Research on the Interrelationships Between Costs of Highway Construction Maintenance and Utilization

Summary · Midterm Report · Preliminary Results and Analyses · November 1977

TRDF
Texas Research and Development Foundation   A Non-Profit Corporation

ICR/BCB/123/78   11 May 1978

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<div align="right">Ref: Summary - Midterm Report</div>

Dear Bob,

        Enclosed for your use are English and Portuguese copies of our most recent publication "Summary - Midterm Report". I am still waiting for the English Midterm to be published and will forward a copy as soon as it is ready.

        I hope we can get together later in May as noted in my earlier letter.

<div align="right">Sincerely,</div>

BCB/zdc

<div align="right">B. C. Butler, Jr.
Deputy International Director</div>

4 Enclosures

c.c.: Dr. Teixeira
      Dr. Flavio
      Prof. Hudson
      Mr. Visser

Research on the Interrelationships Between Costs of Highway Construction Maintenance and Utilization

PREFACE

This report summarizes the results and status of the project entitled "Research on the Interrelationships between Costs of Highway Construction, Maintenance and Utilization." A detailed Midterm Report has been prepared and should be used by those desiring a complete detailing of the progress of the work. The Inception Report of the project, published in early 1976, is a useful reference for a detailed background on the planning of the project.

Although the project was intended primarily to produce results at the end of the full term in the form of a computer-based model, this report attempts to present some of the interim results of the project that may have immediate application.

The project is the result of an agreement signed in January 1975 between the Government of Brazil and the United Nations Development Program (UNDP). According to this agreement, the Ministry of Transport of Brazil is the Government Cooperating Agency, through "Empresa Brasileira de Planejamento de Transportes" - GEIPOT, and the International Bank for Reconstruction and Development (IBRD) is the executing agency for UNDP.

The project is being conducted by GEIPOT and by the "Departamento Nacional de Estradas de Rodagem" (DNER), through its "Instituto de Pesquisas Rodoviárias" (IPR), and both have received grants from the "Instituto de Planejamento Econômico e Social" (IPEA) and from the "Secretaria de Cooperação Econômica e Técnica Internacional" (SUBIN), respectively. In addition, the project has the technical support of research institutions and universities, both in Brazil and overseas.

The IBRD has contracted with the Texas Research and Development Foundation (TRDF) to provide the international staff, and to select and purchase overseas the equipment needed to conduct the project.

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LIST OF PROJECT PUBLICATIONS

for

Research on the Interrelationships Between
Costs of Highway Construction, Maintenance
and Utilization

REPORT № 1, <u>Project Inception Report - Research Concepts and Procedures</u>, April 1976; describes and condenses the project details and presents the overall research approach to be taken in the project.

REPORT № 2, <u>Project Midterm Report - Preliminary Results and Analyses</u>, September 1977; describes project achievements at midterm and presents some preliminary results on relationships identified.

WORKING DOCUMENT № 1, "<u>Project Background Documents for the Expert Working Group</u>," November 1975; describes the beginning of the project activity and the mobilization of the Project Staff.

WORKING DOCUMENT № 2, "<u>Summary of Findings EWG Meeting</u>," December 1975; describes the basic experiments agreed on for further development in the pre-pilot studies of the project.

WORKING DOCUMENT № 3, "<u>Appendix to the Project Inception Report-Research Concepts and Procedures</u>," April 1976; describes material useful for consideration in the project but too detail<u>l</u> ed for publication in the formal report.

WORKING DOCUMENT № 4, "<u>Project Technical Memos</u> 1976;" 24 Technical papers describing completed phases of work or revisions to project study procedures during the year 1976.

ABSTRACT

This summary of the project midterm report presents achievements and results at Midterm. The accomplishments of the 150-man research team are presented, and include preliminary equations relating roadway characteristics to vehicle speed and fuel consumption. The extent of vehicle overloads in Brazil is highlighted. A program is outlined to update the combined MIT/TRRL/World Bank Highway Design and Maintenance Standards Model (HDM).

SENIOR PROJECT STAFF

José Teixeira de Carvalho	General Director	GEIPOT
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(*) On loan from Departamento de Estradas de Rodagem de Goiás
(**) On loan from the Government of the Federal District

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INTRODUCTION

This Research Project aims at establishing relationships between the costs of highway construction and maintenance, and the operational costs of vehicles that will use those highways during their useful life. These interrelationships will be incorporated in a computer-based mathematical model, which can be used to cheaply and quickly establish the costs of alternative highway construction and maintenance policies, as well as those of highway users.

Such a model would enable Brazilian authorities to optimize highway investments and vehicle operational costs, with a view to improving the allocation of limited resources for investments on infrastructure.

Within the general scope of obtaining these interrelationships, three immediate sub-objectives have been identified for this project:

1) To establish the relationships between road user costs, road geometric standards and surface conditions for rural roads.

2) To measure the relationships of road deterioration and maintenance costs, as a function of pavement and geometric design standards, as well as of traffic volume and composition, and climatic conditions in Brazil.

3) To develop new or modify and adapt existing mathematical models for Brazilian use, with parameters developed from experiments and measurements carried out to meet the preceding items.

These objectives are being achieved through the following project activities:

1) A road user costs survey, where a diversified vehicle fleet, drawn from organizations operating buses, trucks, and automobiles, is monitored to determine actual user costs for a variety of operating conditions in Brazil.

2) A series of experiments to measure speed and/or fuel consumption for both existing traffic and a controlled fleet of instrumented project vehicles over a range of roadway geometric, operational and environmental conditions.

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3) A study of the behavior of selected road test sections to establish roadway performance and maintenance requirements, as a function of different pavement and geometric design standards and maintenance levels, in the Brazilian environment.

This report presents a summary of project achievements at the midpoint, and also accomodates the early dissemination of project results. Where data were available, preliminary analyses were made and the results presented. However, the reader is reminded that all results presented in this report are preliminary in nature and are only early indicators of the types of relationships being found. Further, the influence of some of the factors being studied on the early analyses has not been fully considered.

Existing Models

The framework for the desired model already exists as a result of a series of studies initiated by the World Bank in 1968. The Bank desired to develop an analytic model for use in evaluating alternative design, construction and maintenance strategies at the project level for low-volume roads. In the first study, the Massachusetts Institute of Technology (MIT) developed an integrated framework relating construction, maintenance and road user costs. Most of the relationships were based on information available from published literature, and could not be confirmed by empirical data.

In a subsequent World Bank cooperative effort in Kenya with the Transportation and Road Research Laboratory (TRRL), field studies produced empirical relationships which were incorporated into a revised version of the MIT model entitled road Transport Investment Model. Following the publication of this model by TRRL in 1975, the Bank coordinated an agreement with both TRRL and MIT to produce a unified model which combined the strengths of each model, while avoiding the weaknesses of both. Therefore, the current model version, the Highway Design and Maintenance Standards Model (HDM), uses the structural frame-

work of MIT's first model, results from field investigations in Kenya, as well as new technology published in current literature. It includes modules to predict roadway performance and maintenance quantities and the impact on the costs to users operating on roads with varying characteristics. Automatic costing with current unit prices permits an economic evaluation of the implications of alternate design and maintenance strategies on total transportation costs.

The HDM will be tested by the research team in connection with several highway projects in Brazil.

Although the HDM is operational, it is not necessarily applicable to Brazilian conditions. Many of its underlining relationships need to be verified before results can be accepted for Brazil. Also, it has a number of acknowledged limitations, and many of these are being directly addressed in the current study. For example, road performance relationships are based on high-standard asphalt roads used in the AASHO road test and bituminous-treated, cement-stabilized base roads in Kenya. In the case of unpaved roads, relationships reflect Kenya gravel roads. Therefore, as part of this project, a series of pavement and maintenance studies are being made on typical Brazilian roads. These studies will establish performance relationships for roads in Brazil, subject to different levels of maintenance.

The relationships developed between road user costs and roadway geometrics in Kenya do not cover the wider range existing in Brazil. Further, the HDM embraces only a limited number of vehicles which are not necessarily typical of those used in Brazil. The major thrust of this study is to develop more comprehensive information and relationships on vehicle user costs. In addition to fuel consumption, special efforts are being directed to the development of tire wear, vehicle maintenance and vehicle depreciation.

Finally, the effect of congestion and traffic composition

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on operating costs is not based on empirical data in the HDM. Special studies and experiments in this study address these influences in greater detail.

Scope of the Study

This study has been organized to make use of sound experimental design and survey techniques to minimize the magnitude of the data collection effort, yet ensuring where practical that quantitative statements of accuracy can be made about models developed in the study. Data are collected through controlled experiments, direct measurements and from information contributed by participants in the user surveys.

