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BRIDGE WEIGH-IN-MOTION VS. LOADOMETER

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U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

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16. Abstract

This report demonstrates the use of the Bridge WIM System as an alternative to the traditional loadometer study. The system uses the bridge girders as an equivalent static scale, which measures individual axle weight and gross weight. The system also uses tape switches which measure axle spacing and speed. In order to fulfill the objectives of the study, two sites were chosen: Site 1 was located on I-76 east of Denver, close to a weigh station; and Site 2 was located on I-25, south of Colorado Springs, with no weigh station nearby. Histograms of hourly and daily truck weights variation were developed and truck traffic characteristics were compared. A loadometer station was employed in conjunction with the weigh-in-motion station to analyze the truck diversion and assess the operational performance of WIM.

Implementation: The outcome of this study will demonstrate the Highway Department's need for automation of truck size and weight studies.

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I. INTRODUCTION

In-Motion-Weighing of trucks has received considerable attention from highway engineers and highway planners. For decades, pavement distress and structural failures of bridges have been the focus of attention of highway officials all across the United States. In Colorado, the traditional biennial loadometer study provides sample data to meet the Highway Department's needs for planning and pavement design. Under the loadometer study, trucks (single units and combinations) are weighed for a period of 8 hours every two years at 12 stations. Six stations are located on interstate highways, five on primary highways, and one on a secondary highway. The results of the loadometer survey are analyzed for these 12 stations in order to develop equivalency factors for pavement design (flexible and rigid). Seasonal bias, locational bias, and an overall insufficient sample size are some of the problems associated with the biennial loadometer study.

The loadometer station on I-25 north of Denver weighs approximately 250 trucks every two years. The annual average daily truck traffic for this location is 4,000 a day which adds up to 2,880,000 every two years. For an exceptionally high truck traffic route like I-25, the 250 trucks interviewed every two years are not very representative of the total truck traffic characteristics. The inadequacy of the biennial loadometer program is evident because of the lack of adequate sample data.

Premature distress of pavement on Colorado's highways may be due, in part, to the lack of adequate truck sample and axle load information. Colorado highways are normally designed for a 20 year life expectancy but the consensus of maintenance authorities of the Colorado Department of Highways is that most of these highways will lose their rideability before the end of their design life. For decades, Colorado has been furnishing design and material engineers with a very generalized average truck traffic data. As a result, some roads have experienced substantial over-design, while other roads have prematurely disintegrated. The application of weigh-in-motion (WIM) technology could be a cost-effective answer for most of the above mentioned problems. The WIM system will provide immediate benefits to the truck weight study including comprehensive data to fulfill the need for pavement management, reducing costs per sample, and will minimize trucker avoidance of scales.

II. OBJECTIVES

The primary objectives of this study are:

a) To assess the operational performance of the undetectable weigh-in-motion (WIM) as compared to previous methods of weighing vehicles.

b) To estimate the truck traffic diversion from a fixed loadometer station.

c) To compare the accuracy of WIM with a certified weigh station.

d) To analyze truck traffic characteristics as a function of time of day, and day of the week.

e) To demonstrate the use of a WIM system to provide effective and statistically reliable truck information.

III. BRIDGE WEIGH-IN-MOTION (WIM)

The need for a dependable and comprehensive method of weighing the axle loads of a moving vehicle has long been recognized by those agencies and individuals concerned with the planning, design, and operation of highway systems. Utilizing static scales for collecting axle load data is slow, costly, and unsafe. In an attempt to modernize the loadometer study, the Colorado Department of Highways conducted a research study using the bridge weigh-in-motion equipment to acquire truck data. The system was developed by the Bridge Weighing Systems, Inc., of Warrensville Hts., Ohio, and was borrowed from the State of Washington. The system uses highway bridges as an equivalent static scales to obtain truck axle weights and gross weights, dimensions and speed.

There is no interference with the flow of traffic and truck drivers are unaware of the weighing operation. A two-man team can complete the field set-up in less than two hours. Reusable strain transducers which measure the bridge structural response for the vehicle weight are attached to the girder by means of C-clamps. Tape switches to determine vehicle speed and dimension are installed on the pavement surface. As an option, a key pad may be used to categorize the truck by body type and hauling materials. All the acquired data is transmitted to a mobile instrumentation van parked inconspicuously under the bridge. Here a mini computer system receives, analyzes, and stores the data. Data acquisition can be monitored by a CRT.

After the completion of the weighing operation, all the equipment can be quickly packed in the van and moved to another site. It should be noted that the Colorado Department of Highways does not necessarily endorse the above mentioned equipment. However, the equipment is felt to be most efficient providing the needed accuracy. The following is a summary of the equipment installation and the data that was acquired.

1) Equipment Set-up

Figure 1 illustrates a typical field operation of the WIM system which consists of the following:

a) Tape Switches

The primary function of the tape switches is to determine velocity, axle spacing, and to alert the strain transducers for acquiring strain data.

Tape switches, mounted on the roadway, are made of two copper strips covered by a layer of insulation. Each lane requires two tape switches which can be easily installed on the pavement surface by means of duct tape (photograph 1). On wet roadways standard traffic counting hoses could be used; however, they were not used in this demonstration. Once an axle crosses the switch, the two copper strips would come together producing an electric pulse of 15 milli seconds which will be transmitted to a signal conditioning device located in the instrumentation van. For accurate weight data and velocity the distance between tape switches must be measured precisely.

b) Strain Transducers

Strain transducers are composed of a series of wires which, when pulled or compressed, change electrical resistance and will produce an analog signal proportional to the compression or tension. The strain transducers used for the WIM system are reuseable and can be easily installed by means of C-clamps or bolts (photographs 2 and 3).

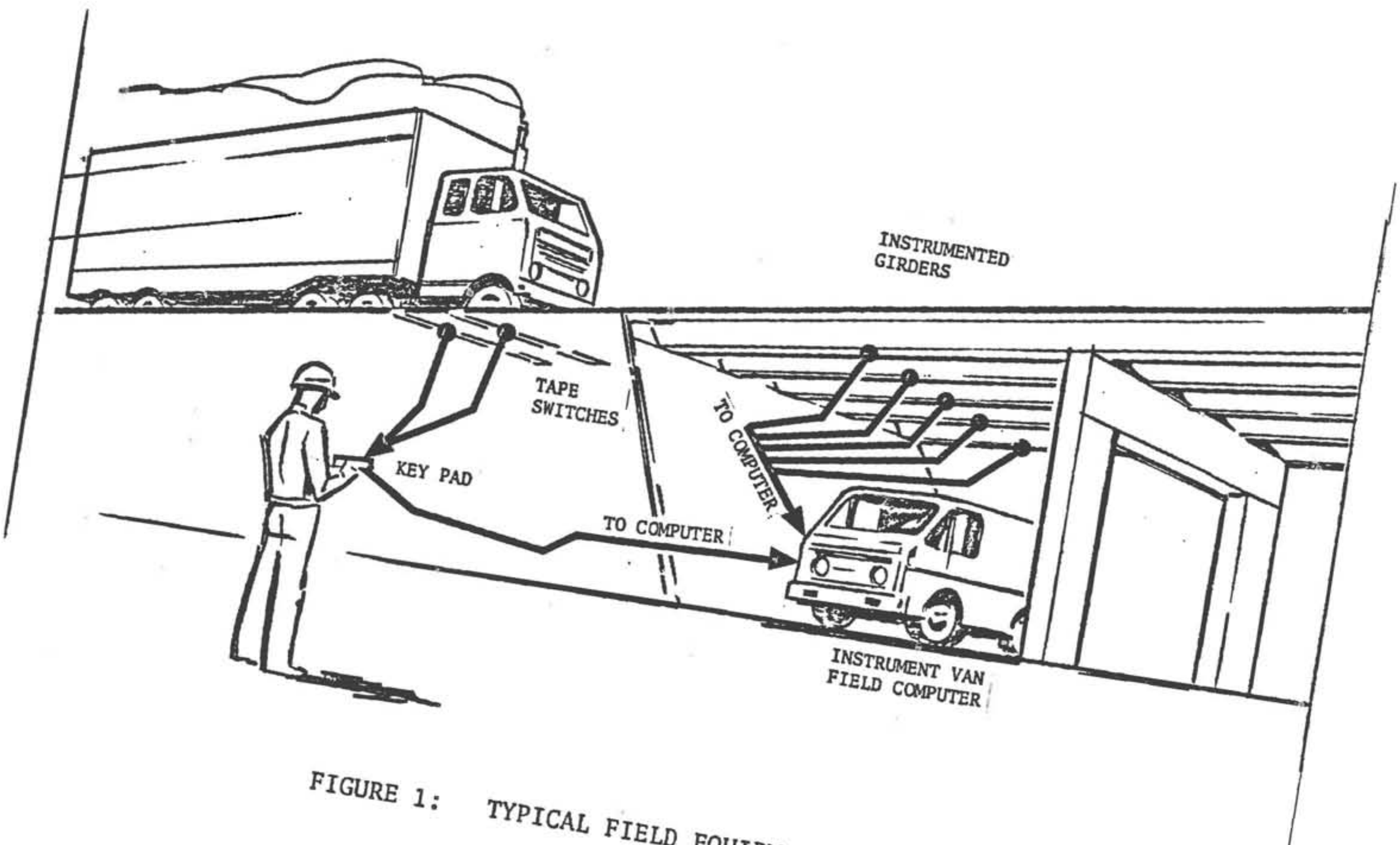
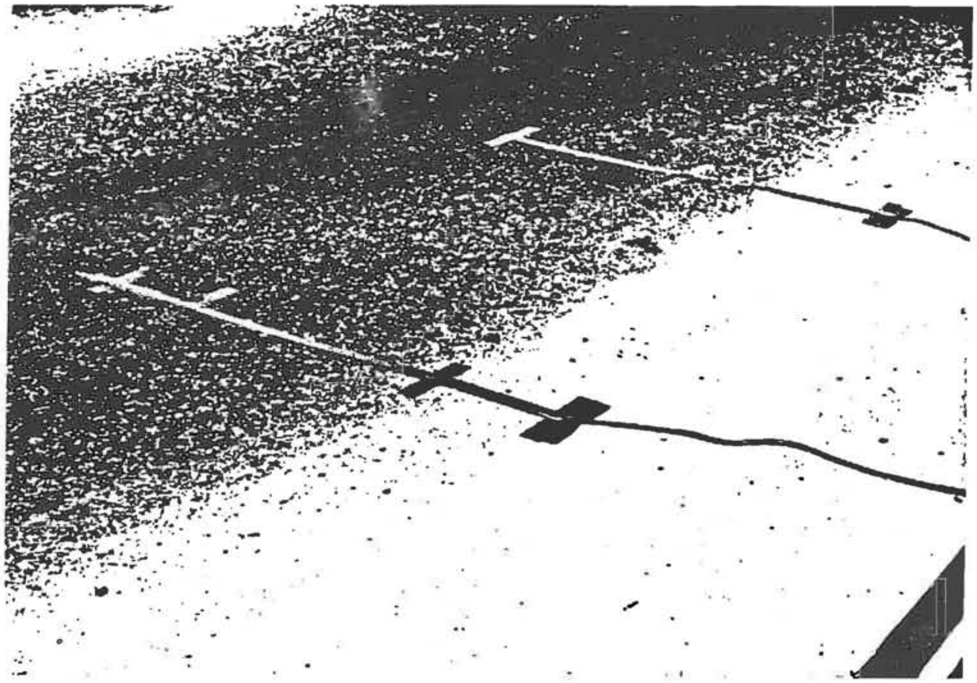
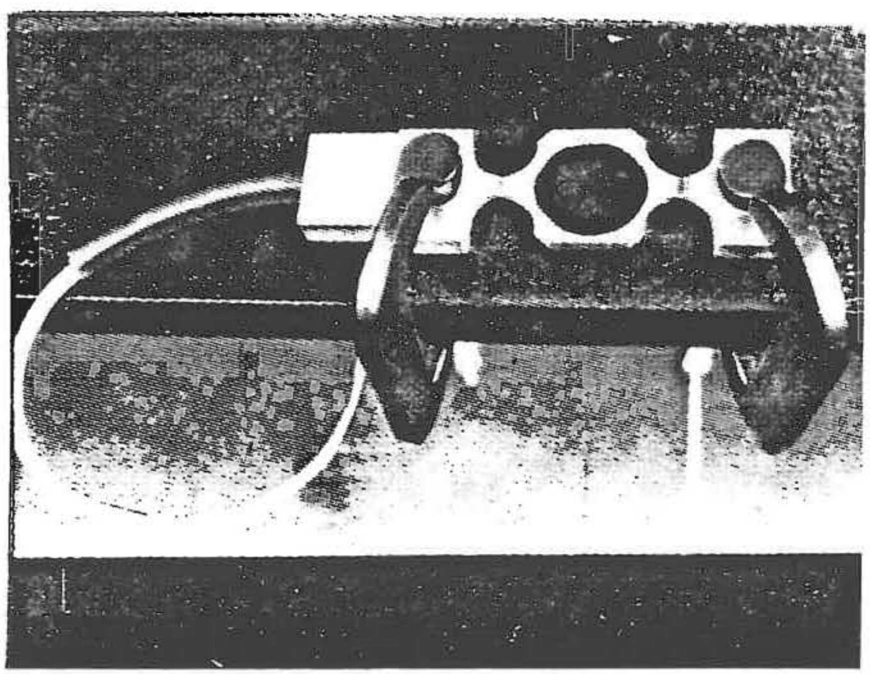


