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16. Abstract

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AUTOMATIC VEHICLE IDENTIFICATION TECHNIQUES

by

Charles W. Blumentritt

Research Report 291-1F

Automatic Vehicle Identification Techniques

Research Study Number 2-18-81-291

Sponsored by the Texas
State Department of Highways and Public Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

Texas Transportation Institute
Texas A & M University
College Station, Texas

October, 1982

ABSTRACT

Conceptual techniques are discussed for the proximity measurement of vehicle characteristics as detected on freeway entrance and exit ramps. These characteristics, such as magnetic profile and wheelbase, would be recorded over a contiguous set of entrance and exit ramps defining a freeway section. At a later time, these data would be processed to develop correlations for predicting the entrance and associated exit points of individual vehicles for the purpose of conducting freeway origin-destination surveys by automatic means. This report is a feasibility study for the described techniques.

SUMMARY

It is desirable to know the travel patterns of vehicles utilizing specific freeway sections. Traditionally, these data are acquired by license plate studies, interviews, and/or questionnaires which are labor intensive and necessarily limited in duration due to costs and other considerations. This research study is the outgrowth of the need for a system which will automatically and economically provide a means for performing freeway origin-destination (O-D) studies over an uninterrupted, indefinite time period.

The automatic system is envisioned to consist of equipment placed at each of a series of contiguous entrance and exit ramps for a given freeway section. Each of these stations would be composed of detection elements which may or may not be permanently installed in the roadway, together with a portable control cabinet housing electronic sensing, processing, and recording units. Ideally, each station would be battery powered and capable of unattended recording of data over a period of from one day to one week. These data would not be processed until some future date when all of the site-specific data could be entered into a data base representing the total duration of the study. At this point, the use of a general purpose computer would be employed in a matching process to correlate entering and exiting vehicles. Continuous processing of the data over

shorter time intervals is possible, though not necessary except as a verification of the integrity of data.

The feasibility study considers many of the properties of a typical vehicle using a freeway, and seeks to delineate those properties which might be measurable by proximity means. Some examples of these properties are dimensional, statistical, mass, magnetic, acoustic, seismic and others. While the technology exists for measuring all of these properties, it is sometimes questionable as to whether such measurements are economically justifiable, let alone sufficiently discriminatory to distinquish individual vehicles. For example, could a sniffer be designed that could identify a vehicle on the basis of exhaust emissions? For a small population of vehicles with varying year models and states of tune, and measured in a laboratory environment, the answer might be a qualified yes. Such is the case with many of the vehicle properties that are theoretically capable of proximity measurement. The success of field measurements is quite a different matter, however.

This study concludes that a system of vehicle identification for freeway O-D's is feasible, but the number of vehicle characteristics to be measured has not been determined by field testing. Recommendations are made for the testing of a minimum prototype system which measures two vehicle characteristics: wheelbase and inductance signature. The latter is the electronic profile of a vehicle resulting from the change in inductance as detected by a wire loop in the pavement as the vehicle passes over. The inductance signature can be measured by a single loop detector while the wheelbase measurement requires a speed measurement. This implies the use of a second loop or road tube in addition to the primary road tube which measures wheelbase.

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INTRODUCTION

1.1 Overview of Study

This study is a report on the feasibility of a system to automatically acquire freeway origin-destination (O-D) data. Such a system is envisioned to consist of equipment stations placed at each of a set of contiguous entrance and exit ramps. The equipment would measure certain vehicle characteristics by proximity means, such as wheelbase, weight, length, etc. Given a traffic stream which consists of vehicles with varying measurable characteristics, a correlation of these characteristics would be necessary to match the entering and exiting vehicles.

The basis of this study has been to search the literature for techniques that fall within the scope of the conceptual framework of the proposed automatic O-D system. The area that was isolated for the literature review was that of automatic vehicle identification (AVI), which suggests some kinship to the application of generalized vehicle identification. Generally speaking, however, it was found that the purpose of the existing AVI technique went far beyond the requirements of an automatic O-D system. This previous work remains significant, however, and would provide an important source of vehicle movement data should major breakthroughs occur in the application of AVI techniques.

This report covers the theoretical aspects of vehicle classification properties in Chapter II, with a discussion of past research efforts in Chapter III. Chapter IV discusses the equipment requirements and design of a conceptual system. Finally, Chapter V details the conclusions and recommendations for further research.

CHAPTER II

VEHICLE CLASSIFICATION PROPERTIES(1)*

1.1 Scope of Vehicle Classification

The topic of vehicle classification may be considered the parent of the topic of vehicle identification. Classification implies a broader range and granularity than identification. It is appropriate at this point to discuss vehicle properties that contribute to classification. A typical list of vehicle classifications is shown in Figure 1.

1.2 Vehicle Properties

Each member of a broad vehicle "classification" will have certain vehicle "properties". In many instances all members of the classification will share some "properties" in common. If the "property" shared is a crucial one to the generation of the information required, then it is highly desirable that the vehicle "classification" be made in such a way that all members of the classification share its "property".

The vehicle properties are considered to be subelements

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* Underlined numbers in parenthesis denote references at end of report.

Note: The material in this chapter is principally derived from Reference 1, and is included in some detail since it is not available from the National Technical Information Service (NTIS).

(1) Automobiles, Gasoline Powered

   (a) Conventional-size (liquid cooled)
   (b) Compact-size (liquid cooled)
   (c) Compact-size (air cooled)

(2) Automobiles, Diesel Powered

   (a) Conventional-size (liquid cooled)
   (b) Compact-size (liquid cooled)

(3) Trucks, Gasoline-Powered (liquid cooled)

   (a) Non-trailer
   (b) Tractor trailer

(4) Trucks, Diesel Powered (liquid cooled)

   (a) Large, interstate
   (b) Small

(5) Buses, Gasoline Powered (liquid cooled)

   (a) Large, interstate
   (b) Small

(6) Buses, Diesel Powered (liquid cooled)

   (a) Large, interstate

(7) Two-Wheeled Vehicle (powered)

   (a) Large motorcycle
   (b) Small motorcycle

(8) Electric Cars

List of Vehicle Classifications

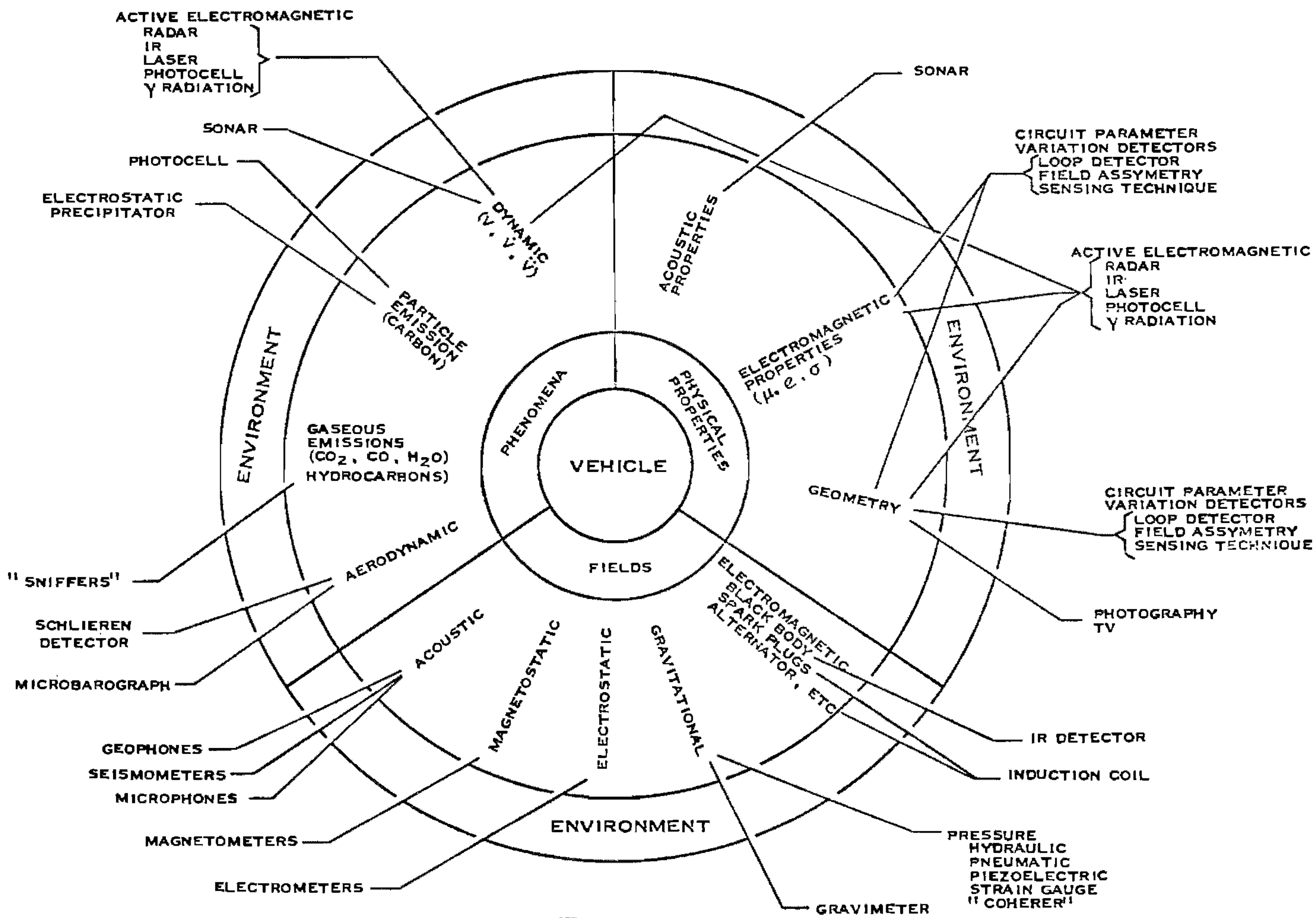
Figure 1

of what can be termed "basic vehicle elements". Thus, the rather detailed "vehicle properties" have been grouped into three broad categories called "vehicle elements" as shown in Figure 2. The intent is to categorize the ways in which a vehicle manifests its existence to the external observer who is constrained to obtain information about the vehicle by means of various sensors. The basic "elements" of "physical properties" and "fields" are chosen in accord with the physicist's traditional dichotomy of the world into "fields and "matter". For the purposes of this study, a third "element" vaguely labeled "phenomena" has been added in order to more conveniently handle such things as particle and gaseous emissions, velocity, acceleration, deceleration, etc.

The approach embodied in Figure 2 might thus be termed an "empirical", "black-box" or a "sensor-oriented" grouping of the vehicle properties.

An alternate approach to the grouping of physical properties of vehicles is that shown in Figure 3. In this more "analytical approach", the basic vehicle properties and operating modes are used as the basis for grouping and "deriving" the vehicle properties.

A comprehensive list of vehicle properties is shown in Figure 4. This list has been compiled in such a way that it is compatible with the philosophy of either the "empirical" or the "analytic" approach.



SOURCE: TEXAS INSTRUMENTS SEMI-ANNUAL REPORT, FHWA NO. FH-11-6973 (DECEMBER 1968)

Figure 2. Sensor Oriented Approach

Vehicle/Engine Mode: Vehicle dynamic and engine dynamic

Transducer: Microbarograph, interferometer, and schlieren detector

Natural Environment:* Wind and atmospheric pressure

Traffic Environment:** na

Vehicle Material Properties: na

Vehicle Capabilities: Velocity, acceleration

Vehicle Properties: Mass, shape, size

Engergy Field or Source: Aerodynamic

* The traffic environment includes other vehicles for all transducers.

** The natural environment includes temperature, precipitation, and humidity for all transducers.

Source: Adapted from Texas Instruments Semi-Annual Report, FHWA No. FH-11-6973 (Dec., 1968)

Figure 3. Vehicle Oriented Approach

Vehicle/Engine Mode: Vehicle static or dynamic and engine dynamic

Transducer: Sniffer and electrostatic precipitator

Natural Environment:* Wind and atmosphere

Traffic Environment:** na

Vehicle Material Properties: na

Vehicle Capabilities: Efficiency of fuel consumption

Vehicle Properties: Power plant

Engergy Field or Source: Chemical

* The traffic environment includes other vehicles for all transducers.