The study areas are in central Brazil as originally planned. One exception is the inclusion of user survey routes in the State of Mato Grosso to capture flat routes for the user survey factorial. This is illustrated in Figure 1 where the actual area covered by user survey routes is shown. The pavement and maintenance study locations are shown in Figure 2 and embrace a three-state area. Finally, the sections selected for the various controlled experiments on vehicle speed, fuel and traffic-interaction effects are indicated in Figure 3. These latter sections were located close to Brasilia, where possible, to minimize the logistics costs associated with moving the project's fleet of instrumented test vehicles.

This study which started in July 1975 is at the halfway point.

Schedule

The formation of staff in Brazil began in July 1975. The primary data collection effort started in July 1976 although the phasing for various facets of the project varied. Data analysis began in January 1977 and the final analysis is scheduled to commence in July 1978. Project termination is now scheduled for November 30, 1978, but proposals for a one-year extension are now being reviewed. Analysis techniques developed
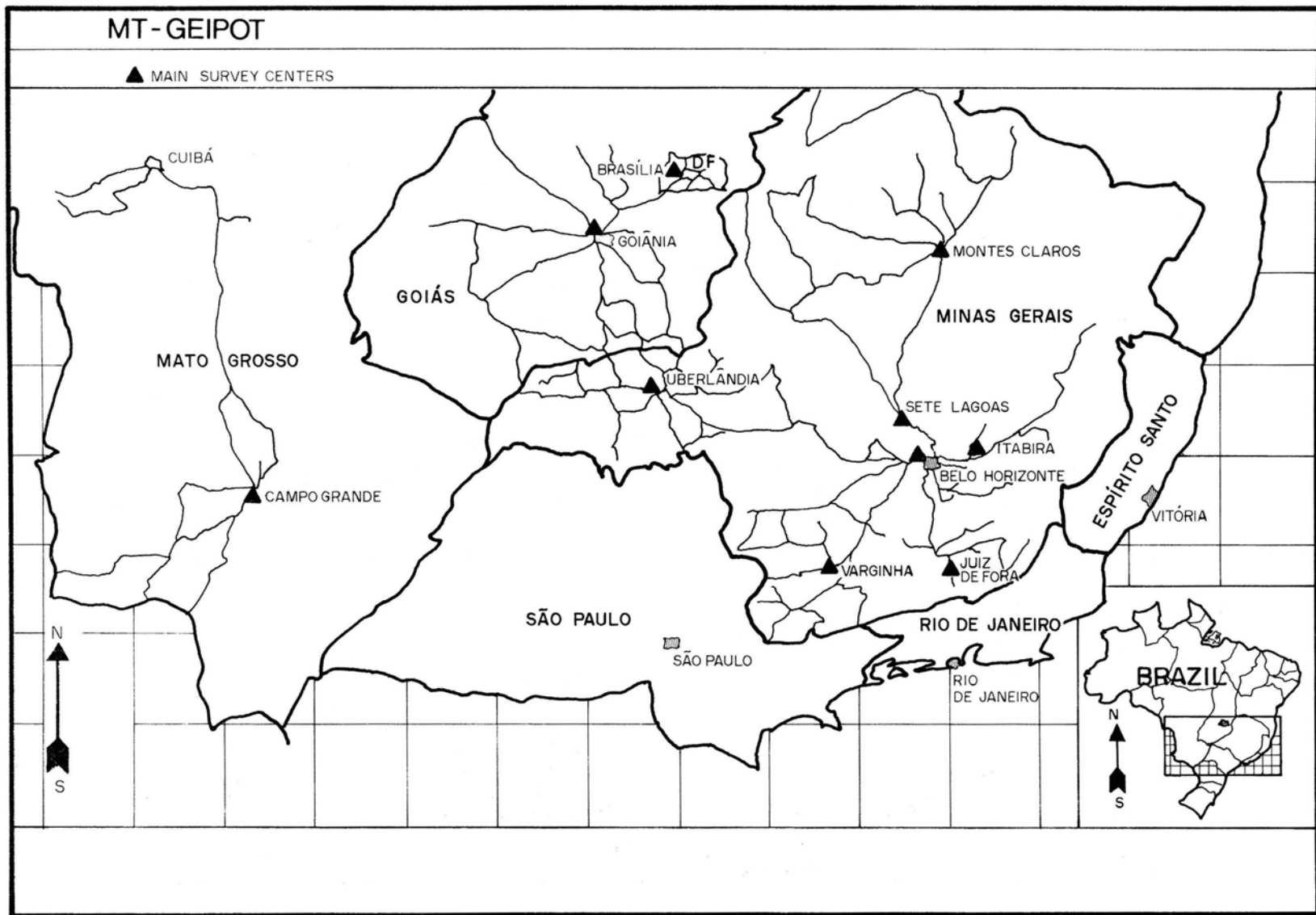
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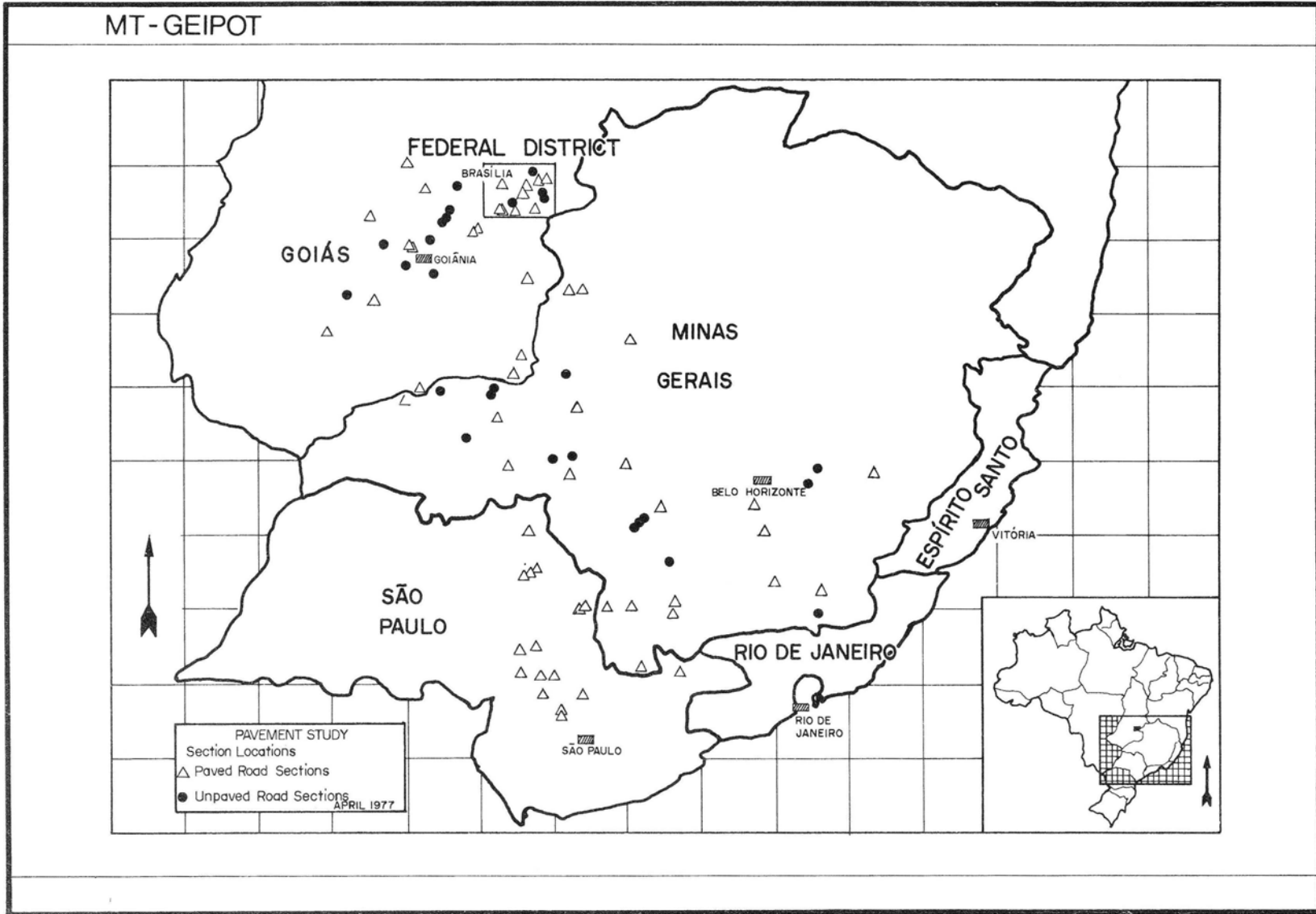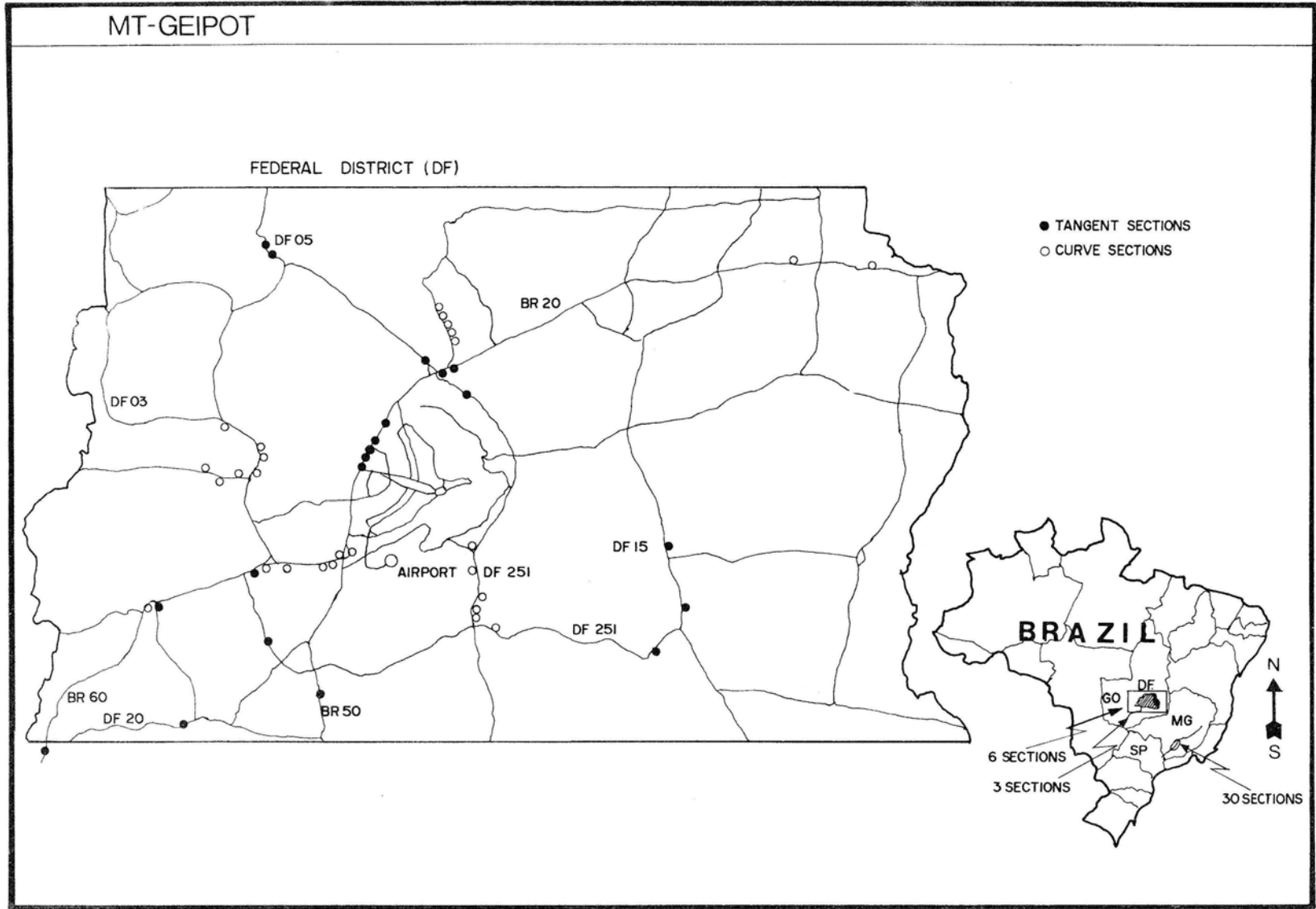Figure 1 - Location of Routes Included in the Road User Costs Surveys