FIGURE 1: TYPICAL FIELD EQUIPMENT SET-UP



Photograph 1: Installation of tape switches by means of duct tape.



Photograph 2: Specially designed reuseable strain transducer.

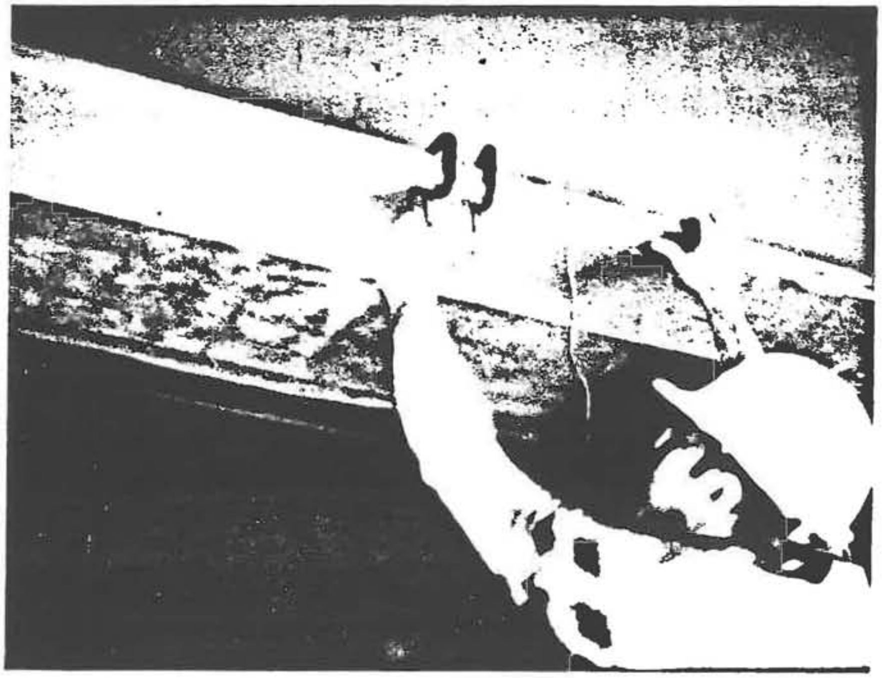
It is important that all the transducers be located at the same distance from the end of the girders. The outside girders supporting the shoulders do not contribute significantly to the analysis of the load moving on the bridge and may be eliminated for instrumentation.

The strain signal from each girder is recorded separately and summed to produce a total signal. This signal is proportional to the bending moment produced by all the girders. The values of E (modulus of elasticity) and S (section modulus) and I (moment of inertia) of all the instrumented girders must be calculated or obtained from the construction plans prior to operation.

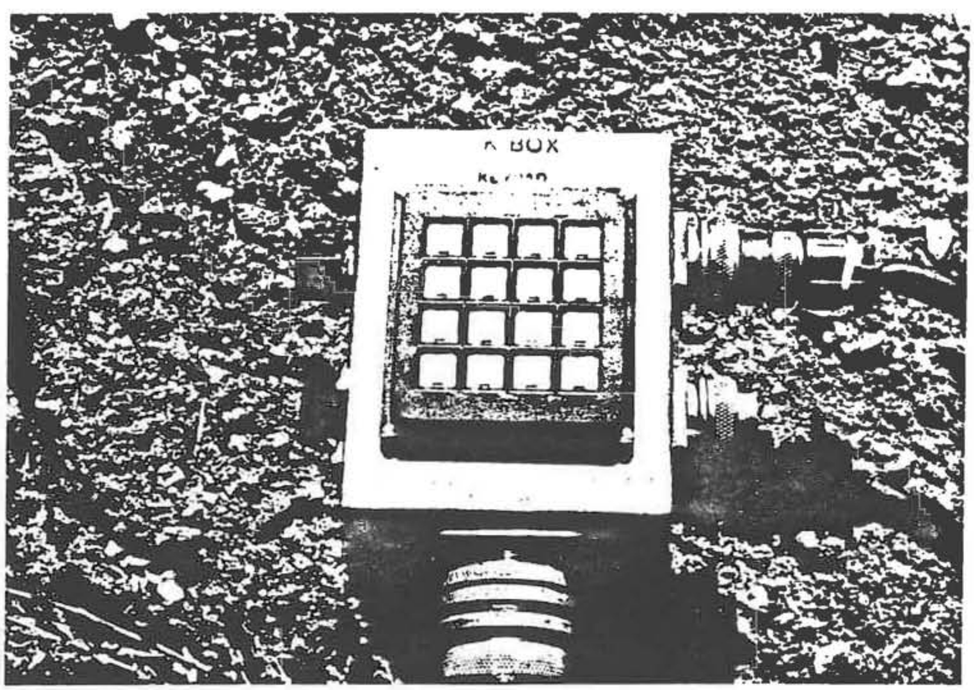
c) Key Pad -

The key pad is a manually operated box consisting of 15 buttons (Table 3 describes individual button) used to categorize the trucks by body type and hauling materials (photograph 4). There are three ways of operating the system with regard to the key pad.

- The key pad may be omitted entirely permitting the system to take responsibility of obtaining all the truck information.
- The key pad may be used optionally to supply truck type and hauling category while the system is deciding on which vehicle to detect (as above).
- The key pad may be used as the only source of alerting the computer on the vehicle's arrival. This last mode is suitable for high truck traffic routes.



Photograph 3: C clamps are used to attach a strain transducer to the bottom flange of a girder.



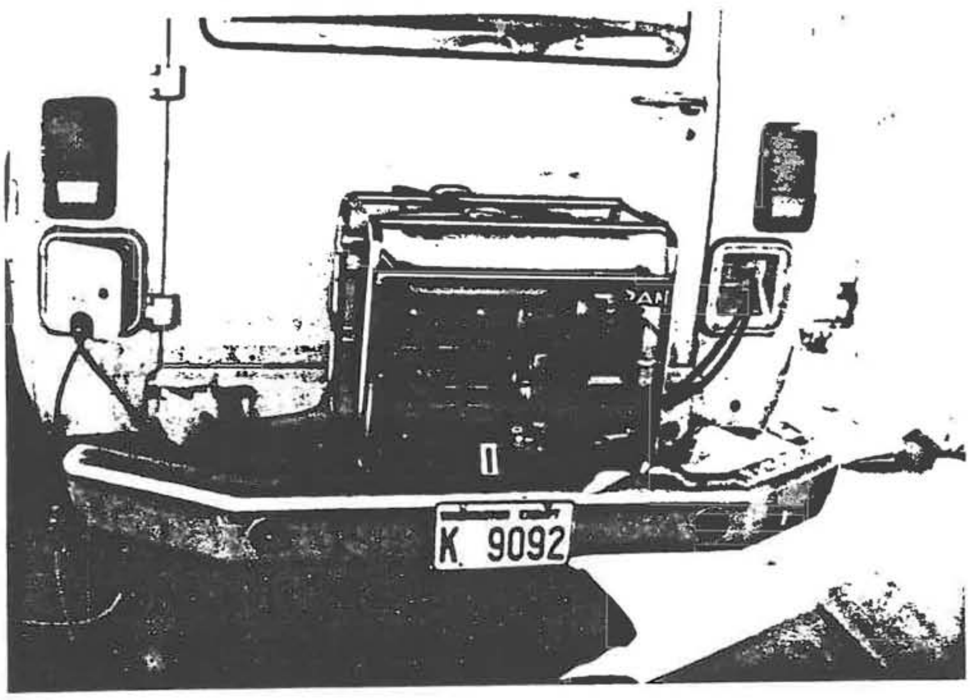
Photograph 4: An optional key pad may be used to categorize truck body types.

