	4	1	2	3	4	305
Laser	5	3	2	2.5	3	2	305

LENGTH

Length solution technologies considered were: 1) Weight Sensor Speed Average, 2) Radar Speed Average, 3) Ultrasound, 4) Ultrasound with velocity compensation, 5) Electromagnetic Ranging, 6) Image Processing, 7) Infrared Interferometer, and 8) Laser Scanning.

1. Weight Sensor Speed Average. The preferred method to measure length of a moving truck was by the use of a weight sensor layout which was embedded in the pavement. A detailed description of this method can be found in *Appendix C: Length Measurement Using Axle Detectors*. The basic concept behind this method was to start a timer when the truck enters the system and stop it when the truck exits. This would yield the amount of time the truck took to pass through the system. While the timer was running, the truck would move over, and trigger each road sensor. When the sensors were triggered, they would be given a time-tag. By knowing the distance between sensors and by knowing the time intervals between adjacent sensors, a velocity curve could be obtained. Then by calculating the average velocity, and using the amount of time it took for the truck to pass though the system, a length of the truck could be found. Accuracy of the system depended on the number and the layout of the sensors in the pavement. Difficulties of this system were the cost of each piezoelectric sensor and the amount of computation required to time-tag and compute.

2. Radar Speed Average. The Radar Speed Average method of length measure used similar concept as the Weight Sensor Speed Average method. The velocity curve would be arrived at by sampling a radar gun periodically as the truck passed through the system. An average speed of the truck and length of the truck would be determined in the same manner as used by the Weight Sensor method. The major drawback of this system was the accuracy of radar speed measuring devices. To derive a measurement that was accurate to ±1 inch on a 65 foot truck, system required a radar speed measurement that was accurate to 0.01 mph. The most accurate radar on the market only measures speed to within 0.1 mph.

3. Ultrasound. The technology of ultrasonics was thought to be useful to measure the length of trucks on an off-ramp. It was thought that an ultrasonic sensor would be placed at the rear of a passing truck. As the truck's front bumper breaks a beam break of the measurement system, the sensor would range to the rear of the truck to get a distance reading. The measured distance would be subtracted from the distance to the plane of the system and the length could be derived. The major problem with this idea was that the signal would be interrupted by trucks following closely behind the truck being measured. Also, the speed of sound (speed of ultrasonic signal) in air was not extremely great compared to the speed of the truck. This would mean that the truck would move an appreciable distance before the ultrasonic signal could arrive, resulting in inaccurate length measurements.

4. Ultrasound with Velocity Compensation. The problem of the propagation delay when measuring a moving truck was accounted for and corrected by attaching a speed measuring device near the beginning of the plane of the system. This speed measuring device would be a radar speed gun or a loop detector. The measured speed would be used to adjust the distance the truck would move in the time between the signal was sent from the sensor and the time the signal arrived at the back of the truck. This solution was still susceptible to trucks following too closely as to interfere with the ultrasonic signal.

5. Electromagnetic Ranging. The technology of Electromagnetic (EM) Ranging was also developed to measure length of moving trucks. This system would work much like the Ultrasound systems in that it would range to the rear of the truck as it was triggered by the front bumper of the truck. Distance measured would be subtracted from the distance to the front plane of the system to derive the length of the truck. Like the Ultrasound sensors, the EM measuring system was subject to the same problems as the ultrasonics. Trucks following too closely would interfere with the EM signal. The major problem, however, was that the cost of the least expensive ranging device was over our $5000 budget.

6. Image Processing . Image processing was considered for a possible solution to the entire dimension problem. This solution required the use of a television cameras to take a snapshot of the truck as it passed. The image would then be processed by a computer to find height, width, and length. The major drawback of this alternative was the expense of the television cameras and the computer used to process the mass of data collected.

7. Infrared Interferometer. The electromagnetics technology was used to measure length in the Infrared Interferometer. By placing an infrared emitter on on side of the roadway, and a receiver on the other, a signal could be sent across the road. If there was no signal received it could be assumed that a truck was directly between the sensors. When the truck moved past the sensors a dual path for the signal would exist. One path directly across the road and the other path from the transmitter to the back of the truck and then to the receiver. The two different path lengths that the signal took would result in a received signal with two phase quantities. The phase difference would result in constructive or destructive addition of the signal. By measuring the constructive interference maximums and counting them as the truck passed by, the length of the truck could be found as a function of number of wavelengths of infrared light. The major principal of using such a system was the difficulty of getting strong reflected signals at a wide range of angles, the complexity of calculation of received data and the difficulty of maintaining the very sensitive transmitter.

8. Laser Scanning . The idea of scanning the truck with a laser was developed slightly. The length of a truck could be found by scanning the entire length of the truck at a large distance from the roadway. By finding the angular range of reflected laser signal, trigonometry could be used to find the length. The major problem with this system was the large distance that the laser signal was required to travel. It was likely that some object, like insects, rain, leaves, etc. would block the signal.

Decision Matrix

The following is the decision matrix that was used to determine the best overall method to measure length. Each criteria was assigned an appropriate weight and each method was ranked according to how it performed in each category. (1 = bad, 5 = great)

Technology	Accuracy	Reliability	Cost	Feasibility	Maintenance	Acceptance	Total
	20%	20%	20%	20%	15%	5%	100%
Weight Sensors	5	5	1	4	4	4	380
Radar Speed	3	4	3.5	3.5	4	3.5	375.5
Ultrasound	3	1	4.5	4	4	3	325
Ultrasound V.C.	5	1	4	4	4	4	360
EM Ranging	5	2	3	4	4.5	4	367.5
Image Process.	5	4	1	2	3	4	305
Infrared Inter.	5	1	2	2	3	2	255
Laser Scanning	5	2	2.5	1.5	1	2	245

APPENDIX C

LENGTH MEASUREMENT USING AXLE DETECTORS

APPENDIX C

LENGTH MEASUREMENT USING AXLE DETECTORS

An array of axle detectors in combination with a plane break was studied to see if it could be a viable method for measuring the length of a vehicle as it moves through a weigh station. This appendix will 1) define the terms used to describe the hardware, 2) explain how the proposed system works, 3) describe an error analysis done on the system, 4) describe a FORTRAN program used to simulate the system, and 5) describe the results of the computer simulation.

1. DEFINITIONS

Plane Break - A plane break is an array of photoelectric beam breaks arranged to detect the presence of any object as it enters the plane that is perpendicular to the direction of travel on the roadway and perpendicular to the surface of the roadway.
Axle Detector - An axle detector is a piezoelectric pressure sensor that will detect the presence of an axle (tire) of the vehicle being measured. The DOT has information on some axle detectors from Pennwalt Corporation.

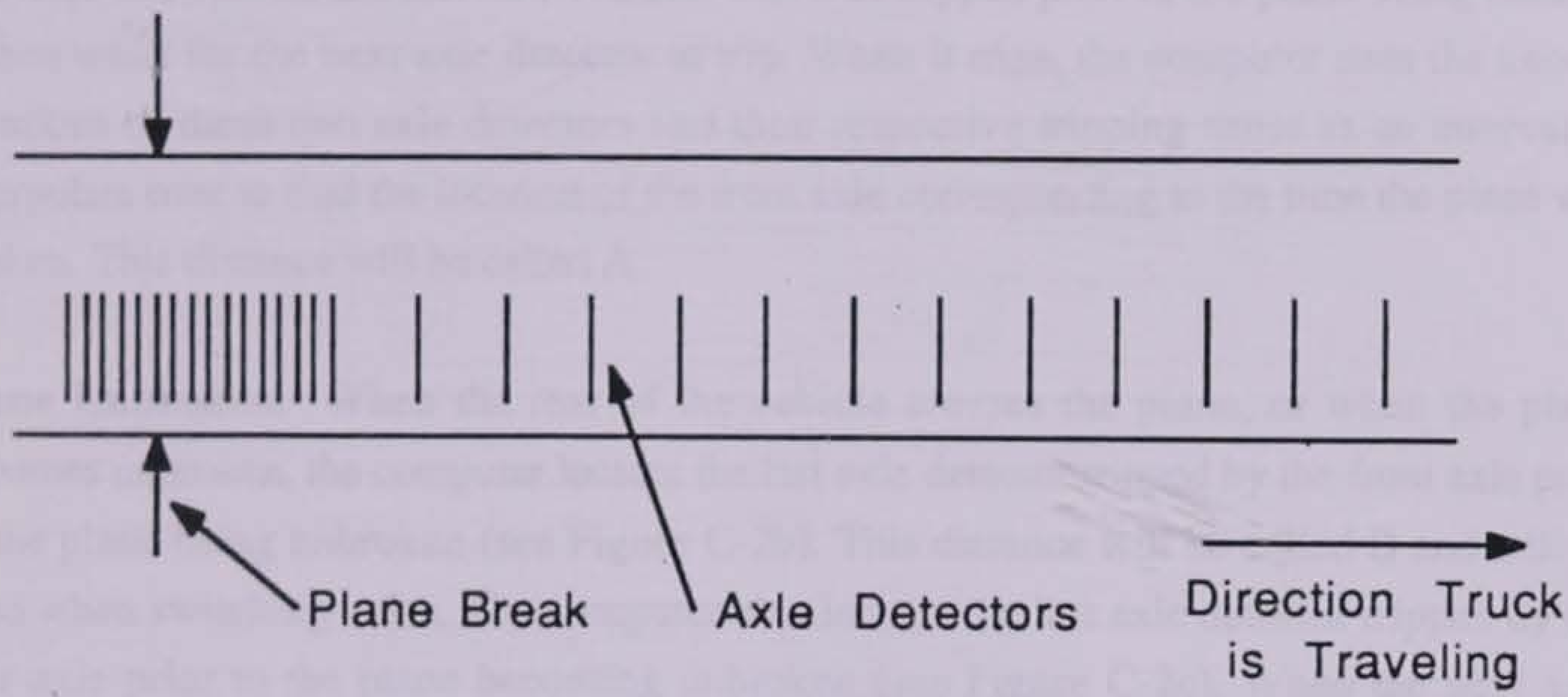
2. HOW IT WORKS

This section will describe the physical layout of the system, the method used to obtain a measurement from this system, and some variations of the system.

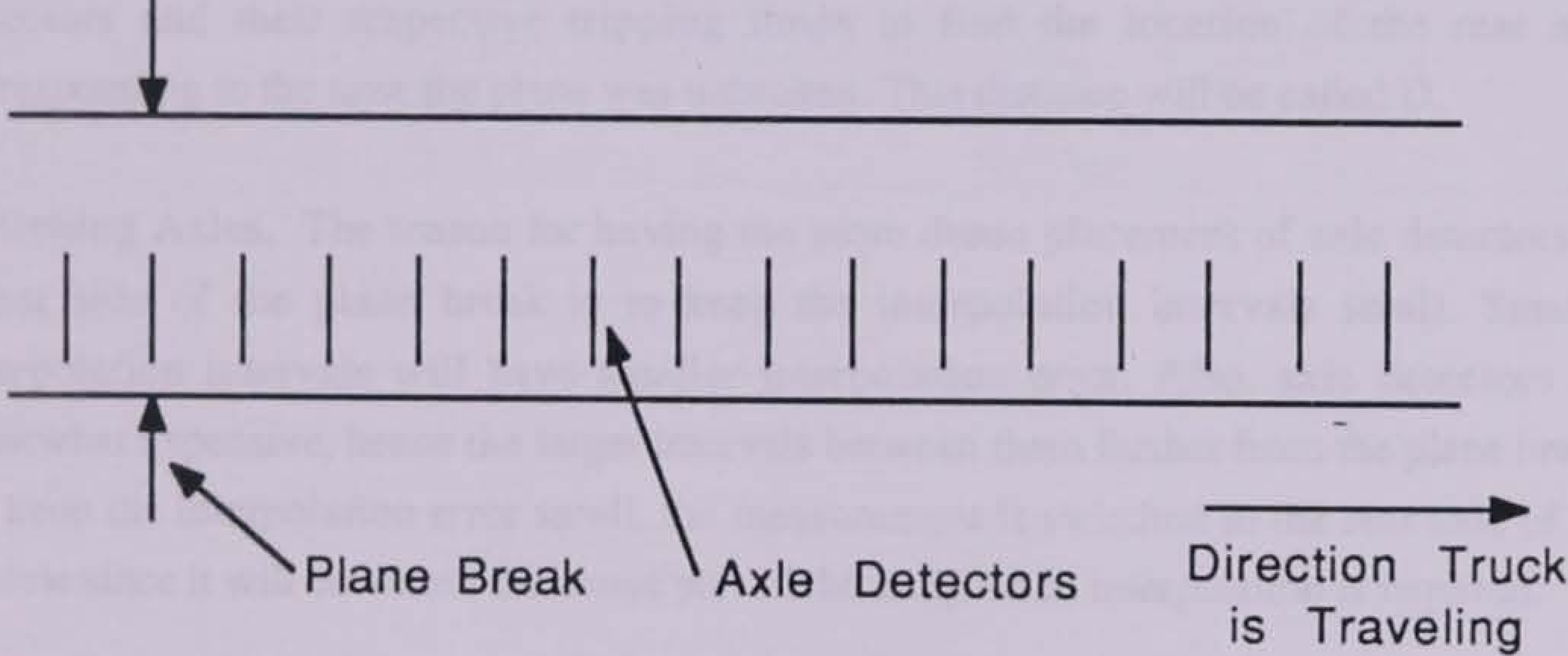
Physical Layout

The axle detectors are imbedded in the roadway perpendicular to the direction of travel as shown in Figure C-1a. The plane break must be located far enough down the roadway such that when the front of the vehicle breaks the plane, the front axle must already have crossed at least one axle detector. The array of axle detectors must continue beyond the plane break so that when the plane becomes unbroken, the vehicle's front axle is still within the array. It will be shown that this distance could be shortened to the largest interaxle distance when variations of the system are discussed.

The axle detectors should be placed nearer to each other on the approaching side of the plane break and also for a somewhat larger distance on the departing side. The larger distance on the departing side of plane break is to ensure that the rear axle of the vehicle is still within the more dense placement of axle detectors when the plane break becomes unbroken.



(a)



(b)

Figure C-1. Axle Detector Layouts

Method of Measurement

The locations of all axle detectors and plane breaks are known with respect to the location of the first axle detector and are stored in the system's computer. The computer will continually sample the system at a uniform sampling rate to determine the status of the sensors. There are basically three times that the computer interpolates to find axle locations:

1) When the plane is broken, 2) When the plane is unbroken, and 3) When switching to the rear axle.

Plane Broken. As a vehicle (see Figure C-2a) enters the system, the front axle will successively trip the axle detectors. The computer temporarily stores the time at which each axle detector is tripped. When the front of the vehicle breaks the plane, the computer stores this time and locates the last axle detector that was tripped prior to the plane being broken. It then waits for the next axle detector to trip. When it trips, the computer uses the known locations of these two axle detectors and their respective tripping times as an interval to interpolate over to find the location of the front axle corresponding to the time the plane was broken. This distance will be called A.

Plane Unbroken. When the rear of the vehicle crosses the plane, or when the plane becomes unbroken, the computer locates the last axle detector tripped by the front axle prior to the plane being unbroken (see Figure C-2b). This distance will be called B and will be used when switching axles. The computer also locates the last axle detector tripped by the rear axle prior to the plane becoming unbroken (see Figure C-2c). When the next axle detector is tripped by the rear axle, the computer uses the known locations of these two axle detectors and their respective tripping times to find the location of the rear axle corresponding to the time the plane was unbroken. This distance will be called D.

Switching Axles. The reason for having the more dense placement of axle detectors on either side of the plane break is to keep the interpolation intervals small. Smaller interpolation intervals will have smaller interpolation error. Also, axle detectors are somewhat expensive, hence the larger intervals between them further from the plane break. To keep the interpolation error small, the measurement is switched to the rear axle of the vehicle since it will be within the dense part of the array when interpolation is required.

To switch axles, the axle detector that was last tripped by the front axle prior to the plane being unbroken was located (see Figure C-2b) and the distance is called B. The computer then searches for the two axle detectors that were tripped by the rear axle just prior to and after the axle detector at B was tripped. It uses their times and locations to find the location of the rear axle corresponding to the time when the axle detector at B was tripped. This new distance will be called C. Now that all of the measurements are known, the vehicle length is computed.

$$\text{length} = (B - A) + (D - C) \qquad \text{(C-1)}$$

This is a sample of how the length of the vehicle could be measured. There are other variations that can be used to reduce the number of sensors needed. These variations will be discussed next.

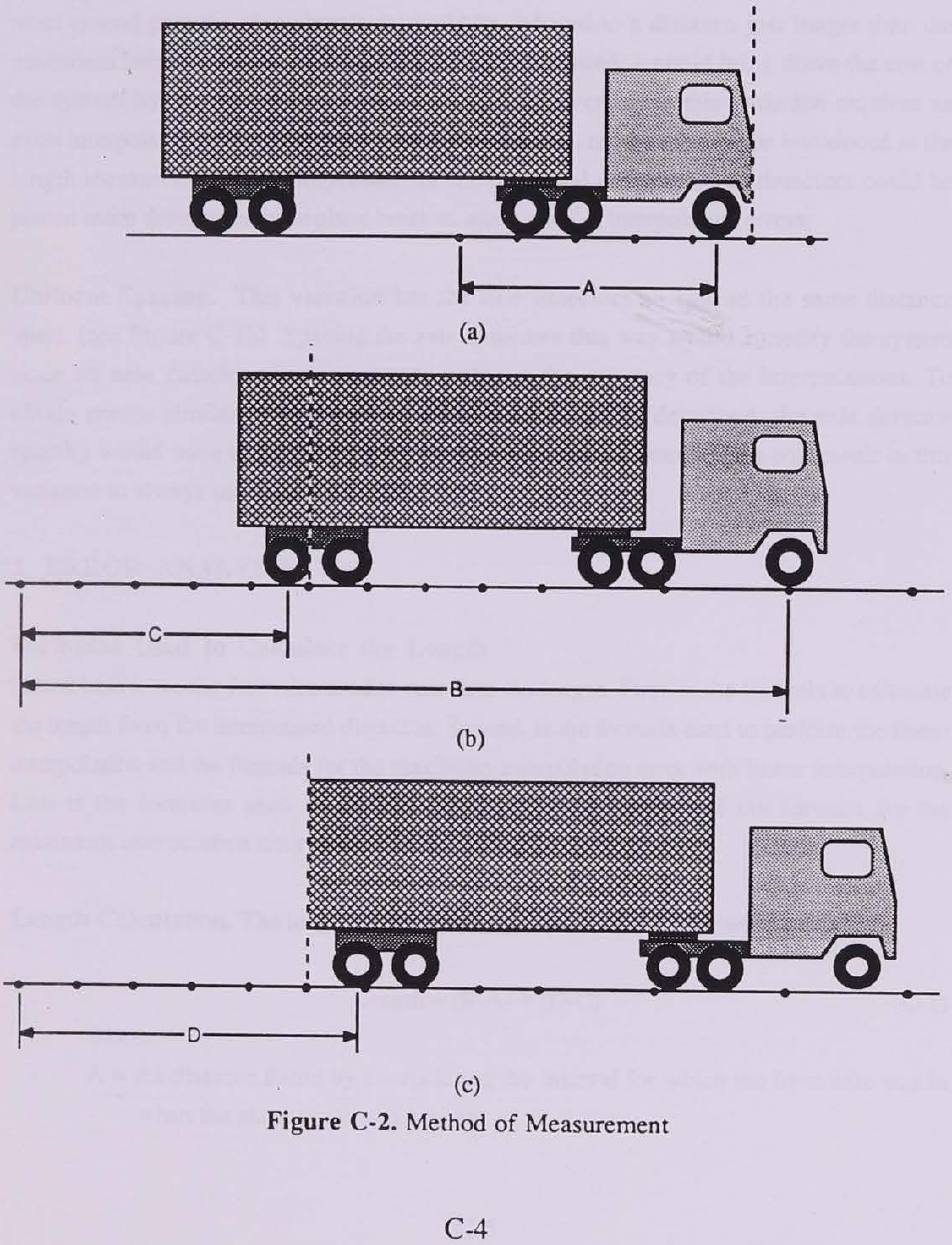


Figure C-2. Method of Measurement

Variations

Multiple Axle. One variation of the measurement system takes advantage of the multiple axles on the vehicles such as tractors pulling two trailers. This simply means switching from the front axle to an intermediate axle, and then switching again from the intermediate axle to the rear axle. This variation would reduce the distance that the axle detector array must extend past the plane break. It would be reduced to a distance just longer than the maximum interaxle distance that is desired to be measured. It could bring down the cost of the system by requiring fewer axle detectors. However, since this variation requires an extra interpolation for each interaxle distance measured, more error will be introduced in the length measurement. To compensate for the increased error, the axle detectors could be placed more densely near the plane break to attain smaller interpolation errors.