Figure 2 - Location of the Paved and Unpaved Test Sections for the Pavement and Maintenance Studies

Figure 3 - Location of Test Sections for the User Costs and Traffic Experiments

during the project will continue to be applicable for such a follow-up.

STATUS OF STUDIES

Each of the three principal study groups has refined their field study procedures and a comprehensive data collection program is now well underway.

Road User Costs Surveys

The User Costs Surveys Group has developed procedures that are generating vehicle operating-cost data from a wide variety of survey participants who are becoming increasingly cooperative. An average of over 6000 vehicle-months of data covering different items of user costs are in hand and ready to be processed. Detailed inventory information covering road way characteristics on over 12000 km of user surveys routes has been developed by two survey vehicles that have been operating continuously since the beginning of 1977.

All of the inventory data are validated on computer files, but only 20 percent of operating-cost data has passed preliminary processing and been completely validated for analysis. High priority has been placed on processing all existing data and establishing the exact disposition of participants in a newly established quantified version of the users surveys design factorial. In the future, highest priority will be given to filling identified gaps in this factorial and efforts will concentrate on developing information on those items that have the most impact on user costs.

Road User Costs and Traffic Experiments

This group has identified 13 required and nine additional desired experiments needed in developing a deterministic model to predict vehicle speeds and fuel consumption. This includes nine required speed studies with a nine-man crew, that are 44% complete, and four required fuel studies with a 19-man crew,

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that are 74% complete. Preliminary equations developed from the fuel data are summarized below, and final relationships will be established in the near future, as each of the experiments is completed and data validated.

It was necessary to expand the driver-behavior studies because in November 1976 the Brazilian Government implemented a policy of strict enforcement of speed limits. This influenced operating speeds, and has confounded the data analysis requirements. Programming was missing to generate summary reports which would permit field-data screening to locate discrepancies and errors. A conceptual framework has been developed for a deterministic model to predict time and fuel consumption, while different traffic simulation programs are being examined, for use in explaining traffic-composition effects on speed.

A tight schedule has been planned for finishing the required traffic experiments. The fuel crews who are expected to complete their studies early in 1978 will then be diverted to help with traffic-behavior experiments.

Pavement and Maintenance Studies

This group has established 86 paved sections. They have completed at least one cycle of roughness, deflection and condition survey measures on every section and this measurement program is running smoothly. Material characterization on 21 sections is complete, while a material consultant is currently conducting tests on another 30 sections and a contract is pending on the remaining sections.

Axle-loading data has been collected on 30 of the sections and this program will continue. Traffic-classification information has been developed for only a limited number of test sections. However, in the future considerable assistance is expected from the DNER-DER agencies, so no problems are expected in completing this work.

The methodology for testing the unpaved roads sections

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was defined on six test sections, while the more time-dependent paved sections were being located. The major work program on unpaved road began in July 1977 and 19 sections have now been located.

The measurement time cycles on the unpaved roads are relatively short, so there will be little problem collecting data to develop time relationships on these roads. We expect to cover 50 unpaved sections before the end of the study period.

An additional Maysmeter is needed to ensure continuous monitoring of roughness on the unpaved roads and this unit is currently being fabricated.

Our laboratory facilities are not adequate to handle the control testing work from two material consultants concurrently. We will need to use the assistance of the DER-DF laboratory which has been offered to complete this work.

A work schedule and the necessary resources to complete the pavement study objectives by November 1978 has been presented. However the time dependent nature of the pavement-main tenance studies indicates that the period of observation may be too short to produce meaningful results. This is particularly true for the maintenance studies where the monitoring period will be as little as nine months. Arrangements are being pursued for long-term monitoring.

INTERIM RESULTS

Well trained field teams in all areas of the research are now productively generating research data, but only limited da ta are currently in a form which permits reasonable preliminary evaluation. The information available has been analyzed and some of these preliminary results are being presented. Also, information developed on factors affecting fuel savings ident- ified during the study are summarized. For a more complete re- view of the project and findings to date, the reader is direct- ed to the complete report of interim results published as "Re- port II - Midterm Report - Preliminary Results and Analyses" - September 1977 (Ref. 1).

VEHICLE SPEEDS

A series of traffic-behavior experiments were designed to develop data needed for modeling vehicle speeds as a function of roadway characteristics. Nine main experiments were design- ed, six for measuring the free speed of vehicles, two for measu ring operating speed, and one for measuring acceleration using project test vehicles. Also, four satellite studies were de- fined. This group of experiments is summarized in Table 1.

Even though only one of the experiments (TB-2) has been completed at this time, it is possible to report partial re- sults. The analysis represents only a portion of the total amount of data currently available. In addition, analysis of the impact of the speed-limit enforcement law has been perform- ed.