** The natural environment includes temperature, precipitation, and humidity for all transducers.

Figure 3 (Continued). Vehicle Oriented Approach

Vehicle/Engine Mode: Vehicle static or dynamic or engine dynamic

Transducer: Geophone, seismometer, microphone

Natural Environment:* Natural vibrations

Traffic Environment:** na

Vehicle Material Properties: na

Vehicle Capabilities: Engine speed

Vehicle Properties: Power plant mass

Engergy Field or Source: Acoustic

* The traffic environment includes other vehicles for all transducers.

** The natural environment includes temperature, precipitation, and humidity for all transducers.

Figure 3 (Continued). Vehicle Oriented Approach

Vehicle/Engine Mode: Vehicle static and dynamic and engine dynamic

Transducer: Induction coil

Natural Environment:* EMI

Traffic Environment:** EMI (other vehicles)

Vehicle Material Properties: na

Vehicle Capabilities: Engine speed

Vehicle Properties: Power plant aspect angle

Engergy Field or Source: Electromagnetic EMI

* The traffic environment includes other vehicles for all transducers.

** The natural environment includes temperature, precipitation, and humidity for all transducers.

Figure 3 (Continued). Vehicle Oriented Approach

Vehicle/Engine Mode: Vehicle static or dynamic and engine static or dynamic

Transducer: Microphone

Natural Environment:* Topo;ogy, terrain, wind

Traffic Environment:** Bridges, tunnels, signs

Vehicle Material Properties: Acoustic reflectivity

Vehicle Capabilities: na

Vehicle Properties: Size, shape, aspect angle

Engergy Field or Source: External acoustic

* The traffic environment includes other vehicles for all transducers.

** The natural environment includes temperature, precipitation, and humidity for all transducers.

Figure 3 (Continued). Vehicle Oriented Approach

Vehicle/Engine Mode: Vehicle static or dynamic and engine static or dynamic

Transducer: Gravimeter

Natural Environment:* Topology

Traffic Environment:** Bridges, tunnels

Vehicle Material Properties: Specific gravity

Vehicle Capabilities: na

Vehicle Properties: Mass

Engergy Field or Source: Gravitational

* The traffic environment includes other vehicles for all transducers.

** The natural environment includes temperature, precipitation, and humidity for all transducers.

Figure 3 (Continued). Vehicle Oriented Approach

Vehicle/Engine Mode: Vehicle static or dynamic and engine static or dynamic

Transducer: Peizoelectric strain guage, pressure pad, hydraulic, pneumatic

Natural Environment:* Topology

Traffic Environment:** na

Vehicle Material Properties: Specific gravity

Vehicle Capabilities: na

Vehicle Properties: Mass, shape, size

Engergy Field or Source: Compressive

* The traffic environment includes other vehicles for all transducers.

** The natural environment includes temperature, precipitation, and humidity for all transducers.

Figure 3 (Continued). Vehicle Oriented Approach

Vehicle/Engine Mode: Vehicle static or dynamic and engine static or dynamic

Transducer: Radar, laser, IR, photocell, radiation

Natural Environment:* Topology, terrain, EMI

Traffic Environment:** Bridges, tunnels, EMI (vehicles), signs, headlights

Vehicle Material Properties: Permeability, conductivity, permittivity

Vehicle Capabilities: na

Vehicle Properties: Type and distribution of size, material, shape and aspect angle

Engergy Field or Source: External electromagnetic field

* The traffic environment includes other vehicles for all transducers.

** The natural environment includes temperature, precipitation, and humidity for all transducers.

Figure 3 (Continued). Vehicle Oriented Approach

Vehicle/Engine Mode: Vehicle static or dynamic and engine static or dynamic

Transducer: IR, television, photography

Natural Environment:* Topology, terrain, EMI

Traffic Environment:** Bridges, tunnels, EMI (vehicles), signs, headlights

Vehicle Material Properties: Permeability, conductivity, permittivity

Vehicle Capabilities: na

Vehicle Properties: Type and distribution of material, size, shape and aspect angle

Engergy Field or Source: Natural electromagnetic field

* The traffic environment includes other vehicles for all transducers.

** The natural environment includes temperature, precipitation, and humidity for all transducers.

Figure 3 (Continued). Vehicle Oriented Approach

Vehicle/Engine Mode: Vehicle static or dynamic and engine static or dynamic

Transducer: Electrometer, capacitive detector

Natural Environment:* EMI and natural electric field

Traffic Environment:** Bridges, tunnels, EMI (vehicles), lamposts

Vehicle Material Properties: Conductivity, permittivity

Vehicle Capabilities: na

Vehicle Properties: Type of material, distribution of material

Engergy Field or Source: External electric field

* The traffic environment includes other vehicles for all transducers.

** The natural environment includes temperature, precipitation, and humidity for all transducers.

Figure 3 (Continued). Vehicle Oriented Approach

Vehicle/Engine Mode: Vehicle static or dynamic and engine static or dynamic

Transducer: Electrometer, capacitive detector

Natural Environment:* EMI

Traffic Environment:** Bridges, tunnels, EMI (vehicles), lamposts

Vehicle Material Properties: Conductivity, permittivity

Vehicle Capabilities: na

Vehicle Properties: Type of material, distribution of material

Engergy Field or Source: Natural electric field

* The traffic environment includes other vehicles for all transducers.

** The natural environment includes temperature, precipitation, and humidity for all transducers.

Figure 3 (Continued). Vehicle Oriented Approach

Vehicle/Engine Mode: Vehicle static or dynamic and engine static or dynamic

Transducer: Magnetometer, loop detector

Natural Environment:* EMI, natural magnetic field

Traffic Environment:** Bridges, tunnels, reinforced concrete, EMI (vehicles), lamposts

Vehicle Material Properties: Permeability

Vehicle Capabilities: na

Vehicle Properties: Type of material, distribution of material

Engergy Field or Source: External magnetic field

* The traffic environment includes other vehicles for all transducers.

** The natural environment includes temperature, precipitation, and humidity for all transducers.

Figure 3 (Continued). Vehicle Oriented Approach

Vehicle/Engine Mode: Vehicle static or dynamic and engine static or dynamic

Transducer: Magnetometer

Natural Environment:* EMI

Traffic Environment:** Bridges, tunnels, reinforced concrete, EMI (vehicles), lamposts

Vehicle Material Properties: Permeability

Vehicle Capabilities: na

Vehicle Properties: Type of material, distribution of material

Engergy Field or Source: External magnetic field, intrinsic vehicle magnetic moment

* The traffic environment includes other vehicles for all transducers.

** The natural environment includes temperature, precipitation, and humidity for all transducers.

Figure 3 (Continued). Vehicle Oriented Approach

(1) Dimensional Properties

(a) length
(b) width
(c) wheelbase
(d) height
(e) axle height
(f) tread
(g) tire diameter
(h) other

(2) Statistical Properties

(a) number of axles
(b) number of wheels
(c) number of cylinders in power plant
(d) alternator or generator equipped

(3) Mass Properties

(a) mass of non-ferrous metals
(b) mass of ferrous metals
(c) total metallic mass
(d) total vehicular mass (loaded)

(4) Dynamic Properties

(a) maximum acceleration
(b) maximum deceleration

(5) Magnetic Properties

(a) location and size of permanent moments
(b) induced moment as function of heading and latitude
(c) total moment as function of heading and latitude

(6) Electromagnetic Radiator Properties

(a) radiated RF power from ignition, alternators, etc. as a function of frequency and position
(b) temperature, location, and emissivity of vehicle heat sources (radiators, mufflers, manifolds, etc.)

Vehicle Properties

Figure 4

(7) Acoustic Radiator Properties

(a) location, strength, and frequency description of vehicular primary acoustic sources as a function of sensor position
(b) location, strength, and frequency description of induced acoustic sources as a function of sensor position.

(8) Scattering Properties

(a) electromagnetic - RF, radar, IR, etc.
(b) acoustic

(9) Chemical Properties

(a) hydrocarbon emissions
(b) water vapor emissions
(c) carbon particle emissions

(10) Aerodynamic Properties (Turbulence Production, etc.)

(11) Seismic Radiator Properties

(a) description in time, space, and frequency of vibrations produced in the earth

(12) Electrostatic Properties

(a) electrostatic charge
(b) capacitance effect

(13) Other Properties

(a) color

Vehicle Properties (Continued)

Figure 4

1.3 Quantitative Definition of Vehicle Classifications/ Properties

1.3.1 Introduction

The general approach to the "quantification" or "profiling" of vehicle properties is one of pairing specific vehicle properties and vehicle classes and then, in each case, quantifying the physical properties with respect to appropriate variables such as frequency, aspect angle, engine RPM, etc. Wherever possible, the quantifications are presented in the form of probability density functions representing averages over large numbers of vehicles. In those instances in which a large statistical sample is not available, the quantifications are presented in the form of a plot of the measured quantity versus some variable (such as frequency) for the specific vehicles measured. In the interest of conciseness in the data presentation, vehicle classes and vehicle properties will be referenced by the number-letter codes of Figures 1 and 4. For example, vehicle type (1) (a) is a "conventional" size, gasoline powered, liquid cooled automobile, while vehicle property (5) (b) is "induced" magnetic moment as a function of heading and latitude. In this case, the quantification for vehicle type (1) (a) and vehicle property (5) (b) would involve specifying the induced magnetic moments in some statistical way for this class of vehicle.

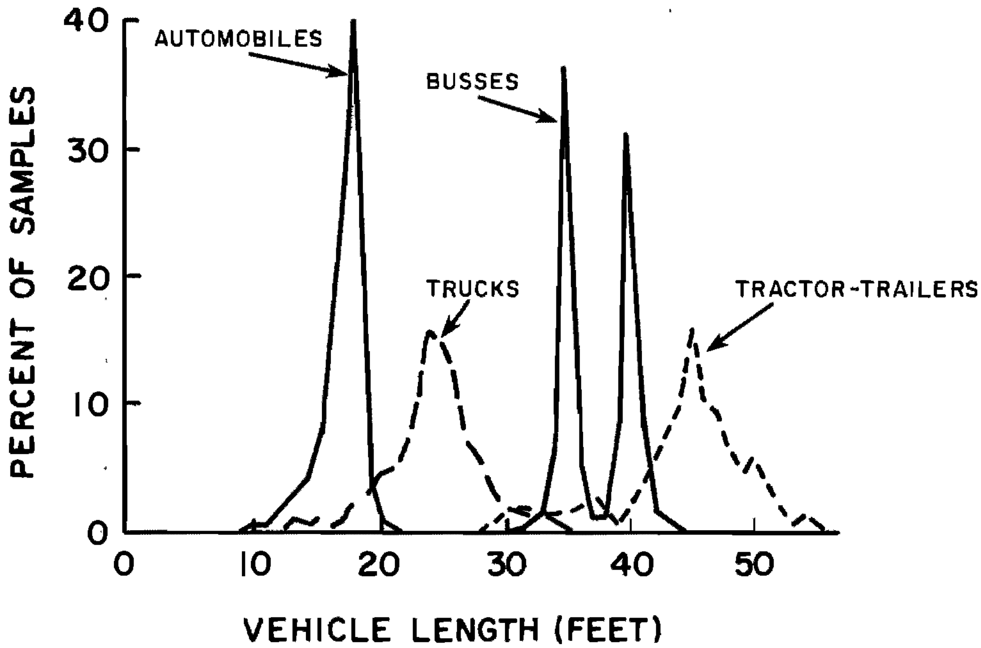
1.3.2 Dimensional Properties

The dimensional properties of vehicles will be examined and quantified with particular emphasis on those dimensional properties which are known to significantly influence the vehicle sensing function.