Uniform Spacing. This variation has the axle detectors all spaced the same distance apart. (see Figure C-1b) Spacing the axle detectors this way would simplify the system since no axle switching is necessary to improve the accuracy of the interpolations. To obtain results similar to that obtained with the first system described, the axle detector spacing would have to be that of the closer spaced axle detectors. This will result in this variation to always use more axle detectors.

3. ERROR ANALYSIS

Formulas Used to Calculate the Length

Listed below are the formulas used to calculate the length. First, is the formula to calculate the length from the interpolated distances. Second, is the formula used to perform the linear interpolation and the formula for the maximum interpolation error with linear interpolation. Last is the formulas used to perform the cubic interpolation and the formula for the maximum interpolation error with cubic interpolation.

Length Calculation. The length of a truck is calculated by the following formula:

$$\text{Length} = (B-A) + (D-C) \qquad \text{(C-1)}$$

where,

A = the distance found by interpolating the interval for which the front axle was in when the plane break was broken.

B = the distance of the beginning of the interval for which the front axle was in when the plane break was unbroken.

C = the distance found by interpolating the interval for which the rear axle was in when the front axle was at distance B.

D = the distance found by interpolating the interval for which the rear axle was in when the plane break was unbroken.

Linear Interpolation. The distance found by using linear interpolation was found by the following formula:

$$\text{Dis} = \frac{L_2 + L_1}{T_2 - T_1}(T - T_1) + L_1 \qquad \text{(C-2)}$$

where,

L_1 = the distance of the beginning of the interval.

L_2 = the distance of the end of the interval.

T_1 = the time in which an axle crossed the beginning of the interval.

T_2 = the time in which an axle crossed the end of the interval.

T = the time in which the distance is to be found.

The maximum interpolation error for the above linear interpolation formula is:

$$\frac{1}{8} a_{max} \Delta t^2 = \frac{1}{8} a_{max} \frac{d^2}{\bar{v}^2} \qquad \text{(C-3)}$$

where,

a_{max} = the maximum acceleration over the interval.

Δt = the time the truck took to pass over the interval.

d = the length of the interval or the distance between the axle detectors.

$\bar{v}$ = the truck's average velocity over the interval.

Cubic Interpolation. The distance found by using cubic interpolation was found by the following formulas:

$$\text{Dis} = \frac{\text{DIVDF3}}{(T_2 - T_1)^2}(T - T_1)^3 + \frac{\text{DIVDF1 - S0 - DIVDF3}}{T_2 - T_1}(T - T_1)^2 + \text{S0}(T - T_1) + L_1 \qquad \text{(C-4)}$$

$$DIVDF1 = \frac{L_2 - L_1}{T_2 - T_1} \tag{C-5}$$

$$S0 = \left(\frac{T_2 - T_1}{T_2 - T_0}\right)\left(\frac{L_1 - L_0}{T_1 - T_0}\right) + \left(\frac{T_1 - T_0}{T_2 - T_0}\right)\left(\frac{L_2 - L_1}{T_2 - T_1}\right) \tag{C-6}$$

$$S1 = \left(\frac{T_3 - T_2}{T_3 - T_1}\right)\left(\frac{L_2 - L_1}{T_2 - T_1}\right) + \left(\frac{T_2 - T_1}{T_3 - T_1}\right)\left(\frac{L_3 - L_2}{T_3 - T_2}\right) \tag{C-7}$$

$$DIVDF3 = S0 + S1 - 2\left(\frac{L_2 - L_1}{T_2 - T_1}\right) \tag{C-8}$$

where,

L_0 = the distance of the beginning of the interval before the interval being interpolated.

L_1 = the distance of the beginning of the interval being interpolated.

L_2 = the distance of the end of the interval being interpolated.

L_3 = the distance of the end of the interval after the interval being interpolated.

T_0 = the time in which an axle crossed the beginning of the interval before the interval being interpolated.

T_1 = the time in which an axle crossed the beginning of the interval being interpolated.

T_2 = the time in which an axle crossed the end of the interval being interpolated.

T_3 = the time in which an axle crossed the end of the interval after the interval being interpolated.

T = the time in which the distance is to be found.

The maximum interpolation error for the above cubic interpolation formula is:

$$\frac{1}{384}\max(a'')\,\Delta t^4 = \frac{1}{384}\max(a'')\,\frac{d^4}{\bar{v}^4} \tag{C-9}$$

where,

max(a") = the maximum 2nd derivative of acceleration over the interval.

Δt = the time the truck took to pass over the interval.

d = the length of the interval or the distance between the axle detectors.

$\bar{v}$ = the truck's average velocity over the interval.

Error Formulas

An error analysis was done on the above formulas which calculated the length using linear interpolation. The first step was to introduce an uncertainty in all the measurements. For example, the measured location of an axle detector is L. While the actual location of the axle detector is the measured location (L) plus an uncertainty or error (δL).

The next step was to find the formula for the uncertainty in the Length (δLength) and the uncertainty in the interpolated distance (δdis). This was done by taking the partial derivatives of the formulas with respect to each of the measured quantities. After this was done, each partial derivative was multiplied with its corresponding uncertainty and added together quadraturely.

The results of the error analysis for the length formula, Length = (B-A) + (D-C) was:

$$\delta \text{Length} = \sqrt{(\delta L)^2 + 3(\delta \text{dis})^2} \quad \text{(C-10)}$$

where,

δLength = the uncertainty in the measured length.

δL = the uncertainty in the location of an axle detector.

δdis = the uncertainty in the distance found by the interpolation.

The results of the error analysis for the linear interpolation formula was very complicated when it was summed quadraturely. The quadrature sum produces a much better estimate of the error than an ordinary sum does, since it takes into account any cancellation between error terms. The ordinary sum does not include any cancellation effects and therefore gives an uppper bounds for the error. Since the formula for δdis could be greatly simplified if the ordinary sum was taken, it was decided that the ordinary sum would give the most usable answer. The result found for δdis was:

$$\delta \text{dis} = \delta L + 2\,\bar{v}\,\delta T \quad \text{(C-11)}$$

where,

δL = the uncertainty in the location of an axle detector.

$\bar{v}$ = the truck's average velocity over the interval.

δT = the uncertainty in the time that an axle crossed an axle detector. This uncertainty is equal to half the sampling time.

The formula for δdis accounts for the uncertainty due to the uncertainties in the location of the axle detectors and in the measuring of the times that an axle crossed an axle detector. The total uncertainty in the linear interpolation not only is due to these uncertainties, but also the uncertainty in the interpolation process itself. The total uncertainty for δdis is therefore:

$$\delta dis = \delta L + 2\,\bar{v}\,\delta T + \frac{1}{8}\,a_{max}\,\frac{d^2}{\bar{v}^2} \qquad \text{(C-12)}$$

where,

δL = the uncertainty in the location of an axle detector.

$\bar{v}$ = the truck's average velocity over the interval.

δT = the uncertainty in the time that an axle crossed an axle detector.

a_{max} = the maximum acceleration over the interval.

d = the length of the interval or the distance between the axle detectors.

Numerical Evaluation of the Error Formulas

The formulas for $\delta Length$ and δdis found in the last section were then evaluated numerically to better understand their behavior. $\delta Length$ was calculated for average velocities ranging from 2 to 60 mph and maximum accelerations ranging from 0 to 25 ft/s^2. The uncertainty in the position of the axle detectors (δL) was taken to be 3 mm and a sampling time of 100 μs was used. Table C-1 on page 10 shows the results for $\delta Length$ when the distance between axle detectors (d) is 40 cm. A plot of these results are shown in Figure C-3 on page 11. Table C-2 on page 12 shows the results for $\delta Length$ when the distance between axle detectors (d) is 1 m. A plot of these results are shown in Figure C-4 on page 13. These axle detector spacings are the same used for the two layouts analyzed with the computer simulation described later in this appendex.

The plots show that the uncertainty becomes infinitely large when the average velocity approaches zero. This part of the curve is due to the interpolation error. At higher velocities, the error is a straight line which is very slowly increasing as the velocity gets larger. This part of the curve is due to the uncertainties in the measurements.

Even though the formula has the uncertainty becoming infinitely large as the average velocity approaches zero, it does have an upper bounds. The maximum interpolation error that could ever occur could never be larger than the interval in which the interpolation is done over. Therefore, the maximum uncertainty in Length would be about 700 mm for the 40 cm system and 1700 mm for the 1 m system. These maximum uncertainties could be reduced by half, if the midpoint of the interval was used instead of the interpolation when the average velocity was very slow.

Table C-1
Linear Interpolation Error with d = 400 mm
(error in mm)

δL = 3 mm   Sampling Time = 100 µs   d = 400 mm

Average Velocity (mph)	Max. Acceleration (ft/s^2)					
	0	5	10	15	20	25
2	3.09	41.22	79.35	117.48	155.61	193.74
4	3.18	12.71	22.24	31.78	41.31	50.84
6	3.27	7.50	11.74	15.98	20.21	24.45
8	3.36	5.74	8.12	10.51	12.89	15.27
10	3.45	4.97	6.50	8.02	9.55	11.07
12	3.54	4.60	5.65	6.71	7.77	8.83
14	3.63	4.40	5.18	5.96	6.74	7.52
16	3.72	4.31	4.91	5.50	6.10	6.69
18	3.80	4.28	4.75	5.22	5.69	6.16
20	3.89	4.28	4.66	5.04	5.42	5.80
22	3.98	4.30	4.61	4.93	5.24	5.56
24	4.07	4.34	4.60	4.87	5.13	5.40
26	4.16	4.39	4.61	4.84	5.06	5.29
28	4.25	4.45	4.64	4.84	5.03	5.22
30	4.34	4.51	4.68	4.85	5.02	5.19
32	4.43	4.58	4.73	4.88	5.03	5.18
34	4.52	4.65	4.78	4.92	5.05	5.18
36	4.61	4.73	4.84	4.96	5.08	5.20
38	4.70	4.80	4.91	5.02	5.12	5.23
40	4.79	4.88	4.98	5.07	5.17	5.26
42	4.88	4.96	5.05	5.14	5.22	5.31
44	4.97	5.05	5.12	5.20	5.28	5.36
46	5.06	5.13	5.20	5.27	5.34	5.42
48	5.15	5.21	5.28	5.34	5.41	5.48
50	5.24	5.30	5.36	5.42	5.48	5.54
52	5.32	5.38	5.44	5.49	5.55	5.61
54	5.41	5.47	5.52	5.57	5.62	5.68
56	5.50	5.55	5.60	5.65	5.70	5.75
58	5.59	5.64	5.68	5.73	5.77	5.82
60	5.68	5.72	5.77	5.81	5.85	5.89

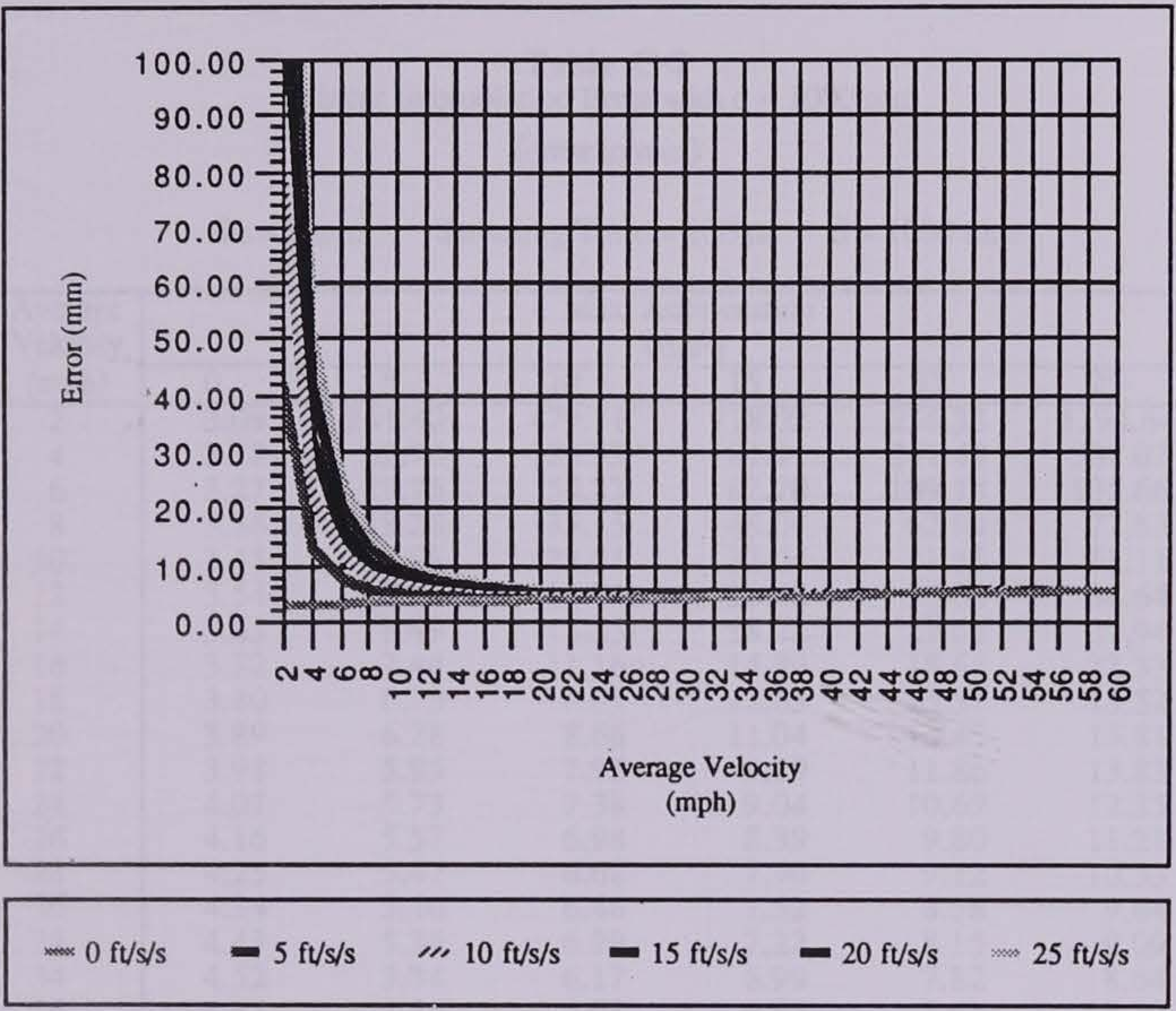


Figure C-3. Linear Interpolation Error with d = 400 mm
δL = 3 mm, Sampling Time = 100 μs

Table C-2
Linear Interpolation Error with d = 1000 mm
(error in mm)

δL = 3 mm   Sampling Time = 100 μs   d = 1000 mm

Average Velocity (mph)	Max. Acceleration (ft/s^2)					
	0	5	10	15	20	25
2	3.09	241.40	479.71	718.02	956.33	1194.64
4	3.18	62.76	122.33	181.91	241.49	301.07
6	3.27	29.75	56.23	82.70	109.18	135.66
8	3.36	18.25	33.15	48.04	62.94	77.83
10	3.45	12.98	22.51	32.04	41.58	51.11
12	3.54	10.16	16.78	23.40	30.02	36.64
14	3.63	8.49	13.35	18.22	23.08	27.94
16	3.72	7.44	11.16	14.89	18.61	22.33
18	3.80	6.75	9.69	12.63	15.57	18.52
20	3.89	6.28	8.66	11.04	13.43	15.81
22	3.98	5.95	7.92	9.89	11.86	13.83
24	4.07	5.73	7.38	9.04	10.69	12.35
26	4.16	5.57	6.98	8.39	9.80	11.21
28	4.25	5.47	6.68	7.90	9.12	10.33
30	4.34	5.40	6.46	7.52	8.58	9.64
32	4.43	5.36	6.29	7.22	8.15	9.09
34	4.52	5.34	6.17	6.99	7.82	8.64
36	4.61	5.34	6.08	6.82	7.55	8.29
38	4.70	5.36	6.02	6.68	7.34	8.00
40	4.79	5.38	5.98	6.58	7.17	7.77
42	4.88	5.42	5.96	6.50	7.04	7.58
44	4.97	5.46	5.95	6.44	6.94	7.43
46	5.06	5.51	5.96	6.41	6.86	7.31
48	5.15	5.56	5.97	6.39	6.80	7.21
50	5.24	5.62	6.00	6.38	6.76	7.14
52	5.32	5.68	6.03	6.38	6.73	7.09
54	5.41	5.74	6.07	6.39	6.72	7.05
56	5.50	5.81	6.11	6.42	6.72	7.02
58	5.59	5.88	6.16	6.44	6.73	7.01
60	5.68	5.95	6.21	6.48	6.74	7.01

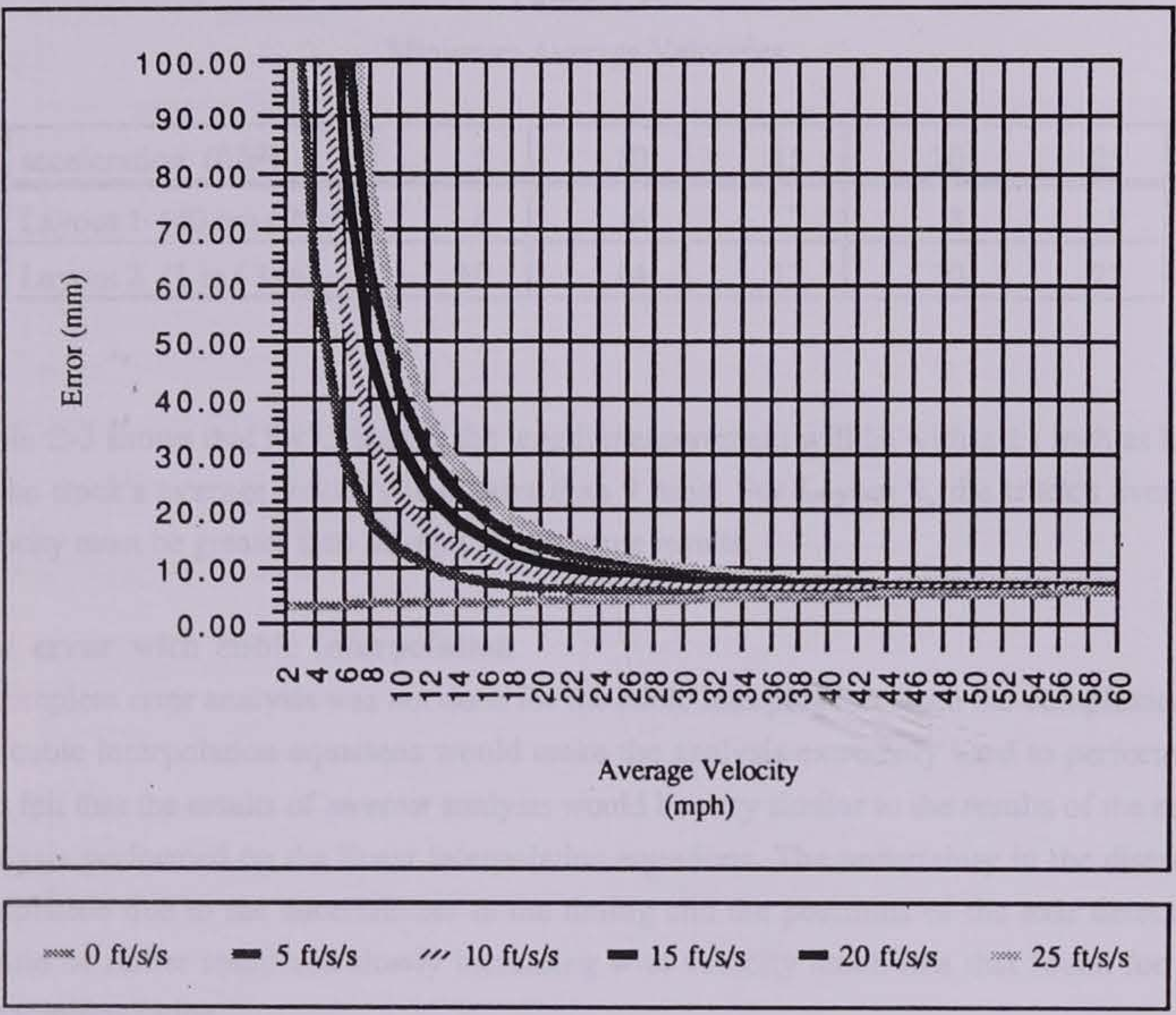


Figure C-4. Linear Interpolation Error with d = 1000 mm, δL = 3 mm, Sampling Time = 100 μs

Evaluation of the results of the Error Formulas

By using the formulas for the uncertainties, one can work backward and find the minimum average velocity for various accelerations given the uncertainty in the length measurement. If the length measurement is to be within ±1 inch or ±25 mm, then the uncertainty from each of the interpolations needs to be less than 14 mm. This assumes that δL is about 3 mm. Using a sampling time of 100 μs and the axle detector layouts, Layout 1 and Layout 2 (which are described in detail in the Computer Simulation Results, System Layouts Used section on page 17), the minimum average velocities for various accelerations were calculated and are shown in Table C-3.