d) Instrument Van -

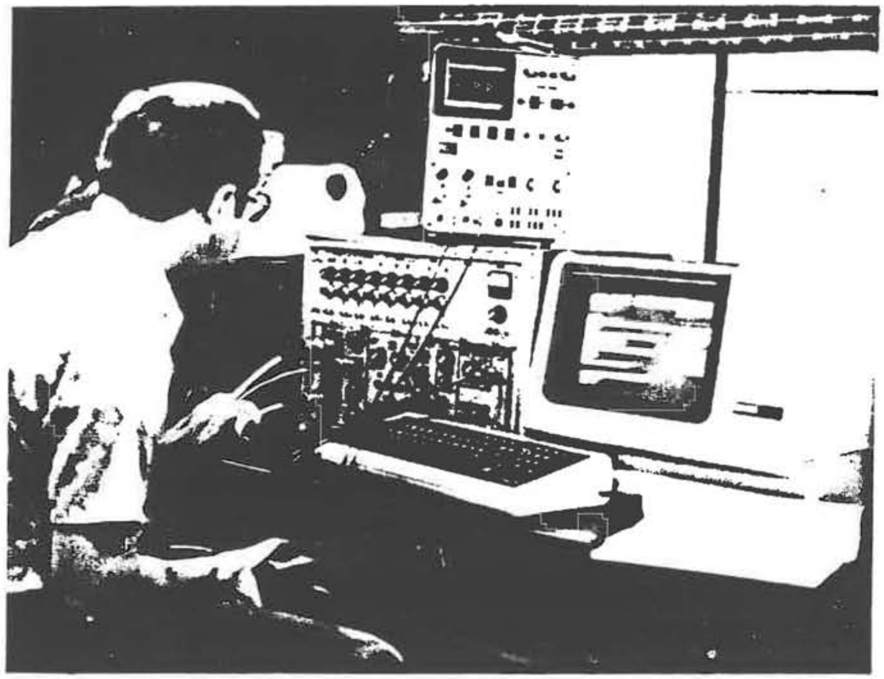
In a typical set-up, signals from the tape switches and the strain transducers are transmitted to the instrument van located beneath a bridge (photograph 5). An instrument van consists of the following components:

- Signal Conditioning Device: This device receives the analog signals from the strain transducers, and digital signals from the tape switches. These signals will be conditioned, amplified, and directed towards the central processing unit (CPU) for processing. A signal conditioning device consists of 5 channels, each accommodataing one strain transducer. A digital voltmeter may be used to check the excitation voltage on all channels. During data acquisition, the signal conditioning modules automatically maintain the strain signals at zero. The auto-balancing of the strain transducer is deactivated when the first axle of the truck crosses the first tape switch.
- The MINC minicomputer: The MINC is the main part of the system which consists of a dual floppy disk drive for software and data storage, a keyboard, and a CPU. The computer begins sampling the strain transducers when the first truck axle crosses the first tape switch. Truck speed and axle spacings are determined and once the last axle has left the instrumented span the weight processing begins. Table 1 shows a list of the data acquisition and processing programs for the Bridge Weigh-In-Motion.

Photograph 5: The mobile van (above) easily accommodates all the equipment, and can inconspicuously acquire truck data.



Photograph 6: A portable generator provides electric power for the system.



Photograph 7: Monitoring the data acquistion on the CRT

TABLE 1
PROGRAM DIRECTORY

The following is a list of the data acquisition and processing programs for the WIM System.

NAME	FUNCTION
BILINE.SAV	Computes the influence line for statically indeterminate structures.
DP7.SAV	Acquires data and performs in-field weight calculations.
FICREA.COM	Formats, initializes and creates Files 14 and 15 on blank disks.
FIND.SAV	Searches File 14 (FTN14.DAT) for the last truck written.
FIXX.SAV	Inspect and correct raw data stored in File 14.
PLDATA.SAV	Plots the strain data stored on File 14.
PLINFL.SAV	Plots the influence line on the CRT.
PROCES.SAV	Labaoratory processing of the raw data on File 14 and stores results on File 15.
READ15.SAV	Reads the processed data stored on File 15.
READ15.SAV	Reads the processed data stored on File 15 (FTN15.DAT).
SIMPLE.SAV	Computes the influence line for simply supported structures.
SUMARY.SAV	Tabulates truck data and provides individual and summarized tables.

- Generator: A portable generator installed in the rear of the van is used to provide electric power for the system. The entire system requires 1500 watts of power (photograph 6).
- Output System: A CRT is used to monitor the data acquisition while it is being stored on a floppy disk (photograph 7). A hard copy may be obtained via a printer.

2. Data Acquisition

As soon as the first tape switch is contacted by the truck steering axle the computer starts acquiring data from the strain transducers. Meanwhile, velocity and axle spacing are being received from the tape switches. Velocity, axle spacing, axle weights, and gross weights are then displayed on the CRT monitor. Two conditions must be met before the computer stops acquiring axle information and strain data. The first condition is a maximum spacing of 37 feet between two axles and the second condition is a maximum vehicle length of 65 feet (the distance between the front and the last axle).

As soon as one of the conditions is met, the computer classifies the vehicle. A car may be defined as any vehicle with axle spacing of less than 12.1 feet or any vehicle that does not meet the minimum pre-set girder strain. The reason for the second constraint is to prevent the computer from classifying a car pulling a trailer as a truck.

If a vehicle is classified as a car, the strain processing is discontinued. However, the velocity is detected, and the data will be stored in a separate file for other uses (velocity statistics).

Depending on the type of truck, it takes the computer from 1.2 to 2.0 seconds for data acquisition, and 1.7 to 2.5 seconds for data processing.

3. Data Processing

For every four days of data acquisition, the operator should allow approximately one day of data reduction. A hard copy of all the processed data may be obtained via the printer. Table 2 represents a typical example of processed data, furnishing truck ID number, time, lane number, speed, truck body type, axle configuration, gross weights, axle weights, axle spacings, and total length. The processed truck data can be easily classified by gross weight, body type, and axle configuration. For example, the list of all the trucks that fall into the 3S-2 axle configuration category (FHWA Code 8) can be easily scanned and printed. Table 3 shows the FHWA codes used to classify the trucks by body type and axle configuration.

4. Calibration

A loaded 3-axle or 5-axle truck of known weight may be used to calibrate a bridge. Normally, it takes 2 to 3 passes of a test truck to establish a calibration factor. Calibrating a bridge is a one time event unless the bridge has undergone structural changes, or has been resurfaced. The calibration process may be performed before, during or after the weighing operation. Once a calibration factor is established the factor may be entered into the computer program during data processing or data acquisition.

TABLE 2: TYPICAL EXAMPLE OF THE PROCESSED DATA

ID#	TIME	LANE	SPEED	TYPE	CONFIG	GVW	< AXLE WEIGHTS						>	< AXLE SPACINGS					>	LENGTH
1	841	1	62	136	8	66.6	10	15	15	13	13	0	0	117	44	356	41	0	0	55
2	845	1	61	8	1	6.1	4	2	0	0	0	0	0	115	0	0	0	0	0	11
3	4	1	60	8	8	76.0	11	17	17	15	15	0	0	104	44	346	42	0	0	53
4	5	1	67	136	8	75.5	13	16	16	15	15	0	0	183	45	319	42	0	0	59
5	6	1	61	130	2	46.4	13	17	17	0	0	0	0	246	41	0	0	0	0	28
6	7	1	61	136	8	49.0	10	12	12	8	8	0	0	140	42	327	40	0	0	55
7	9	1	62	136	6	49.8	10	19	11	11	0	0	0	132	347	41	0	0	0	52
8	11	1	64	136	8	73.9	9	17	17	16	16	0	0	117	41	301	39	0	0	50
9	17	1	58	136	8	69.2	11	15	15	14	14	0	0	185	45	331	41	0	0	60
10	17	1	62	40	8	36.0	9	7	7	6	6	0	0	171	45	299	40	0	0	55
11	20	1	64	136	1	11.3	3	8	0	0	0	0	0	125	0	0	0	0	0	12
12	36	1	61	136	7	58.6	12	16	12	19	0	0	0	148	219	102	0	0	0	46
13	36	1	61	136	11	36.5	10	13	14	-1	1	0	0	145	175	218	83	0	0	62
14	46	1	61	136	8	62.6	9	14	14	13	13	0	0	151	44	324	40	0	0	56
15	51	1	54	130	1	15.6	5	10	0	0	0	0	0	171	0	0	0	0	0	17
16	52	1	58	136	8	38.9	8	9	9	6	6	0	0	139	41	331	41	0	0	55
17	55	1	58	136	12	57.0	8	15	10	13	10	0	0	101	209	93	214	0	0	61
18	102	1	67	136	1	14.4	4	10	0	0	0	0	0	151	0	0	0	0	0	15
19	105	1	64	136	8	61.9	9	14	14	13	13	0	0	163	41	367	40	0	0	61
20	117	1	54	136	15	44.1	8	7	7	4	9	8	0	97	42	187	95	205	0	62
21	118	1	54	136	8	65.3	10	15	15	13	13	0	0	109	44	326	40	0	0	52
22	126	1	63	40	8	66.5	8	15	15	14	14	0	0	116	42	285	39	0	0	48
23	3	1	57	72	8	57.1	10	12	12	12	12	0	0	166	44	327	42	0	0	58
24	8	1	59	40	1	21.2	7	14	0	0	0	0	0	166	0	0	0	0	0	16
25	12	1	64	136	8	40.4	7	9	9	7	7	0	0	155	44	320	39	0	0	56
27	23	1	57	72	8	37.4	8	12	12	3	3	0	0	159	43	343	39	0	0	58
28	8	1	56	40	8	60.6	10	13	13	13	13	0	0	144	45	295	42	0	0	52
29	16	1	54	136	8	63.0	10	17	17	9	9	0	0	144	44	276	42	0	0	50
30	25	1	53	136	8	72.8	10	18	18	13	13	0	0	179	43	297	41	0	0	56
31	36	1	69	136	8	74.9	12	19	19	13	13	0	0	113	44	317	48	0	0	52
32	41	1	53	130	1	5.3	3	3	0	0	0	0	0	85	0	0	0	0	0	8
33	42	1	78	130	1	7.2	5	3	0	0	0	0	0	144	0	0	0	0	0	14
34	43	1	59	72	8	84.3	12	18	18	18	18	0	0	128	45	313	42	0	0	52
35	46	1	64	130	2	47.1	14	16	16	0	0	0	0	189	45	0	0	0	0	23
39	2	1	56	136	6	45.8	11	18	8	8	0	0	0	109	257	49	0	0	0	41
40	3	1	61	136	1	21.8	8	13	0	0	0	0	0	191	0	0	0	0	0	19
41	7	1	59	136	8	91.5	11	21	21	19	19	0	0	170	44	364	40	0	0	61
42	11	1	62	136	8	50.7	10	12	12	8	8	0	0	117	44	327	42	0	0	53
43	17	1	51	136	8	83.8	14	17	17	18	18	0	0	120	45	361	41	0	0	56
44	17	1	59	136	1	25.5	8	17	0	0	0	0	0	199	0	0	0	0	0	19
45	19	1	57	72	8	67.5	10	16	16	13	13	0	0	194	45	288	43	0	0	57
46	24	1	58	72	8	88.3	11	21	21	18	18	0	0	125	44	299	42	0	0	51

Table 3: FHWA truck type, and axle configuration codes

FHWA CODE	BODY TYPE	FHWA CODE	AXLE CONFIGURATION
24	Test	1	2 Single
33	Chemical	2	3 Single
34	Fuel	3	2S-1
36	Concrete	4	4 Single
40	Tank	5	3S-1
65	Open Hauler	6	2S-2
66	Machinery	7	2S-2 Split
68	Steel	8	3S-2
72	Flat	9	3S-2 Split
129	Dump	10	2S-3
130	Bus	11	2S-3 Split
132	Car Carry	12	2S-1-2
136	Box	13	3S-3
0	Unclassified	14	3S-3 Split
		15	3S-1-2
		16	Other

5. Site Selection

Even though most of the bridges are good candidates for weighing sites some are not suitable for weighing. They may be unsuitable because they are very hard to access like bridges over the stream and valleys. Bridges with heavy traffic jeopardize the accuracy of the weighing operation. Ideal weighing conditions isolate the individual truck. Bridges with high skew (> 45°), long span (> 75') or excessive vibration should only be used after careful review of calibration test data. Span length of 40' - 60' is ideal. Bridges with simply supported girders are preferred to continuous girders.