1.3.2.1 Length Property

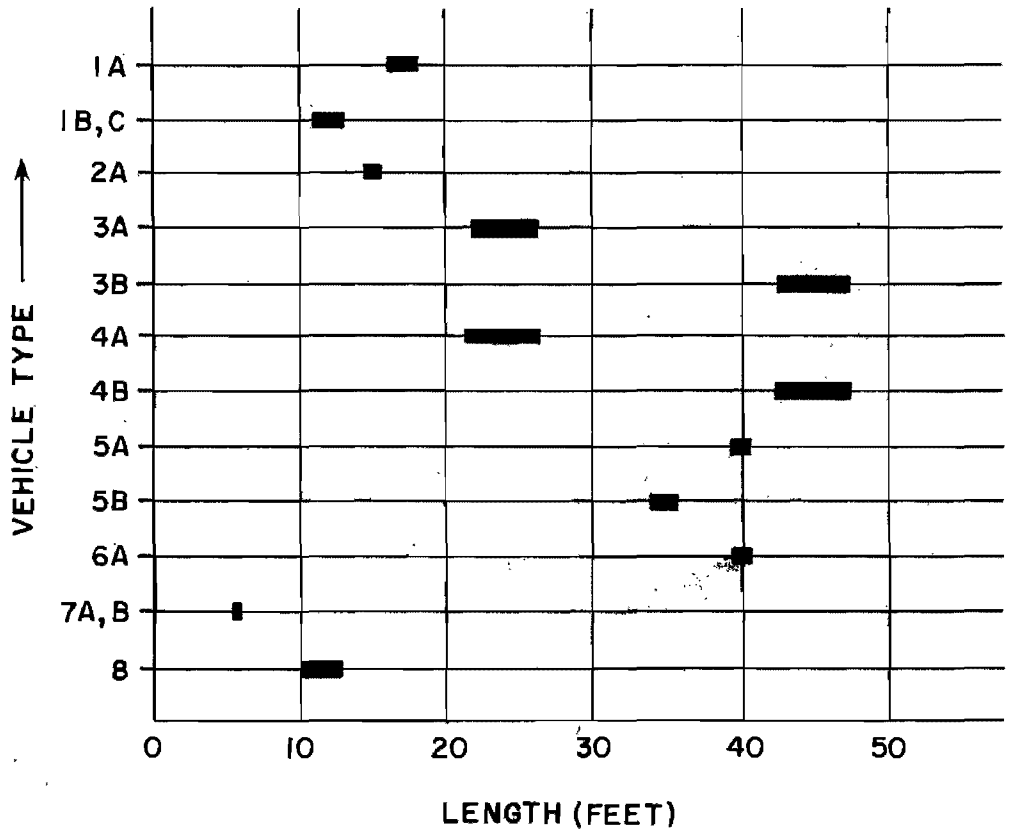
Vehicle length may be an important property both with regard to the classification and sensing functions. As indicated by the probability density functions of Figure 5, the measurement of a vehicle's length may be considered a statistical estimate of its membership in certain vehicle classes. Thus, if one were able to determine, for example, from sensed data that a vehicle's length was 17 feet, one could state the probability (which would be fairly high) that the sensed vehicle was a member of "class (1)(a)" (conventional size, gasoline powered, liquid cooled automobile). Conversely, some sensors respond in an ambiguous way to both vehicle speed and vehicle length. When it is necessary to resolve this ambiguity, either an independent length measurement must be obtained or some statistically weighted average length must be used.

A summary of the length data of Figure 5 plus that derived from other sources is presented in Figure 6. In this figure, expected length ranges are displayed as a function of vehicle type using the number-letter codes previously presented. In those cases where probability



SOURCE: R.S. FOOTE, "SPECIAL PURPOSE TRAFFIC SURVEY DEVICES," PRESENTED AT 33rd ANNUAL MEETING OF THE INSTITUTE OF TRAFFIC ENGINEERS, TORONTO, CANADA. (AUGUST, 1963)

Figure 5. Plot of Frequency Distribution by Percent of Vehicle Lengths in One-Foot Classes



SOURCE: TEXAS INSTRUMENTS SEMI-ANNUAL REPORT,
FHWA NO. FH-11-6973 (DECEMBER 1968)

Figure 6. Length Ranges Versus Vehicle Type

density functions or histograms are available, the "spread" in length depicted by the bars of Figure 6 was determined from the width of the density functions at "half-height".

1.3.2.2 Other Dimensional Properties

The ranges of the dimensional properties of width (1)(b) and wheelbase (1)(c) are presented in the bar graphs of Figure 7 as a function of vehicle type. Vehicle height "property (1)(d)" and axle height "property (1)(e)" are presented in a similar manner in Figure 8.

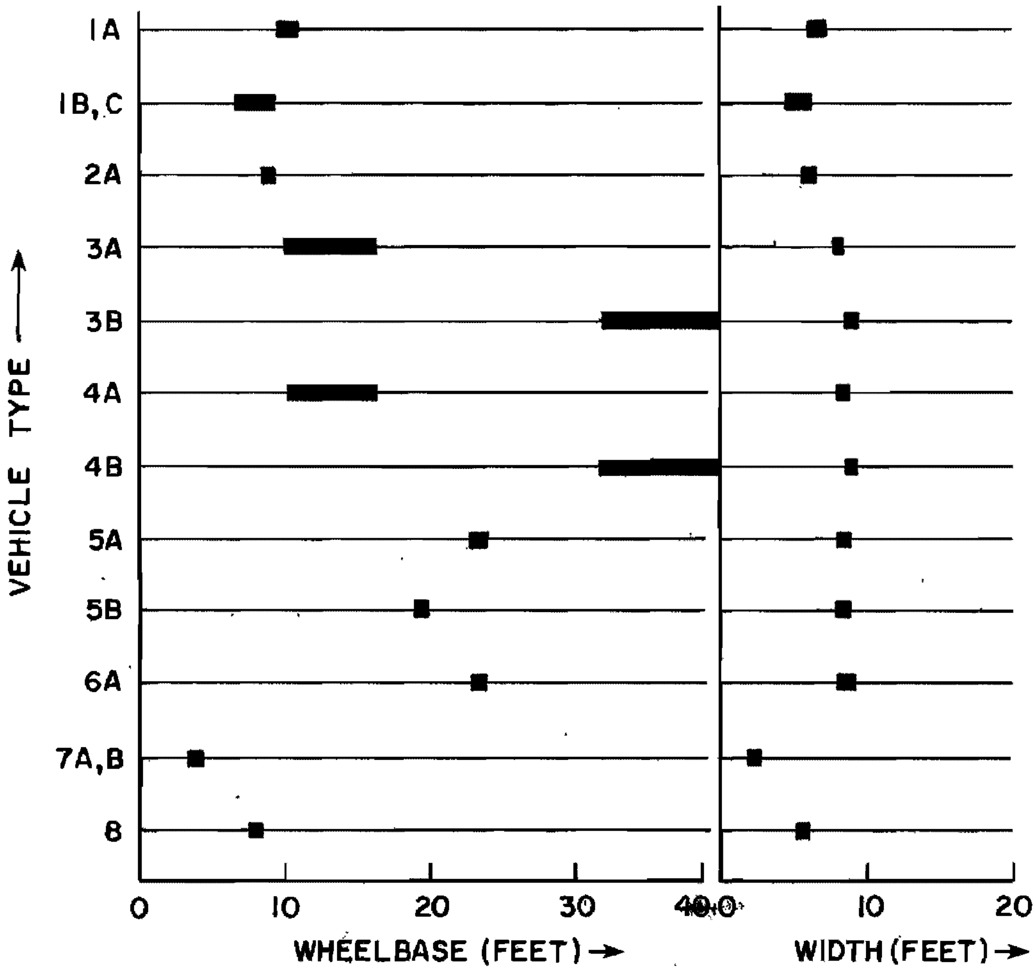
1.3.3 Statistical Properties

The statistical properties (2)(a) - "number of axles", (2)(b) - "number of wheels", and (2)(c) - "number of cylinders in power plant", are quantified in Table 1 for the vehicle types considered.

In the case of statistical property (2)(d) - "alternator or generator equipped", most U.S. made cars and trucks built after 1964 are alternator equipped. As of July 1967, pre-1964 models made up 57 percent of U.S. car registration. This statistic is time sensitive, shifting each year toward lower percentages of pre-1964, generator equipped vehicles. Today, generator equipped vehicles are very low in number.

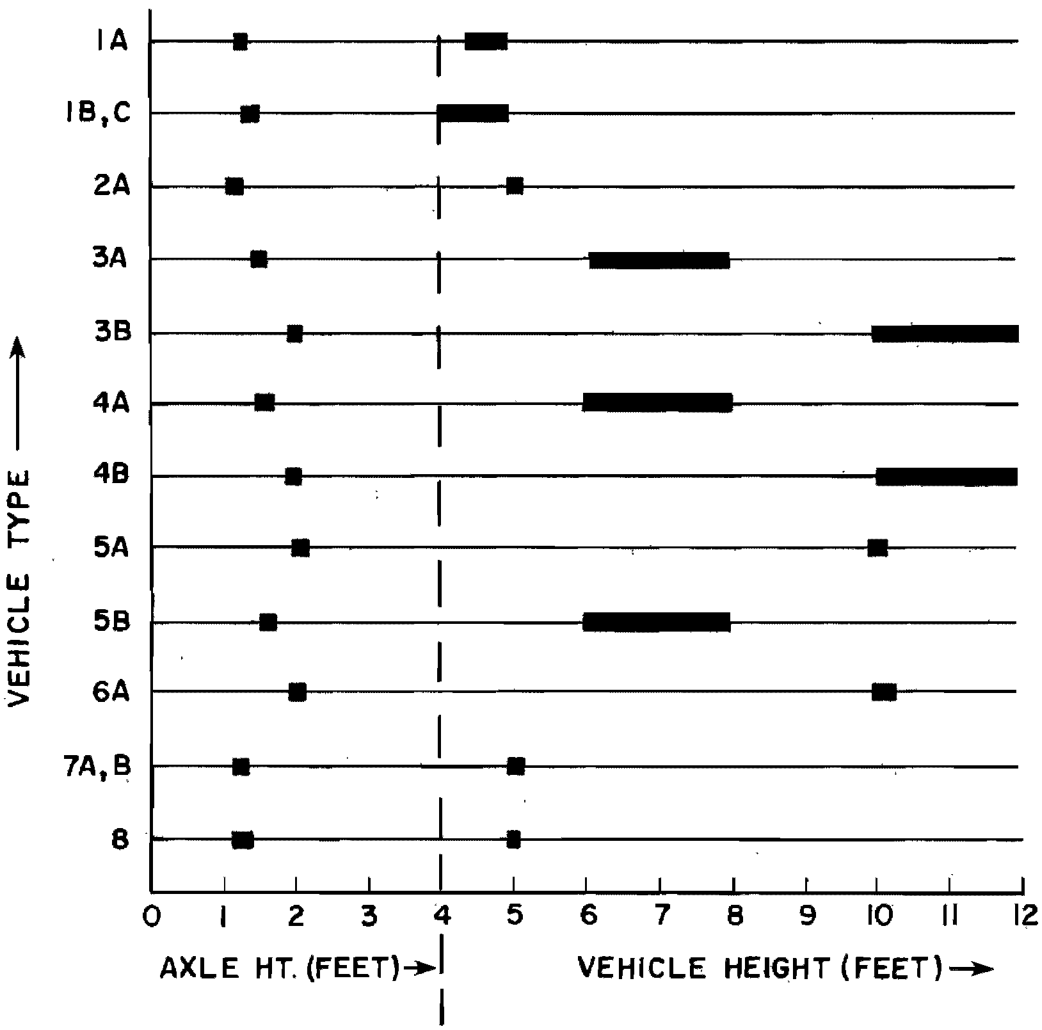
1.3.4 Mass Properties

It is readily apparent that the total mass of a vehicle will be significant when detection of the vehicle is to be accomplished by means of compressive type sensors (strain gauges, pressure pads, hydraulic, etc.) or by gravimeters.