Table C-3

Minimum Average Velocities

acceleration (ft/s^2)	5	10	15	20	25
Layout 1 (40 cm / 2 m)	4	6	7	8	9
Layout 2 (1 m / 3 m)	10	14	17	20	22

Table C-3 shows that for Layout 1, the length measurement will be within ±1 inch as long as the truck's average velocity is greater than 9 mph. For Layout 2, the truck's average velocity must be greater than 22 mph for the same results.

The error with cubic interpolation

A complete error analysis was not done for the cubic interpolation since the complexity of the cubic interpolation equations would make the analysis extremely hard to perform. It was felt that the results of an error analysis would be very similar to the results of the error analysis performed on the linear interpolation equations. The uncertainty in the distance calculation due to the uncertainties in the timing and the positions of the axle detectors should be rather small and slowly increasing with velocity much like that found for the linear interpolation.

For the linear interpolation, the error that limited the accuracy the most was the error in the interpolation. This should continue to be the case with the cubic interpolation. The formula stating the upper bounds for this component of the error is known for the cubic interpolation and is $\frac{1}{384}\max(a'')\,\Delta t^4 = \frac{1}{384}\max(a'')\,\frac{d^4}{\bar{v}^4}$. This function stays small for all velocities except the very slow velocities in which this function becomes quite large. It is hard to tell exactly when this function becomes large since it depends on the second derivative of the acceleration, a quantity which little is known about.

The cubic interpolation should perform as good as the linear interpolation for velocities which linear interpolation does a good job with. At slower velocities, the cubic interpolation should continue to perform good up to a lower limit that is lower than that obtained with linear interpolation.

4. COMPUTER SIMULATION

This length measurement system was simulated using a FORTRAN computer program. This section will overview the structure of the program, describe the conventions used in the program, and describe the results of the simulation.

Overview

The program performs four basic functions as shown in Figure C-5: 1) It reads in the data describing the system and the vehicle, 2) It simulates the sensor data that should result from the vehicle moving through the system, 3) It calculates the length of the vehicle from the sensor data, and 4) It outputs all information.

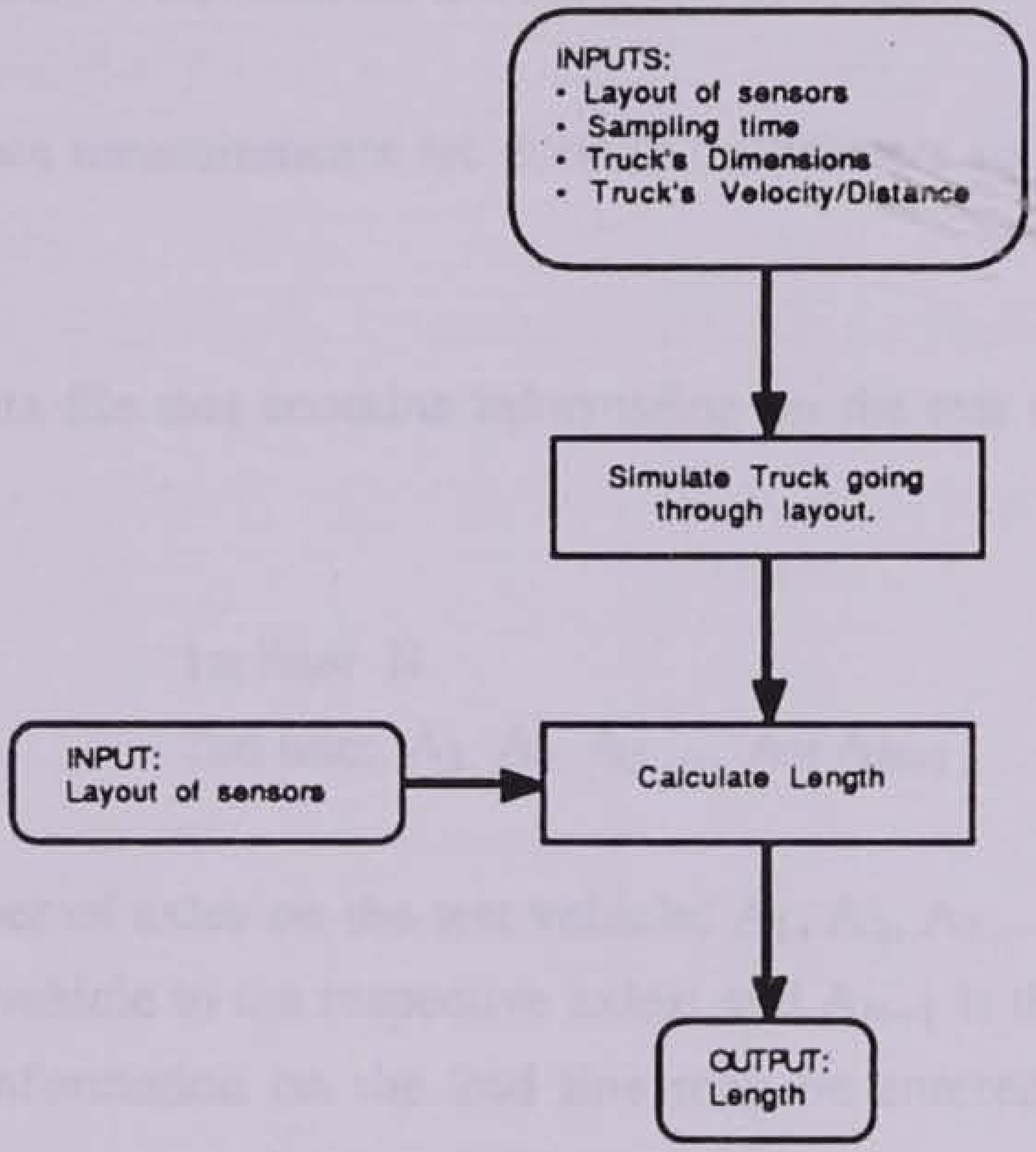


Figure C-5. Simulation Flow Chart

Inputs. Subroutine SETUP prompts the user for a filename that contains the distance from the front of the vehicle to each of its axles, and then prompts the user for a filename that contains the layout of the plane break and axle detectors. It then prompts for the sampling time to be used.

Sensor Data. Subroutine SENSORS uses function DIST1(T), to locate the front of the truck at any given time. By incrementing the time by the sampling time in each loop, it simulates the vehicle moving through the system, and stores the times that each axle detector or plane break is tripped into array SDATA.

Length Calculation. The layout and SDATA are then passed to two subroutines, CALLIN and CALCUB, which calculate the length of the vehicle using linear interpolation and cubic interpolation, respectively.

Outputs. All information is then passed to subroutine OUTPUT to write the results to a user-specified file.

Conventions

The following conventions were used for the computer simulation.

Distances. All distance measurements are done in millimeters so that integer arithmetic can be used.

Test vehicle. The data file that contains information on the test vehicle must be in the following format:

1st line: N

2nd line: A_1 A_2 A_3 ... A_N A_{N+1}

Where N is the number of axles on the test vehicle; A_1, A_2, A_3,...,A_N are the distances from the front of the vehicle to the respective axles; and A_{N+1} is the actual length of the vehicle. Note: The information on the 2nd line may be entered on multiple lines if necessary.

Layout. The data file that contains the information about the locations of the axle detectors and plane breaks must use the following format:

1st line: m

2nd line: P_1 ... P_m

3rd line: n

4th line: D_1 D_2 D_3 D_4 ...D_n

Where m is the number of plane breaks used; $P_1 \ldots P_m$ are the locations of the plane breaks; n is the number of axle detectors used; and $D_1\ D_2\ D_3\ D_4 \ldots D_n$ are the locations of the axle detectors. All locations are referenced from axle detector #1 or D_1=0.

Notes: 1) The information on the 4th line may be entered on multiple lines if necessary.

2) Althouth the simulation is capable of reading in the locations of multiple plane breaks, the length computation subroutines must be written for the specific number of plane breaks used.

Distance Function. The distance function DIST1(T) must return a location (in millimeters) given a time in seconds. Each distance function must be linked separately with the rest of the program.

5. COMPUTER SIMULATION RESULTS

System Layouts Used

Two different layouts of axle detectors were analyzed with the computer simulation. Both layouts have the axle detectors placed similar to the layout shown in Fig. C-1a. The axle detectors near the plane break are spaced closer than the axle detectors farther down the road.

The first layout, Layout 1, uses 28 axle detectors. Near the plane break the axle detectors are spaced 40 cm apart, otherwise they are spaced 2 m apart. Listed below is the data file used to define Layout 1 for the computer simulation.

Layout 1

```
1
2000
28
       0       400       800      1200      1600
    2000      2400      2800      3200      3600
    4000      4400      4800      5200      5600
    6000      8000     10000     12000     14000
   16000     18000     20000     22000     24000
   26000     28000     30000
```

The second layout, Layout 2, uses 20 axle detectors. Near the plane break the axle detectors are spaced 1 m apart, otherwise they are spaced 3 m apart. Listed below is the data file used to define Layout 2 for the computer simulation.

Layout 2

```
1
3500
20
    0     1000     2000     3000     4000
 5000     6000     7000     8000     9000
10000    11000    14000    17000    20000
23000    26000    29000    32000    35000
```

Truck Used

The dimensions of the truck used in the computer simulation are shown in Fig. C-6. Only the positions of the front and rear axles were defined for the computer simulation. Even though the computer simulation can handle the other axles, they were left out to simplify and speed up the computer simulation. The data file used to define this truck is as follows:

Truck 1

```
2
850      13450      15000
```

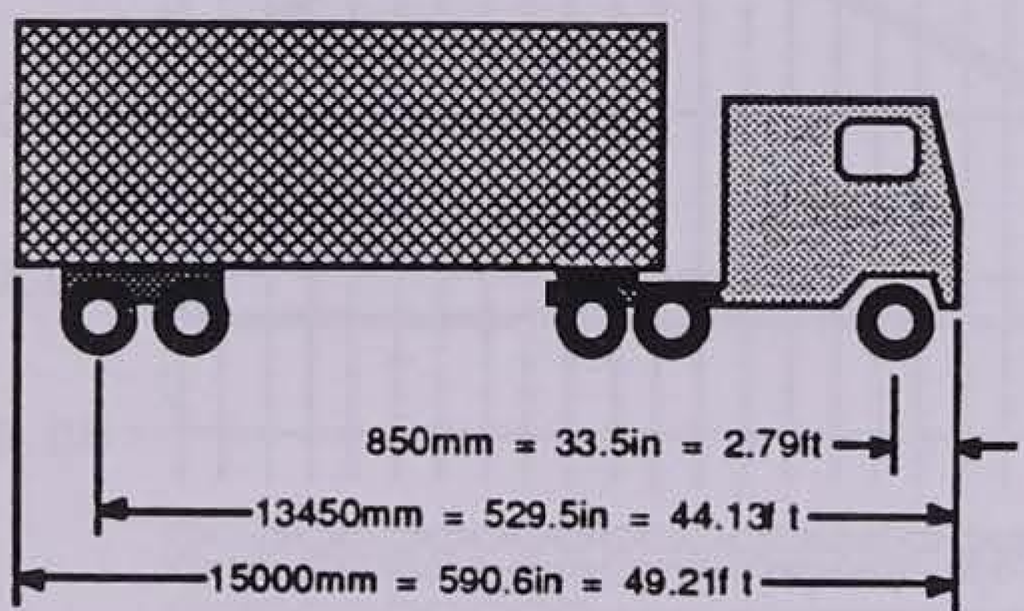


Figure C-6. Truck 1

Distance Functions

Two different distance functions were used with the computer simulation to describe the truck's velocity as it travels through the system.

The first distance function is constant velocity. This is the simplest function used and has the truck moving through the system at a constant velocity. Only the magnitude of the velocity can be varied in this distance function.

The second distance function is constant acceleration. This is a more complicated function and has the truck deaccelerating at a constant rate until the velocity reaches zero, and then has the truck accelerating at the same constant rate. If the switch between deaccelerating and accelerating wasn't made, the truck's velocity would go negative meaning the truck is moving backward. Since the system in its present form can not handle the truck moving backward, the switch was made which keeps the velocity in the forward direction. The graph in Figure C-7 plots the acceleration, velocity, and distance for the constant acceleration distance function. This function can be varied two ways: the magnitude of the acceleration and the initial velocity of the truck.

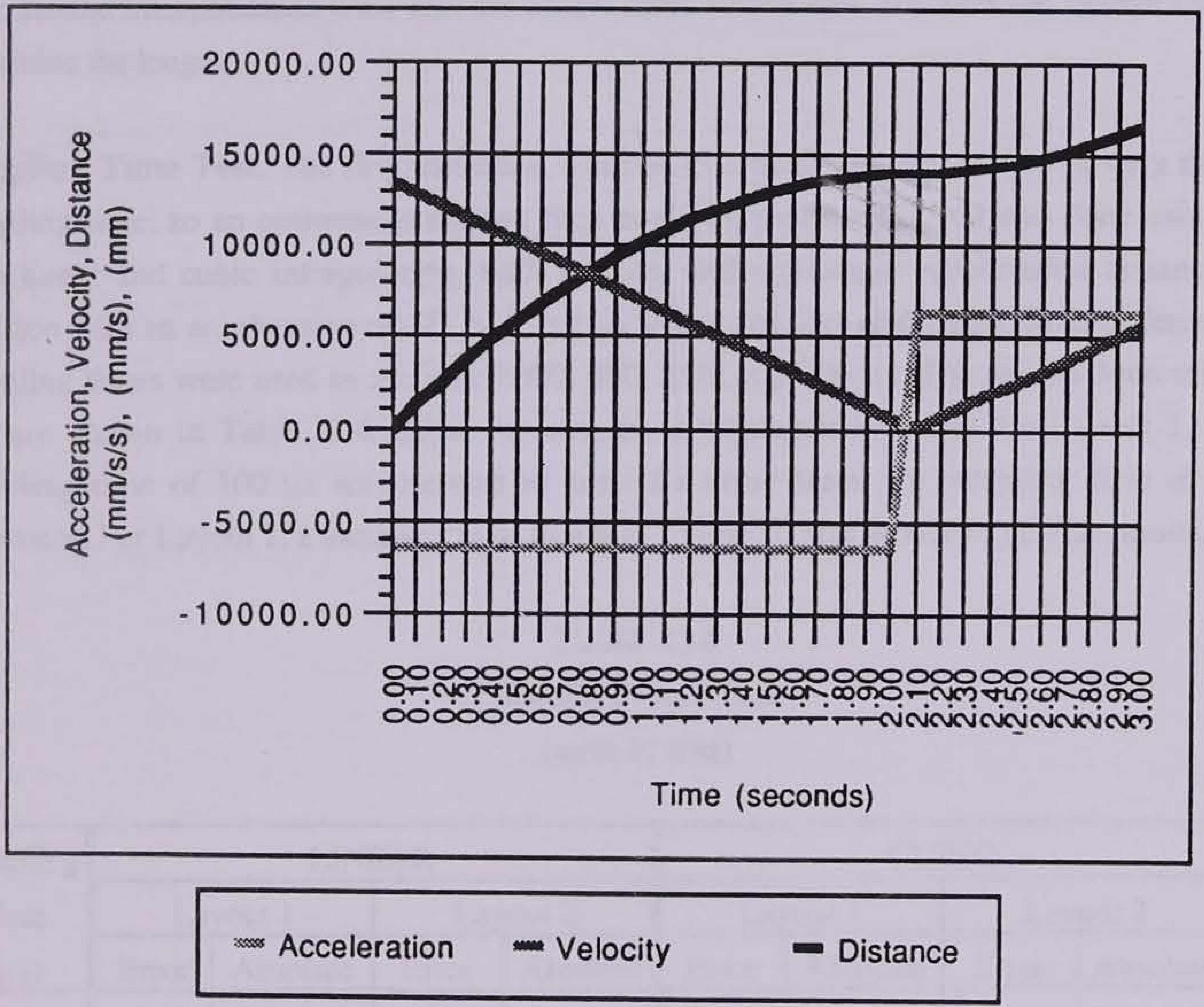


Figure C-7. Constant Acceleration

Results From the Computer Simulation

Three test were performed with the computer simulation. These tests involved finding the optimum sampling time and testing the system with the two distance functions describe in the last section.

In these tests, two types of errors were recorded. The first error is the actual error in the length and is the difference between the length determined by the system and the actual length. The second error is the absolute error and is the sum of the errors in each of the three interpolations. The absolute error eliminates any cancellation in the interpolation errors, making the absolute error larger than the actual error. The absolute error shows how accurate the interpolations were and the actual error shows how accurate the system can determine the length.

Sampling Time Test. The first test done with the computer simulation was to vary the sampling time, so an optimum sampling time could be found. This test was done using both linear and cubic interpolation, both layouts, and a constant acceleration distance function with an acceleration of -21 ft/s^2 and an initial velocity of 60 mph. Four different sampling times were used in the test: 1000, 500, 250, and 100 μs. The results from this test are shown in Table C-4. From the results, it was observed that for Layout 1, a sampling time of 100 μs was needed to keep the error from the sampling time to a minimum. For Layout 2, a sampling time of either 250 or 100 μs produced similar results.