Preliminary Analysis on TB-2

The purpose of this analysis was to develop a preliminary regression equation which would predict the free speeds on neg- ative grades. The data were collected before the enforcement of the 80-km/h speed-limit law, and the radar meters were in view of the drivers. Because of the possible effects of the

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TABLE 1 - ROAD USER COSTS AND TRAFFIC EXPERIMENTS

CATEGORY	NUMBER	TITLE	PURPOSE
TRAFFIC BEHAVIOR MAIN EXPERIMENTS	TB-1	Free Speed on Positive Grades	Determine the distribution of free speeds on positive grades for each vehicle class
	TB-2	Free Speed on Negative Grades	Determine the distribution of free speeds on negative grades for each vehicle class
	TB-3	Acceleration on Grades	Use test vehicles to determine acceleration rates on positive and negative grades
	TB-4	Free Speed on Curves	Determine the distribution of free speeds on horizontal curves for each vehicle class
	TB-5	Trip Purpose	Determine if free speeds are a function of trip purpose or length
	TB-6	Free Speed Calibration	Independent data collection for verifying and calibrating models from experiments TB-1 through TB-5
	TB-7	Radar Effect	Determine if speed data is being affected by test procedures
	TB-8	Speed/Capacity	Collect data for developing speed versus volume relationships for simulating operating speeds on rural roads
	TB-9	Operating Speed Calibration	Independent data collection for verifying and calibrating models from experiment TB-8
TRAFFIC BEHAVIOR SATELLITE STUDIES	TBS-1	Wet/Dry	Define differences in driver behavior due to climatic conditions
	TBS-2	Surface Types	Define differences in driver behavior due to different gravel surface types
	TBS-3	Deceleration	Collect data on deceleration rates used when approaching a horizontal curve
	TBS-4	Dust Effect	Collect data on the effect of dust on vehicle speeds and headways

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exposed radar on these data and the effect of the speed-limit
enforcement program on future observations, the analysis pres-
ented here will have to be modified. The analysis and results
are described simply to explain the types of relationships that
will be developed in the future. They are not to be accepted
as final since the speed-limit and exposed-radar effects are
not explained in these equations.

Background - The sampling frame used for this study is
given in Figure 4. A total of six smooth paved sections were
used in the experiment. On each section spot speeds of vehi-
cles were collected at five stations 500-m apart. Eleven se-
parate vehicle classes were used for classification of the ob-
served vehicles as well as four load classifications. More
than 17,000 vehicles were observed.

Analysis - It was impossible to observe many of the vehi-
cle classes under various load conditions on all of the sections
and at all of the stations. Of particular difficulty were the
truck classes. To ensure that data were available for all
classes, at all sections, and at all stations, new vehicle classes
were defined by grouping the original load and vehicle class
combinations. The new classes are defined as follows:

    New Class
    1 = Cars
    2 = Buses, All Loads
    3 = Utilities, Empty
    4 = Utilities, Half and Full Load
    5 = Trucks, Empty
    6 = Trucks, Half and Full Load

    As a preliminary analysis procedure, the mean spot speeds
were analyzed "as if" they were all estimated from equal sample
sizes.

    Weighted regression analysis was performed on the func-

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Figure 4 - Sampling Frame for Free-Speeds-on-Negative-Grades Pilot Study

tions and the following equation represents the best fit on the functions tried.

$$S = 59.3 + 7.3 \left[18.6 - (G-3.8)^2\right]^{.5} - 3.25C + .56L + .240 \ L^{G/2.6}$$

where S = mean spot speed

      L = station (1, 2, 3, 4, 5)

      1 is equivalent to 2000 meters up a negative grade

      2 is equivalent to 1500 meters up a negative grade

      3 is equivalent to 1000 meters up a negative grade

      4 is equivalent to 500 meters up a negative grade

      5 is equivalent to the bottom of a negative grade

      C = new vehicle class (1, 2, 3, 4, 5, 6)

      G = grade in percent

The equation is graphically presented in Figures 5, 6, and 7.

Effect of the Speed-Limit Enforcement Program

Free-speed data from four negative grade sections have been collected with the radar units in view before and after the speed-limit law. The four sections have grades of 1.3%, 3.6%, 6.0%, and 6.1%. As a preliminary examination, it is possible to compare the effects of the speed-limit law on the speed patterns of the four sections.

Analysis of the results indicates that the speeds measured after the speed-limit law are significantly lower than those measured before the law. The effect of the law is much more pronounced on the steeper grades where speeds are in general higher.

Conclusions - A large mass of free-speed data was collected within three months after initiation of the speed-limit law with the radar visible. The preliminary analysis of these data indicates the speed-limit law has reduced speeds significantly on negative grades when the radar units are visible. Recommendations are being considered now for further work, so that adjustments can be made on these reduced speeds.

FUEL CONSUMPTION
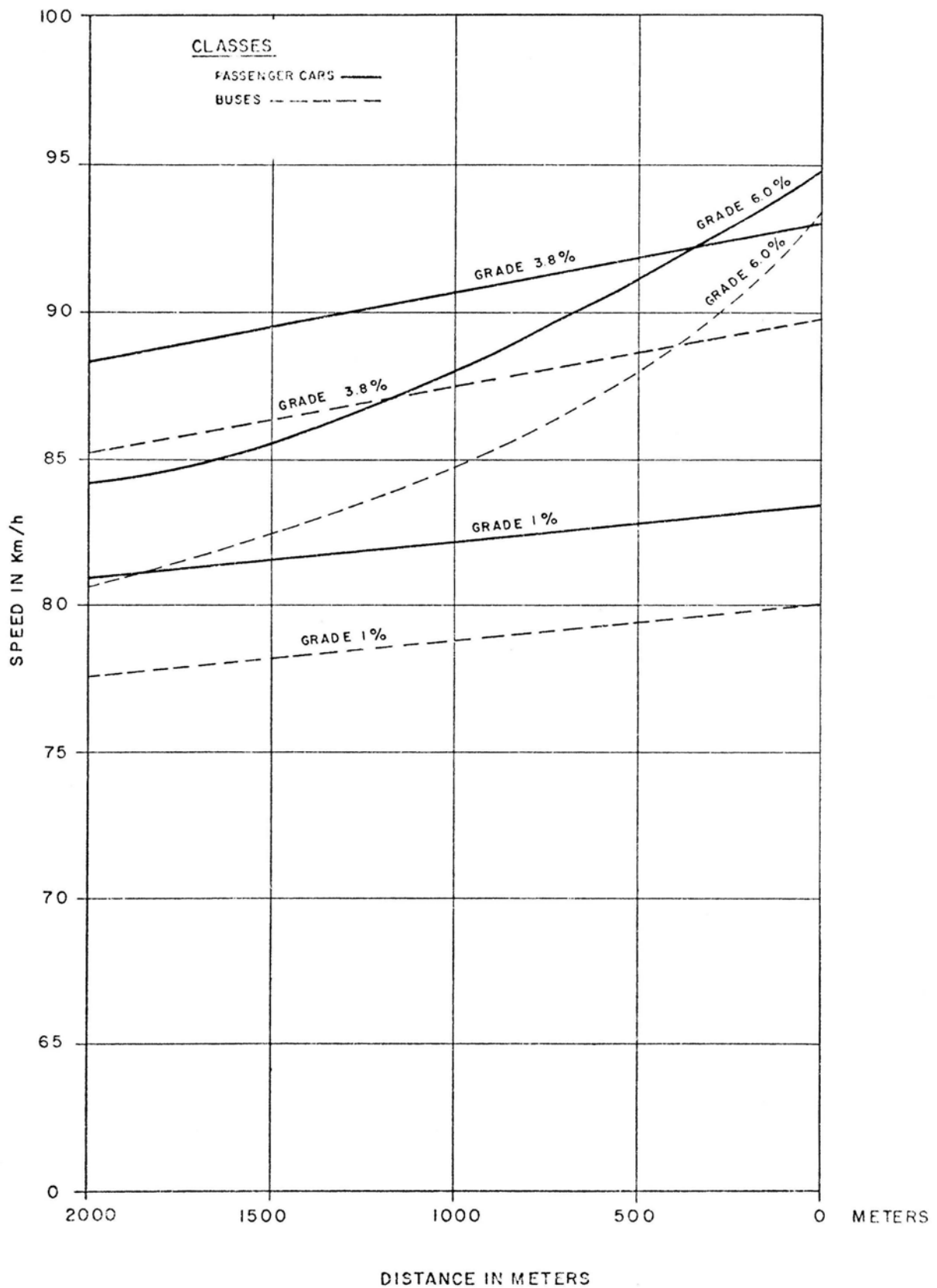
The fuel-consumption experiments will provide the data re-