IV. STATISTICAL ANALYSIS OF THE RESULTS

The data used to develop the statistical analysis in this report was obtained from two distinctively different test sites. Site 1 was located on I-76 80 miles east of Denver, close to a Port of Entry weigh station. Most of the truck traffic in this area is generated by the grain elevators located in Wiggins which is a farm community. The vehicle classification for this site is as follows:

Passenger cars & pickups	6,690
Single unit truck	360
Combination trucks	1,350
TOTAL ADT	8,400

Site 2 was located on I-25, seven miles south of Colorado Springs with no weigh station nearby. Most of the truck traffic in this area is commuting trucks between Pueblo and Denver. The vehicle classification for this site is as follows:

Passenger cars & pickups	17,870
Single unit trucks	960
Combination trucks	1,670
TOTAL ADT	20,500

The following is the summary of the data analyzed in this study:

1) Accuracy of the WIM System

To verify the accuracy of the truck weight acquired by the WIM system comparisons were made with a weigh station. The results are shown in Table 4. The deviations for the steering axle were somewhat high (between 3 to 17 percent); however, the deviations for the gross weight were under 2 percent.

2) Truck Weight Variations

The 24-hour average truck weight variations for 3S-2 trucks and for the total trucks are shown by Figure 2 for I-76 and by Figure 3 for I-25. The predominant truck class for both sites was 3S-2 trucks (more than 80 percent). The hourly variation of average truck weights on the I-76 site was greater than the variation on the I-25 site. The two distinctive peaks for I-76 were at 8 p.m. and at 1 a.m. They occurred at 2 p.m. and 7 a.m. for I-25. Because of the proximity of the I-76 site to a legal weigh station, the overall average truck weights were lighter than the average truck weights at the I-25 site. Figure 4 showing the heaviest truck of each hour and Figure 5 showing the 85th percentile average truck weights are also indications of heavier truck weights on I-25. Figure 6 shows that the frequency of the trucks over 80 kips was minimal for I-76. Average daily truck weight variations shown by Figure 7 show that there is heavier truck weight during the weekend on I-76.

TABLE 4

COMPARISON OF TRUCK WEIGHTS FROM WIM AND WS (WEIGH STATION)

	STEERING AXLE	% DEV.*	FRONT TANDEM	% DEV.	REAR TANDEM	% DEV.	GROSS WEIGHT	% DEV.
WIM	9.7	-17	36.0	0	34.2	10.0	79.9	1.3
WS	11.7		36.0		31.1		78.9	
WIM	10.2	5.0	23.2	1.8	18.2	-1.6	51.6	1.2
WS	9.7		22.8		18.5		51.0	
WIM	10.5	16.6	16.6	-10	13.8	3.8	40.9	0.25
WS	9.0		18.5		13.3		40.8	
WIM	8.5	-7.6	36.0	0.3	35.8	3.5	80.3	0.75
WS	9.2		35.9		34.6		79.7	
WIM	11.2	-3.4	20.0	4.2	24.2	1.7	55.4	1.5
WS	11.6		19.2		23.8		54.6	
WIM	8.8	-3.3	36.8	2.5	35.4	1.4	81.0	1.4
WS	9.1		35.9		34.9		79.9	

ALL WEIGHTS ARE IN KIPS (1 KIP = 1000 LB)

WIM = Bridge Weigh-in Motion Site.
WS = State of Colorado Port of Entry Weigh Station

$$* \ \% \text{ Dev.} = \frac{\text{WIM - WS}}{\text{WS}} \times 100$$

The above information is for six different trucks.

3) WIM Versus Loadometer

A typical loadometer study requires people: flagman, scale operator, interviewer, and a manual counter. Trucks are directed toward the scales by the flagman, and each individual axle is weighed statically by means of the specially designed platform scales. Next, the truck driver is interviewed, and information in regard to state of registration, type of engine (gasoline or diesel), and cargo material is obtained. In addition, the distance between the axles is also measured. The loadometer operation is a slow process, and in many cases a dangerous one because of the exposure of the field crew to traffic. Of Colorado's twelve loadometer stations only two have specially designed ramps for weighing the trucks. The truck weighing for the other ten stations requires closing a traffic lane or stopping the traffic.

A loadometer station was set up on I-25 south of Colorado Springs to acquire truck weights in conjunction with the WIM system during the same time period (Figure 11). The comparison of the two systems yielded the following results:

a) The number of hourly truck traffic volume detected by the WIM system were about 300 percent higher than those interviewed by the loadometer system (Figure 8). This difference could have been much higher if a high truck traffic route was chosen.

b) Comparison of the average truck weights for the two systems are shown by Figure 9. Detection of higher truck weights by the inconspicuous WIM system is an indication of heavy truck diversion from the loadometer station.

c) Truck diversion analysis - In order to quantify the truck traffic diversion which takes place during a loadometer study the same loadometer station was used as above. The location was carefully selected so the truck drivers were easily able to divert from the loadometer station. The survey took place during two days between the hours of 9 a.m. and 4 p.m. The loadometer station was closed for the first day and truck traffic was monitored by a WIM system located 3 miles south of the loadometer station. In addition, a manual counter was monitoring the truck traffic turning from I-25 northbound to SH 85 (Figure 10 and 11). For the first day, 45 trucks were detected by the manual counter. During the second day of the survey both sytems were in operation and it was noted that the number of trucks using the ramp between I-25 and SH 85 increased by 122 percent to 100 trucks. Meanwhile, 40 overweight trucks were detected by the WIM system which reasonably agrees with the increase of trucks on the ramp. It was apparent that the increase in the number of trucks on the ramp was associated with the operation of the loadometer system. Monitoring the conversation of the truck drivers with a CB radio also supports this conclusion.

d) Truck speed frequency histogram - In addition to acquiring weight data the WIM system is also capable of acquiring speed data for all types of vehicles. Speed frequency histograms developed for these two sites indicates that more than 75 percent of all trucks were traveling higher than 55 mph. Figures 12 and 13 illustrate the findings.

V. PROBLEMS ENCOUNTERED USING THE DEMONSTRATION EQUIPMENT

- Equipment Reliability: The equipment used to perform the weighing operation was reliable for the most part but some problems resulted in lost time with the system. One of the main problems with the system was the operation of the generator installed on the rear of the van. The generator would not operate continuously for more than 45 minutes. There was nothing wrong with the generator itself; the problem lay in the poor installation of the generator.

  The generator was installed so that the exhaust system vented at a distance of six inches from the back door of the van. Poor ventilation caused the exhaust system to produce back pressure which in turn developed into overheating and shut the engine off. To solve this problem, the generator was turned 180 degrees facing the free flow of air, and from then was operating properly for the rest of the study.

  Another problem associated with the equipment was a burned out fuse within the disk drive, which prevented the system to boot-up and as a result caused the study to be delayed further. Mr. Harold Bosch of the Turner-Fairbank Research Center was contacted and notified of the problem. He made a trip to Denver and it took him almost one day to address the problem which was a simple burned-out fuse.

- The equipment used for this demonstration was borrowed from the State of Washington; as a result, problems were encountered in insuring the van and the computer, which delayed the study for almost four weeks.

- Many bridges are not suitable for the brige weigh-in motion because they are not easily accessible, or do not have the requirements (high skew bridges, bridges over streams, etc.).
- For those bridges with continuous beam the program could not accommodate more than three section modulii changes.
- The equipment was not proven or tried on concrete girders.
- Tape switches are not waterproof and would stop working during rainy weather.

VI SUMMARY OF FINDINGS

- One of the main objectives of this study was to evaluate the accuracy of the weigh-in-motion with respect to other weighing approaches. In order to verify the accuracy of the WIM system a comparison was made with respect to a weigh station. Individual axle weight, especially the steering axle, showed rather high deviation (between 3 to 17 percent). However, the standard deviation for the gross weight was under 2 percent.
- Only a two-man team is required to operate the system as opposed to a loadometer system which requires at least four men.
- The WIM system is inconspicuous. As a result, data appears to be unbiased (no truck diversion).
- Nighttime weighing has been conducted with no danger to the field crews and to the motoring public.
- If a key pad operator is present, the WIM system is capable of classifying the trucks very accurately. However, when the system is operating automatically, small compact cars (VW Rabbit, Honda Civic) are occasionally detected as three-axle trucks. At the time of data processing, the undesirable data could be easily edited.

- The WIM system is economically more feasible than the loadometer system (reduced costs per sample).
- Higher truck weights detected by the WIM system can result in a better pavement design and management.
- The system is capable of acquiring data in two lanes. However side-by-side trucks can introduce significant errors to the individual axle weights.
- In addition to acquiring weight data, the WIM system is also capable of obtaining speed data for all types of vehicles.
- Investigation of data acquired under the WIM system suggests the following:
- a) Truck weights were heavier on roads with no Port of Entry.
- b) Truck weights were heavier during weekends.
- c) Number of trucks detected by WIM system were 300 percent higher than those interviewed by the Loadometer system.
- d) Detection of heavier trucks by the inconspicuous WIM is an indication of heavier trucks avoiding the loadometer station.
- e) More than 75 percent of trucks were traveling faster than 55 m.p.h.

VII. CONCLUSION:

The use of weigh-in motion technology for accelerated truck weighing looks promising. However, there is still room for improvement in a fully implemented weighing operation. The WIM system will provide immediate benefits to truck weight studies enabling engineers and planners to better assess loads on pavements and bridges. It also provides a strong informational tool for enforcement and should prove to be a cost-effective means of gathering load information.

VIII RECOMMENDATIONS & IMPLEMENTATION:

This research study has demonstrated that in-motion weighing can be an attractive alternative to the traditional loadometer study. The accuracy and the quality of truck weight information acquired under the WIM system is comparable to, or perhaps better than, that normally achieved by the portable static scales. The initial investment for the system may be high but the manpower will be much less.

Incorporating the application of Bridge Weigh-in-Motion into traffic survey programs appears to be practical. This system may also prove useful for load limit enforcement at the ports of entry or other locations.