Table C-4

Sampling Time Test

(error in mm)

Sampling Time (μs)	LINEAR				CUBIC			
	Layout 1		Layout 2		Layout 1		Layout 2	
	Error	Absolute	Error	Absolute	Error	Absolute	Error	Absolute
1000	-26	40	-4	14	-26	40	-8	14
500	-10	22	6	6	-9	23	3	5
250	-5	9	4	4	-5	7	1	3
100	0	2	2	4	0	2	-1	3

Constant Velocity Test. The second test done tested the system with constant velocity. This test used both linear and cubic interpolation, both layouts, and a sampling time of 100 μs. Five different velocities were used in the test: 5, 10, 20, 40, 60 mph. The results from this test are shown in Table C-5. The results from this test shows that the system performs very well with constant velocity. The error in this test is due to the sampling time and round-off in the calculations.

Table C-5

Constant Velocity Test

(error in mm)

Velocity (mph)	Layout 1				Layout 2			
	Linear		Cubic		Linear		Cubic	
	Error	Absolute	Error	Absolute	Error	Absolute	Error	Absolute
5	0	0	1	1	1	1	1	1
10	1	1	1	1	2	2	2	2
20	1	1	1	1	1	1	1	1
40	2	2	2	2	1	1	2	2
60	-1	3	-1	3	0	4	0	4

Constant Acceleration Test. The last test done tested the system with constant acceleration. This test used only linear interpolation, both layouts, and a sampling time of 100 μs. Six different constant acceleration distance functions were used. The results from this test are shown in Table C-6. The results from this test shows that the system can measure the truck fairly accurately even when the truck is accelerating or deaccelerating. This test also shows a large error for the case of an acceleration of -5 ft/s^2, an initial velocity of 10 mph, and using Layout 2. The reason for this large error was that the truck traveled through one of the interpolated intervals very slowly, which caused a large interpolation error to occur.

Table C-6

Constant Acceleration Test

(error in mm)

Velocity (mph)	Layout 1		Layout 2	
	Error	Absolute	Error	Absolute
10 mph -5 ft/s^2	9	9	-74	76
30 mph -5 ft/s^2	2	2	4	4
60 mph -5 ft/s^2	2	2	2	2
10 mph -21 ft/s^2	0	2	-10	14
30 mph -21 ft/s^2	2	4	3	19
60 mph -21 ft/s^2	0	2	2	4

6. CONCLUSION

The results of the error analysis and the computer simulation shows that this system of using an array of axle detectors with a plane break can measure the length of a truck within ±1 inch as long as the truck is not moving very slowly. The error analysis showed that the lower limit for the truck's velocity depended on the spacing of the axle detectors. The lower limit for the two layouts analyzed was found to be 9 and 22 mph. The closer the axle detectors are spaced, the lower this minimum speed limit is. The problem with spacing the axle detectors close is that more axle detectors are needed and that increases the cost of the system.

The cost of the system is fairly high since the axle detectors used in this system are relatively expensive, $300 each. There are two ways to reduce the cost of the system. The first way is to reduce the number of axle detectors used. This method has the previously mentioned problem of raising the minimum speed limit of the system. The second way is to modify the system to use a different lower cost sensor than the axle detector. Possible sensors that could be used include beam breaks and loop detectors. It hasn't been determined whether these other sensors could be used instead of the axle detectors or even if they are less expensive than the axle detectors.

This system can measure the length of a truck as it passes the system to within ±1 inch as long as the truck is not moving very slowly. Presently this system is not too practical, but with more work to improve the accuracy and reduce the cost, this system may become practical.

7. COMPUTER SIMULATION PROGRAM

```
      PROGRAM AXLES
************************************************************************
*  Written by Alan Eichmann and Paul Fritz           October, 1989     *
*                                                                      *
*      for EE 461/462  DOT Truck Monitor Design Project                *
*                                                                      *
* Program AXLES is a simulation of a system that uses axle detectors   *
*  and a plane break to measure the length of a vehicle that is moving *
*  through a weigh station.  It prompts the user to input files that   *
*  contain the locations of the axle detectors and plane break, and the*
*  location of the axles and the actual length of the test vehicle with*
*  respect to the front of the vehicle.  It then simulates the sensor  *
*  data that would result from the vehicle moving through the system.  *
*  The sensor data and layout are then passed to subroutines that      *
*  compute the length of the vehicle.                                  *
*                                                                      *
* VARIABLES USED:                                                      *
*                                                                      *
*  N      : the number of axles of the test vehicle                    *
*  TRDIM  : an array that contains the distances from the front        *
*              of the test vehicle to each of its axles                *
*  LAYOUT : an array that contains the location of each axle sensor    *
*             with respect to the first axle sensor to be encountered  *
*              by the vehicle.  LAYOUT(0) contains the number of       *
*              axle sensors used.                                      *
*  PBREAK : an array that contains the location of each plane break    *
*              with respect to the first axle sensor.  PBREAK(0)       *
*              contains the number of plane breaks used.               *
*  SDATA  : an array [(sensors + plane breaks)  X  axles]  that        *
*              contains the times at which event(n) occurs at sensor(m)*
*  TS     : sensor sampling time                                       *
*  DISTx  : external functions that can be passed in argument lists    *
*              for subprograms.  These functions are used to compute   *
*              the placement of the test vehicle on the sensor array.  *
*  TESTL  : internal length calculation information for linear interp *
*  TESTC  : internal length calculation information for cubic interp  *
*  LINLEN : computed length using linear interpolation                 *
*  CUBLEN : computed length using cubic interpolation                  *
*                                                                      *
* SUBROUTINES CALLED:                                                  *
*          INITZE : initializes variables                              *
*          SETUP  : collects user input for LAYOUT, PBREAK, TS         *
*          SENSORS: generates sensor output                            *
*          CALLIN : computes vehicle length using linear interpolation*
*          CALCUB : computes vehicle length using cubic interpolation *
************************************************************************

      INTEGER*2 N
      INTEGER*4 SDATA(54,0:7),TRDIM(8), PBREAK(0:4)
      INTEGER*4 LAYOUT(0:50),TESTL(0:50),TESTC(0:50),DIST1
      INTEGER*4 LINLEN, CUBLEN
      DOUBLE PRECISION TS
      EXTERNAL DIST1

      CALL INITZE(TRDIM, PBREAK, LAYOUT, SDATA)

      CALL SETUP(N, TRDIM, PBREAK, LAYOUT, TS)

      CALL SENSORS(N, TRDIM, PBREAK, LAYOUT, TS, DIST1, SDATA)
```

```
      CALL CALLIN(PBREAK, LAYOUT, SDATA, LINLEN, TESTL)

      CALL CALCUB(PBREAK, LAYOUT, SDATA, CUBLEN, TESTC)

      CALL OUTPUT(N,TRDIM,PBREAK,LAYOUT,TS,SDATA,LINLEN,
     +     TESTL,CUBLEN,TESTC)

      END
```

```
*** INITZE ************ by Paul J Fritz ******** October 29, 1989 ******
*   This subroutine initializes the arrays of program AXLES            *
************************************************************************

      SUBROUTINE INITZE(TRDIM, PBREAK, LAYOUT, SDATA)

      INTEGER*2 I,J
      INTEGER*4 SDATA(54,0:7), TRDIM(8), PBREAK(0:4), LAYOUT(0:50)

      DO 20 I=1,8
           TRDIM(I) = 0
20    CONTINUE

      DO 30 I=0,4
           PBREAK(I) = 0
30    CONTINUE

      DO 40 I=0,50
           LAYOUT(I) = 0
40    CONTINUE

      DO 60 I=1,54
           SDATA(I,0) = 0
           DO 50 J=1,7
                SDATA(I,J) = -1
50         CONTINUE
60    CONTINUE

****  END OF SUBROUTINE  INITZE  ****
      END
```

```
*** SETUP ************ by Paul J Fritz ******** October 29, 1989 *******
*                                                                      *
* This subroutine prompts the user for the filename that contains      *
*  the information on the axle placement of the test vehicle. It then  *
*  opens that file and reads the information into the array  TRDIM.    *
* The user is then prompted for the filename which contains the        *
*  layout of the axle sensors and plane breaks.  The information is    *
*  read into arrays  PBREAK  and  LAYOUT.                              *
* Finally, the user is prompted for the sampling time  TS.             *
*                                                                      *
* USER INPUTS:   TRFILE  -  name of an ASCII file containing the       *
*                           distances to the axles from the front of   *
*                           truck and the truck's length               *
*                SFILE   -  name of ASCII file containing the locations*
*                           of the plane break and axle detectors      *
*                TS      -  sampling time                              *
*                                                                      *
* OUTPUTS :      TRDIM    - contains information read from TRFILE      *
*                PBREAK   - contains locations of plane break          *
*                PBREAK(0) contains the number of plane breaks         *
*                LAYOUT   - contains locations of axle detectors       *
*                LAYOUT(0) contains the number of axle detectors used  *
*                                                                      *
* SUBROUTINES CALLED:  none                                            *
************************************************************************

      SUBROUTINE SETUP(N, TRDIM, PBREAK, LAYOUT, TS)

      INTEGER*2 N, I
      INTEGER*4 TRDIM(8), PBREAK(0:4), LAYOUT(0:50)
      CHARACTER*12 TRFILE, SFILE
      DOUBLE PRECISION TS

****  OPEN  TRUCK DATA FILE  ****

      PRINT *
      PRINT *, '      Please enter the filename that'
      PRINT *, '      contains the axle distances'
      PRINT *, '      of the test vehicle.'
      PRINT *, ' (Axle distances must be in millimeters)'
      PRINT *
      PRINT *

      READ '(A)', TRFILE
      OPEN(UNIT=10, FILE=TRFILE, STATUS='OLD')

****  READ IN TEST TRUCK DIMENSIONS  ****

      READ(10,*) N
      READ(10,*) ( TRDIM(I), I=1,N+1 )

      CLOSE(10)

****  READ IN SENSOR LAYOUT  ****

      PRINT *
      PRINT *, '      Please enter the filename that'
      PRINT *, '      contains the sensor layout.'
      PRINT *, ' (all distances must be in millimeters)'
      PRINT *
      PRINT *
```

```
      READ '(A)', SFILE
      OPEN(UNIT=10, FILE=SFILE, STATUS='OLD')

****  READ IN PLANE BREAK LOCATIONS  ****

      READ(10,*) PBREAK(0)
      READ(10,*) ( PBREAK(I), I=1,PBREAK(0) )

****  READ IN AXLE SENSOR LOCATIONS  ****

      READ(10,*) LAYOUT(0)
      READ(10,*) ( LAYOUT(I), I=1,LAYOUT(0) )

      CLOSE(10)

****  INPUT SAMPLING TIME (TS)  ****

      PRINT *, '       Please enter the SAMPLING TIME'
      PRINT *, '       ( in seconds )'
      PRINT *
      PRINT *
      READ *, TS

****  END OF  SUBROUTINE SETUP  ****
      END


**** FCN V30A5  ** by Paul J Fritz  **************************
* This is a sample distance function for use with subroutine*
*   SENSORS.  This function starts the truck moving with a  *
*   negative acceleration.  To keep the truck moving in the *
*   positive direction, its acceleration becomes positive   *
*   when the truck is moving at 1 mph.                      *
* Almost any function can be used as long as it depends only*
*   on time and it does not move the truck in the negative  *
*   direction                                               *
*                                                           *
*   V = 30mph = 44ft/sec = 13411mm/sec                      *
*   A = -5ft/sec^2 = -1524mm/sec^2                          *
*      1mph = 1.466ft/sec = 447mm/sec                       *
*   TVO = time at which the forward velocity of the truck   *
*          becomes 1 mph.                                   *
*************************************************************
      FUNCTION DIST1(T)

      DOUBLE PRECISION T, DIST1, V, A, TVO

      V = 13411.
      A = -1524.

      TVO =  -V/A

      IF ( T .LT. TVO ) THEN
            DIST1 = IDINT( (V + 0.5*A*T)*T )
      ELSE
            DIST1 = IDINT( ((V + 0.5*A*TVO)*TVO) - 0.5*A*(T-TVO)**2 )
      END IF

      END
```

```
*** SENSORS *********** by Paul J Fritz ******** October 31, 1989 ******
* Subroutine SENSORS generates the sensor output that would result from*
*   the vehicle moving over the axle detectors.                        *
*                                                                      *
* INTERNAL VARIABLES:                                                  *
*                                                                      *
*      T      : number of sampling time intervals                      *
*      I,J    : loop control variables                                 *
*      TIME   : T * TS = actual time at which sample is taken          *
*      TRKLOC : location of the front of the truck wrt 1st axle sensor*
*      AXLLOC : location of each axle at sampling time T               *
*         AXLLOC(N+1) contains location of rear of truck               *
*      PRVLOC : location of each axle at sampling time T-1             *
*         PRVLOC(0) contains previous location of front of truck       *
*         PRVLOC(N+1) contains previous location of rear of truck      *
*                                                                      *
* INPUTS:  N      - number of truck axles                              *
*          TRDIM  - array containing length of truck and axle locations*
*          PBREAK - array containing location of plane breaks          *
*          LAYOUT - array containing location of axle detectors        *
*          TS     - sampling time of the system                        *
*          DIST   - name of function to compute location of truck      *
*                                                                      *
* OUTPUTS: SDATA  - 2 dimensional array containing times at which each *
*                   axle detector was tripped by each axle and times   *
*                   that the planes were broken or unbroken            *
*                                                                      *
* FUNCTIONS CALLED: DIST(T) - location of front of truck               *
*                                                                      *
* SUBROUTINES CALLED: none                                             *
************************************************************************

      SUBROUTINE SENSORS(N, TRDIM, PBREAK, LAYOUT, TS, DIST, SDATA)

      INTEGER*2 N, I, J
      INTEGER*4 T, SDATA(54,0:7),TRDIM(8), PBREAK(0:4), LAYOUT(0:50)
      INTEGER*4 TRKLOC, AXLLOC(8), PRVLOC(0:8),VELOC
      DOUBLE PRECISION TS, TIME

****  INITIAL CONDITIONS  ****

      TRKLOC = -50
      T = 0
      PRVLOC(0) = TRKLOC
      DO 20 I=1,N+1
           PRVLOC(I) = TRKLOC - TRDIM(I)
           AXLLOC(I) = TRKLOC - TRDIM(I)
20    CONTINUE

****  START PRODUCING SENSOR DATA  ****

25    IF( AXLLOC(N+1) .LT. ( PBREAK(PBREAK(0))+ 4000 ) ) THEN
**       ( 4000 is an arbitrary number to ensure enough samples taken)
      T = T + 1
      TIME = DBLE(T) * TS
      TRKLOC = DIST(TIME) - 50
***              ( -50 is initial position of truck)

*** (update position of each axle)

      DO 30 I=1,N+1
```

```
            AXLLOC(I) = TRKLOC - TRDIM(I)
30      CONTINUE

****    CHECK FOR AXLE SENSOR CROSSING  ****
***         (for each axle detector, check for any axle crossing)

        DO 50 J=1,LAYOUT(0)
            DO 40 I=1,N

                IF ( ( PRVLOC(I) .LT. LAYOUT(J) ) .AND.
     +                  ( AXLLOC(I) .GE. LAYOUT(J) ) ) THEN

                        SDATA(J,I) = T
                        SDATA(J,0) = SDATA(J,0) + 1

                END IF
40          CONTINUE
50      CONTINUE

****    CHECK FOR PLANE BREAK CROSSING  ****
****    J corresponds to the sensor number  ****
****    I corresponds to the axle number    ****

        DO 60 J=1,PBREAK(0)

            IF ( (TRKLOC .GE. PBREAK(J) ) .AND.
     +              ( PRVLOC(0) .LT. PBREAK(J)) ) THEN

                SDATA( LAYOUT(0) + J ,1) = T

            ELSE IF (( AXLLOC(N+1) .GT.  PBREAK(J)) .AND.
     +              ( PRVLOC(N+1) .LE. PBREAK(J) )) THEN

                SDATA( LAYOUT(0) + J ,2) = T
                SDATA( LAYOUT(0) + J ,0) = 2

            END IF
60      CONTINUE

****    PUT AXLLOC INTO PRVLOC  ****

        PRVLOC(0) = TRKLOC

        DO 70 I=1,N+1
            PRVLOC(I) = AXLLOC(I)
70      CONTINUE
        GO TO 25

****    END OUTERMOST LOOP  ****
        END IF

****    END OF SUBROUTINE SENSORS  ****
        END
```

```
************************************************************************
* Subroutine CALLIN calculates the length of a truck using the sensor  *
*     data contained in SDATA. SDATA was generated by a sensor layout  *
*     which is defined by PBREAK and LAYOUT. This subroutine calls     *
*     subroutine LINEAR to interpolate the intervals. The algorithm    *
*     used requires the sensor layout to consist of one plane break.   *
*     The algorithm uses the front axle data to determine the position *
*     of the front axle of the truck and the rear axle data to         *
*     determine the position of the rear axle of the truck.            *
*                                                                      *
*     Inputs: SDATA - data from the sensor layout.                     *
*             PBREAK - array defining the number and location of       *
*                      the plane breaks.                               *
*             LAYOUT - array defining the number and location of       *
*                      the axle detectors.                             *
*                                                                      *
*     Outputs: LENGTH - the calculated length of the truck.            *
*              TEST - internal length calculation information.        *
*                     (0)-number of items in TEST, equals 8.           *
*                     (1)-interval # in event1 containing TA.          *
*                     (2)-distance found by LINEAR for above interval. *
*                     (3)-interval # in event1 containing TB.          *
*                     (4)-distance of beginning of above interval.     *
*                     (5)-interval # in eventN containing TC.          *
*                     (6)-distance found by LINEAR for above interval. *
*                     (7)-interval # in eventN containing TB.          *
*                     (8)-distance found by LINEAR for above interval. *
*                                                                      *
*     Subroutines called: LINEAR                                       *
*                                                                      *
*     Internal Variables:  N - the number of axles.                    *
*                         TA - time plane break was broken.            *
*                         TB - time plane break was unbroken.          *
*                         TC - time of switch between event 1 and      *
*                              event N (front and rear axle data).     *
*                         D1, D2 - distance.                           *
*                         I - index.                                   *
*                                                                      *
*     Written by: Alan Eichmann                                        *
************************************************************************

      SUBROUTINE CALLIN(PBREAK, LAYOUT, SDATA, LENGTH, TEST)

      INTEGER*4 PBREAK(0:4), LAYOUT(0:50), SDATA(1:54,0:7),LENGTH
      INTEGER*4 TEST(0:20), TA, TB, TC, D1, D2
      INTEGER*2 N, I

      N = SDATA(1,0)
      TA = SDATA(LAYOUT(0)+1,1)
      TB = SDATA(LAYOUT(0)+1,2)
      TEST(0) = 8

* find interval in event 1 containing TA
      I = 2
      DO WHILE (TA .GE. SDATA(I,1))
          I = I + 1
      END DO
      CALL LINEAR(SDATA, LAYOUT, I-1, 1, TA, D1)
      TEST(1) = I-1
      TEST(2) = D1
```

```
* find interval in event 1 containing TB
      DO WHILE (TB .GE. SDATA(I,1))
            I = I + 1
      END DO
      LENGTH = LAYOUT(I-1) - D1
      TC = SDATA(I-1,1)
      TEST(3) = I-1
      TEST(4) = LAYOUT(I-1)

* find interval in event N containing TC
      I = 2
      DO WHILE (TC .GE. SDATA(I,N))
            I = I + 1
      END DO
      CALL LINEAR(SDATA, LAYOUT, I-1, N, TC, D1)
      TEST(5) = I-1
      TEST(6) = D1

* find interval in event N containing TB
      DO WHILE (TB .GE. SDATA(I,N))
            I = I + 1
      END DO
      CALL LINEAR(SDATA, LAYOUT, I-1, N, TB, D2)
      TEST(7) = I-1
      TEST(8) = D2

      LENGTH = LENGTH + D2 - D1
      RETURN
      END

************************************************************************
* Subroutine LINEAR interpolates an interval to find an intermediate   *
*     distance given an intermediate time. The interval is between     *
*     two times which are found in SDATA and corresponding distances   *
*     for these times are found in LAYOUT. Linear interpolation is     *
*     the method used in this routine to perform the interpolation.    *
*                                                                      *
*     Inputs: SDATA - data from the sensor layout.                     *
*             LAYOUT - array defining the number and location of       *
*                      the axle detectors.                             *
*             I - sensor number defining start of the interval to      *
*                 interpolate.                                         *
*             N - defines which event to use.                          *
*             T - the time for which distance is to be found.          *
*                                                                      *
*     Outputs: D - the distance found to correspond to time T.         *
*                                                                      *
*     Subroutines called: none                                         *
*                                                                      *
*     Written by: Alan Eichmann                                        *
************************************************************************

      SUBROUTINE LINEAR(SDATA, LAYOUT, I, N, T, D)

      INTEGER*4 SDATA(1:54,0:7), LAYOUT(0:50), T, D
      INTEGER*2 I, N

      D = ((LAYOUT(I+1)-LAYOUT(I))*(T-SDATA(I,N)))/
     C     (SDATA(I+1,N)-SDATA(I,N))+LAYOUT(I)

      RETURN
      END
```

```
************************************************************************
* Subroutine CALCUB calculates the length of a truck using the sensor  *
*      data contained in SDATA. SDATA was generated by a sensor layout *
*      which is defined by PBREAK and LAYOUT. This subroutine calls    *
*      subroutine CUBIC to interpolate the intervals. The algorithm    *
*      used requires the sensor layout to consist of one plane break.  *
*      The algorithm uses the front axle data to determine the position *
*      of the front axle of the truck and the rear axle data to        *
*      determine the position of the rear axle of the truck.           *
*                                                                      *
*      Inputs: SDATA - data from the sensor layout.                    *
*              PBREAK - array defining the number and location of      *
*                       the plane breaks.                              *
*              LAYOUT - array defining the number and location of      *
*                       the axle detectors.                            *
*                                                                      *
*      Outputs: LENGTH - the calculated length of the truck.           *
*               TEST - internal length calculation information.        *
*                      (0)-number of items in TEST, equals 8.          *
*                      (1)-interval # in event1 containing TA.         *
*                      (2)-distance found by CUBIC for above interval. *
*                      (3)-interval # in event1 containing TB.         *
*                      (4)-distance of beginning of above interval.    *
*                      (5)-interval # in eventN containing TC.         *
*                      (6)-distance found by CUBIC for above interval. *
*                      (7)-interval # in eventN containing TB.         *
*                      (8)-distance found by CUBIC for above interval. *
*                                                                      *
*      Subroutines called: CUBIC                                       *
*                                                                      *
*      Internal Variables: N - the number of axles.                    *
*                          TA - time plane break was broken.           *
*                          TB - time plane break was unbroken.         *
*                          TC - time of switch between event 1 and     *
*                               event N (front and rear axle data).    *
*                          D1, D2 - distance.                          *
*                          I - index.                                  *
*                                                                      *
*      Written by: Alan Eichmann                                       *
************************************************************************

      SUBROUTINE CALCUB(PBREAK, LAYOUT, SDATA, LENGTH, TEST)

      INTEGER*4 PBREAK(0:4), LAYOUT(0:50), SDATA(1:54,0:7), LENGTH
      INTEGER*4 TEST(0:20), TA, TB, TC, D1, D2
      INTEGER*2 N, I

      N = SDATA(1,0)
      TA = SDATA(LAYOUT(0)+1,1)
      TB = SDATA(LAYOUT(0)+1,2)
      TEST(0) = 8

* find interval in event 1 containing TA
      I = 2
      DO WHILE (TA .GE. SDATA(I,1))
            I = I + 1
      END DO
      CALL CUBIC(SDATA, LAYOUT, I-1, 1, TA, D1)
      TEST(1) = I-1
      TEST(2) = D1
```

```
* find interval in event 1 containing TB
      DO WHILE (TB .GE. SDATA(I,1))
            I = I + 1
      END DO
      LENGTH = LAYOUT(I-1) - D1
      TC = SDATA(I-1,1)
      TEST(3) = I-1
      TEST(4) = LAYOUT(I-1)

* find interval in event N containing TC
      I = 2
      DO WHILE (TC .GE. SDATA(I,N))
            I = I + 1
      END DO
      CALL CUBIC(SDATA, LAYOUT, I-1, N, TC, D1)
      TEST(5) = I-1
      TEST(6) = D1

* find interval in event N containing TB
      DO WHILE (TB .GE. SDATA(I,N))
            I = I + 1
      END DO
      CALL CUBIC(SDATA, LAYOUT, I-1, N, TB, D2)
      TEST(7) = I-1
      TEST(8) = D2

      LENGTH = LENGTH + D2 - D1
      RETURN
      END
```

```
***********************************************************************
* Subroutine CUBIC  interpolates an interval to find an intermediate  *
*     distance given an intermediate time. The interval is between    *
*     two times which are found in SDATA and corresponding distances  *
*     for these times are found in LAYOUT. Piecewise-cubic Bessel     *
*     interpolation is the method used in this routine to perform the *
*     interpolation.                                                  *
*                                                                     *
*     Inputs: SDATA - data from the sensor layout.                    *
*             LAYOUT - array defining the number and location of      *
*                      the axle detectors.                            *
*             I - sensor number defining start of the interval to     *
*                 interpolate.                                        *
*             N - defines which event to use.                         *
*             T - the time for which distance is to be found.         *
*                                                                     *
*     Outputs: D - the distance found to correspond to time T.        *
*                                                                     *
*     Subroutines called: none                                        *
*                                                                     *
*     Internal Variables: DX0, DX1, DX2 - interval spacing.           *
*             DIVDF0, DIVDF1, DIVDF2, DIVDF3 - divided differences.   *
*             S0, S1 - slopes at begining and end of interval.        *
*             C1, C2, C3, C4 - coefficients for cubic.                *
*                                                                     *
*     Written by: Alan Eichmann                                       *
***********************************************************************

      SUBROUTINE CUBIC(SDATA, LAYOUT, I, N, T, D)

      INTEGER*4 SDATA(1:54,0:7), LAYOUT(0:50), T, D
      INTEGER*2 I, N
      DOUBLE PRECISION DX, DX0, DX1, DX2, DIVDF0, DIVDF1, DIVDF2, DIVDF3
      DOUBLE PRECISION S0, S1, C1, C2, C3, C4

* Calculate interval spacing
      DX0 = DBLE(SDATA(I,N) - SDATA(I-1,N))
      DX1 = DBLE(SDATA(I+1,N) - SDATA(I,N))
      DX2 = DBLE(SDATA(I+2,N) - SDATA(I+1,N))

* Calculate divided differences
      DIVDF0 = DBLE(LAYOUT(I) - LAYOUT(I-1)) / DX0
      DIVDF1 = DBLE(LAYOUT(I+1) - LAYOUT(I)) / DX1
      DIVDF2 = DBLE(LAYOUT(I+2) - LAYOUT(I+1)) / DX2

* Calculate slopes
      S0 = (DX1 * DIVDF0 + DX0 * DIVDF1) / (DX0 + DX1)
      S1 = (DX2 * DIVDF1 + DX1 * DIVDF2) / (DX1 + DX2)

* Calculate coefficients for cubic
      DIVDF3 = S0 + S1 - 2. * DIVDF1
      C1 = DBLE(LAYOUT(I))
      C2 = S0
      C3 = (DIVDF1 - S0 - DIVDF3) / DX1
      C4 = DIVDF3 / (DX1 * DX1)

* Evaluate the cubic at T
      DX = DBLE(T - SDATA(I,N))
      D = IDINT(C1 + DX * (C2 + DX * (C3 + DX * C4)))

      RETURN
      END
```

```
*************************************************************************
* Subroutine OUTPUT writes an output file which displays the            *
*     contains of the input variables. The user is prompted for the     *
*     the filename of the output file.                                  *
*                                                                       *
*     Inputs: N - number of axles.                                      *
*             TRDIM - array defining the location of the axles and      *
*                     the actual length of a truck.                     *
*             FUNC - character string telling which distance function   *
*                    was used.                                          *
*             PBREAK - array defining the number and location of        *
*                      the plane breaks.                                *
*             LAYOUT - array defining the number and location of        *
*                      the axle detectors.                              *
*             TS - sampling time.                                       *
*             SDATA - data from the sensor layout.                      *
*             LINLEN - the calculated length of the truck using         *
*                      linear interpolation.                            *
*             CUBLEN - the calculated length of the truck using         *
*                      cubic interpolation.                             *
*             TESTL - internal length calculation information for       *
*                     linear interpolation.                             *
*             TESTC - internal length calculation information for       *
*                     cubic interpolation.                              *
*                                                                       *
*     Outputs: none                                                     *
*                                                                       *
*     Subroutines called: none                                          *
*                                                                       *
*     Internal Variables: I, J - indexes.                               *
*                                                                       *
*     Written by: Alan Eichmann                                         *
*************************************************************************

      SUBROUTINE OUTPUT(N, TRDIM, PBREAK, LAYOUT, TS, SDATA, LINLEN,
     C       TESTL, CUBLEN, TESTC)

      INTEGER*4 TRDIM(1:8), PBREAK(0:4), LAYOUT(0:50), TESTC(0:20)
      INTEGER*4 SDATA(1:54,0:7), LINLEN, CUBLEN, TESTL(0:20)
      INTEGER*2 N, I, J
      DOUBLE PRECISION TS
      CHARACTER*12 FNAME

      PRINT *, 'Enter filename for output file: '
      READ '(A)', FNAME
      OPEN (6, FILE = FNAME, STATUS = 'NEW')

      WRITE(6,*) '# of axles   position of axles'
      WRITE(6,*) N, (TRDIM(I), I=1,N)
      WRITE(6,*)
      WRITE(6,*) 'Actual length of truck = ', TRDIM(N+1)
      WRITE(6,*)
      WRITE(6,*) 'Number of plane break(s):', PBREAK(0)
      WRITE(6,*)
      WRITE(6,*) 'Numbler of axle detectors:', LAYOUT(0)
      WRITE(6,*)
      WRITE(6,*) 'Sampling time used: ', TS
      WRITE(6,*)
      WRITE(6,*) 'Axle detectors:'
      WRITE(6,80)
80    FORMAT (1X,'Sensor #  Location  # of events   Event1   Event2   ',
     C      'Event3   Event4   Event5   Event6   Event7')
```

```
      DO 100 I = 1, LAYOUT(0)
      WRITE(6,90) I, LAYOUT(I), (SDATA(I,J), J=0,SDATA(I,0))
90    FORMAT (1X, I5, 3X, I9, 8X, I2, 4X, 7I9)
100   CONTINUE
      WRITE(6,*)
      WRITE(6,*) 'Plane Break:'
      WRITE(6,80)
      DO 120 I = LAYOUT(0)+1, LAYOUT(0)+PBREAK(0)
      WRITE(6,110) I, PBREAK(I-LAYOUT(0)),
     C       (SDATA(I,J), J=0,SDATA(I,0))
110   FORMAT (1X, I5, 3X, I9, 8X, I2, 4X, 7I9)
120   CONTINUE
130   FORMAT(1X,8I10)
      WRITE(6,*)
      WRITE(6,*) 'Internal length calculation information ',
     C       'for linear interpolation :'
      WRITE(6,130) (TESTL(I), I=1,TESTL(0))
      WRITE(6,*)

      WRITE(6,*) 'Internal length calculation information ',
     C       'for cubic interpolation :'
      WRITE(6,130) (TESTC(I), I=1,TESTC(0))
      WRITE(6,*)
      WRITE(6,*)

      WRITE(6,*) 'Computed length (linear) = ', LINLEN
      WRITE(6,*)
      WRITE(6,*) 'Error (linear) = ', LINLEN-TRDIM(N+1)
      WRITE(6,*)
      WRITE(6,*)

      WRITE(6,*) 'Computed length (cubic) = ', CUBLEN
      WRITE(6,*)
      WRITE(6,*) 'Error (cubic) = ', CUBLEN-TRDIM(N+1)

      CLOSE (6)
      RETURN
      END
```