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Figure 5 - Preliminary Relationships Between Speed and
Distance on Negative Grades Between 1 and 6
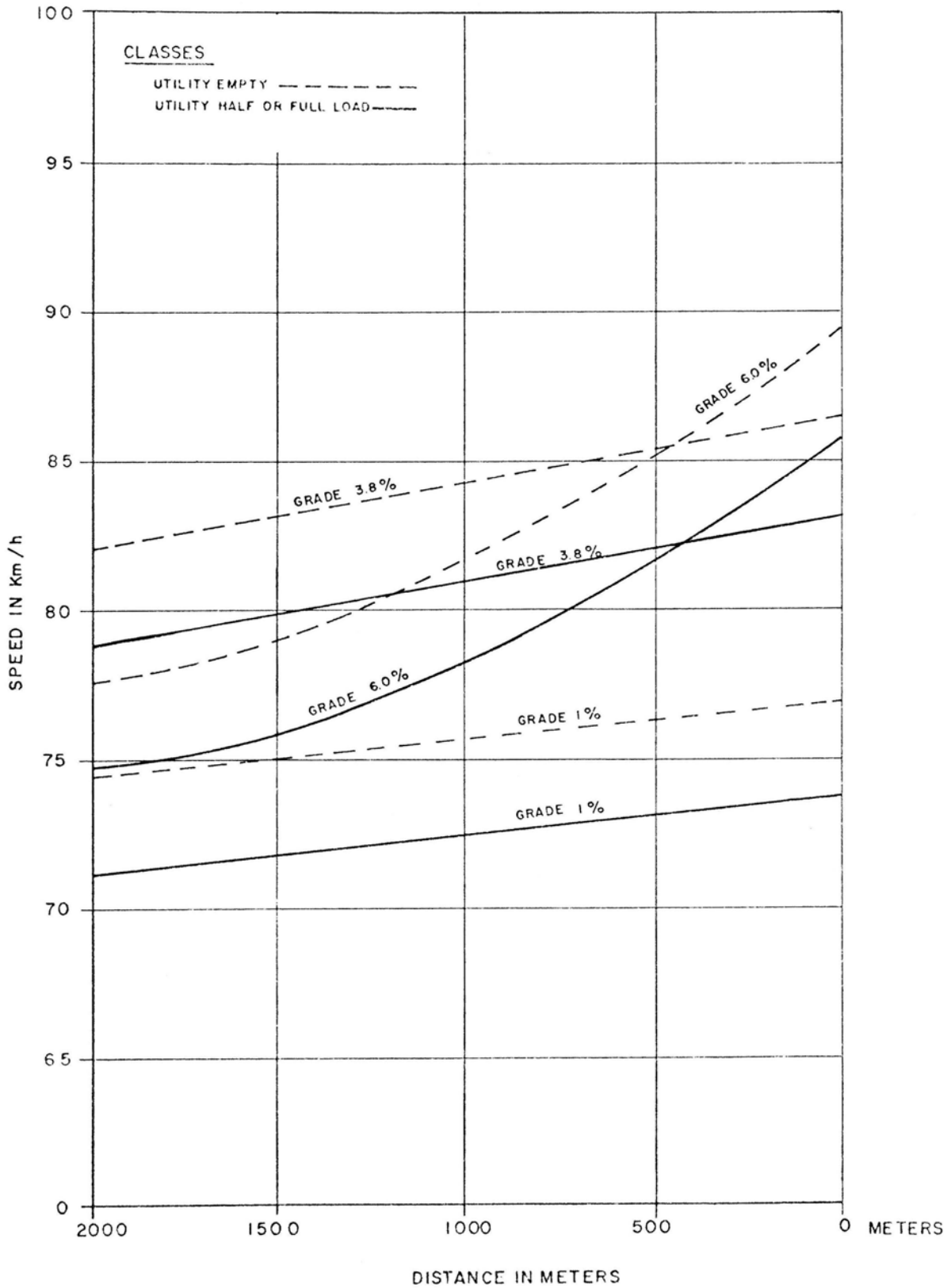Percent for Passenger Cars and Buses

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Figure 6 - Preliminary Relationships Between Speed and Distance on Negative Grades Between 1 and 6 Percent for Utility Vehicles
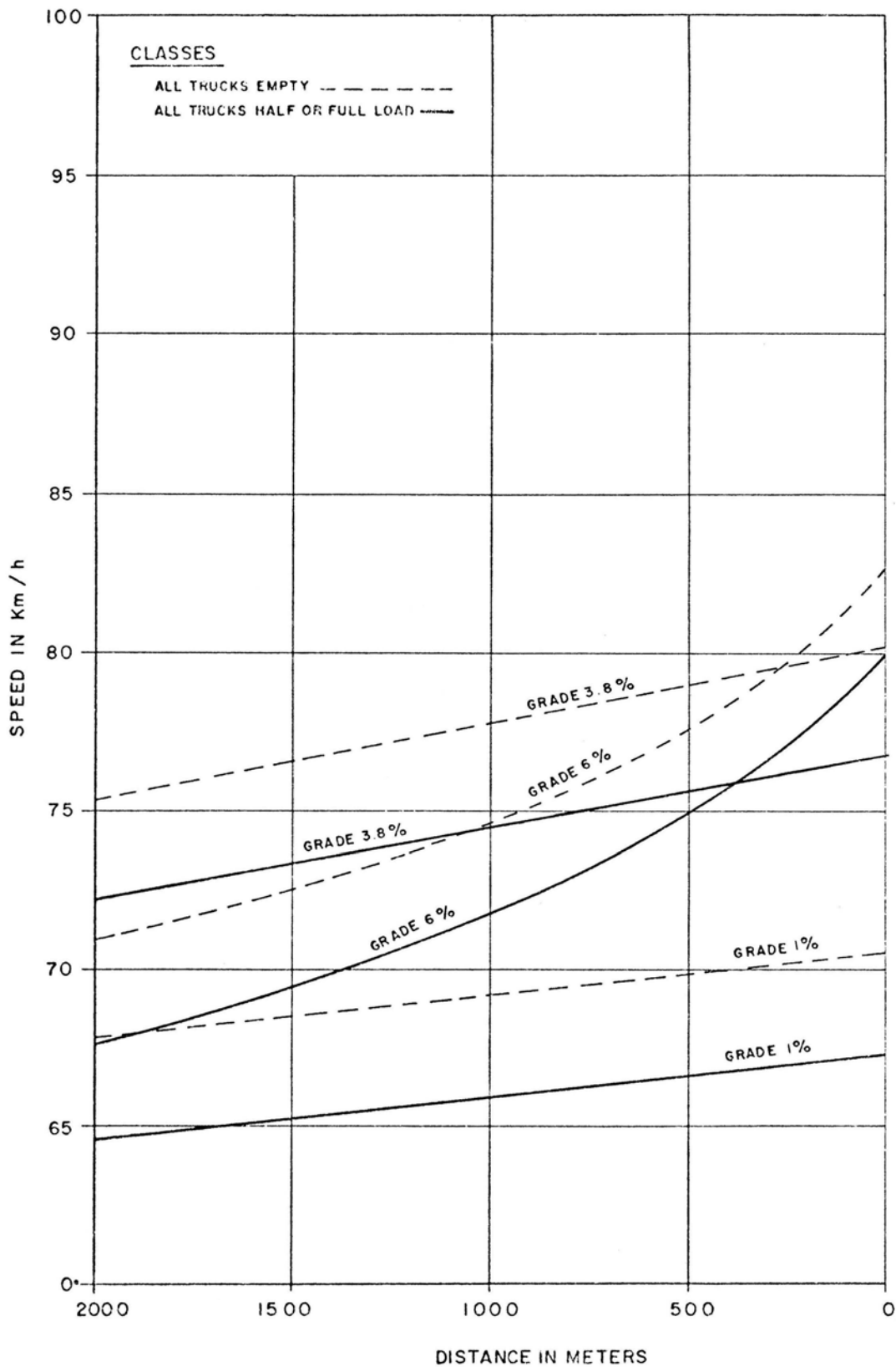
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Figure 7 - Preliminary Relationships Between Speed and
Distance on Negative Grades Between 1 and 6
Percent for Trucks

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quired for modeling fuel consumption as a function of the roadway characteristics. Four main fuel-consumption experiments and five satellite have been defined as shown in Table 2 . One of these experiments has been completed and two are currently in progress.

Unlike the speed-measurement experiments, where the general vehicle population can be sampled for the development of relationships, fuel-consumption data must be taken from measurements made with a fleet of test vehicles. Thus the project pur chased nine vehicles covering seven classes representing the types of vehicle produced in Brazil. As shown by Table 3 , the vehicles used for fuel-consumption measurements are a Volkswagen 1300, two Volkswagen Kombis, a Ford F400 (gasoline), a Ford F4000 (diesel), two Mercedes Benz L-1113/42's, a Mercedes Benz 0-362 bus, and a Scania 110/38.

Each of these vehicles has been fitted with a reservoir type fuel meter, a distance measuring instrument, and a split-second hand stopwatch.

Steady-State Fuel Consumption (FC-1)

The analysis of the steady-state fuel-consumption experiment is presented primarily to demonstrate the types of relationships which are being developed. The relationships presented are only preliminary since more data will be collected and more work is required to refine the analysis.

Fuel consumption is analyzed and discussed in units of mi liliters per second. This form of the dependent variable will be used in the Time and Fuel Algorithm. In many cases, runs were made in more than one gear for a given situation. When this occurred the mean fuel consumption for all gears was analyzed.