SOURCE: TEXAS INSTRUMENTS SEMI-ANNUAL REPORT,
FHWA NO. FH-11-6973 (DECEMBER 1968)

Figure 7. Wheelbase and Widths Versus Vehicle Type



SOURCE: TEXAS INSTRUMENTS SEMI-ANNUAL REPORT, FHWA NO. FH-11-6973 (DECEMBER 1968)

Figure 8. Axle Height and Vehicle Height Versus Vehicle Type

TABLE 1

STATISTICAL PROPERTIES OF VEHICLES

Vehicle Types	Number of Axles	Number of Wheel Position	Number of Cylinders
1a	2	4	6-8
1b,c	2	4	4-6
2a	2	4	4-8
3a	2	4	6-8
3b	4-5	8-10	6-8
4a	2	4	6-8
4b	4-5	8-10	6-8
5a	2-3	4-6	6-8
5b	2	4	6-8
6a	2-3	4-6	6-8
7a	2	2	4
7b	2	2	2-4
8	2	4	0

The total mass is also an important factor in determining the amplitude of seismic signatures from vehicles.

Estimated vehicle weights, "vehicle property (3)(d)", are presented in Table 2. In the case of vehicles of Classes 1 and 2 (private automobiles) the total weight is given for the vehicle without passengers, whereas the weights for trucks and buses are given for full cargo or passenger loads.

The mass of ferrous metals, "property (3)(b)" is of prime importance to magnetometers since they respond to the permanent and induced magnetic moments of vehicles.

In the case of loop detectors the masses of non-ferrous and ferrous metals, "properties (3)(a) and (3)(b)", and their ratio is significant, since these detectors respond to both permeability and eddy current effects.

Sensors such as the Field Asymmetry Sensing Technique (FAST) device respond primarily to the metallic mass of the vehicle, and thus "property (3)(c)" will be of primary importance.

While the unloaded weights of Class 1 vehicles is primariy made up of ferrous metals, the recent trend has been to incorporate more nonferrous metals in vehicle manufacturing.

1.3.5 Magnetic Properties

The magnetostatic fields around vehicles arise from two classes of sources called "permanent" and "induced" magnetic

TABLE 2

WEIGHT DISTRIBUTION BY VEHICLE TYPE

Vehicle Types	Weight (Pounds)
1a	3,400 - 4,400
1b, c	1,700 - 2,600
2a	2,700
3a	35,000 - 75,000
3b	60,000 - 100,000
4a	35,000 - 75,000
4b	60,000 - 100,000
5a	35,000
5b	26,000
6a	35,000
7a	500
7b	200
8	1,800

moments. The permanent magnetism of the various parts of the vehicle is defined as that which is independent of the relative orientation of the vehicle and the earth's magnetic field. This magnetism should also be relatively stable in time (over time scales of the order of a few days). These permanently magnetized bodies are comparable in every way with the smaller permanent magnets encountered in everyday life.

The so-called induced magnetism of various parts of vehicles arises from their permeability to the earth's magnetic field. In the temperate latitude zones, the earth's magnetic field is of the order of 0.5 oersted or 50,000 gamma (1 gamma = 10^{-5} oersted) and may be considered a constant vector over dimensions typical of a vehicle. The high permeability of these ferrous materials (relative to that of air) causes the flux lines of the earth's magnetic field to be concentrated in the vicinity of these permeable bodies and to be channeled through them. The resultant field may be considered as the sum of an anomalous field (usually a dipole field) and a constant vector. Since the anomalous field component is the one which reflects the presence of the vehicle, it is the usual practice to eliminate the constant vector either instrumentally, or in the data processing. When this is done, the remaining magnetism is that due to the "induced" magnetic moment. Observationally speaking, the magnetostatic fields due to induced magnetism may be distinguished from those of permanent magnetism by the fact that the strength of the induced moments will normally vary with the relative orientation of the vehicle and the earth's magnetic field. For example, a cigar-shaped, permeable body will have its greatest magnetic moment when its longitudinal axis is parallel to the constant earth field vector.

Measurements made at the Dallas Magnetic Observatory and by others have shown that the overall magnetic moments of motor vehicles are largely of the induced type and, at distances of 20 feet or more, may be considered as point dipole sources whose magnetic moments range from 10^5 and 10^6 Centimeters/Grams/Seconds (CGS) units for cars and from 10^7 to 10^8 CGS units for trucks.

It is anticipated that a mapping along the roadway of the magnetic field underneath a vehicle at a distance of the order of two feet will exhibit fine structure due to the magnetic moments of component parts such as the engine block, transmission, drive shaft, differential, rear axle, etc., as well as that due to the body shell of the vehicle. Figure 9 depicts the configuration of lines of magnetic force produced by the introduction of a vehicle into the uniform earth's magnetic field. The effect depicted is one of induced magnetism of the engine, transmission, drive shaft, and differential of a vehicle which is assumed to be headed north in a region where the undisturbed earth field

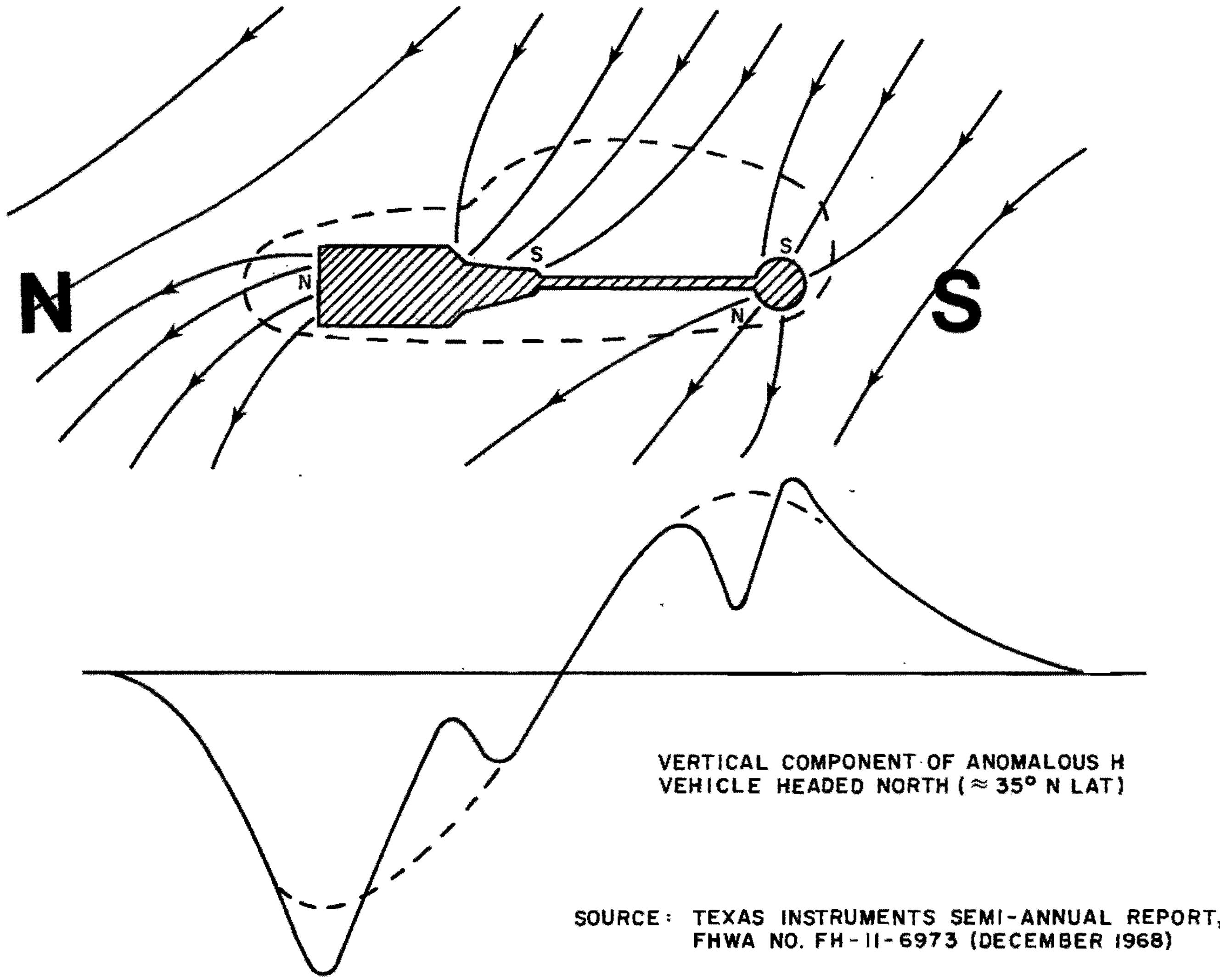


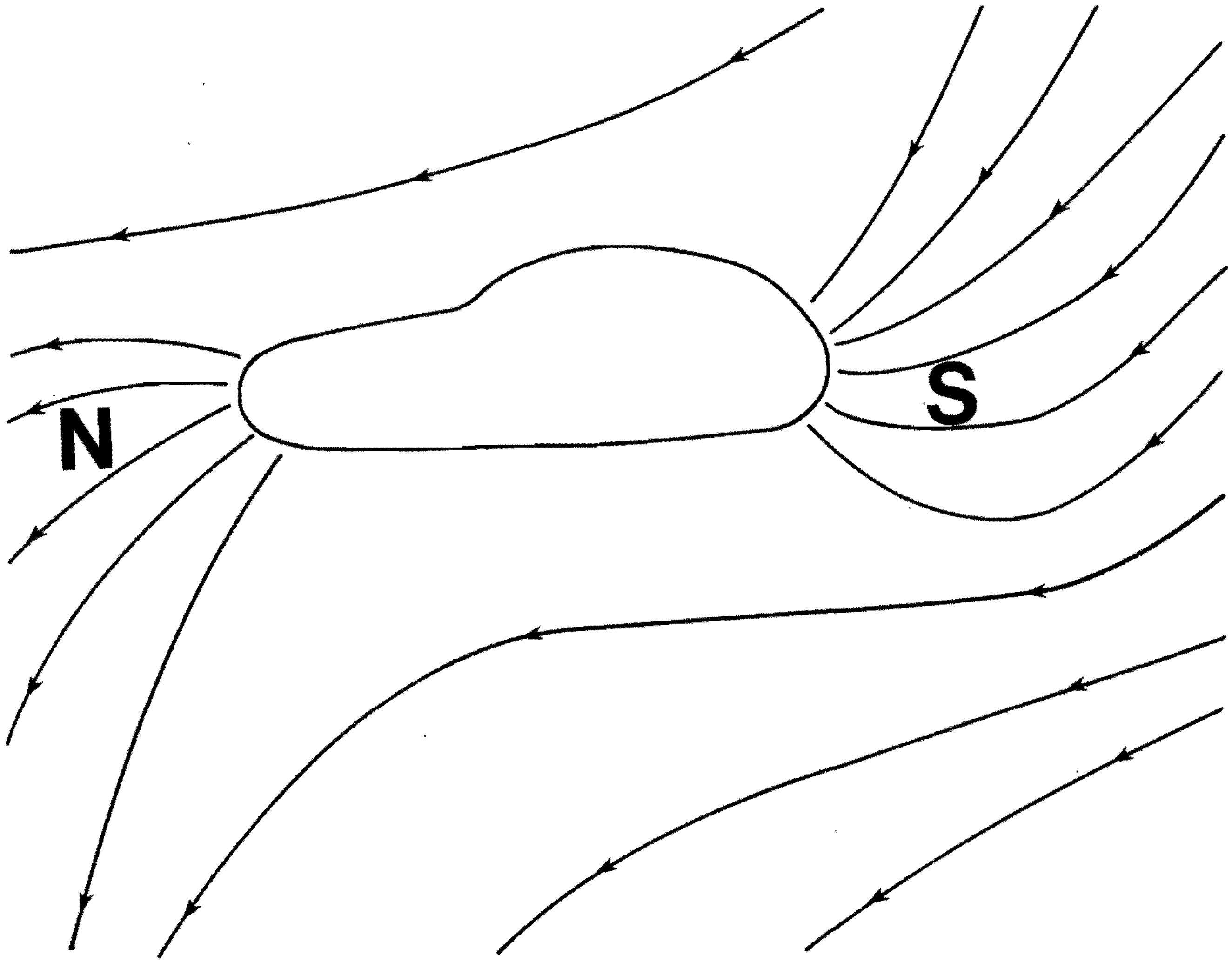
Figure 9. Influence of Vehicle on Earth's Magnetic Field

makes an angle of about 60 degrees with the horizontal (N 35 degree North Latitude). Small letters indicate effective north and south magnetic poles of the aforementioned drive train components. The large "N" and "S" designate the induced magnetic poles due to the shell of the vehicle. To avoid confusion in the illustration, the field pattern of the body shell is not drawn on Figure 9 but is shown separately in Figure 10.