APPENDIX D

TESTS ON POLAROID EXPERIMENT KIT

This appendix covers the various experiments that were performed on the Polaroid transducer experiment kit. There were five tests performed on the kit. These were; 1) distance and angle test, 2) motion measurement test, 3) cold weather test, 4) wind test, and 5) rain test. It should be noted that the transducer utilized was not environmental grade.

1. Angle and Distance Test

This experiment was used to determine how accurately the kit measured distance and the dispersion angle of the transducer. The tests were performed by John Leick and Paul Seppa on November 11, 1989 in the Maple-Willow-Larch commons area.

To determine if the kit measures distances accurately, the transducer was aimed directly at a plaster wall. The true distance to the wall was determined using a measuring tape. The display on the kit measures the distance in feet and tenths of feet with a maximum of 35 feet. By varying the distance to the wall, it was determined the the kit could accurately distinguish the distance to the nearest tenth of a foot.

In order to measure the dispersion angle, two chairs were placed a distance Y apart. The transducer was then aimed directly between them a distance X back. Then the chairs were slowly moved together until the transducer reflected off one or both of them. When this happens the dispersion angle can be calculated using the equation:

$$\text{Angle} = \text{Tan}^{-1}(Y/X)$$

The measurements taken were: Y=14", X=66" giving an angle of 12 Degrees.

2. Motion Measurement Test

The purpose of this experiment was to determine if the kit could measure distances to a moving object. The objects used were cars entering a parking lot. The test was performed on November 11, 1989 by John Leick and Paul Seppa at the Target parking lot in Ames, Ia. The weather conditions at the time of the test were: 15-20 mph wind and a temperature of 40 Fahrenheit.

To have a measurement to compare to the kit display, strips of tape were placed on the roadway at distance intervals of 1 foot. From these, it was visually estimated how far the car was from the curb. These estimations were crude, probably having an error of +/- 5". Below in table D-1 is a comparison of kit measurements and visual estimates.

Table D-1

Motion Measurement Results

Sighted Distance	Kit Display
14.0'	14.5'
13.0'	12.6'
14.2'	14.6'
12.1'	12.2'
13.0'	13.3'
13.0'	12.9'
13.2'	13.6'

It should be noted that about 3 readings were obtained on each passing car. The second measurement was the one used in Table D-1. The speed of the passing cars varied between 5 and 25 mph.

3. Cold Weather Test

This test was used to determine how the transducer operated under relatively cold temperatures. The test was performed by Paul Seppa on the night of December 12, 1989 outside the Willow Dormitory. The temperature at the time was 11 Degrees Fahrenheit. There was also light blowing snow.

The transducer was aimed at a brick wall and accurately measured the distance for 10 minutes. When distances of over 7 feet were measured, the reading became sporadic. Readings varied by as much as one or two feet. Since it occasionally read high, snow flakes prematurely reflecting the sound back could not be the only reason for errors. The circuit boards also were exposed to the cold and some snow did get on them.

4. Wind Test

The purpose of this test was to examine how wind might affect the transducers accuracy. The test was performed by Paul Seppa in his dormitory room on December 20, 1989. The transducer was aimed at a large board 6 feet away and a reading of the kit was taken without any wind. Then a medium household fan was used to simulate a 5-15 mph wind. The wind was directed at, from behind, and crossways to the transducer-board line. No difference in reading was noted. Next, a hair dryer was used to simulate a wind of about 25 mph. The same procedure that was used with the fan was used with the hair dryer. The only time the readings varied was when the hair dryer was directly behind the transducer and within an inch of it. Here, the distance readings became sporadic. A possible explanation might be the electrical noise from the hair dryer was sending false signals to the transducer cable.

5. Rain Test

This test examined what effect rain might have on the transducer reading. It was performed by Paul Seppa on December 20, 1989 on Schaefer dormitory floor in Willow. The first rain test used a plant mister to simulate a heavy mist. The transducer was aimed at a cement wall at a distance of 4 feet. The heavy mist was placed in its reading path. No difference in readings were noted with the mist present. For the second rain test, the transducer was taken into the shower. The transducer was aimed at the wall of the shower from about 4 feet back. The shower was turned on and the reading was noted. The reading varied by 6 to seven inches, indicating that a heavy rain will give false reflections.

APPENDIX E

PROPOSED HEIGHT AND WIDTH MEASUREMENT SYSTEM
(COPY OF INITIAL PROPOSAL)

To: Bill McCall, Director of DOT Planning and Research

From: Truck Measurement Design Team

Subject: Proposed Budget for Height and Width Measurement System

Date: December 13, 1989

After careful consideration, our group has estimated the total cost of a system, which will measure the height and width of trucks as they enter the new DOT weigh station. The station is to be constructed on I-80, west of Des Moines. This memo will briefly discuss the items which we included and excluded in our budget, and it will also describe some possible alternatives. A specification sheet for the transducers, the multiplexer, and the measurement board is also attached.

BUDGET

Refer to Table 1 while following the description of the contents of our budget.

Table l. Price List.

* Prices do not include tax or shipping and handling.

Item	Quantity	$ each	Total	Comments
Polaroid US Transducer	7	$ 18	$180	Minimum Order Quantity of 10.
Environmental Housings	7	$ 12	$120	Minimum Order Quantity of 10.
Packaged Multiplexer	1	$500	$500	Includes Power Supply and Operating Instructions.
Transducer Cable	300 ft	---	$500	Actual Footage and Price is Dependent on Final Structure Dimensions and Location.
IBM PC/XT/AT Measurement Board	1	$500	$500	Includes Driver and Demo Software and Operating Instruction Manual.
Signal/Control Cable	60 ft	$3/ft	$180	Cable From PC to Multiplexer.
Miscellaneous			$1000	

APPROXIMATE TOTAL COST:$3000

INCLUSIONS

The following items are included in our budget proposal.

Ultrasonic Transducers. The current design calls for seven transducers mounted on an overhead structure; 3 on top and 2 on each side as shown in Figure E-l. We need to order 10 to comply with Polaroid's minimum order. The three extra transducers can be used as replacements should any of them fail.

Environmental Covers, These will also be ordered from Polaroid, and are subject to the same minimum order number as the transducers. They are necessary to protect the transducers in adverse weather conditions.

Signal Multiplexer. The signals from each of the transducers need to be multiplexed, so the distance measuring card can calculate a distance for each transducer separately. The multiplexer will be located adjacent to the structure over the roadway.

Cable from Transducer to multiplexer. The signals from each transducer must be fed to the multiplexer. A rough cost estimate has been provided. The cost is dependent on the specific grade of cable needed and on the dependency of the measuring card on equal length cables for each transducer. It is likely that the cost listed is a maximum value rather than a projected cost. Before the cables can be ordered, the exact dimensions of the structure are needed. The reason for this is that the multiplexer has to be factory-tuned to match the cable lengths.

Distance Measuring Card. This card is used to decode length information sent to it by the transducers and to communicate that measurement to a computer in a form it can use.

Cable from Multiplexer to Measuring Card. The cable between the multiplexer and the distance measuring card is needed to get the information from the transducers to the computer card. Its length is dependent on the distance between the multiplexer and the computer card.

Miscellaneous Expenses. Various costs may arise which we have not foreseen. Examples of these would be connectors, mounting hardware, circuit tuning, power cables, etc.

EXCLUSIONS

The following items are not included in our budget proposal and are dependent on final system configurations.

Overhead Structure. Original DOT memos stated that any costs of a structure would be paid for from a budget separate from the measurement system's budget.

Conduit. The cables between the transducers and the multiplexer, and the cables between the multiplexer and the measurement card will need to be protected from weather and wildlife.