Analysis Approach - It would be a difficult if not impossible task to develop one general equation for such a wide variety of conditions and for so many vehicles. Different equat-

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TABLE 2 - ROAD USER COSTS AND TRAFFIC EXPERIMENTS

CATEGORY	NUMBER	TITLE	PURPOSE
FUEL CONSUMPTION MAIN EXPERIMENTS	FC-1	Steady-State Fuel Consumption	Collect data for vehicles operating at steady-state speed over tangent test sections on a variety of grades
	FC-2	Momentum	Determine the effect of momentum on fuel consumption. Important at the base of positive grades preceded by negative grades
	FC-3	Curvature	Test the effect of horizontal curvature on fuel consumption
	FC-4	Fuel Consumption Calibration	Collect independent data over long sections to verify and calibrate models developed from FC-1 to FC-3
FUEL CONSUMPTION SATELLITE STUDIES	FCS-1	Tuned vs. Untuned	Test the variability of fuel consumption due to engine condition
	FCS-2	Curvature	Similar to FC-3 but more complete coverage of curvature
	FCS-3	Sag Curves	Determine fuel consumption when sag curves are traversed
	FCS-4	Acceleration	Determine the effect of acceleration on fuel consumption when approaching a sag curve
	FCS-5	Big Cars	Determine the fuel consumption of an Opala and Dodge car at steady-state speed

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TABLE 3 - TEST VEHICLE DESCRIPTION

VEHICLE	FUEL	BRAKE HORSE-POWER	TARE WGT. (KG)	GROSS WGT. (KG)	LOAD*		
					EMPTY	HALF FULL	FULL
Volkswagen 1300	Gasoline	48	780	1,160	0	130	280
Volkswagen Kombi	Gasoline	60	1,195	2,155	0	280	550
Ford F-400	Gasoline	169	2,277	6,000	150	1,730	3,510
Ford F-4000	Diesel	102	2,444	6,000	0	1,540	3,325
Mercedes Benz L - 1113/42	Diesel	147	6,395	18,500	1730	5,985	11,970
Scania 110/38 Articulated	Diesel	285	13,420	40,000	0	13,300	26,600
Mercedes Benz O - 362 Monobloco	Diesel	147	7,500	11,500	0	1,010	2,250

* The loads given do not include the weight of the driver and observer, which is approximately 140 kg.

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ions were therefore developed for positive and negative grades and paved and unpaved roads. Four equations were developed for each vehicle, with the exceptions that the VW-1300 and the Kombis were analyzed together, and the MB 0-362 bus was not analyzed for negative grades. Thus, 18 separate regression equations were developed.

The nonlinear model that produced the lowest residual error and had the simplest form was:

$$\text{Fuel/sec} = A_0 + (A_1 + A_2 C + A_3 I)^{A_4 V} \qquad (1)$$

where $A_0 - A_4$ = coefficients

C = dummy-vehicle class value (1=Volkswagen 2=Kombi)

I = interaction term which consists of a load factor, a class factor and a grade term.

V = true mean speed of the vehicle

The actual equations for the paved and unpaved situations are presented in Table 4 with the others equations.

The same procedures were used for the analysis of the bus and trucks on positive grades. It was found that although the fuel-consumption relationships for the Ford and Mercedes were' similar, the relationship for the Scania was different, since it appeared more linear. For this reason two functions were tested. The nonlinear model (2) is applied to the Ford-400, the Mercedes Benz 1113, and the Mercedes Benz 0-362 bus. The linear model (3) is used for the Scania. The two functions are presented below:

$$\text{Fuel/sec} = (A_0 + A_1 L + \exp(A_2 G (1 + A_3 L)))^{A_4 V} \qquad (2)$$

where $A_0 - A_4$ = coefficients

L = dummy load value (0 = Empty, 1 = Full)

G = percent of the grade

V = true mean speed

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TABLE 4 - FUEL CONSUMPTION REGRESSION EQUATIONS FOR POSIT-
IVE GRADES

Volkswagen and Kombi Unpaved

$$F = -.53 + (1.1 + .189 \ C + .0153(C + .4)(L + 1.7) \ G)^{.035} \ V$$

$$S = .05$$

Volkswagen and Kombi Paved

$$F = -.62 + (1.14 + .17 \ C + .009(C + .4)(L + 2.5) \ G)^{.036} \ V$$

$$S = .05$$

Ford-400 Unpaved

$$F = .84 + (.554 + e^{(.066 \ G(1+1.15 \ L))}).05 \ V$$

$$S = 1.01$$

Ford-400 Paved

$$F = .8 + (.65 + .24 \ L + e^{(.11 \ G(1+1.27 \ L))}).0344 \ V$$

$$S = .82$$

MB-1113 Unpaved

$$F = (\ .95 + .45 \ L + e^{(.21 \ G(1+1.96 \ L))}).0343 \ V$$

$$S = .09$$

MB-1113 Paved

$$F = (1.52 + .627 \ L + e^{(.32 \ G(1+1.32 \ L))}).0236 \ V$$

$$S = .16$$

MB-Bus Unpaved

$$F = (1.36 + .167 \ L + e^{(.3 \ G(1+.44 \ L))}).0245 \ V$$

$$S = .32$$

MB-Bus Paved

$$F = (2.3 + .24 \ L + e^{(.5 \ G(1+.31 \ L))}).015 \ V$$

$$S = .30$$

Scania Unpaved

$$F = 1.02 - .3 \ L + .072(L+1) \ V + .03(L+1)^{1.45} \ G \ V$$

$$S = .30$$

Scania Paved

$$F = 1.35 - .403 \ L + .054(L+1)^{1.32} \ V + .026(L+1)^{1.32} \ G \ V$$

$$S = .54$$

where C = Class,   1=Volkswagen, 2=Kombi
      G = Grade in Percent
      V = Velocity in Km per hour
      L = Load factor, 0=Empty 1=Full
      F = Fuel in ml per second
      S = Standard error of the equation

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$$\text{Fuel/sec} = A_0 + A_1 L + A_2 I \qquad\qquad (3)$$

where $A_0 - A_2$ = coefficients

L = dummy load value (0=EMPTY, 1=FULL)

I = interaction of load, speed, and grade factors

The equations for the paved and unpaved test sections are given in Table 4.

The fuel-consumption regression equations for positive grades are presented in Figures 8 through 19.

For the Volkswagen and Kombis, the same main effects and interactions that were significant for the positive paved sections were also significant for the negative paved sections. The influences, however, are different in some cases. The most obvious difference is related to the effect of the load. For negative grades less than 2%, the empty vehicle consumes less than the laden vehicle, assuming all other effects are held constant. However, for both the Volkswagen and the Kombis, the influence of the load changes as the negative grade increases from 2 to 4%. For negative grades of more than 4%, the laden vehicle consumes less than the empty vehicle.

For negative unpaved sections, all load effects proved to be non-significant. For this reason, different models were used for the paved and unpaved equations for the Volkswagen and Komb is. The function for the paved case is much more complicated since it has to account for the load effects. Since there are many unique functions for the negative grades, the general forms are not presented for each case. Table 5 presents all equations in their final forms.

The load effect for the truck on negative grades was similar to that for the lighter vehicles. For flat sections, the laden vehicle consumed more than the empty vehicle. As the grade becomes steeper the load effect reverses.

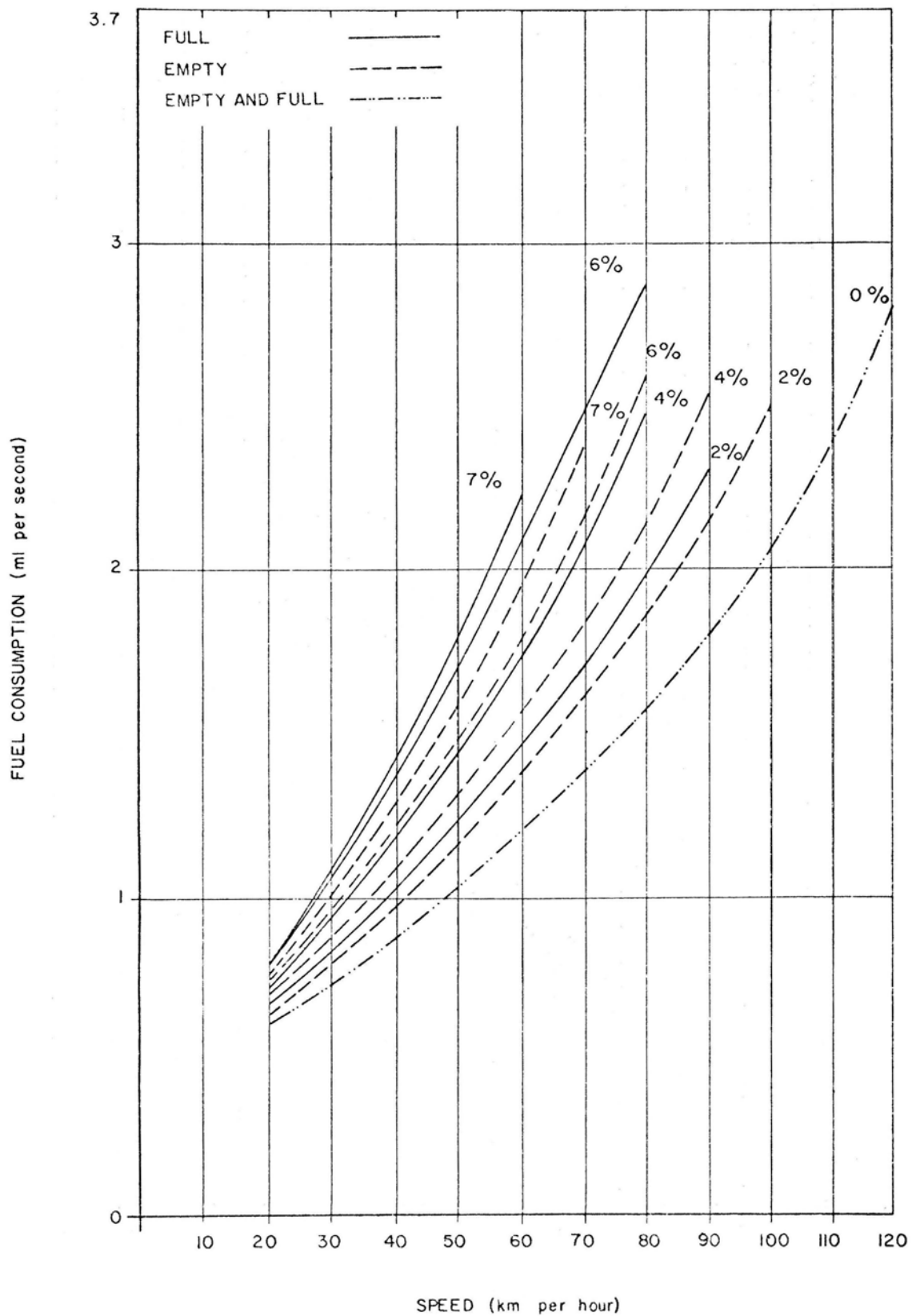A major difference in the effect of speed occurred for the