24-HOUR AVERAGE TRUCK WEIGHT VARIATION

I76 EAST OF DENVER

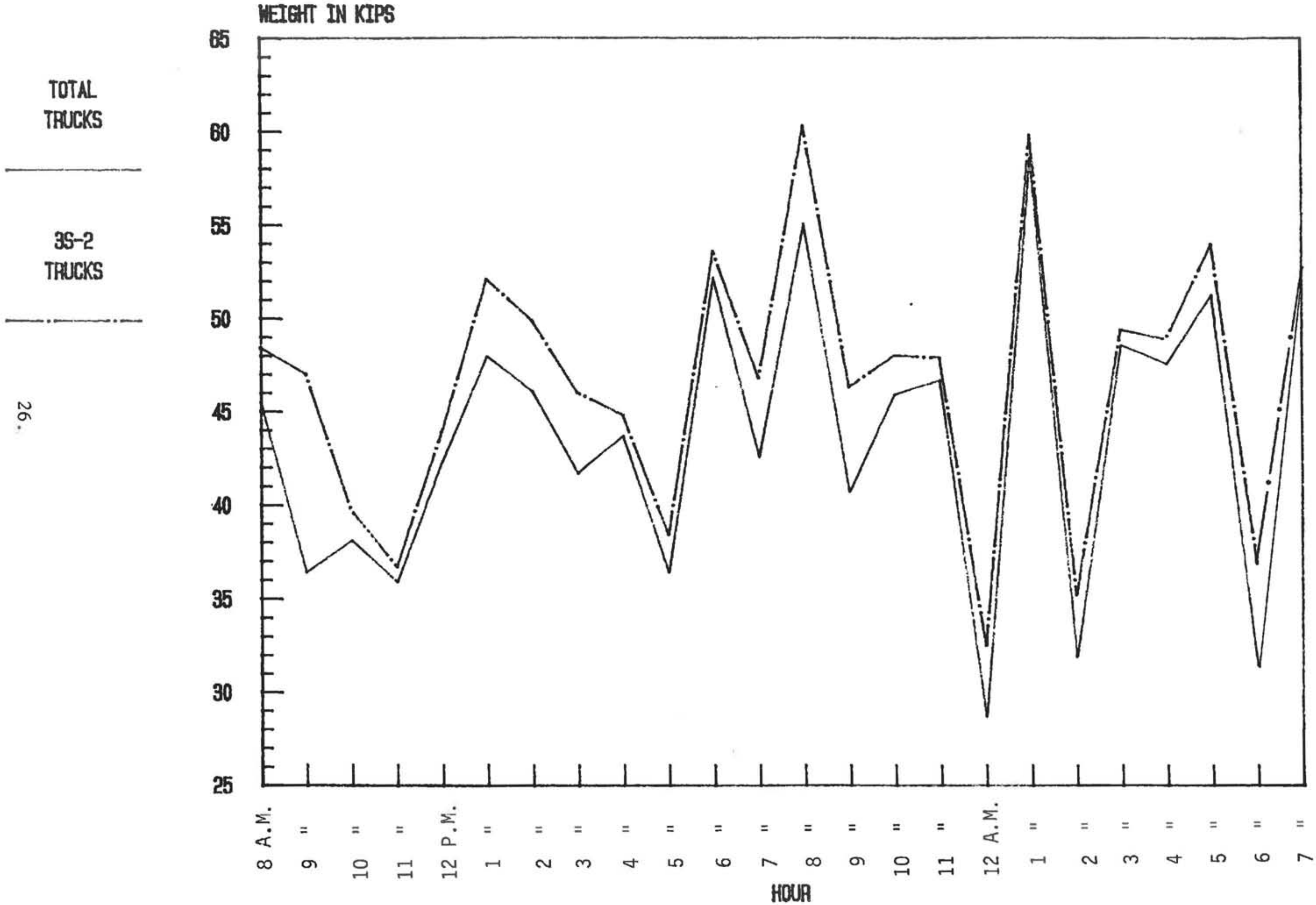


FIGURE 2

24-HOUR AVERAGE TRUCK WEIGHT VARIATION

I25 SOUTH OF COLORADO SPRINGS

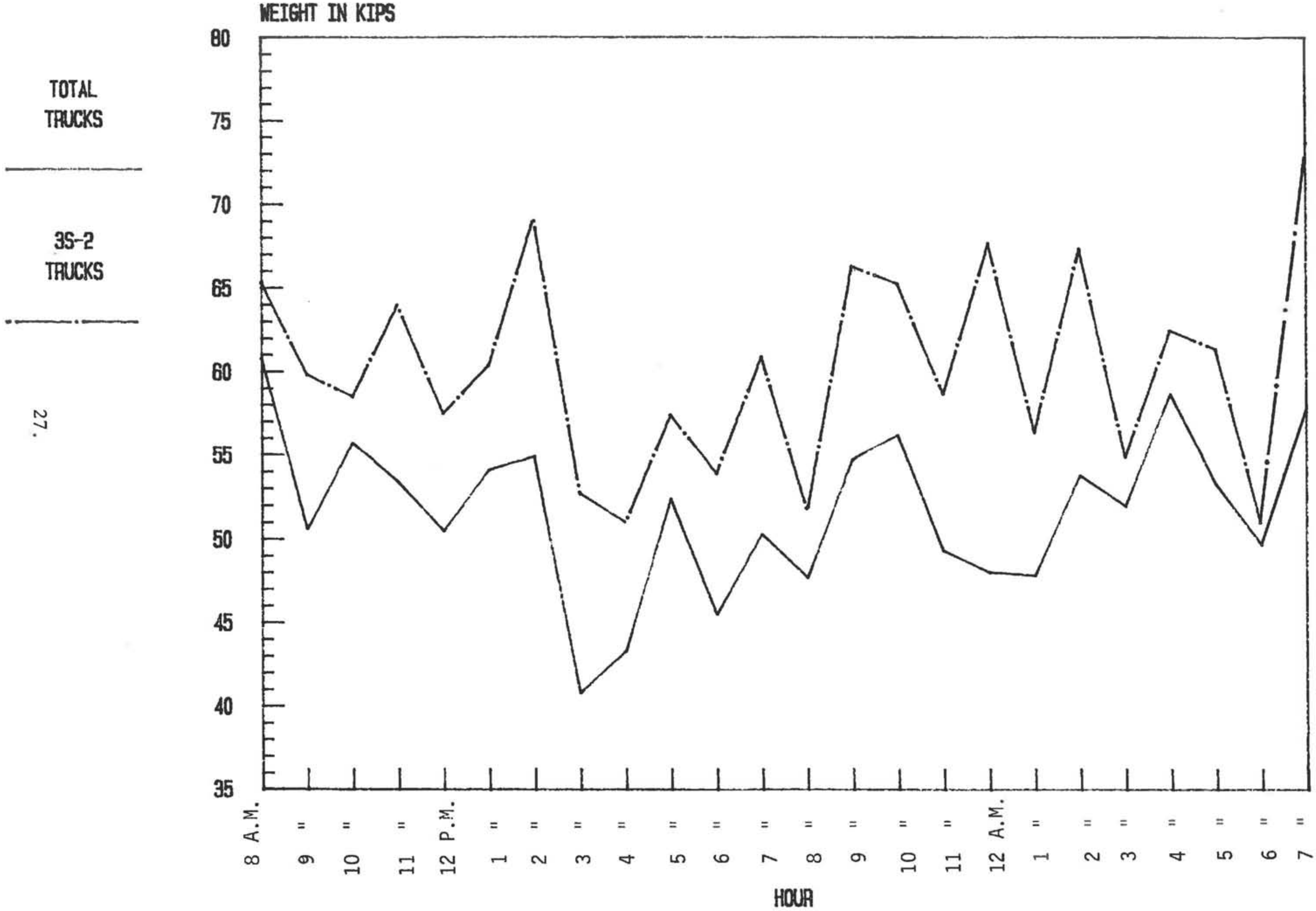


FIGURE 3

HEAVIEST TRUCK OF THE HOUR