Protection of Multiplexer. The multiplexer needs to be protected from precipitation as well as temperature extremes. It has been rated for temperatures between 0 and 70 degrees Celsius (32 to 158 degrees Fahrenheit). Although it has not been tested at colder temperatures, application engineers at Contaq have estimated that it will work in sub-freezing temperatures.

IBM PC/XT/AT Compatible. The distance measuring card requires this type of computer. In addition it will be used to calculate the width and height of trucks from the raw measurement data it receives. It is our understanding that this will be provided by the DOT.

Protection for IBM PC. This computer needs to be in an indoor type environment. It should also be relatively close (50 feet or less) to the measurement system, so that the multiplexer signal will not be attenuated.

IBM, Weight Classification Interface. The type of interface depends on the computer used for weight and classification. The length of cable will depend on the relative position of the two computers.

Power Supplies. Power will be needed for both the IBM compatible and the multiplexer. The power source will be 120 Vac. The multiplexer has a built in power supply to power the transducers.

ALTERNATIVES

Beam Break. An alternative to the use of sensors for the height measurement would be to use photoelectric beam break. The beam break would not be able to obtain the actual height of trucks, as would the sensors, but would only determine whether or not trucks were in violation of height limitations. Use of the beam break would eliminate the need for the overhead structure, but it would not eliminate the need for the sensor card and the multiplexer. An available beam break for our purposes would cost approximately $500 and would require a DC power supply.

Interfaces. If we don't use the ultrasonic measuring card, we need to design our own interface. This interface could be designed a number of ways. One way would be to design a self-contained interface unit that would interface through an I/O port on a computer. Another way would be to design an interface that would make use of a counter/timer on the computer. There are cards available for a PC (XT or AT) that contain a counter/timer. Also most single-board computers have a counter/timer or a counter/timer can be easily added.

Using one of these alternatives would produce a design that is not field tested. This may make the system less reliable than using the already proven ultrasonic measuring card. These alternatives would also require more design time, which would delay the completion of the project. The advantages of these other designs would be more flexibility and possibly lower cost. The designs would be more flexible since we could design it to do what we want, and all the designs could have left-over I/O ports that could be used to interface to a beam break. Using the ultrasonic measuring card, an I/O port would have to be added if it was necessary to interface to a beam break. Since these alternatives should slightly cost less than $1000 to build, these designs should be less expensive.

Using one of these alternative interfaces, a single-board computer could be used instead of a PC. Using a single-board computer would be less expensive, more reliable, able to tolerate a wider temperature range and easier to run than the PC. These advantages are due to the single-board computer being designed for dedicated applications, and to its ability to store the program in ROM without using a disk drive. A disk drive is not necessary in this system, because data will be stored in the weight classification computer.

SPECIFICATIONS

Transducer:

Power Requirements (supplied by multiplexer)	4.8-6.8 Vdc 2.5 A (1 ms pulse) 150 mA quiescent
Operating Conditions	-20 to 160 F 5% to 95% humidity non-condensing
Distance Range Resolution Beam Width	0.9 to 35 ft (+/-) 1% over range 12 degrees

Multiplexer:

Power Requirements	120 Vac / 30 mA / 60 Hz
Operating Conditions	32 to 160 F 5% to 95% humidity non-condensing
Channels	7

Measurement Board:

Power Requirements (supplied by computer)	N/A
Operating Conditions	32 to 160 degrees F 5% to 95% humidity non-condensing
Computer	IBM PC/XT/AT or compatible

APPENDIX F

CONSIDERATION OF LUNDAHL SENSORS

On March 20, 1990, the DOT Truck Monitor Design Team was presented with information on a new sensor technology suited for application in our proposed system. This new sensor which is marketed by Lundahl Instruments Inc. was discovered by Bill McCall. He believes that the sensor would simplify the task of designing the system and that this sensor was more proven when it came to operation in a hostile environment (precipitation, wind, temperature extremes) than were the Polaroid transducers currently in the design.

Research was done on the Lundahl sensors to see whether or not they would work in our system. The DCU-10 made use of a Polaroid transducer, but also had a connected microprocessor which could be programmed to perform several functions. After a side by side comparison of the two systems, the two major concerns of the group were the cost of the system and the time needed to complete the system. Although the group believes that the Lundahl sensor was better than the Polaroid transducers in ways, we opted to remain with our current technology based on a decision matrix shown below in Table F-1. The main reasons for staying with Polaroid/Contaq was cost and time.

Table F-1
Lundahl Decision Matrix

System	Lundahl	Polaroid
Hardware	3 sensors, find interface to PC	7 sensors, Mux, PC
Cable	12 conductors(use about 6)	2 conductors
Cost	$3000(sensors only)	< $3000
Accuracy	+/- 0.6 inch at 20 ft	< 1 inch
Coverage	2.5 ft on each side and on top	5 ft on each side and 7 ft on top
Power Supply	need to purchase	powered by Mux
Housing	$165 / each	$12 / each
Reading Frequency	adjustable	10 Hz
Reliability	no difference	
Control of Sensors	independently controlled	controlled through Mux

COST

The Lundahl sensors cost $950 each compared to about $20 each for the Polaroid transducers. Although the Lundahl sensors performed more functions, they didn't eliminate the need for any of the other hardware in the system. For example, a computer interface still had to be either designed or purchased. While the group think that the Polaroid system could be designed entirely for under $3000, it would that amount of money to simply purchase three Lundahl sensors. Environmental housings needed to be purchased also for either technology. The Lundahl housings cost $165 each where the Polaroid housings cost only $12 each.

Since our budget for the system was limited to $5000, the number of sensors was also limited. The Polaroid system was designed to use 7 sensors (2 on each side and 3 on the top), the maximum number that could be handled by one multiplexor. With the Lundahl sensors, our budget would realistically limit us to 3 sensors (1 on each side and 1 on the top). With fewer sensors, the area of the truck covered would be limited, and hence limit the overall quality of the system.

TIME

The design team also took a look at how much time would be required to complete each design. While it was thought that with the Polaroid transducers an operational test system could be reached by the end of the semester, there would be a need to back up considerably to incorporate to Lundahl sensors. Where the Polaroid transducers came with a pre-tuned 2 conductor cable design, the Lundahl sensors utilize a 12 cables which we would be responsible for tuning. Also, we would have to find or build the Lundahl sensor to computer interface where this task had already been completed for the Polaroid transducers.

The team thinking on time consideration was that with the Polaroid transducers, and operational system could be reached by the end of the semester. If the design team had opted to go with the Lundahl sensors, a proposed system would be the new goal to be reached by May. This would have set back the team roughly an entire semester.

CONCLUSION

While the design team believes that the Lundahl sensor is a better technology, a decision was made to remain with the Polariod/Contaq system. The Lundahl sensor was too expensive prohibitive for our budget and would have limited the systems overall coverage because not as many sensors could have been utilized. A decision to go to the Lundahl sensor would also have set back the design team roughly one semester where the goal would have become to have a proposed system by May instead of a fully designed and operational test system.

APPENDIX G

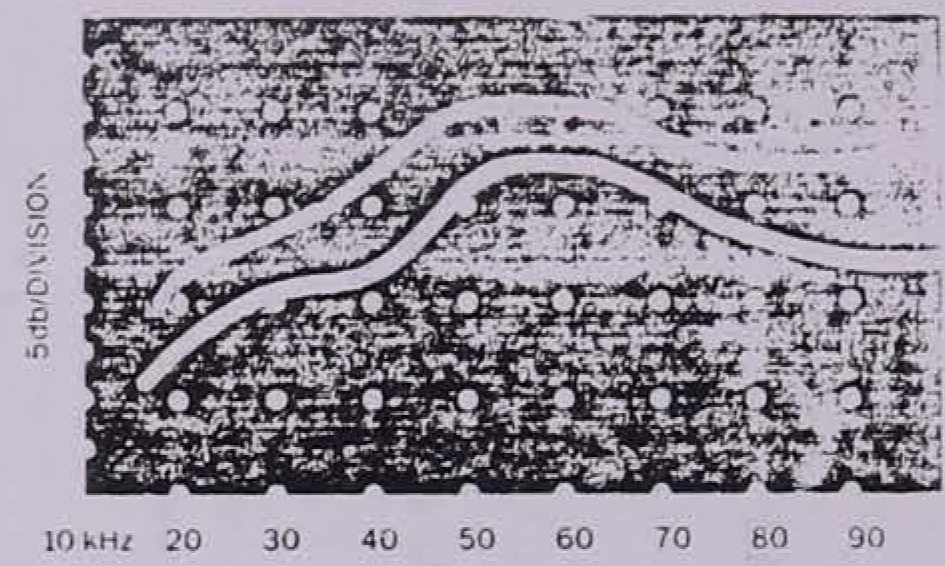
TRANSDUCERS AND ELECTRONICS SPECIFICATIONS

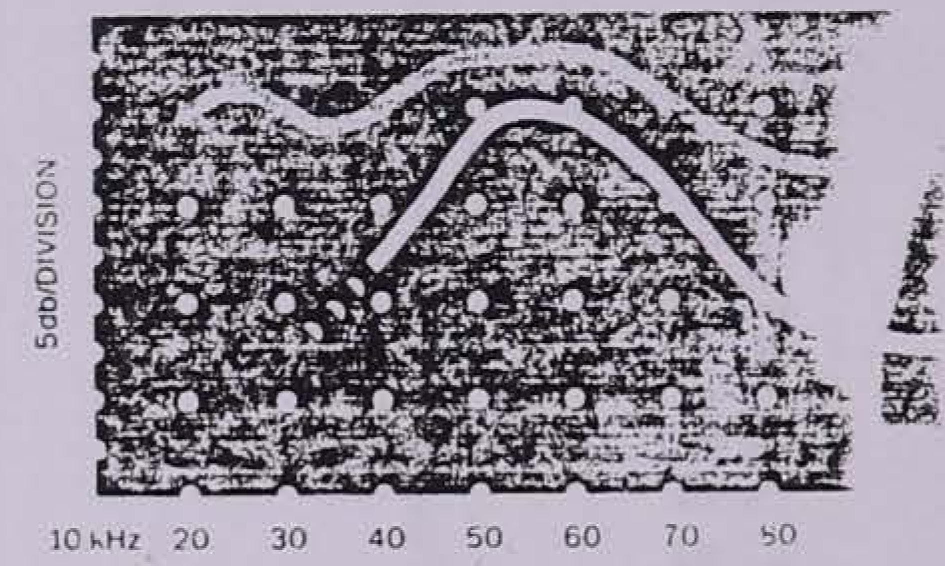
Distance Range	0.26 to 10.7m (0.9 to 35 ft.)	same	same
Resolution ± 1% over entire range	± 3mm to 3m (± .12 to 10 ft.)	same	same
Operating conditions:			
• temperature	−30° to 70°C (−20° to 160F)	same	0°–60°C (32°–140°F)
• relative humidity	5% to 95%	same	same
Beam angle typical, at 3db down	12°	12°	17°
Transducer Drive Signal:			
• gated sine wave	50 khz	same	same
• duration	1.1 ms	same	same
• suggested AC drive voltage (peak)	150v	same	same
• bias level	150vdc	same	same
• maximum combine voltage	400v	same	same
Min. transmitting sensitivity at 50khz	110db	same	106.9db
• 300 vac pk-pk, 150vdc bias			
• (db re 20μ pa at 1 meter)			
Min. receiving sensitivity at 50khz,	−42db	same	−43.4db
• 50khz, 150 vdc bias (db re lv/pa)			
Capacitance at 1khz (typical)	380–410 pf	same	650 pf
Power requirements:			
• voltage	6vdc (4.8–6.8vdc)	same	same
• current	2.5 amps (1 ms pulse)	same	same
	150 ma quiescent	same	same
Standard finish:			
• foil	gold	same	same
• housing	flat black cold roll steel	304 stainless steel	flat black plastic
Weight:			
• transducer	8.2gm (0.29oz)	same	4.6 gm (0.150 oz)
• modules	18.4gm (0.94oz)	same	same
Dimensions:			
• thickness	0.46 in.	0.46 in.	0.41 in.
• diameter	1.69 in.	1.69 in.	1.13 in. sq.

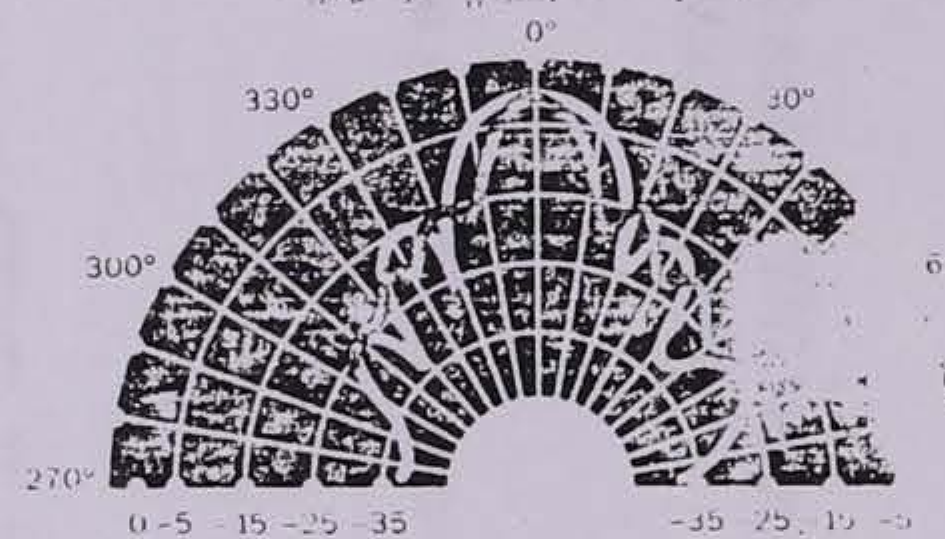
[1] Based on flat target 1 ft. sq. For irregular shape targets far range detection will be less.

* Environmental system is able to withstand salt spray, shock and vibration, water immersion, chemical exposure and sand bombardment when housed in "The Polaroid Test Enclosure"

Specifications subject to change without notice







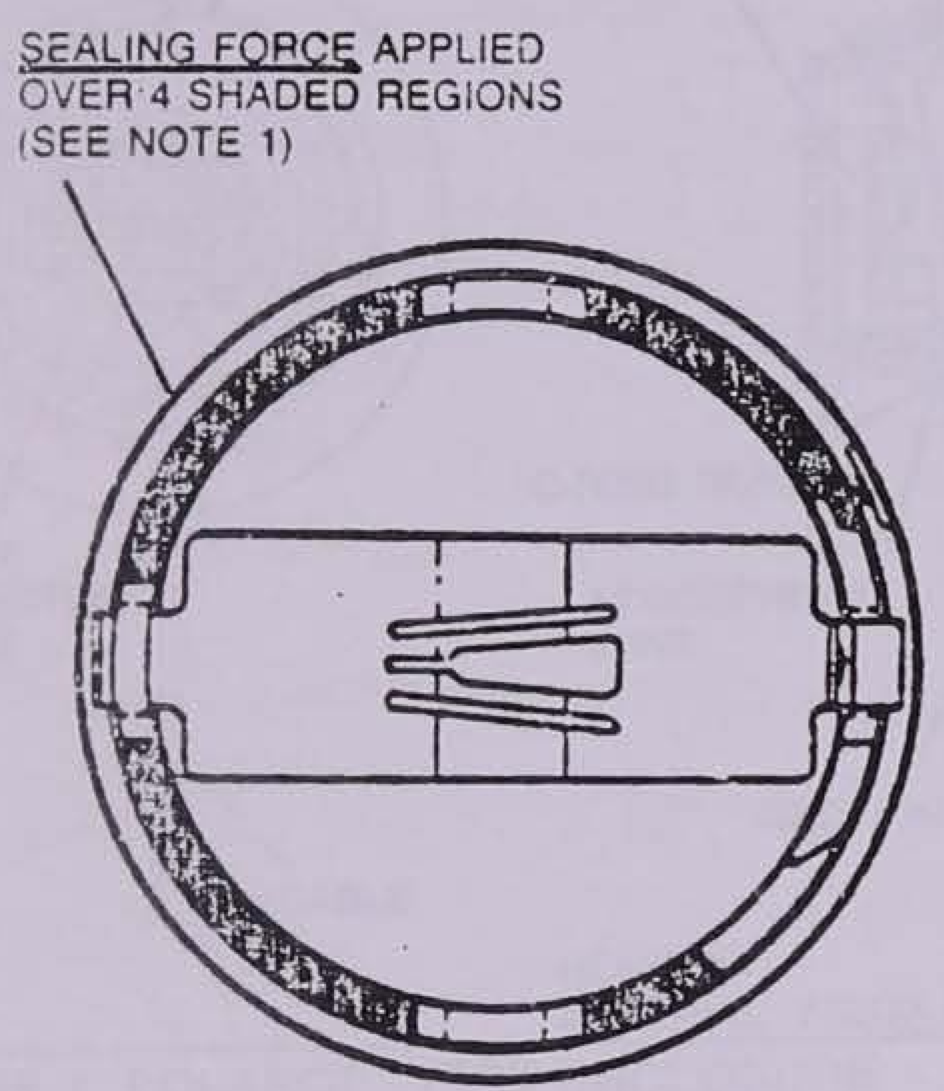
Note: db normalized to on axis response
Note: Curves are representative only. Individual responses may differ.

• Instrument Grade Transducer Environmental Transducer

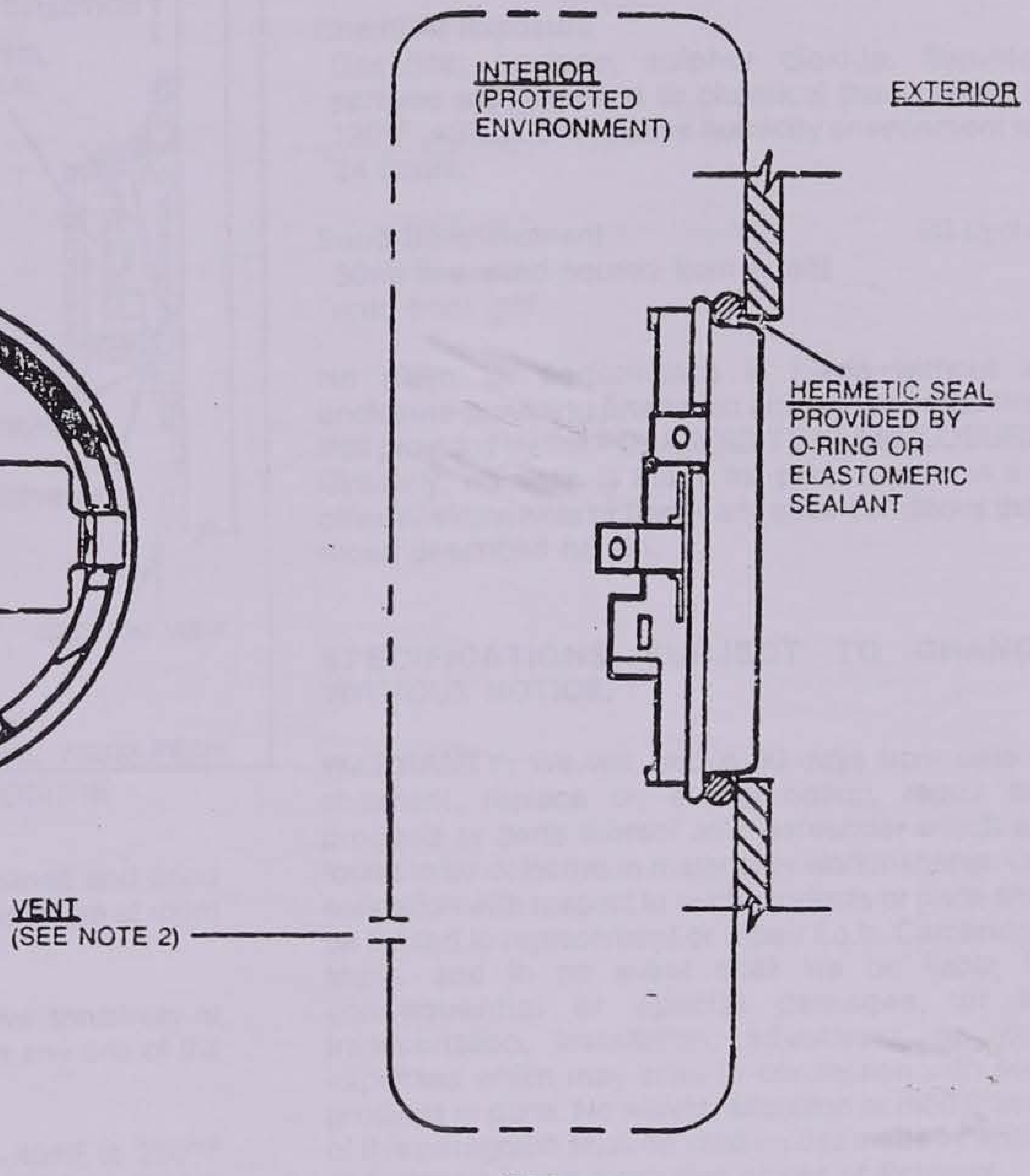
7000 Transducer

ENVIRONMENTAL ULTRASONIC TRANSDUCER MOUNTING SUGGESTIONS

The following guidelines should be used when designing your own housing for the Polaroid Environmental Ultrasonic Transducer.