24

Figure 8 - Fuel Related to Speed for a Full and Empty
Volkswagen 1300 Operating on Positive Paved
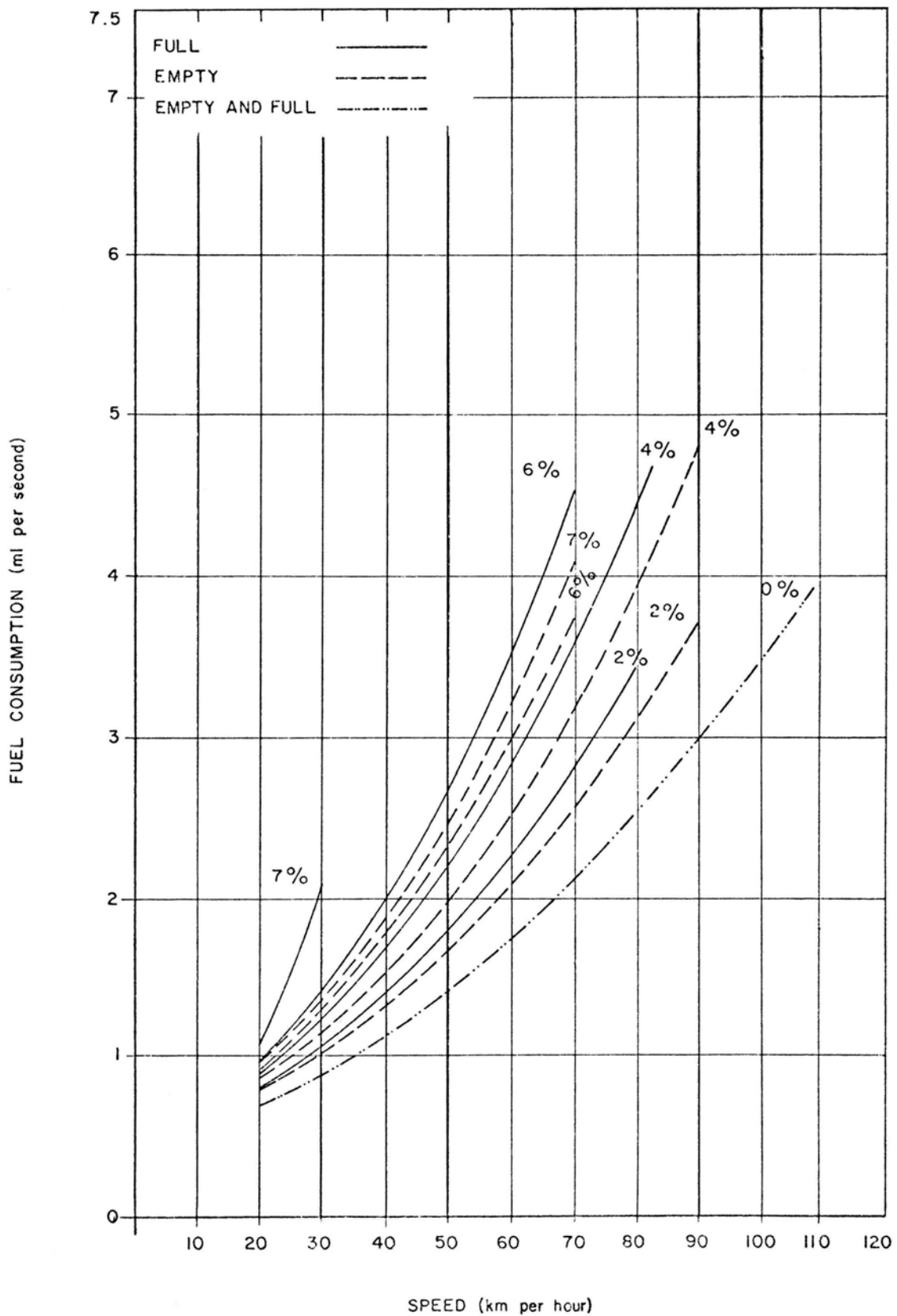Grades Between Zero and Seven Percent

25

Figure 9 - Fuel Related to Speed for a Full and Empty
Kombi Operating on Positive Paved Grades
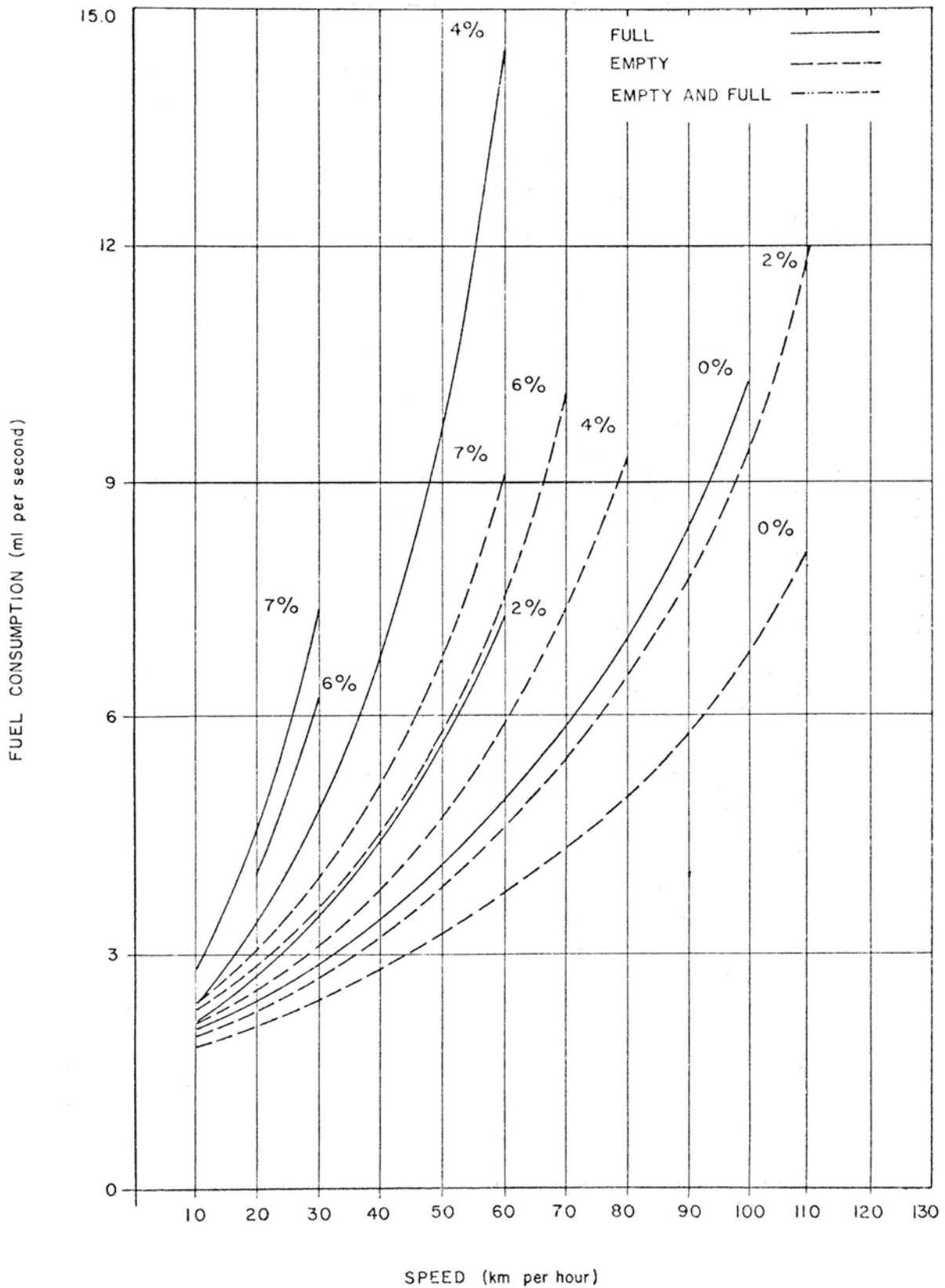Between Zero and Seven Percent