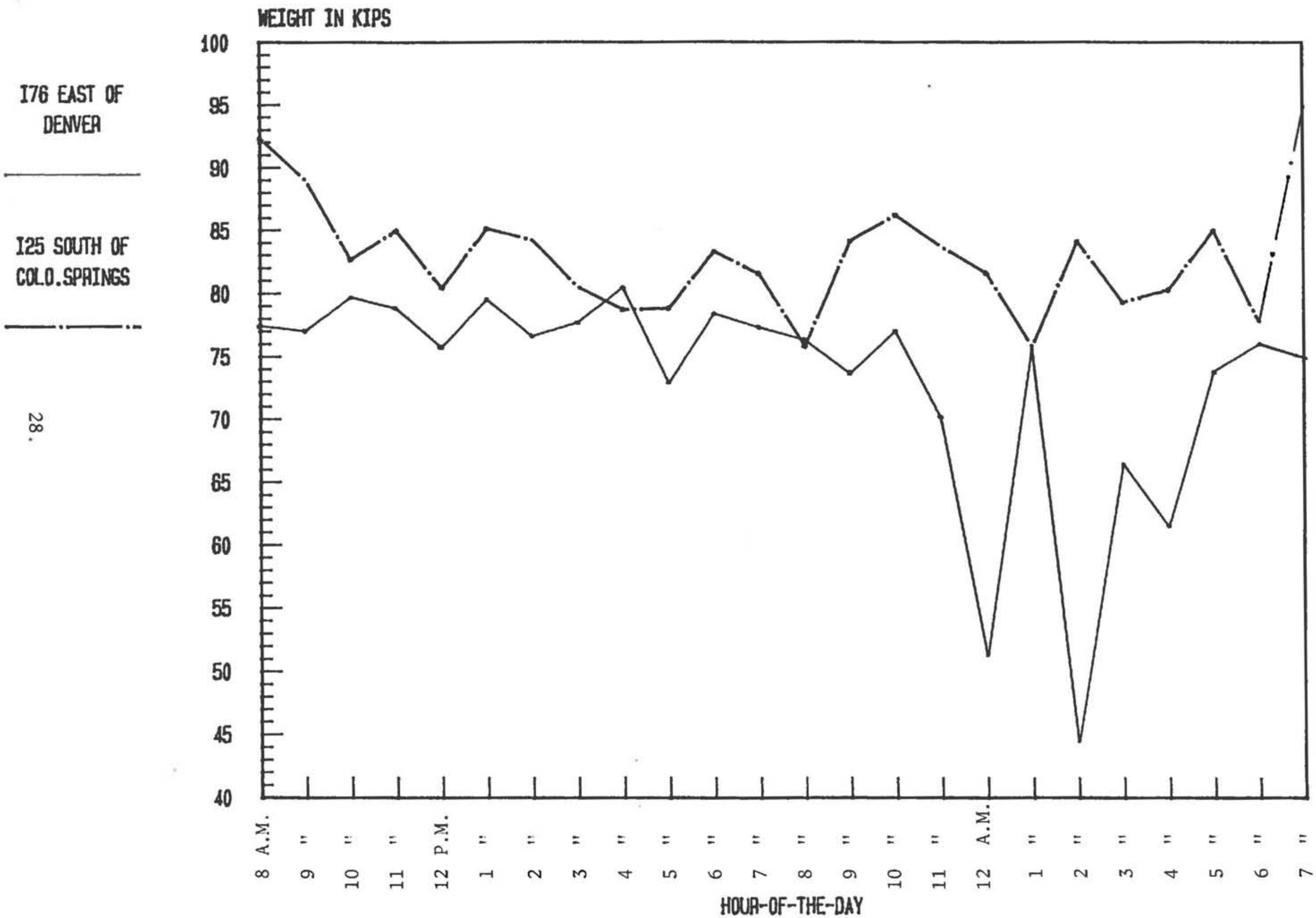


FIGURE 4

HOURLY VARIATION OF 85TH PERCENTILE

AVERAGE TRUCK WEIGHTS

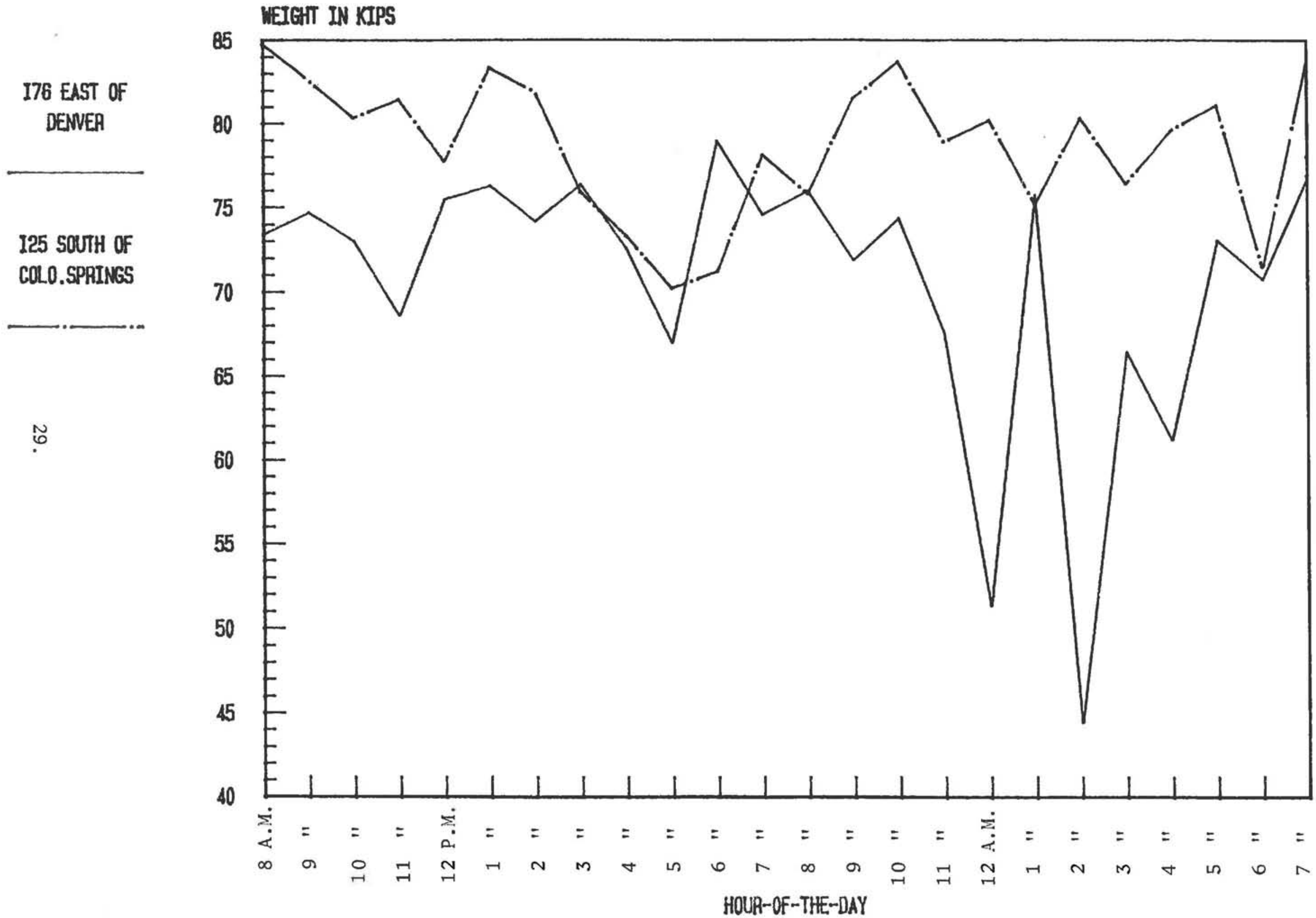


FIGURE 5

FIGURE 6

24-HOUR TRUCK WEIGHT FREQUENCY HISTOGRAM

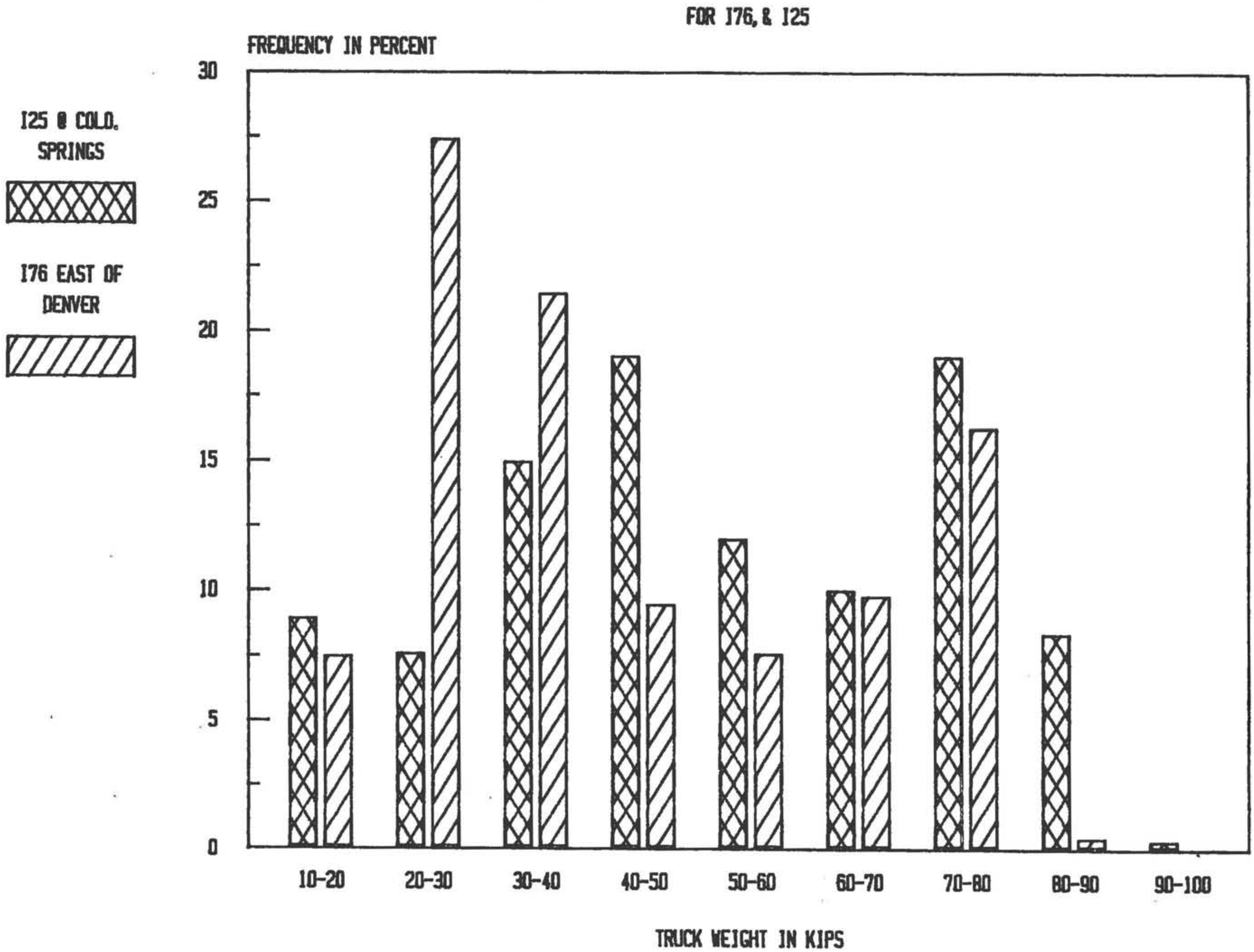