1.3.6 Electromagnetic Radiator Properties

A motor vehicle may be considered as an electromagnetic radiation source over rather a wide range of frequencies. Since periodic or harmonically varying electric currents are potential electromagnetic radiation sources, generators, alternators, spark plugs, ignition points, ignition wires, etc. may all be considered as electromagnetic radiator candidates.

According to Planck's radiation theory for matter in thermal equilibrium with electromagnetic radiation quanta (photons), all material bodies at non-zero temperature will radiate electromagnetic energy. The total power radiated and the frequency distribution of power will be determined by the temperature of the material body. Since the various parts of a vehicle are heated by external sources (such as the sun) and by internal sources (engine heat), we may expect Planck's Law or "thermal" radiation from vehicles.



VEHICLE HEADED NORTH
(≈ 35° N LAT)

SOURCE: TEXAS INSTRUMENTS SEMI-ANNUAL REPORT, FHWA NO. FH-11-6973 (DECEMBER 1968)

Figure 10. Induced Field for Body Shell Alone

1.3.7 Radio Frequency Radiation Property

Because of the variability in lengths and placement of ignition wires, in the placement of metallic objects near the wires, in the degree of suppression equipment installed*, in the type of spark plugs, and because of the differences between transistor and mechanical ignition systems, it is expected that the radio frequency radiation field around ignition-equipped vehicles will exhibit great variability in spatial and spectral descriptions. It is also recognized that diesel powered vehicles will not have ignition systems and will not provide this type of radiation. In spite of the extreme variability of the radiation from vehicles containing ignition systems and the absence of such radiation from diesel powered vehicles, characterization of this radiation in spectral and spatial terms might still prove useful for subsequent evaluation of classification techniques.

If, for example, the Electro Magnetic spectrum of ignition radiation could be unambiguously distinquished from arc and spark spectra from other sources (generators, air conditioners, etc.), then it might prove to be a high confidence method for discriminating between ignition vehicles (gasoline powered) and ignitionless vehicles (diesel powered).

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* Vehicles equipped with two-way radios, telephones, ham radio equipment etc., will often have more elaborate radio frequency interference suppression equipment.

Although ignition radiation would not be a universal primary indicator of vehicle presence or passage, it has potential value as a classifier.

To summarize, the physical model of a general vehicle for the radio frequency radiation property consists of:

(A) Sources

(1) alternator or generator

(2) ignition system

(3) miscellaneous signals, arcs, sparks, etc. from air conditioners, vibrators, small direct current motors, radio receiving equipment, etc.

(B) Radiating elements

(1) ignition harness

(2) coils, field windings, etc.

(3) spark plugs

(C) Parasitic elements

(1) conducting functional objects in the vicinity of the radiating elements

(2) shielding.

Although experimental data on the frequency spectra of the sources above are not available, some rough estimates of the ranges may be made. For example, the ignition current may be considered as a series of oscillatory transients whose durations may be as short as one millisecond. Because of the aperiodic nature of an individual discharge, its Fourier frequency spectrum extends over a wide range. The radiated spectrum will be approximately the product of this spectrum and the frequency dependent "radiation efficiency" functions of the radiating elements. If the ignition wires are of the order of a meter in length, their radiation efficiency functions would be expected to peak up in the vicinity of a few hundred megacycles. For spark plug gaps of the order of 0.75 millimeters, the "antenna gain" can be expected to be high, around 200,000 megacycles. This does not, of course, mean that a great deal of power can be expected at these frequences, since the source transients will have relatively little energy at these frequencies.

However, since it is common knowledge among ham radio operators that ignition interference is experienced at frequencies of a few tens of megacycles, the preceding qualitative discussion can be quantified to the extent of stating that the range of significant ignition radiation probably extends from a few hundred cycles to a few tens of megacycles.

The alternator spectrum may be roughly estimated as follows:

$$f_{alt} = \frac{(\text{REVS})}{(\text{SEC})} \times (\text{PULLEY RATIO}) \times (\text{NO. OF POLE PAIRS})$$

For 3000 revolution per minute (rpm), four pole pairs, and a pulley ratio of three, this would be:

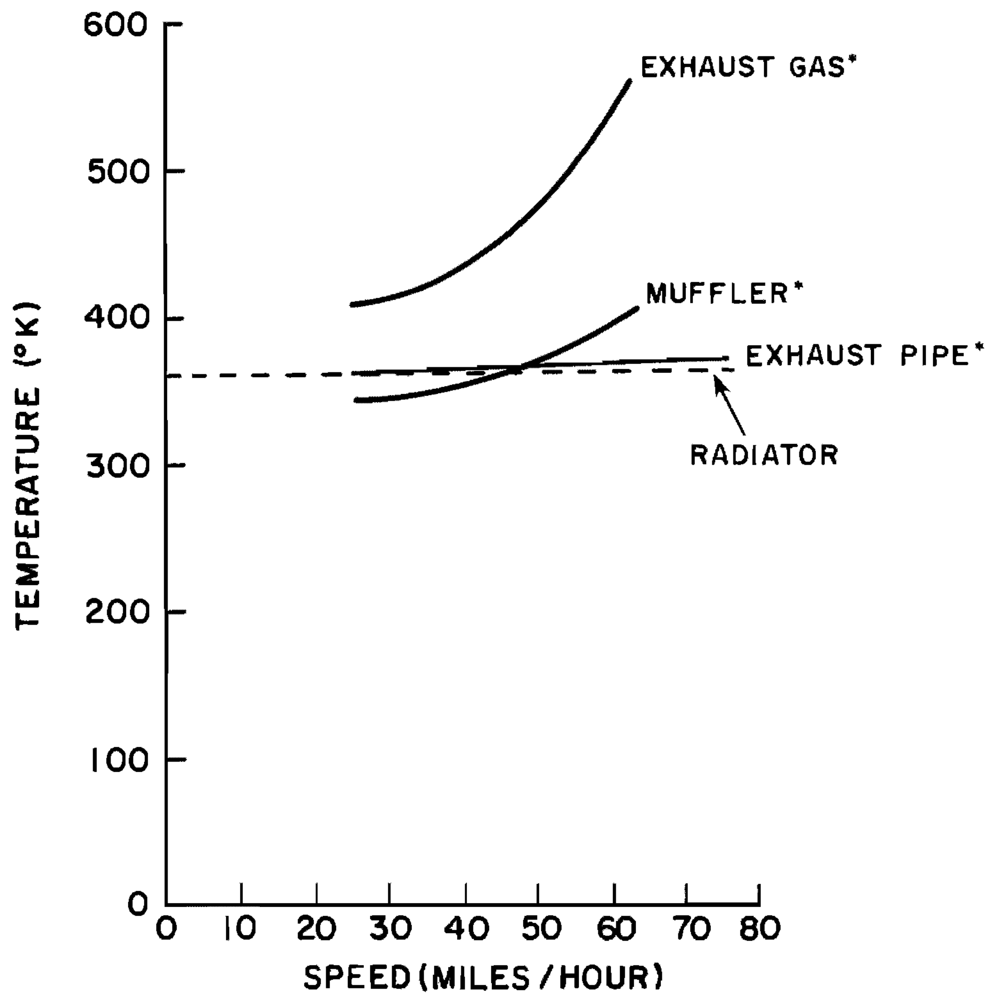
$$f_{alt} = \frac{(3000)}{(60)}\ (3)\ (4) = 600 \text{ cps}$$

Higher harmonics would be present to the extent that the waveform is nonsinusoidal.

1.3.8 Thermal Radiation Property

A physical model of a vehicle with respect to the thermal radiation property is essentially that of a longitudinal train on relatively "hot" objects within a "box" (the body shell) which is normally open on the "bottom" and partially open on the "front". Because of sound deadening materials often placed under the hood, and air flow over the hood and inside the engine compartment, the body shell temperature of a moving vehicle is considered to be essentially independent of the temperatures of the internal hot source objects. The body shell box is open on the bottom because an unobstructed view of mufflers, tailpipes, etc., is usually afforded from beneath a vehicle. Exceptions to this model will be some diesel trucks which have mufflers and exhaust pipes on the side of the body. The box is considered partially open on the front because a partial view of the radiator water jacket is often afforded through the front grill.

Temperatures of the principal hot objects which are visible to an observer are given in Figure 11 as a function of vehicle speed. It should be noted that the exhaust gas temperature is measured inside the tail pipe. Because of the diffuseness of the gas and its rapid cooling and expansion upon exit, an external detector would not "see" this high temperature (for example, one may hold his hand within a few inches of an exhaust pipe outlet without experiencing serious discomfort). Although the temperature of the inter-



*After Mundkowski (1961)

SOURCE: TEXAS INSTRUMENTS SEMI-ANNUAL REPORT, FHWA NO. FH-11-6973, (DECEMBER 1968)

Figure 11. Temperature of Various Items of Underside of a Sample Automobile Vs. its Speed

nal exhaust gas increases dramatically with vehicle speed, the temperature increases of the muffler and exhaust pipe are constrained by air stream cooling. Because of thermostatic control, the radiator water temperature of a "warmed up" vehicle is held relatively constant (in the vicinity of 190 degrees F or 89 degrees C which equals 362 degrees K).

It appears that the thermal radiation from a motor vehicle will be primarily seen from below (sometimes from the front as well) except in the case of side mounted mufflers on diesel trucks. In the case of bottom enclosed vehicles, the only visible objects may be tail pipe tips and relatively cool diffuse clouds of cooling air and exhaust gases.

CHAPTER III

TOPICS OF PREVIOUS PERTINENT RESEARCH

3.1 Radar Discrimination

A study by Funke (2) of the General Motors Research Labs was the outgrowth of the prospect of using radar as a means of antipating an automobile collision. Though not directly applicable to vehicle identification, a conclusion of the study suggests the possibility of using radar for discrimination of vehicle types. However, the data indicated that the scattering centers are associated with the fine structural details which make one type of automobile different from another. This gives some indication that detailed analysis of the amplitude variation of signals reflected from an automobile might be useful in individual vehicle identification.

An earlier paper by Storwick and Nagy (3) of the General Motors Research Labs pointed out that the data collected from automobile targets results in a signature of considerable complexity. These research activities tend to indicate that a radar oriented system would be expensive and complex.

3.2 Automatic Vehicle Identification (AVI)

Literature references to AVI are traditionally bound to the concept of having a transponder or other device (including identification stickers) fitted to a vehicle (4, 5, 6, 7). This device, coupled with a stationary sensing unit, forms the basis of an AVI system. A bus detector used for bus priority traffic control (8) is an example of this technique. Though limited to bus detection, Honeywell (9) has developed a passive bus detector which obviated the need for fitting special equipment on the bus. This detector analyzes vehicle signatures and classifies busses as a group apart from other vehicles with a claimed accuracy of 95%.

Foote (10) of the Port of New York authority has extensively researched automatic vehicle identification in conjunction with prospects for automated non-stop toll collection systems. This effort begain in 1963 and has continued to the present. Early activities followed an optical system developed by the Association of American Railroads (AAR), wherein a retroreflective sticker with color bars of orange, blue, and silver was mounted on the side of the railroad car and scanned by an optical scanner at the track side. The system was widely installed, and AAR gave major efforts to maintaining it. However, reliability was not fully satisfactory, and the AAR has discontinued use of the optical system due to the principal difficulty of dirt obscuring the sticker.

The Port Authority has tested a number of bus transponders, and continues to monitor efforts in this area. A microwave system is currently under investigation, as well as an infrared system. These efforts appear to offer continuing improvement and good possibilities for the realization of automated toll collection systems.