REAR VIEW



SIDE VIEW

NOTE 1

A uniform force must be applied on the plastic ring shown if an O-ring is used as a seal. The use of an elastomeric sealant such as RTV silicone rubber eliminates the need for a seal clamping mechanism.

NOTE 2

Provisions must be made to provide for equalization of air pressure between the front and rear of the transducer. The location and design of this vent must be such that water, dust, corrosives, or foreign matter are prevented from reaching the transducer's interior surfaces.

ENVIRONMENTAL CHARACTERISTICS — EXPOSURE

NOTE: The following tests were performed with the transducer housed in the ***POLAROID TEST ENCLOSURE*** *(see* ***FIGURE 1****). The* ***TEST ENCLOSURE*** *protects the sides and back of the transducer from exposure to any foreign matter. The rear of the transducer is vented to atmospheric pressure. Output and sensitivity of the transducer are reduced slightly when used in this enclosure.*

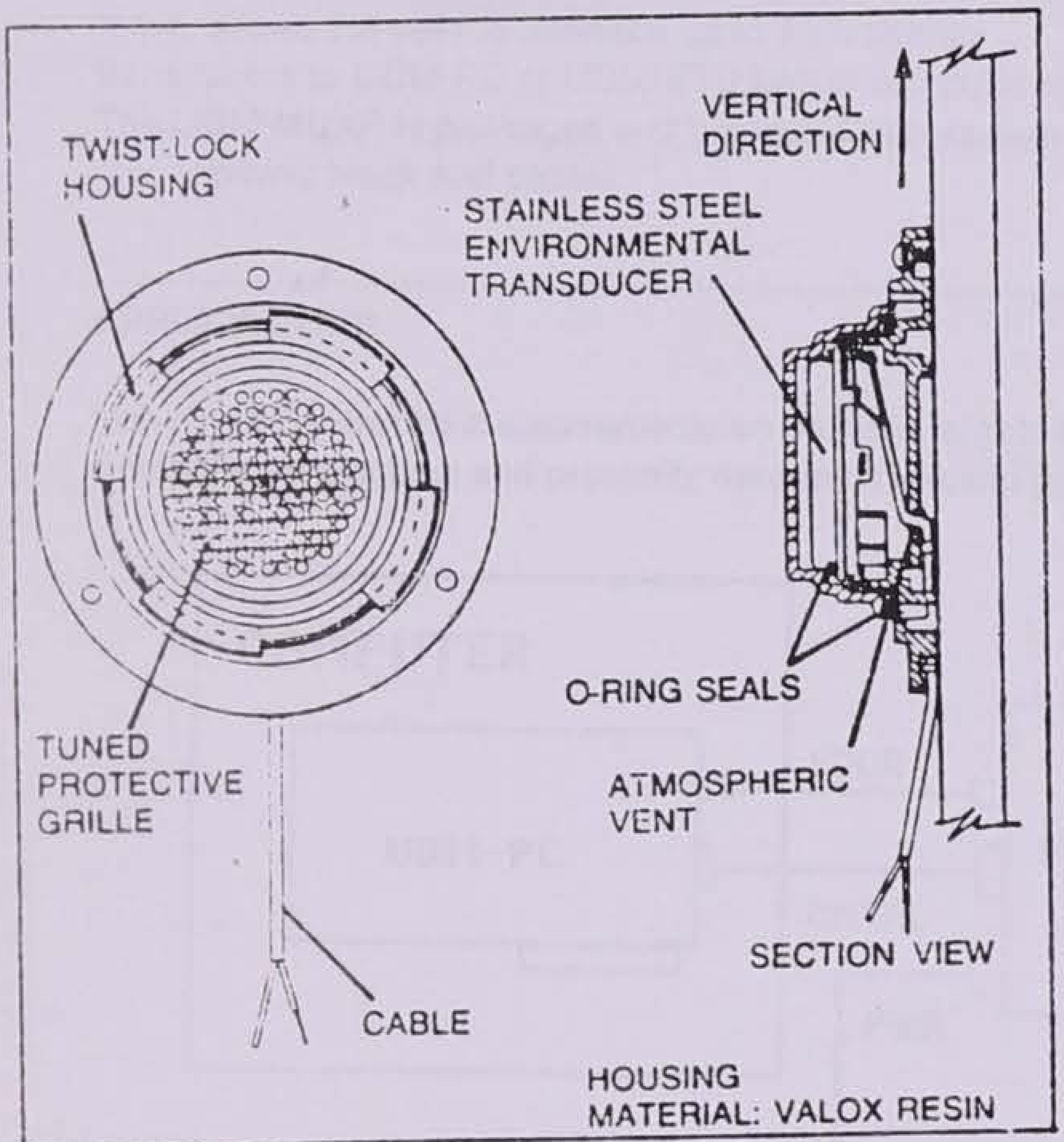


FIGURE 1. POLAROID TEST ENCLOSURE

After each test, transducers were cleaned and dried if necessary. Measurements were then taken at room temperature.

Variation in combined transmit/receive sensitivity at 50kHz was no more than 4.5 dB after any one of the following tests.

Storage Temperature Range — −40°F to 250°F (−40°C to 120°C)

Salt Spray Exposure
5% salt spray solution at 95°F (35°C) — 96 hours

Shock and Vibration
50 G peak in each direction along 3 perpendicular axes, pulse duration: 6.5 ms;
6 G's RMS 20 - 2000 Hz for 6 minutes

Water Immersion (vent hole sealed) — 24 hours

Freeze/Thaw Cycle — 4 cycles
Spray with water, drain, expose to −20ºF (−30ºC) for 20 minutes, allow to warm to room temperature.

Chemical Exposure
Gasoline, acetone, sulphur dioxide. Samples sprayed with/exposed to chemical then placed in 120ºF (49ºC)/90% relative humidity environment for 24 hours.

Sand Bombardment — 20 cycles
50ml fine sand poured from 4 feet onto front grill

No claim for performance is made without an enclosure providing protection equal to or better than that provided by the **POLAROID TEST ENCLOSURE.** Similarly, no claim is made for performance in any other environments or under any other conditions than those described herein.

SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE.

WARRANTY: We will, within 90 days from date of shipment, replace or, at our option, repair any products or parts thereof sold hereunder which are found to be defective in material or workmanship. Our obligation with respect to such products or parts shall be limited to replacement or repair f.o.b. Cambridge, Mass. and in no event shall we be liable for consequential or special damages, or for transportation, installation, adjustment, or other expenses which may arise in connection with such products or parts. No waiver, alteration or modification of this paragraph shall be valid unless made in writing and signed by an executive officer of Polaroid.

For technical assistance call
Polaroid's Applications Engineers at 617-577-4681.

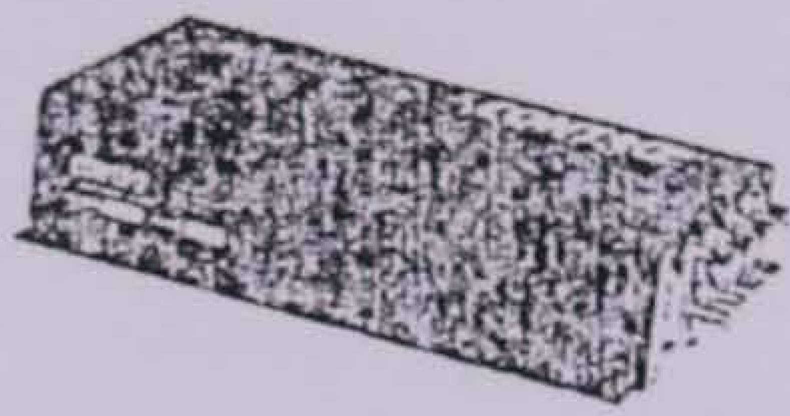
ULTRASONIC DISTANCE MEASUREMENT PRODUCTS

CONTAQ
SENSE THE FUTURE

Model UDM-MUXP

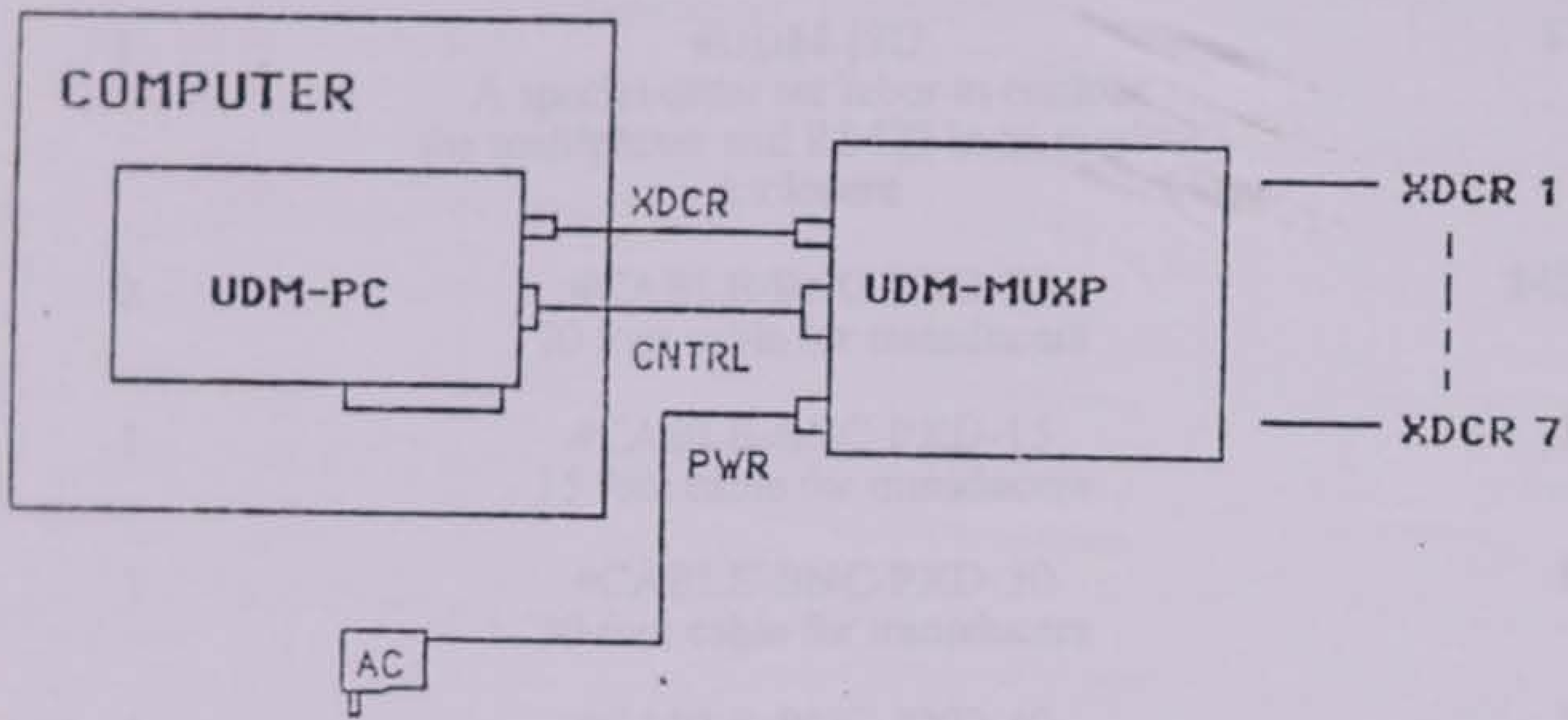
UDM-MUXP Packaged Multiplexer

This standalone multiplexer for the UDM interface board family allows the user to interface up to 7 ultrasonic transducers to UDM-PC or UDM-STD based computer systems. The UDM-MUXP is packaged and equipped with its own wall mount power block and cables.



APPLICATIONS

Non-contact distance measurements on multiple targets in performing level detection, material dimensioning, position and proximity determination, and general control operations.



FEATURES

- Compatible with UDM-PC and UDM-STD boards.
- Expands UDM based computer systems from 1 to 7 transducers.
- Standalone package with independent power supply.
- Programmable or manual transducer channel selection.

SPECIFICATIONS

Power:	120VAC/30ma.
Channels:	7 transducers.
Temp:	0 -70° C
Humidity:	5 -95% RH, non-condensing

CONTAQ TECHNOLOGY CORPORATION 15 MAIN STREET BRISTOL, VERMONT 05443 (802) 453-3332

APPENDIX H

PARTS ORDERED

COMPANY: **Contaq**

Quantity	Item	Price
1	#DMI-3-4-R RS422 serial Port Instrument	$548
1	#UDM-MUXP 7-channel multiplexer	$545
1	#UDM-ISU A special order for labor to enclose the multiplexer and RS422 in an outdoor enclosure	$250
2	#CABLE-BNC-PXD-20 20 foot cable for transducers	$49 each
1	#CABLE-BNC-PXD-15 15 foot cable for transducers	$44
1	#CABLE-BNC-PXD-30 30 foot cable for transducers	$59
1	#CABLE-BNC-PXD-40 40 foot cable for transducers	$69
1	#CABLE-BNC-PXD-55 55 foot cable for transducers	$84
1	#CABLE-BNC-PXD-60 60 foot cable for transducers	$89
1	#CABLE-9D-9D-50 Cable from multiplexer and RS422 to computer (50 feet)	$129
1	#CABLE-15D-15D-50 Cable from multiplexer and RS422 to computer (50 feet)	$159

NOTES: *This entire order was reviewed by Contaq's application engineer Paul Orellana, he is also familiar with the system and could answer any questions pertaining to the order.*

COMPANY: **Polaroid**

Quantity	Item	Price
10	#607281 Environmental Ultrasonic Transducer	$18 each
10	#607943 Environmental Transducer Housing	$12 each

NOTES: Polaroid required a minimum order of 10 for each item.

COMPANY: **Local Vendor**

Quantity	Item	Price
1	RS422 to RS232 adapter	$100 to $200

NOTES: *This item has not been purchased with the other equipment, it may still be needed for the system.*

TOTAL COST FOR ITEMS PURCHASED (excluding the serial port adaptor) **$2374**

APPENDIX I

LIST OF COMPANY CONTACTS

The following is a list of companies and company contacts from which purchases were made by the DOT truck monitor design team. The list also includes companies that were mentioned in the report.

POLAROID CORPORATION
Ultrasonic Components Group
119 Windsor Street
Cambridge, Massachusetts 02139
Contact: Phil Jackman, Senior Sales/Applications Engineer
Phone: 617-557-2496
Telex: 710-320-6611
FAX: 617-577-5989

CONTAQ TECHNOLOGIES CORPORATION
15 Main Street
Bristol, Vermont 05443
Contact: Paul Orellana, Applications Engineer
Phone: 802-453-3332
FAX: 802-453-4250

LUNDAHL INSTRUMENTS INC.
429 South Main
Logan, Utah 84321
Contact: Dan Brown, Technical Representative
Val Potter, Sales Manager
Phone: 801-753-7300
FAX: 801-753-7490

PENNWALT CORPORATION
950 Forge Avenue
Valley Forge, Pennsylvania 19482
Contact: Peter Radice
Phone: 215-666-3523

CMI INCORPORATED
MPH Industries
41011 Old Hwy 6
Minturn, Colorado 81645
Contact: Dale Wall
Phone: 502-685-6545

APPENDIX J

AUTHORS

Below is a brief synopsis of the authors of this report, their areas of expertise, and the sections of this report they wrote. All the authors are senior electrical engineering students at Iowa State University.

Alan Eichmann	-Computer System Design -Appendix C, Length Measurement Using Axle Sensors
Paul Fritz	-Communication Systems, Linear Control Systems -Appendix C, Length Measurement Using Axle Sensors
Ali Ismail	-Analog Electronics -Theory of Ultrasonic Transducers
John Leick	-Power and Energy Systems -Final System Set Up, Appendix H, Parts Ordered -Appendix G, Transducers and Electronics Specifications
Michael Meyer	-Antennas, Communication Systems, Electromagnetics -Appendix F, Consideration of Lundahl Sensors -Hardware Description of Final System
Brian Riesberg	-Communication Systems -Abstract, Figure 1 - Final System Set Up -Appendix B, Alternate Solutions
Paul Seppa	-Analog Electronics -Introduction, Conclusion -Appendix D, Tests on Polaroid Experiment Kit
Dan Wagner	-Power Systems, Control Systems -Appendix A, Weigh Station Trip Report -Description of Prototype System, Figure 2

APPENDIX G

PROTOTYPE SYSTEM SETUP

The prototype system described in this report can be assembled by following the steps shown below. The steps are the same for setup in the lab and in field situations with the exception of the cable between the sensors and the interface. The prototype system diagram is shown on the following page. It is recommended that the system be first assembled in the lab. This will simplify the adjustment of the 232 to 485 interface.

Step 1. Assemble the system as shown in the prototype system diagram. Pay careful attention to wire polarity for the power connections.

Step 2. Apply power to the system and then the computer.

Step 3. Listen for clicking sound from each sensor. Check trouble shooting guide if clicking not present.

Step 4. Load and run program "DOT3.BAS"

Step 5. The screen should display the measurements for each of the three sensors when an object is placed in front of them. If three measurements are present, system is ready to measure trucks using program "DOT6P.BAS".

Step 6. If a "Device Error " occurs, connect a dual trace oscilloscope to the RS-232 transmit and receive lines.

Step 7. Disconnect RS-232 receive line to computer.

Step 8. Restart program DOT3.BAS. This may take a few tries.

Step 9. Adjust potentiometer on interface until RS-232 transmit and receive signals do not overlap (as shown on oscilloscope). If the resistance is too low, no receive signal will be present. If two high, the receive signal will overlaped by the transmit signal.

Step 10. Check oscilloscope to be sure there is a send and receive signal for each transducer connected to the system.