FIGURE 7

7-DAY AVERAGE TRUCK WEIGHT VARIATION

I76 EAST OF DENVER

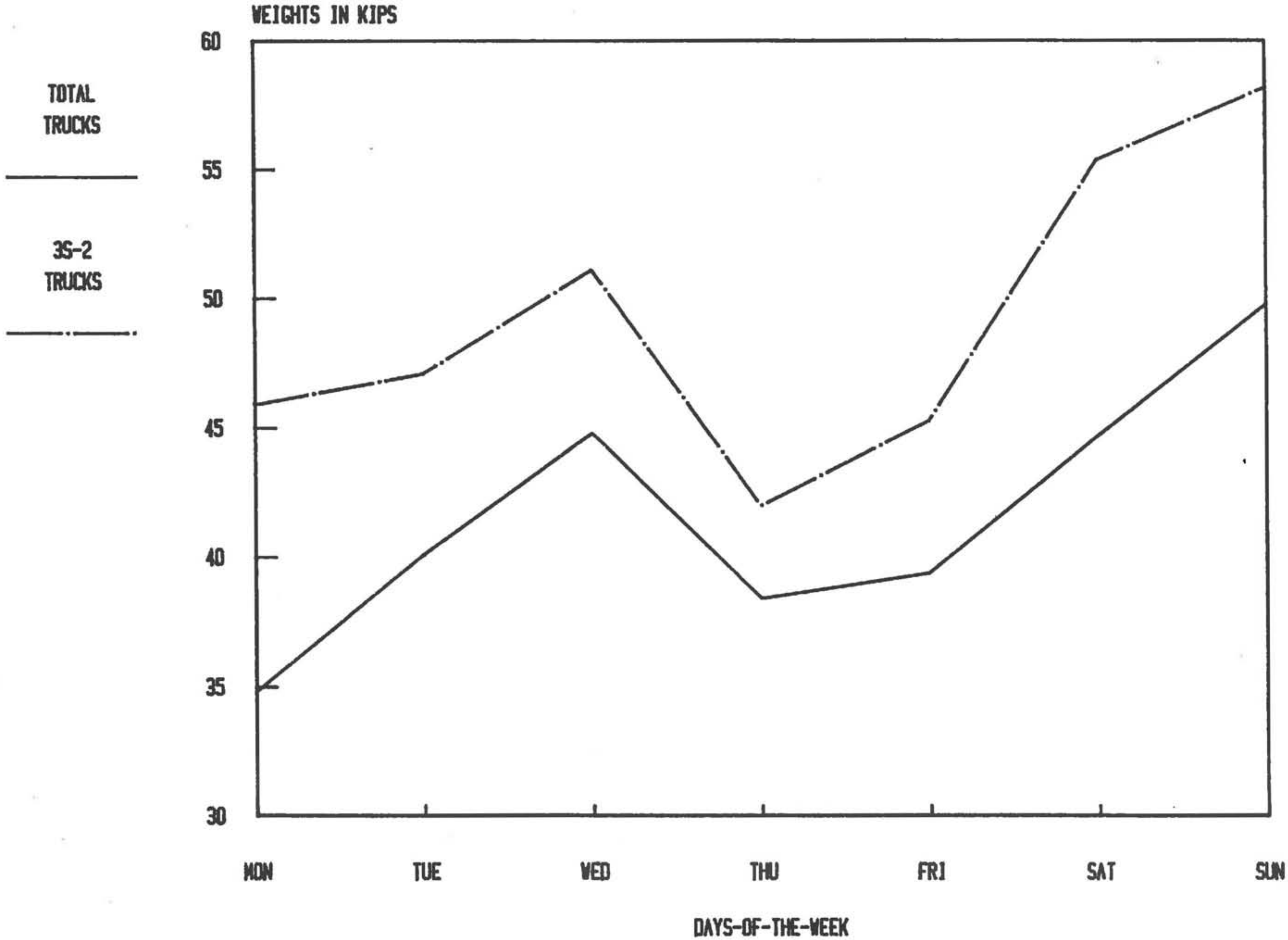


FIGURE 8

VARIATION OF HOURLY TRUCK TRAFFIC

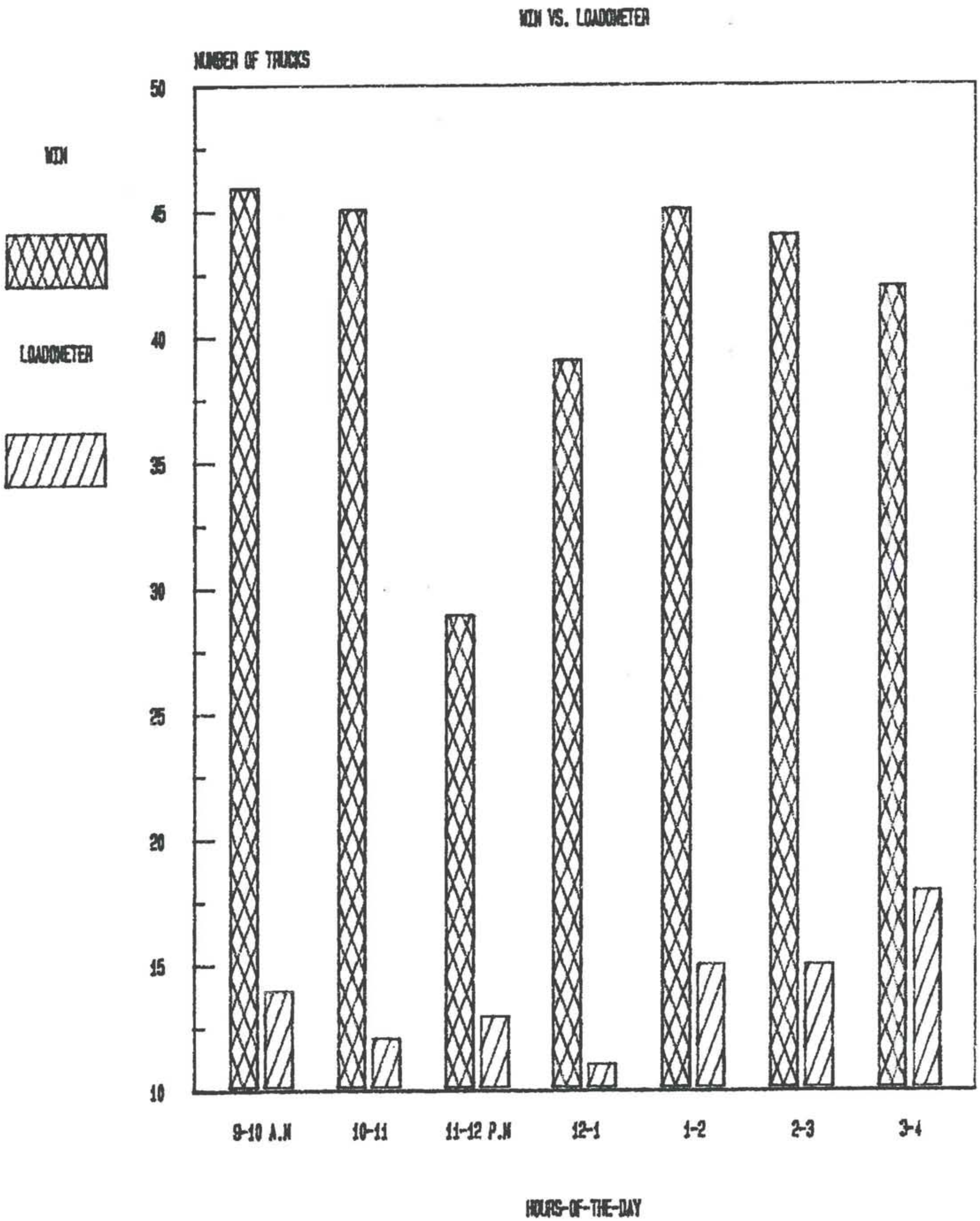
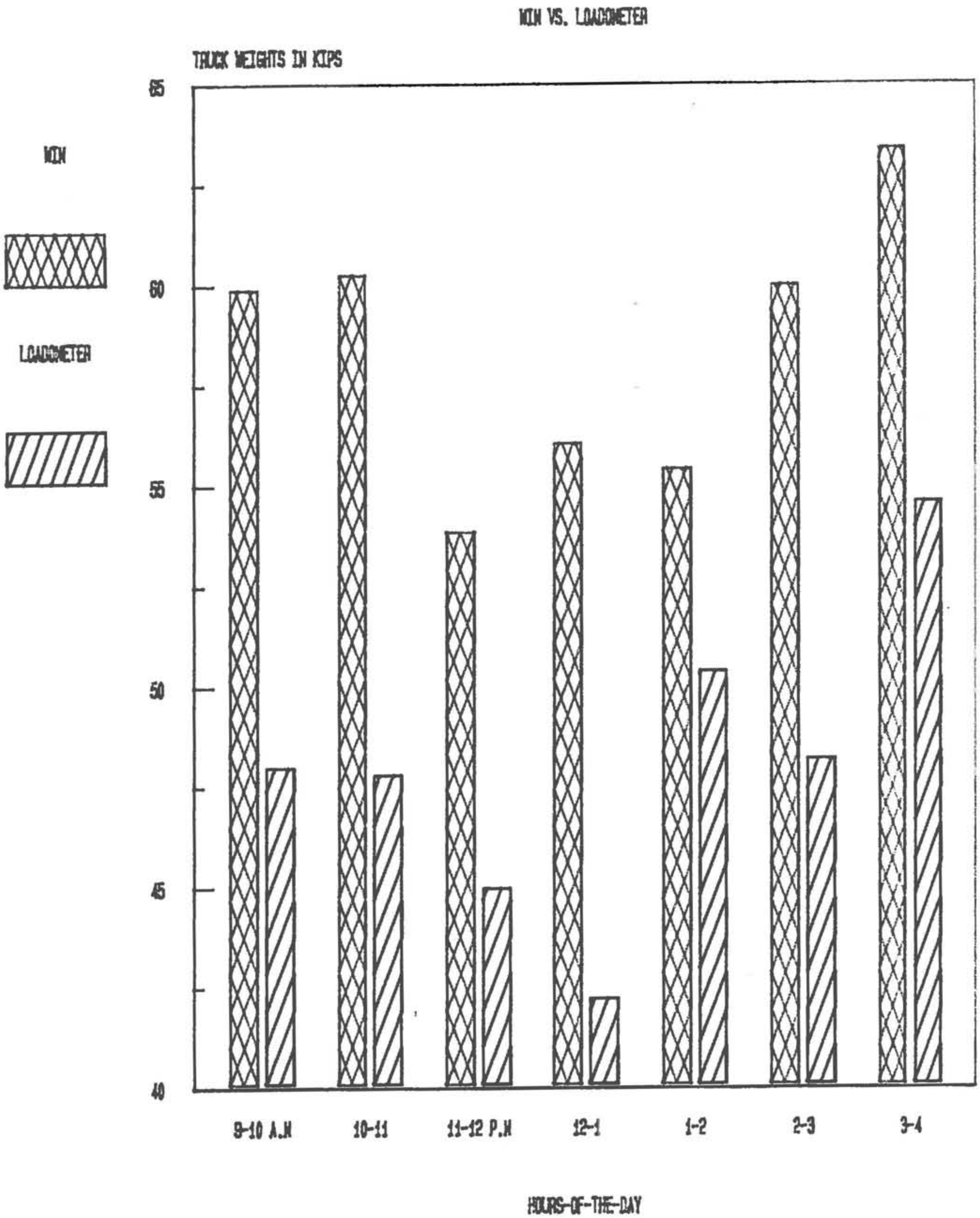