A paper by Hauslen (11) discusses current efforts in AVI. His cogent conclusions are the AVI technology has moved from the laboratory development stage through initial field testing to the point where systems are being tested under operating conditions. In some instances, particularly in the case of optical AVI, the technology is used in operating systems. There is little doubt that the technology is available to meet the accuracy, reliability, digital capacity, and other requirements of a large number of potential AVI applications.

3.3 Vehicle Ignition Noise

Vehicle ignition noise provides a limited identification capability of passing vehicles. Of course, the rapid increase in diesel powered vehicles detracts from this technique. At some point, with a given ratio of gasoline to diesel powered vehicles, the presence or absence of ignition noise could serve as an auxiliary correlation technique used in conjunction with some other identification procedure. A further problem is due to the varying engine RPM's that are encountered at sample stations.

Even with these drawbacks, the measurement and categorization of ignition noise might serve as a supplemental technique for identification of vehicles. Shepherd and Gaddie (12) have measured ignition noise of foreign and domestic vehicles in use in the United States. They found that the following similarities and differences exist between the ignition noise levels of several vehicle sets in service in the U.S.: 1) The difference in ignition noise levels from the noisiest to the quietest individual vehicles of any selected set is as great as 50db or more, 2) even so, the difference from one vehicle set to another is quite small, 3) all the vehicle sets examined contained some very noisy vehicles, 4) the greatest difference between vehicle sets was by categorizing them by vehicle type, 5) foreign vehicles are only slightly noisier than the U.S. vehicles, and 6) age (or model year) differences are more apparent in U.S. vehicles than in foreign.

3.4 Vehicle Identification Using Acoustic Sensing

This facet of vehicle identification is intended to provide insight into the relative acoustic noise generated by passing vehicles. However, the only reference to work in this area was a U.S. Army Training Manual (13) for observers who listen to unattended remote sensors for battlefield monitoring.

Nonetheless, there exists a possibility that acoustic threshhold analysis might provide an additional correlation parameter for vehicle identification. The problem of discrimination between vehicles in the high noise level of freeway operation is a detriment to this approach.

3.5 Vehicle Identification by Seismic Sensing

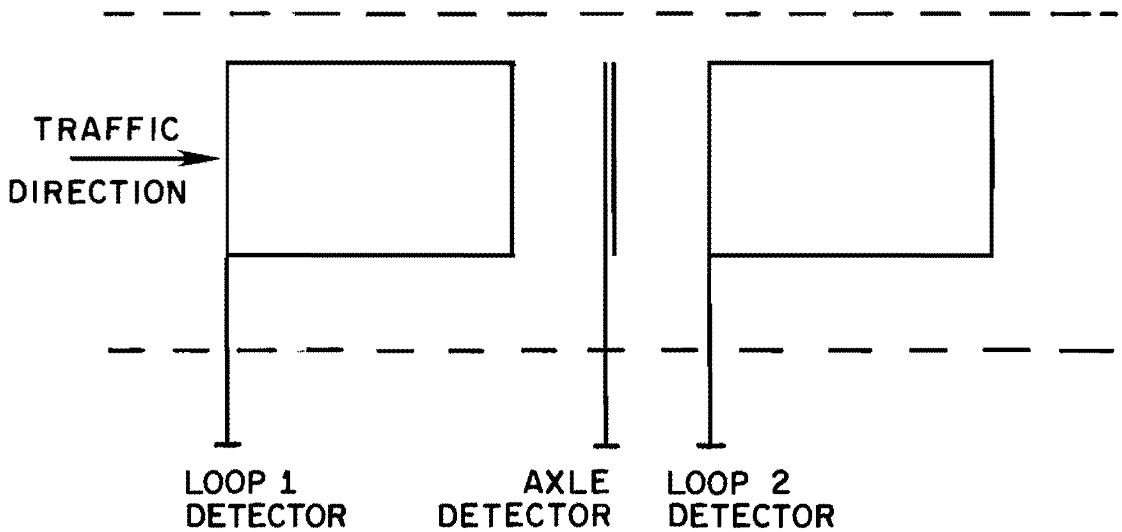
Pykett (14) describes the results of research into the feasibility of seismic vehicle sensing, i.e. the processes of detection, counting, and identification of vehicles on the basis of the ground vibrations which they produce. He concludes that while simple passage detectors and vehicle counters are feasible, the extreme unpredictability of the parameters involved in seismic propagation make more elaborate functions, particularly automatic vehicle identification, difficult to achieve.

Kenney (15) has also investigated vehicle generated seismic disturbances in connection with turning on flush mounted land marker lights when vehicles approached. This was strictly a vehicle presence detector function with limited application to vehicle type identification.

3.6 Automatic Vehicle Classifiers

Several studies have been made to design and test equipment for vehicle classification, for which the main purpose has been to augment the detection counting function and provide more information from the site of detection.

Dalgleiach and Tuthill (16) describe a microprocessor-based vehicle classifier station to meet the requirement for equipment which would both record and classify the characteristics of passing vehicles, rather than just provide an accumulative count. The inputs to the system were defined for four lanes, each with two loop detectors and one axle detector as shown in Figure 12. The two loop detectors supplied inputs to enable the speed of the vehicle



The recommended sensor layout for a single traffic lane.

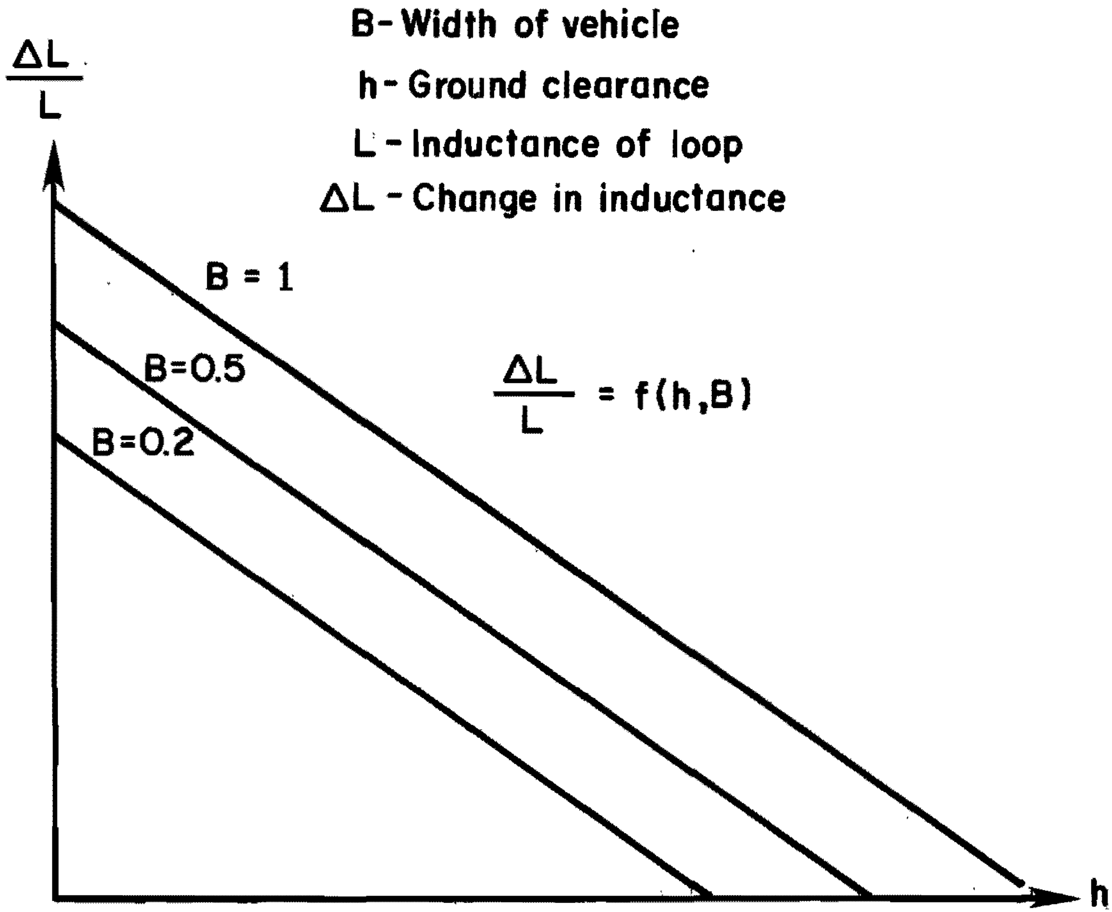
SOURCE: DALGLEISCH AND TUTHILL, "THE DEVELOPMENT OF A MICROPROCESSOR-BASED CLASSIFIER VEHICLE", TRAFFIC ENGINEERING AND CONTROL (MARCH 1978)

Figure 12. Measurement Station for Speed, Wheelbase and Length of Vehicle

to be determined. From either one of the loop detectors the occupancy time, coupled with the derived speed of the vehicle and the length of loop, would provide the total length of vehicle. The axle detector provides a means of determining the individual wheelbases of the vehicle and in some special cases allow the processor to locate the front and rear overhangs individually.

A detailed analysis of the accuracy of Dalgleiach and Tuthill's device was not reported. An example of printed output from the classifier indicated 5 classifications from the unit. The length and wheelbase measurements were reported in hundreths of meters, which is 0.39 inch. Probably, the wheelbase measurement is more accurate than the length measurement, but further information is needed to determine the actual accuracy of this approach.

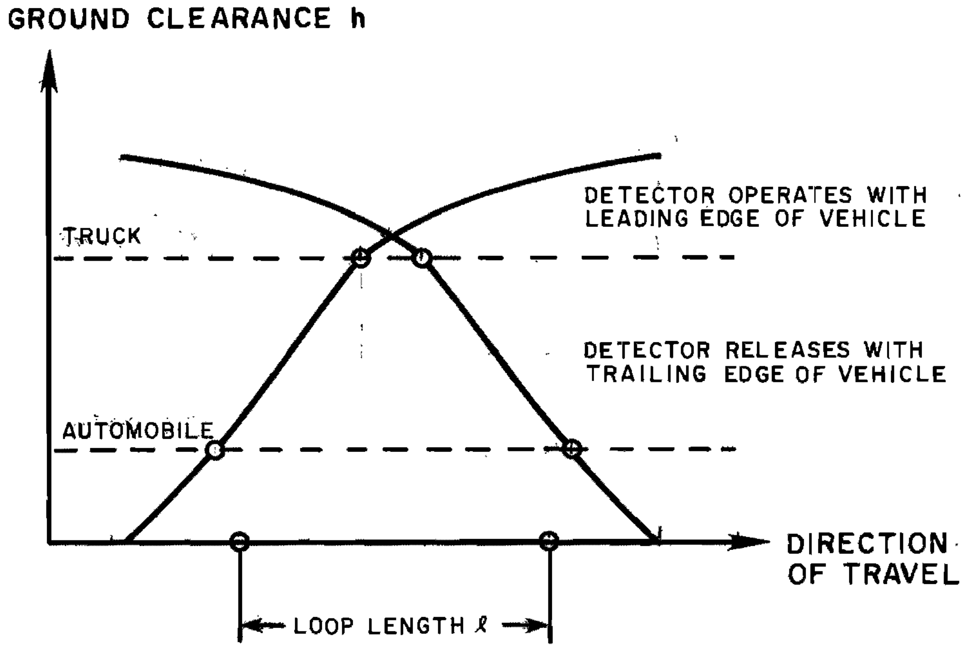
Drebinger and Thilo (17) conducted research using two successive loop detectors for differentiating between vehicle types. The results were optimistic, but reflected a compromise between the traffic engineering and electrical engineering solutions. Their discussions on the relationship of the vehicle to inductance changes are very good, pointing out why some vehicle types are falsely classified. Figure 13 relates change in inductance to vehicle ground clearance and vehicle width, and Figure 14 relates detector operate and release times to ground clearance.