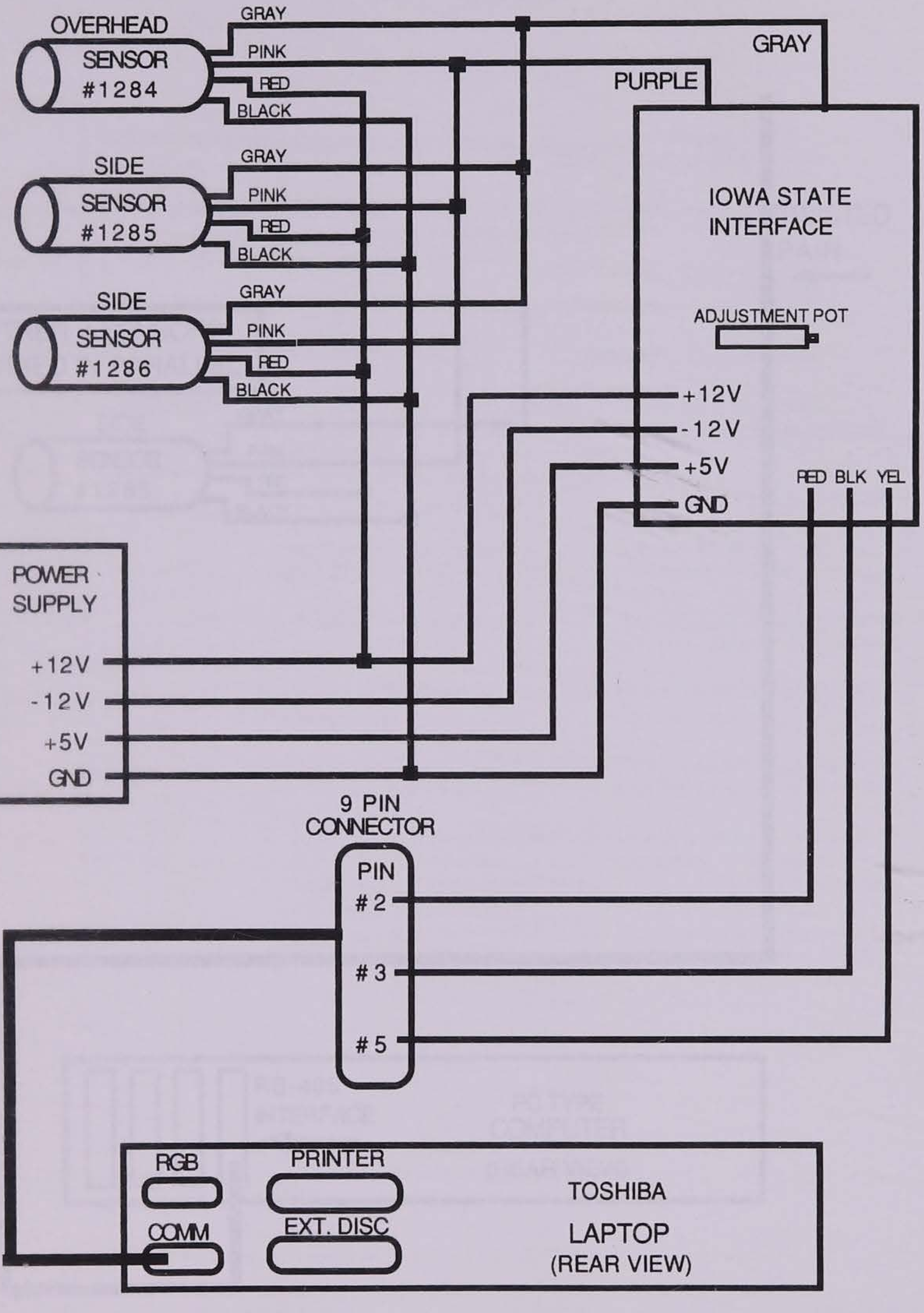
Step 11. Reconnect RS-232 receive line to computer.

Step 12. System should now be ready to measure trucks using program DOT3.BAS.

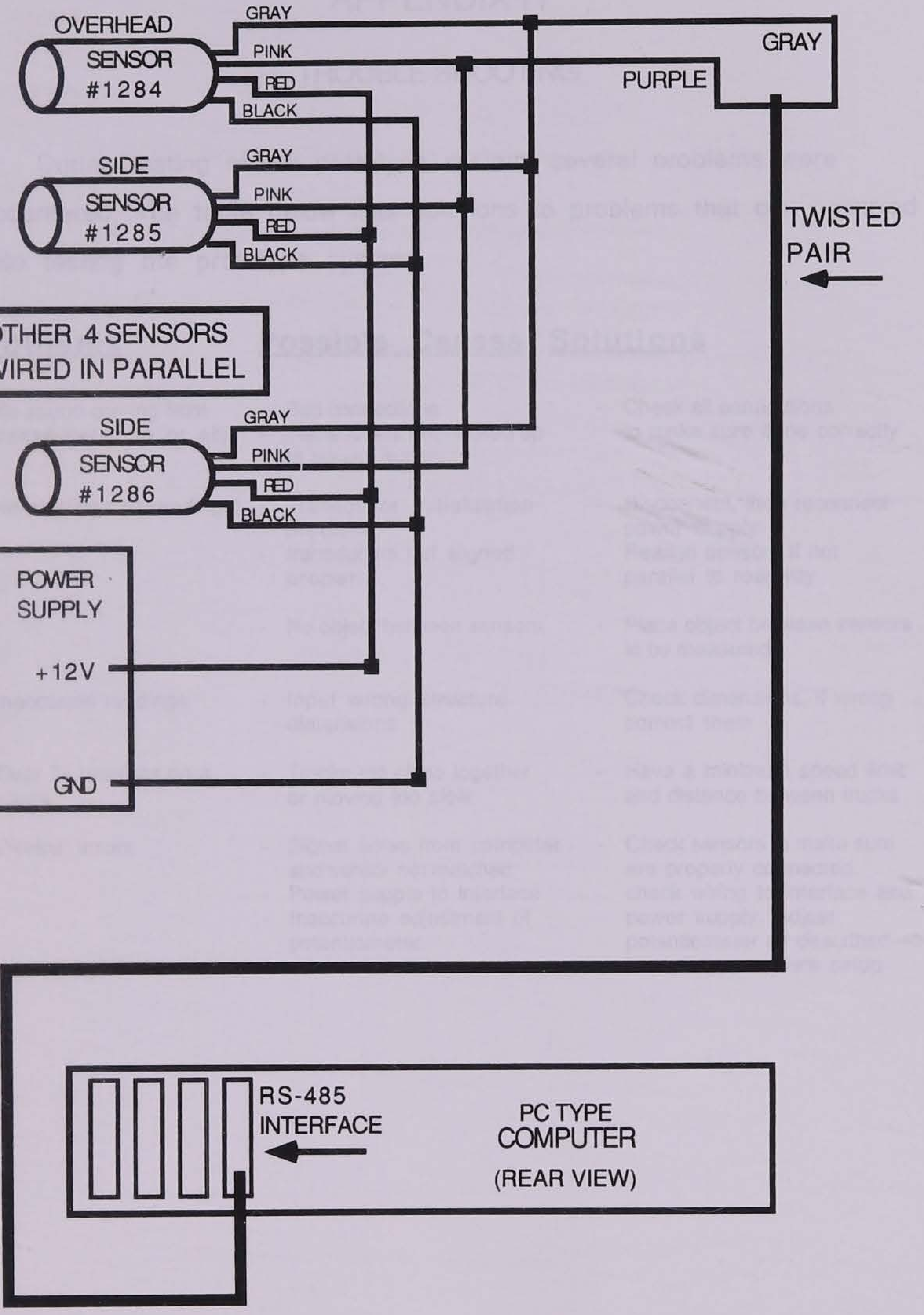
In our testing we used a 12 volt car battery to power the sensors. This was due to a problem with the length of the cable used in testing. Any Supply capable of providing 12 volts at the sensors can be used.

The setup of the final system should be similar but the exact details of the connections between the computer and the sensors will depend on the RS-485 interface used in the computer. The same program should work with the final system as in the prototype system. The Final System Diagram is also included in this appendix.

PROTOTYPE SYSTEM DIAGRAM



FINAL SYSTEM DIAGRAM



APPENDIX H

TROUBLE SHOOTING

During testing of the prototype system, several problems were encountered. The table below lists solutions to problems that can occurred while testing the prototype system.

Problems	Possible Causes	Solutions
- No sound coming from transducers(one or all)	- Bad connections - Transducers not hooked up to power supply	- Check all connections to make sure done correctly
- No readings (0 readings)	- Transducer initialization problem - transducers not aligned properly	- Disconnect, then reconnect power supply - Realign sensors if not parallel to roadway
	- No object between sensors	- Place object between sensors to be measured
- Inaccurate readings	- Input wrong structure dimensions	- Check dimensions, if wrong correct them
- Over 75 readings on a truck	- Trucks too close together or moving too slow	- Have a minimum speed limit and distance between trucks
- Device errors	- Signal wires from computer and sensor not matched - Power supple to interface - Inaccurate adjustment of potentiometer	- Check sensors to make sure are properly connected. check wiring to interface and power supply. Adjust potentiometer as described in prototype system setup

APPENDIX I
Design Team Members:

Michael Dolan
Electrical Engineering

Michael Fritz
Electrical Engineering

Brian Law
Electrical Engineering

Treavor Lenz
Electrical Engineering

William Grupp
Computer Engineering

Project Monitor:

E. C. Jones
Professor of Electrical Engineering

LIST OF APPENDIXES

APPENDIX G

PROTOTYPE SYSTEM SETUP

The prototype system described in this report can be assembled by following the steps shown below. The steps are the same for setup in the lab and in field situations with the exception of the cable between the sensors and the interface. The prototype system diagram is shown on the following page. It is recommended that the system be first assembled in the lab. This will simplify the adjustment of the 232 to 485 interface.

Step 1. Assemble the system as shown in the prototype system diagram. Pay careful attention to wire polarity for the power connections.

Step 2. Apply power to the system and then the computer.

Step 3. Listen for clicking sound from each sensor. Check trouble shooting guide if clicking not present.

Step 4. Load and run program "DOT3.BAS"

Step 5. The screen should display the measurements for each of the three sensors when an object is placed in front of them. If three measurements are present, system is ready to measure trucks using program "DOT6P.BAS".

Step 6. If a "Device Error " occurs, connect a dual trace oscilloscope to the RS-232 transmit and receive lines.

Step 7. Disconnect RS-232 receive line to computer.

Step 8. Restart program DOT3.BAS. This may take a few tries.

Step 9. Adjust potentiometer on interface until RS-232 transmit and receive signals do not overlap (as shown on oscilloscope). If the resistance is too low, no receive signal will be present. If two high, the receive signal will overlaped by the transmit signal.

Step 10. Check oscilloscope to be sure there is a send and receive signal for each transducer connected to the system.

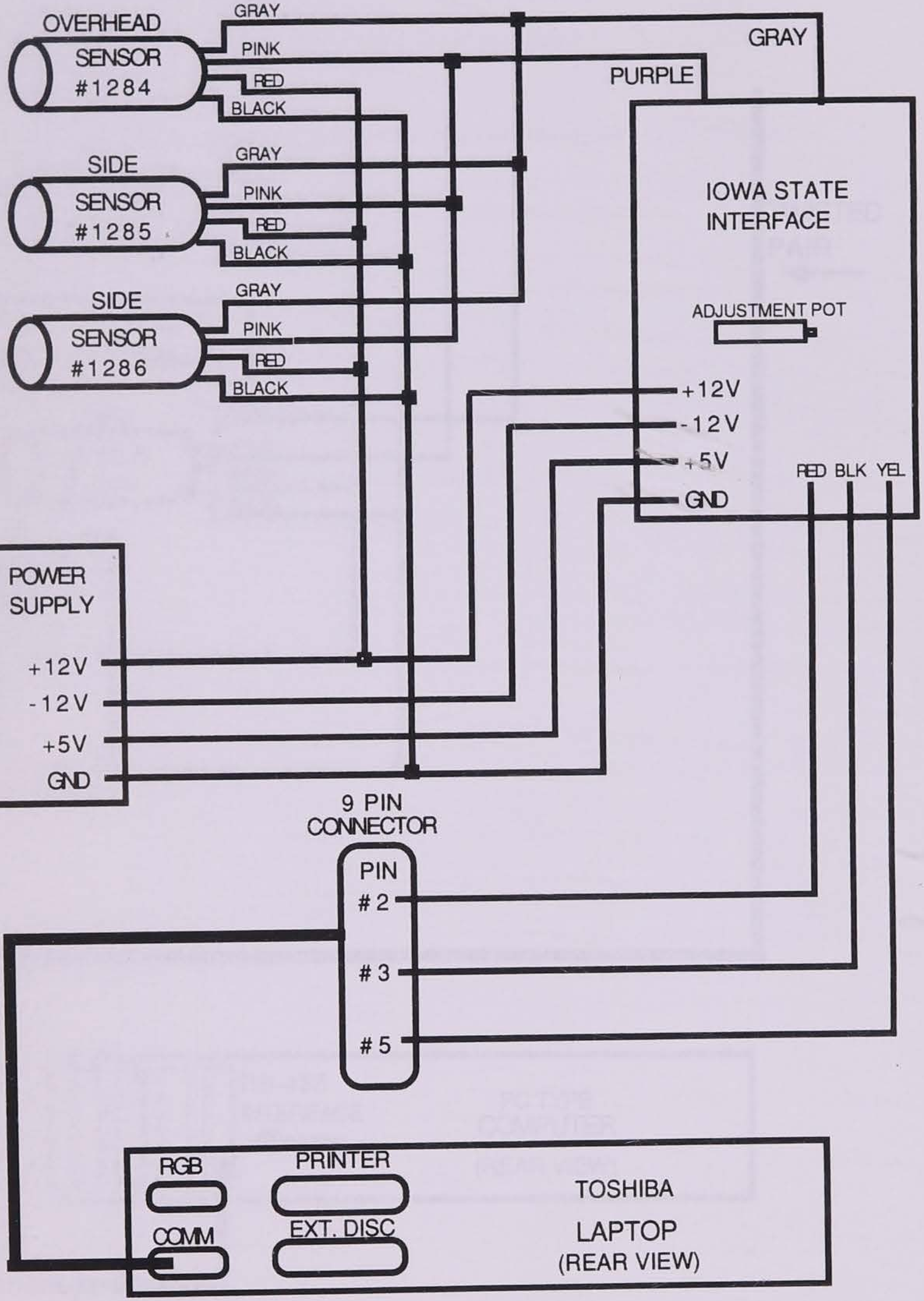
Step 11. Reconnect RS-232 receive line to computer.

Step 12. System should now be ready to measure trucks using program DOT3.BAS.

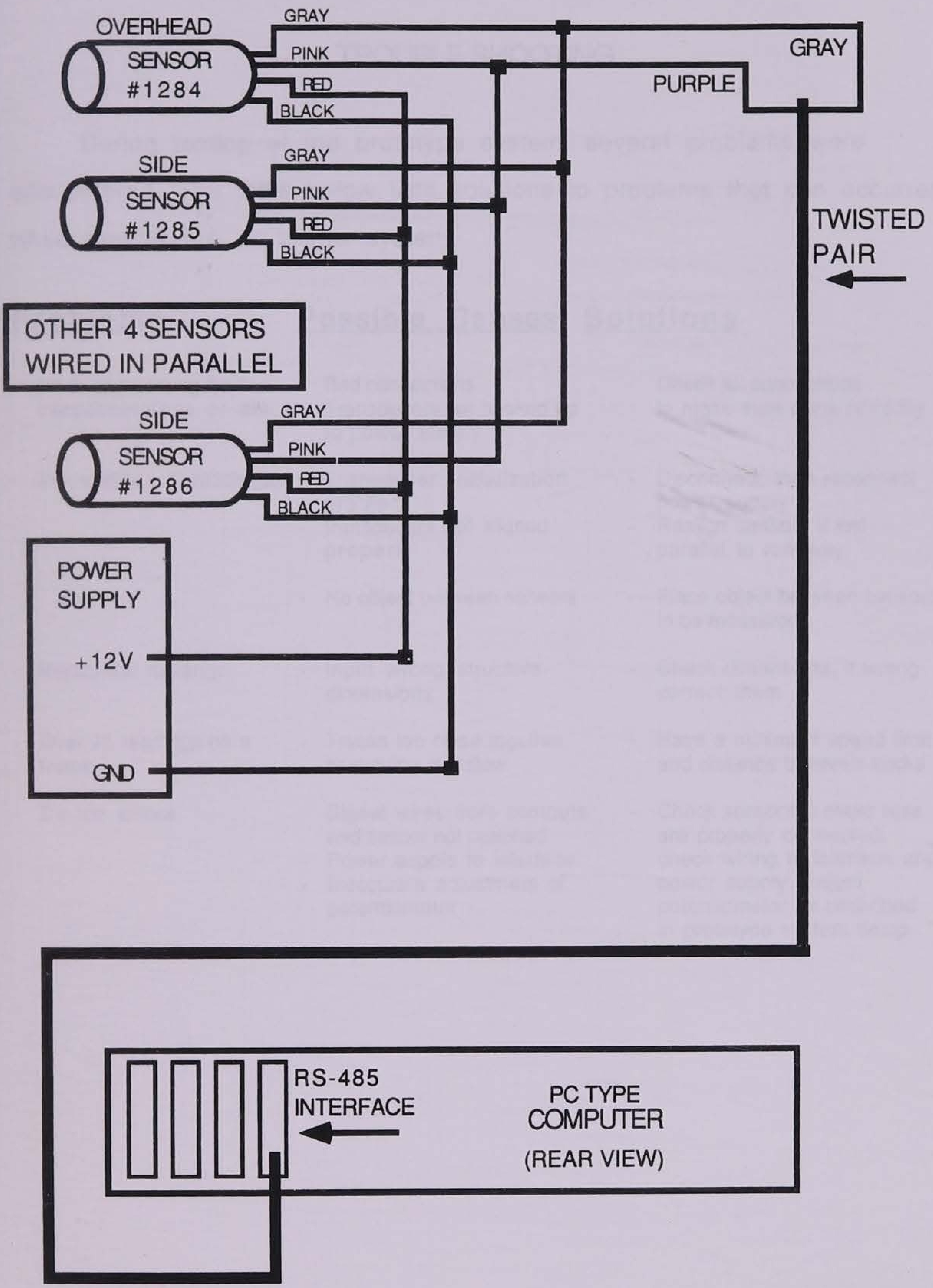
In our testing we used a 12 volt car battery to power the sensors. This was due to a problem with the length of the cable used in testing. Any Supply capable of providing 12 volts at the sensors can be used.

The setup of the final system should be similar but the exact details of the connections between the computer and the sensors will depend on the RS-485 interface used in the computer. the same program should work with the final system as in the prototype system. The Final System Diagram is also included in this appendix.

PROTOTYPE SYSTEM DIAGRAM



FINAL SYSTEM DIAGRAM



APPENDIX H

TROUBLE SHOOTING

During testing of the prototype system, several problems were encountered. The table below lists solutions to problems that can occurred while testing the prototype system.

Problems	Possible Causes	Solutions
- No sound coming from transducers(one or all)	- Bad connections - Transducers not hooked up to power supply	- Check all connections to make sure done correctly
- No readings (0 readings)	- Transducer initialization problem - transducers not aligned properly	- Disconnect, then reconnect power supply - Realign sensors if not parallel to roadway
	- No object between sensors	- Place object between sensors to be measured
- Inaccurate readings	- Input wrong structure dimensions	- Check dimensions, if wrong correct them
- Over 75 readings on a truck	- Trucks too close together or moving too slow	- Have a minimum speed limit and distance between trucks
- Device errors	- Signal wires from computer and sensor not matched - Power supple to interface - Inaccurate adjustment of potentiometer	- Check sensors to make sure are properly connected. check wiring to interface and power supply. Adjust potentiometer as described in prototype system setup

APPENDIX I

Design Team Members:

Michael Dolan
Electrical Engineering

Michael Fritz
Electrical Engineering

Brian Law
Electrical Engineering

Treavor Lenz
Electrical Engineering

William Grupp
Computer Engineering

Project Monitor:

E. C. Jones
Professor of Electrical Engineering