FIGURE 9

VARIATION OF HOURLY AVERAGE TRUCK WEIGHT



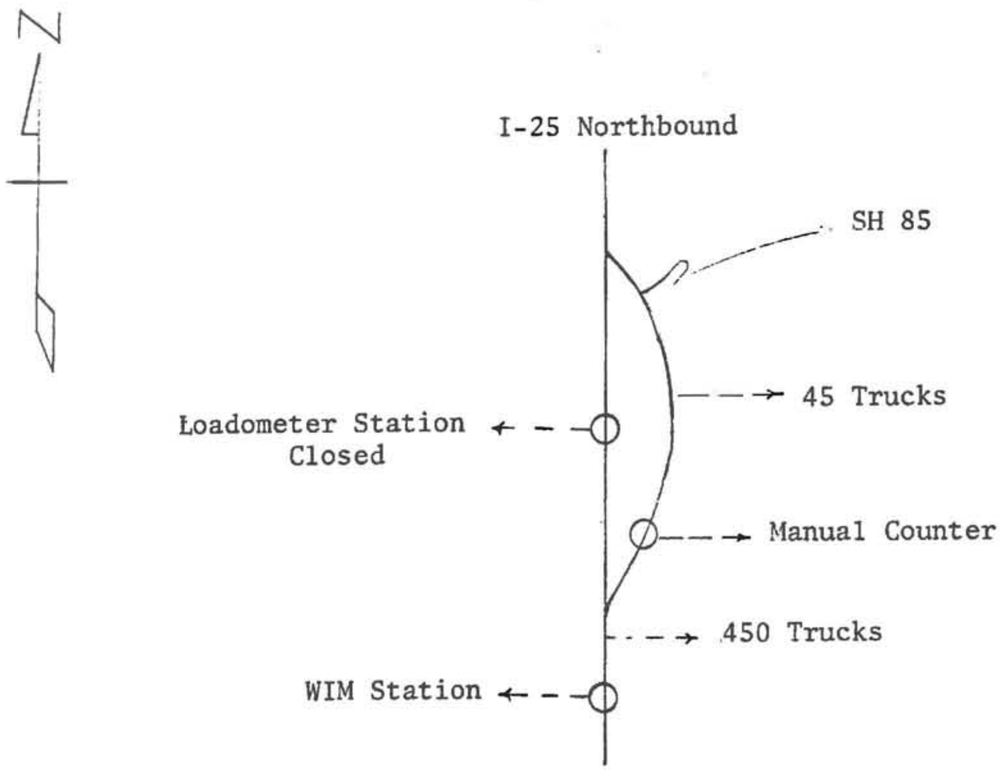


Figure 10

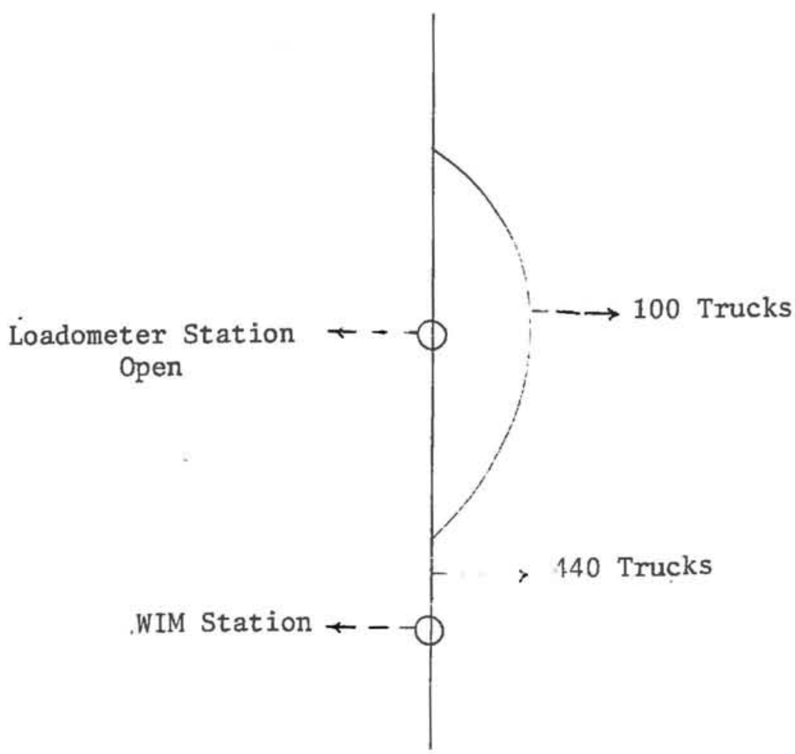


Figure 11

FIGURE 12
TRUCK SPEED FREQUENCY HISTOGRAM

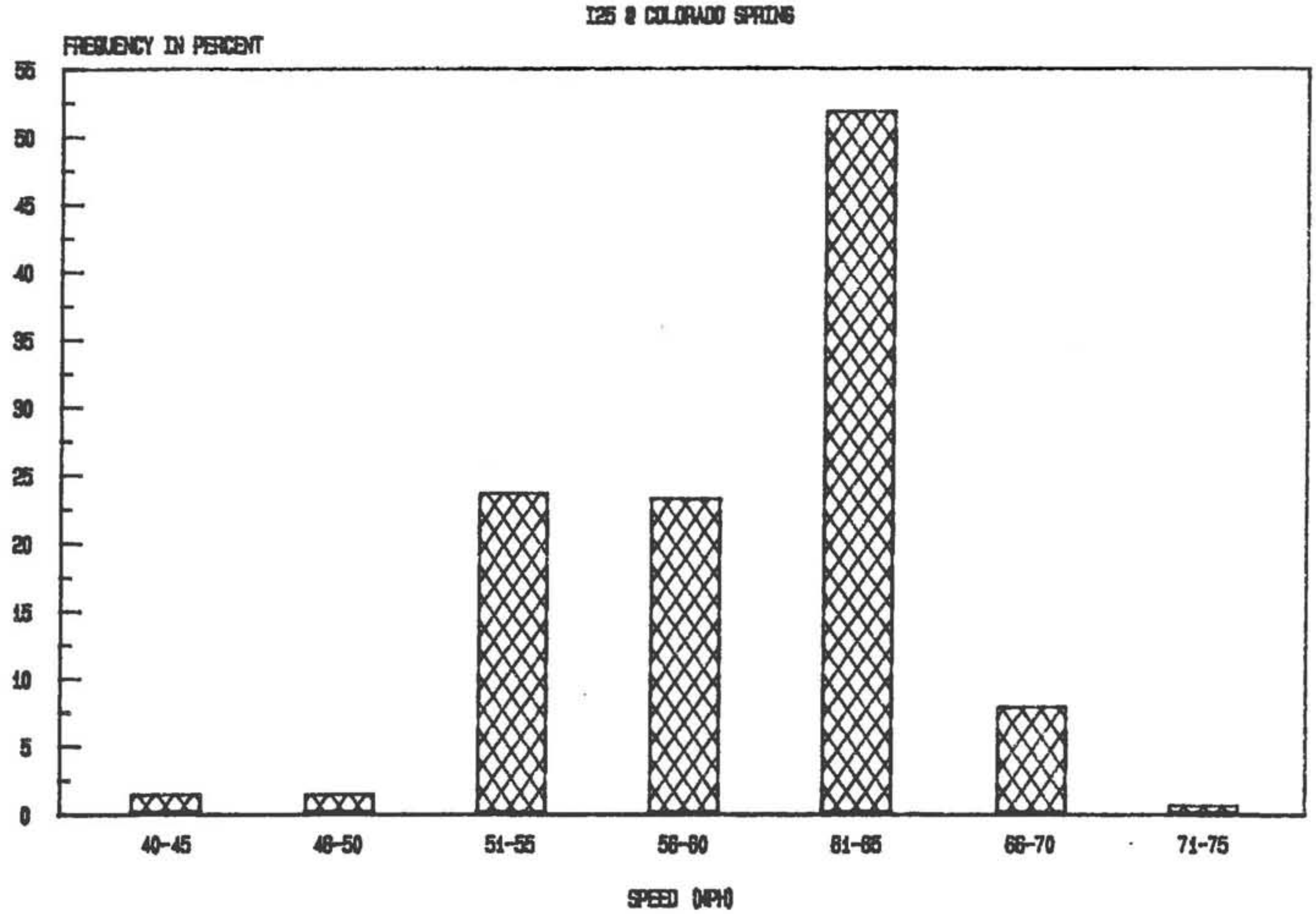
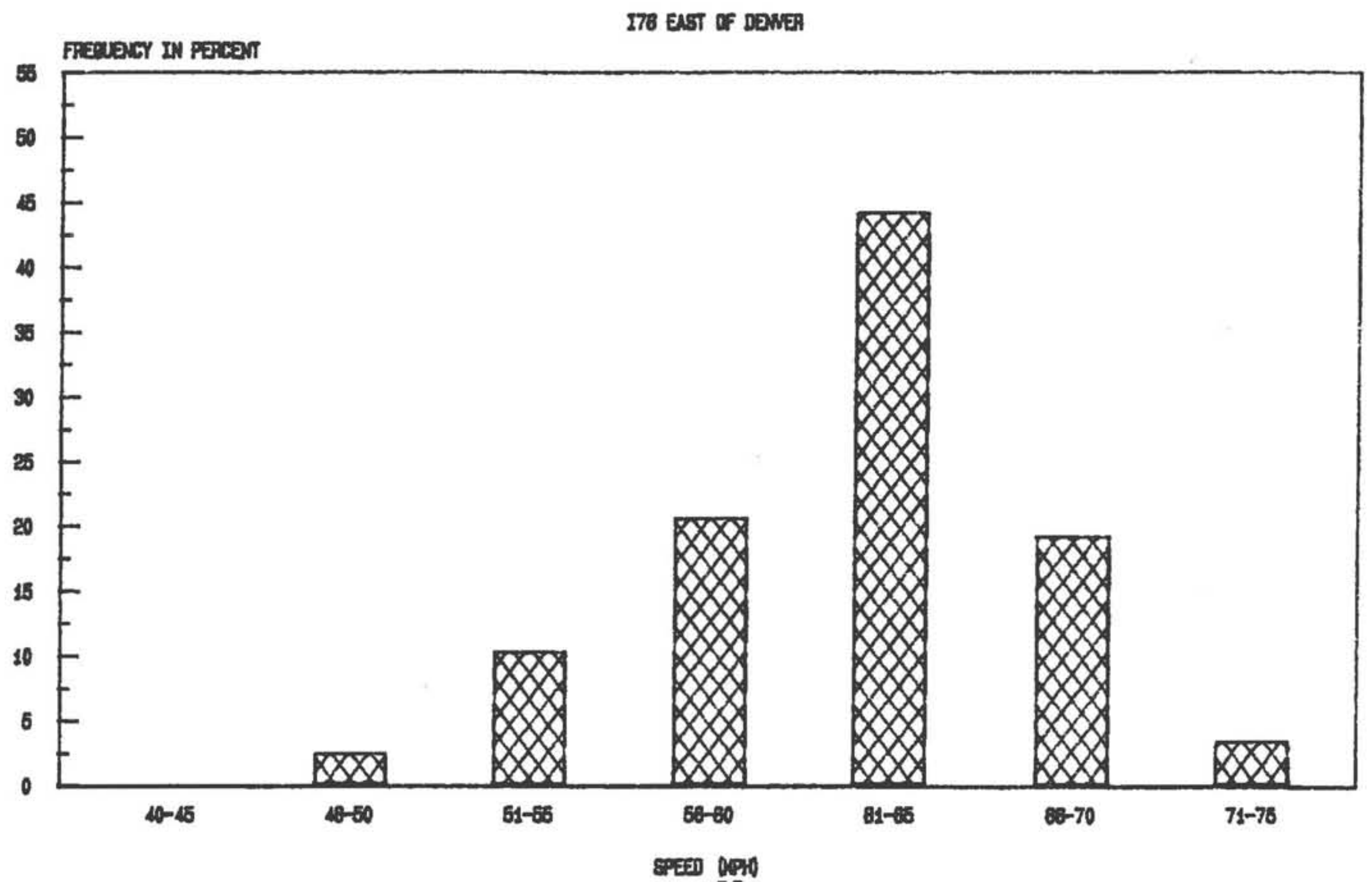


FIGURE 13
TRUCK SPEED FREQUENCY HISTOGRAM



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