Change in inductance $\frac{\Delta L}{L}$ as a function of the ground clearance h; the parameter is the width B of the vehicle

SOURCE: DREBINGER AND THILO, "AUTOMATIC DISCRIMINATION BETWEEN DIFFERENT KINDS OF VEHICLES FOR ROAD TRAFFIC COUNTS", SIEMENS REVIEW, XXXVII (1974) NO. 9

Figure 13. Effect of Vehicle Ground Clearance and Width on Change in Inductance



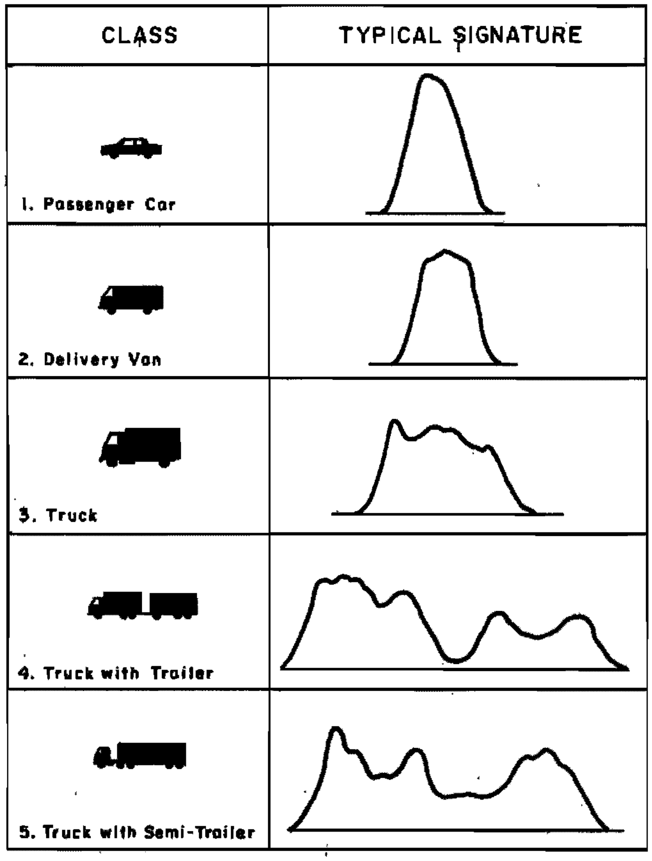
Operate and release instants of the detector as a function of the ground clearance h

SOURCE: DREBINGER AND THILO, "AUTOMATIC DISCRIMINATION BETWEEN DIFFERENT KINDS OF VEHICLES FOR ROAD TRAFFIC COUNTS", SIEMENS REVIEW, XXXVII (1974) NO. 9

Figure 14. Effect of Vehicle Ground Clearance on Detector Operate and Release Times

Nash (18) describes an early effort in vehicle classification, again using two loop detectors and an axle detector. The latter detector is a pneumatic tube or triboelectric detector. The prototype developed for the study measured vehicle length, number of axles, distance between axles, and the speed of each vehicle. The axle, length and wheelbase data were processed to classify vehicles into one of 15 classes.

Reijmers (19) discusses the pertinent topic of vehicle signatures obtained directly from loop detectors. Acknowledging the inaccuracy of speeds and lengths obtained from successive loop measurements, he points out certain features of signatures that can be correlated with vehicle type. An example of vehicle signatures is given in Figure 15.



THE FIVE CLASSES

SOURCE: REIJMERS, "ON-LINE VEHICLE CLASSIFICATION," IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. VT-29, NO. 2, (MAY 1980)

Figure 15. Example of Vehicle Signatures

CHAPTER IV

EQUIPMENT REQUIREMENTS AND DESIGN OF CONCEPTUAL SYSTEM

4.1 General Equipment Requirements

An equipment station will consist of detection and recording instrumentation. Generally speaking, this would consist of sensors semipermanently and/or permanently installed in the roadway, together with the electronic equipment associated with the sensors, interface equipment, microcomputer, recorder, battery power unit, portable cabinet, and associated cable hookups.

A station would be set up on all entrance and exit ramps of a given freeway section. For a given time period, say a month, the equipment would acquire data on all vehicles entering and exiting that freeway section. These data would then be post-processed at a large computer facility and the result would be a 100% sample, 24 hour, origin and destination survey for that freeway section.

4.2 Detection Equipment

The type of proximity measuring equipment would depend on studies not yet conducted. Such studies would pinpoint the exact measurements that can be consistently and reliably obtained, in accordance with the needs for accurate vehicle identification and correlation. A discussion of the preliminary studies necessary to formulate the detection system requirements is given in Section 4.4.

For purposes of discussion, assume that an accurate wheelbase measurement and induction/magnetic profile of the vehicle are sufficient measures to obtain an unspecified accuracy in vehicle identification/correlation. Hence the two parameters to be measured are wheelbase and signature (induction/magnetic profile). Depending on the mix of equipment, the measurement of one parameter can be partially supported by the measurement of the other parameter.

The wheelbase measurement requires an arrangement for sensing the passage of the wheel, such as a pneumatic tube or light beam. Generally speaking, the pneumatic tube suggests economy, while the light beam suggests accuracy, but at this point this is merely an intuitive observation. The use of a laser for a light source would support this observation.

Since the tube/beam is stationary, an ancillary speed measurement for the vehicle must be made. This measurement can be effected by a second tube/beam. Should a light beam be utilized, and in particular a laser, then an estimation of tire diameter can be made if particular attention is paid to aligning the twin beams a certain height above the pavement and a certain distance apart. Unfortunately, this requires that each station adhere to these stricter alignment requirements, although some discrepancy can be compensated by calibration. Figure 16 illustrates the concept of

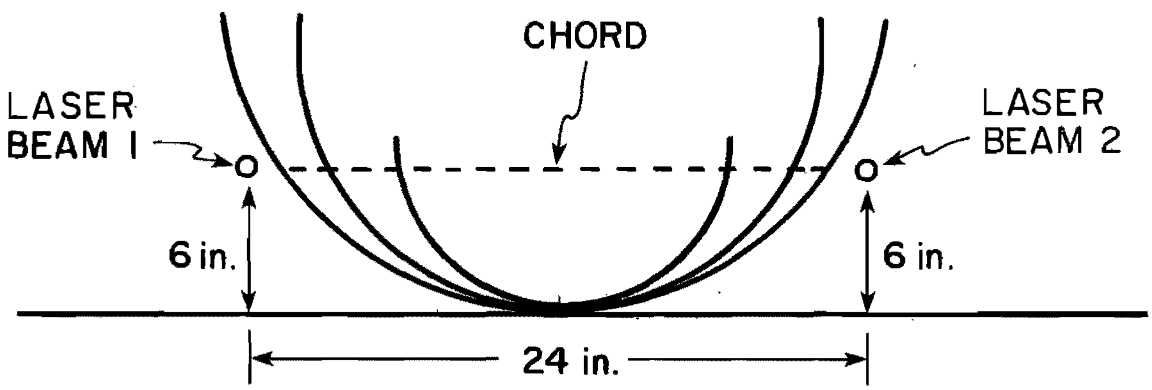


Figure 16. Tire Chord Measurement Concept

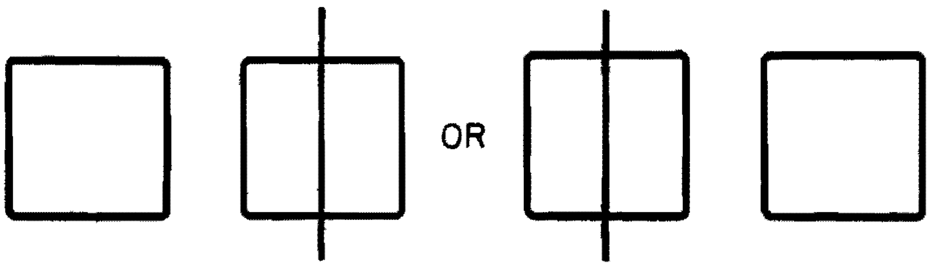
tire diameter estimation which is in effect a tire chord measurement.

The induction signature measurement requires the use of a loop detector. Normally, the output of a loop detector is an indication of the presence of a vehicle over a loop; the output may be preset for the duration of the time the vehicle is over the loop (presence mode) or may be a pulse indication that a vehicle is over the loop (pulse mode). In the latter case, the next pulse will not be output until the present vehicle leaves the loop and the next one enters. For the purpose of this study, the loop detector(s) would be operated in the presence mode. In addition, the loop detector amplifier would be modified so that the amplified induction signal could be extracted. This would be routed (with appropriate conditioning) to an analog-to-digital (A to D) converter. The digital side of the A to D converter would be fed to the monitoring microcomputer.

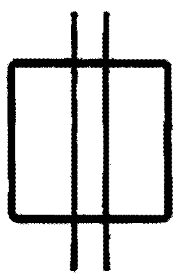
A pair of loops could serve the function of a speed detector. In this case, only a single pneumatic tube would be utilized for the wheelbase measurement contact sensor. While it is questionable whether two loops could provide a sufficiently accurate speed measurement for precision wheelbase measurement, the double loops would provide the means for measurng yet another vehicle characteristic: front and rear overhang. While the term "measuring" of overhang is used, a better descriptor might be "estimating."

The overhang measurement could be accomplished with a configuration shown in Figure 17a, which consists of two adjacent loops with a pneumatic tube over either loop. The principle of this measurement would require the following to occur. As the vehicle enters the loop which has the pneumatic tube overlain, the loop will indicate a presence for a period of time before the front tires reach the pneumatic tube. This is defined as the front overhang time. Similarly, the period of time after the rear tires strike the pneumatic tube to the time that the detector loses its presence indication is defined as the rear overhang time. With the speed measurement, these front and rear overhang times can be converted to effective lengths as reflected by the loop detector measurement. While this sounds ideal, minor variations in the "pull-in" times of different loops might make the overhang measurement a gross estimate only, leading to an overhang classification of categories rather than measurement. The direct monitoring of the inductance signature, coupled with a calibration procedure, might be used as a means of minimizing this variance in "pull-in" times. Figure 17b illustrates an alternate equipment configuration for measuring the same parameters.

An added benefit of using light beams is that at least two speed measurements are made per vehicle, one for each axle. This is particularly useful since, more often than not, vehicles are accelerating or decelerating as they pass



a. TWO LOOPS AND ONE AXLE DETECTOR



b. ONE LOOP AND TWO AXLE DETECTORS

Figure 17. Vehicle Overhang Measurement

the ramp detection station. The ensuing multiple speed measurements per vehicle could be averaged for best resolution of the wheelbase measurement.

Note that whenever a loop detector has been mentioned in connection with the signature detection function, a magnetic detector could be substituted. Since a magnetic detector is essentially a point source of detection or, with several parelleled heads across the ramp, a line of detection, the vehicle overhang would not be measureable. Whether or not this would represent a marked disadvantage is unknown at this point. Intuitively, it seems that the more different types of measurements that can be obtained, the stronger the correlation for identification purposes. On the other hand, the accuracy of the individual measurements is a factor in the correlation as well. Regardless, the manufacturers of magnetic detectors should be able to provide additional information on the configurations of probes for the application.

4.3 Other Categories of Vehicle Characteristics and Their Measurement

This section will deal with some topics of vehicle identification that are not traditionally mentioned among the classic techniques. Some emerging technologies may support these techniques or create new methods yet unmentioned.

4.3.1 License Plate Analysis

The use of license plate studies in traffic analysis is a well utilized technique. Observers can record plate numbers past a given point, and together with a time correlation, establish a positive identification of a vehicle in time and space. This feat hinges, of course, on the fact that each vehicle possesses a unique license plate number. As previously mentioned, the utilization of this technique in freeway O-D's is a labor intensive effort.

The question arises as to whether or not this identical technique might be mechanized, i.e. use a TV camera and computer to accomplish the same task. The TV camera provides the eyes for the computer and a sophisticated program analyzes the scene, localizes the license plate, and identifies the license number which characterically is a mixed combination of letters and numbers. The key to this process is the ability to process huge amounts of visual data in a short period of time, i.e. while the vehicle is passing. Otherwise, the system reduces to a video recorder which stores the image of each passing vehicle instead of its license plate number. The resulting data would then be processed "offline" at a later time. While this latter technique suggests some hint of automation, it really does not provide any substantial improvement over the manual recording of license plate data. For example, an operator who controls the rate of playback by foot pedal and uses a keyboard to transcribe the license plate number would be a very efficient system to try to improve on in the near term. Though slower, a speech recognition unit could be utilized instead of a keyboard, and it would only have to recognize 36 commands (26 letters plus 10 digits). Fairly inexpensive units are available to handle this speech recognition task at this time. Alternately, an operator could guide the computer's "attention" to that portion of the scene which depicted the license plate.

Thus, while there are several combinations of system structure that could be used in this augmented video recording/reduction, there are no clear benefits in this direction. The real payoff would come with a station consisting of a computer and TV camera, and sufficient processing power to interpret license plate numbers in real time.

The entire field of scene analysis is undergoing intensive research at this time, largely due to this country's deficit in robotics technology. The prospects of breakthroughs in this area are bright, and will surely have an impact on the use of TV surveillance in transportation applications. In particular, license plate identification will be an important segment of this methodology.

Finally, it has been suggested (20) that some type of fixture might be attached to license plates as they are manufactured. Such a device would be used as an aid to a particular type of automatic scanning mechanism. This idea may have merit, but has not been investigated in detail. The important point is the availability of this option for scanning devices that might be adapted for this application.

4.3.2 Profile Analysis

Another major vehicle characteristic that is relatively unique in the traffic stream is the profile, which could be utilized from one of several different viewing positions such as front (or back), side, or top. Of these, the side profile seems to be the most desirable, both from the standpoint of richness of detail and also relative ease of acquisition. It should be noted, however, that the ease of acquisition is highly dependent on instrumentation philosophies. For example, an overhead TV camera might be an excellent device for determining the encircling contour of a vehicle, and simple contour analysis of the scene would allow this determination to be made in real time. On the other hand, the data for a side profile might not be available though the use of a TV camera, due to physical limitations on the placement of the camera. The latter is coupled to the requirement that the viewing distance and angle be the same at all ranges.

The side profile data acquisition might be handled more easily through the use of two "standpipes," one at each side of the road. One side would contain a light source, and the other side would contain light sensors. The pinpoint accuracy of lasers might be useful. To limit the height of the standpipes while still achieving the desired data acquisition, it seems that a "profile finder" would only have to be concerned with an area 2 or 3 feet above the ground. In other words, this would amount to a side profile of the lower portion of the vehicle. While the side profile of the underside of the vehicle between the wheels may or may not be distinguishing, the complementary front and rear overhand details (and vehicle length) would be quite distinctive. The desired detail of profile would be achieved by the use of several hundred points of light sensing.

Associated with the profile analysis is the concept that certain ancillary measurements might in themselves be sufficient for relatively unique identification. For example, a very accurate (to within a hundreth of an inch) length measurement would be invaluable. Similarly, an accurate wheelbase measurement is desirable. A good width measurement (derived from an overhead TV) is useful. The vehicle height, as well, is useful but may not be easily obtained as an ancillary measurement within the profile analysis.

In general, it should be pointed out that the trio of accurate height, width, and length measurements would be a respectable achievement and might be sufficient for vehicle correlation. Another measurement only casually mentioned heretofore is color detection, which would be a definite asset as a correlation parameter. This study did not investigate the means and applicability of color detection, but it certainly is a useful distinguishing vehicle characteristic.

Figure 18 depicts two methods of profile detection.

Finally, it should be mentioned that the laser is used for distance measurement, but typically on a smaller scale such as assembly line parts profile analysis. This technique should be investigated further for suitability of application in this area.

4.4 Suggested Studies for Formulating Detection System Requirements

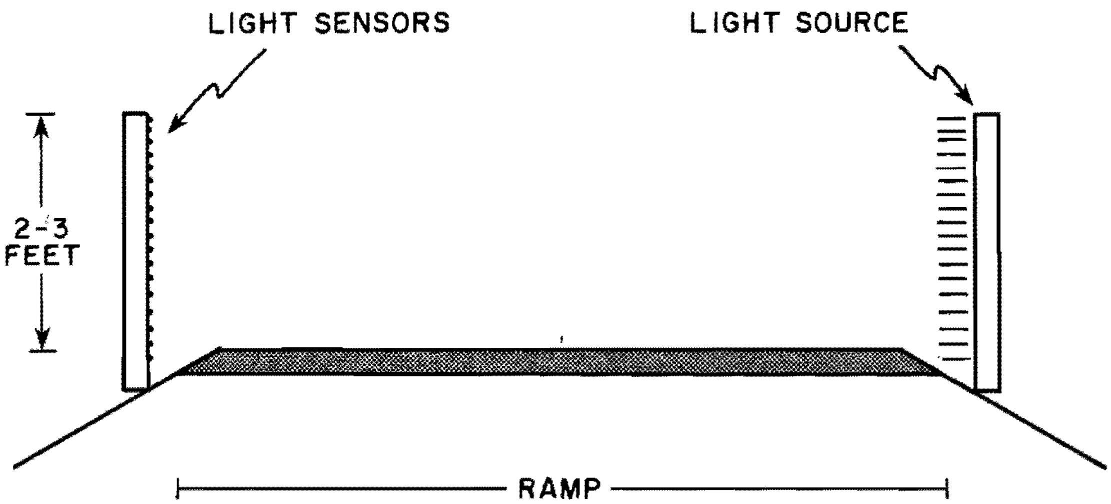
The procedure for implementing a formal study for a prototype system would need to follow a multiphase testing and evaluating sequence. A skeleton of this effort will now be outlined.

PHASE I - Testing Individual Characteristic Measurement Devices

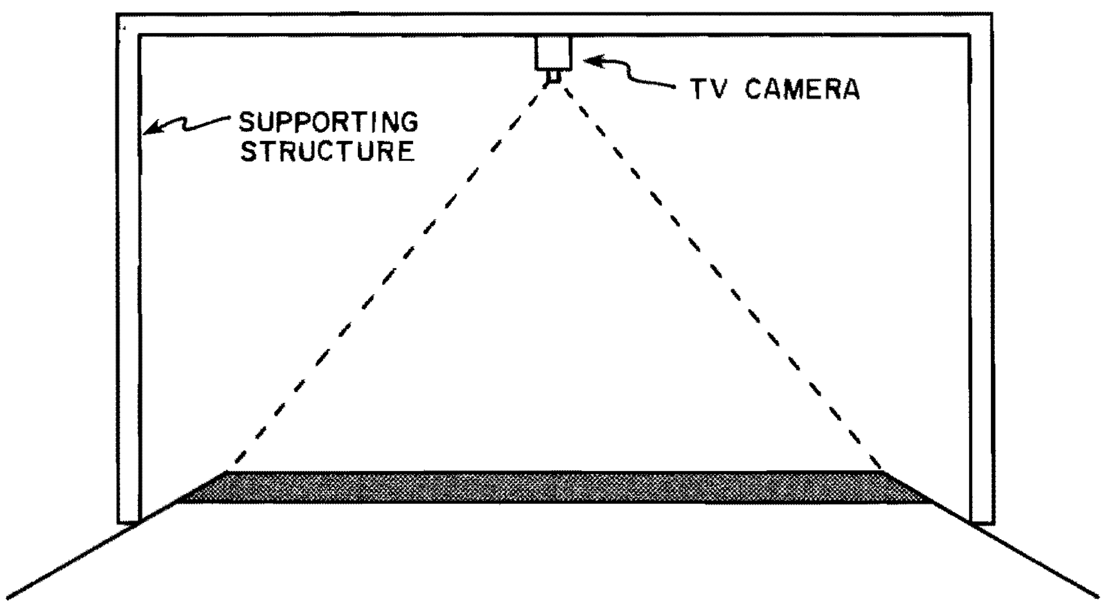
This phase could be divided into essentially two groups: intelligent and non-intelligent devices. Among the non-intelligent devices would be the following vehicle characteristics.

Wheelbase - use of various impact devices such as road tubes of different types.

Speed - test both electronic and impact speed measurement devices.



a. LOWER SIDE-PROFILE DETECTOR



b. OVERHEAD CONTOUR DETECTOR

Figure 18. Vehicle Profile Detectors

Front/Rear Overhang - test combinations of impact/electronic axle/vehicle presence devices (in conjunction with speed measurement).

Length - test electronic vehicle presence devices (in conjunction with speed measurement).

Induction/Magnetic Profile - test electronic detectors for sensitivity and discernability.

Tire Chord Measurement - test light beam interruption concepts.

Lower Side-Profile - test standpipes with light source and multiple sensors for profile (in conjunction with speed measurements).

Color - test color detection devices.

Measurement of characteristics that require a TV camera and real time processing would be in the category of intelligent devices. Among these are

License Plate Identification - test procedures for isolating license plate in TV scene and interpreting alphanumeric characters.

Overhead/Side Contours - test procedures for developing vehicle's contour (outline of silhouette) from TV scene. Additionally, derive vehicle's length and width.

PHASE II - Evaluating Measuring Devices

This phase uses data from Phase I to determine which combinations of measurement devices are likely to produce a satisfying level of vehicle identification.

PHASE III - Install and Test Two Pilot Equipment Stations

Based on the results of Phase II, two monitoring stations would be constructed and tested under actual field conditions. These stations would likely acquire measurements of a full set of vehicle characteristics for maximum probability of identification.

PHASE IV - Determine Subset of Vehicle Characteristic Measurements

The results of Phase III would be analyzed by computer to determine the correlation parameters associated with various subsets of the measured vehicle characteristics. Such an evaluation would provide data on the probability of vehicle identification versus the number of vehicle characteristics measured.

PHASE V - Recommend Equipment Station Configuration

Based on the results of Phase IV, a recommendation would be made on the minimum equipment configuration necessary to provide an acceptable accuracy of vehicle identification.

PHASE VI - Develop Identification Software System

A software system would be developed to accept data from monitoring stations and provide detailed output of travel patterns (O-D's).

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

5.1 Conclusions

This feasibility study has shown that a vehicle identification methodology of the type needed for freeway ramp O-D's does not exist. At the same time, this type of application has not received sufficient attention to warrant the research. The techniques described in this paper suggest the possibility for the acquisition of traffic engineering data heretofore acquired by manual and expensive means, and which now can be automatically and cheaply obtained.

The general technique for performing this task would consist of setting up equipment on all entrance and exit ramps of a given freeway section. For a given time period, e.g. a month, the equipment would acquire data on all vehicles entering and exiting that freeway section. These data would then be post-processed at a large computer facility and the result would be a 100%, 24 hour, origin and destination survey for that freeway section.

This technique hinges on the ability to detect and accurately measure certain vehicle characteristics by proximity means. This feasibility study only considered proximity measurements, that is, no attachments of any kind would be affixed to a passing vehicle. There are a number of candidates for vehicle characteristics that might be used in an automatic vehicle identification system. Generally speaking, a composite measurement involving several vehicle characteristics is necessary. The lone exception is a video technique which interprets the license number of passing vehicles. Otherwise, three to five characteristics would be measured and recorded to achieve a reasonably unique set of parameters for each vehicle. This approach obviously depends on the sampling of a traffic stream which has the normal variation of vehicle types, makes, and models. Some information on freeway travel times may be necessary to assist in the identification process. The number of different characteristics that would have to be measured to achieve an 85% accuracy of identification may be a function of the choice of measurable characteristics. That choice would have to be made after field testing.

The vehicle characteristics that are promising candidates for automatic identification are as follows:

- wheelbase *
- length *
- tire chord *
- front overhang *
- rear overhang *
- induction/magnetic signature
- side profile (lower portion of vehicle)
- top profile (overhead view)

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* requires ancillary speed measurement

- pattern recognition of license plate (TV camera).

Each of these characteristics and their measurement has been discussed in this report. Other characteristics deemed more difficult to measure are also noted.

5.2 Recommendations for Further Research

It is recommended that field studies be conducted to determine which measurement subset of vehicle characteristics is most likely to produce a useful composite vehicle identification. In turn, two equipment stations which utilize these measurements should be constructed for field tests. Coincidentally, the algorithms for processing data from multiple stations should be developed for the comparison software to provide the actual O-D data.

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