26

Figure 10 - Fuel Related to Speed for a Full and Empty
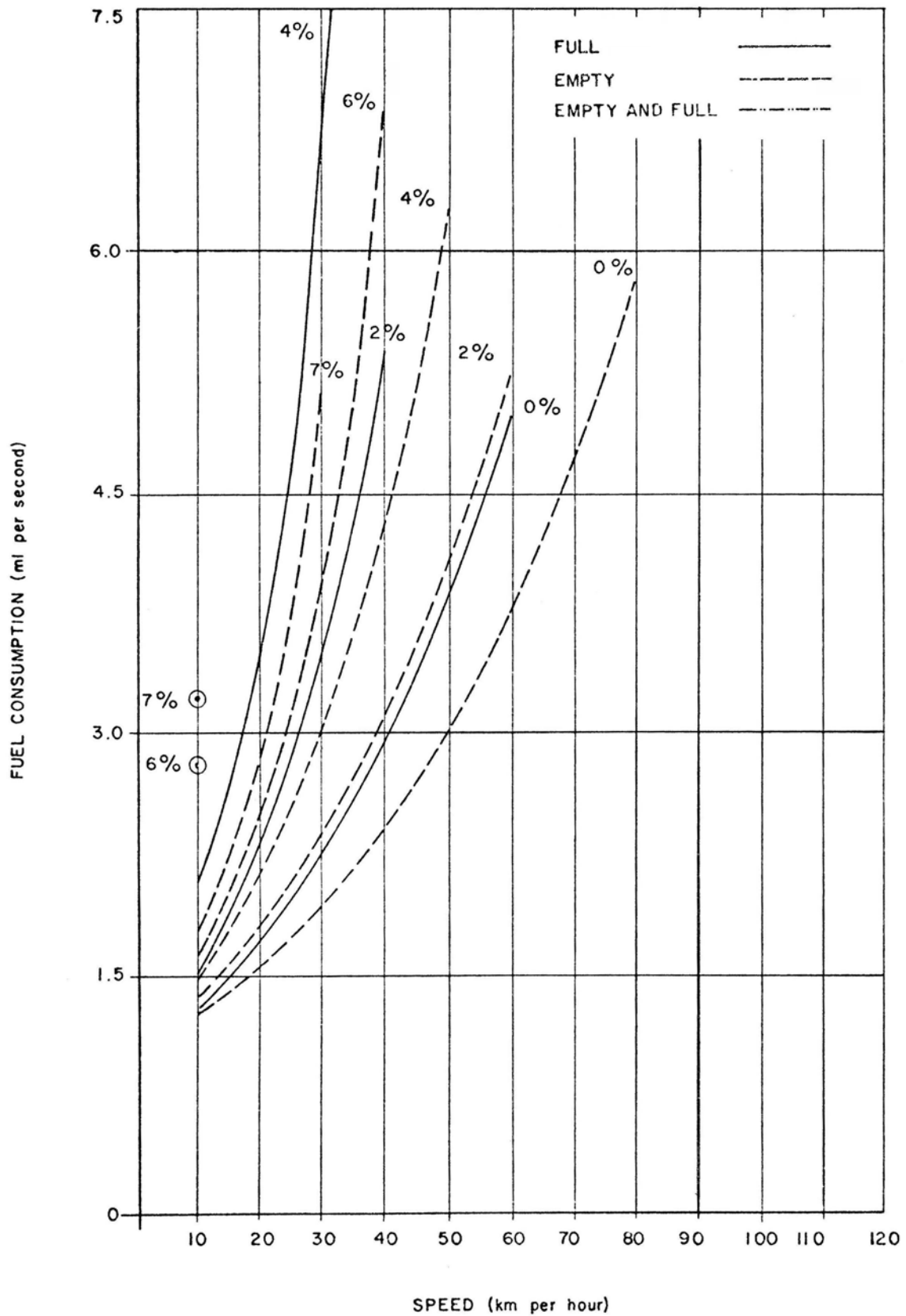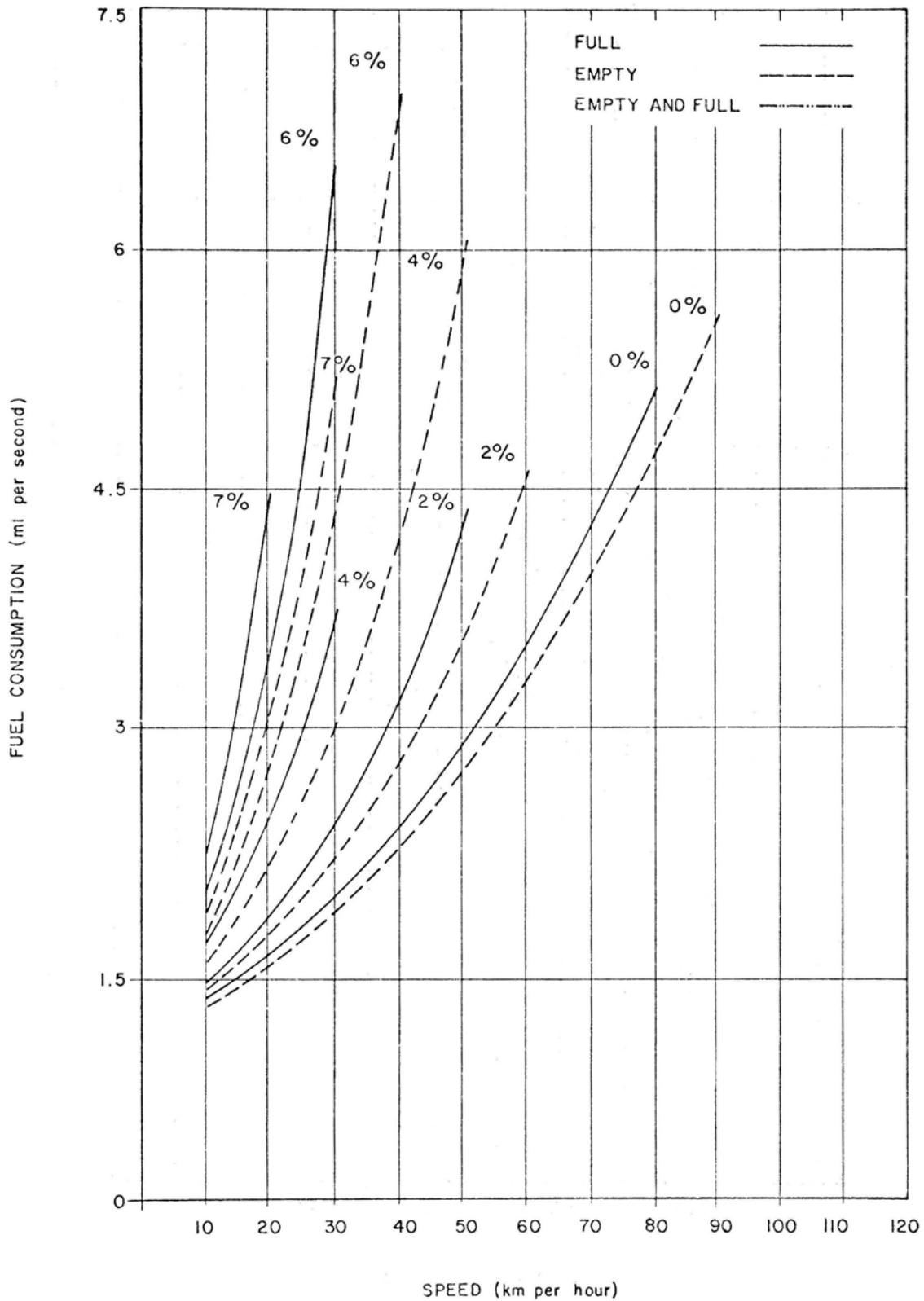Ford 400 Operating on Positive Paved Grades
Between Zero and Seven Percent

27

Figure 11 - Fuel Related to Speed for a Full and Empty
Mercedes Benz 1113 Operating on Positive
Paved Grades Between Zero and Seven Percent

28

Figure 12 - Fuel Related to Speed for a Full and Empty
Mercedes Benz Bus 0-362 Operating on Positive
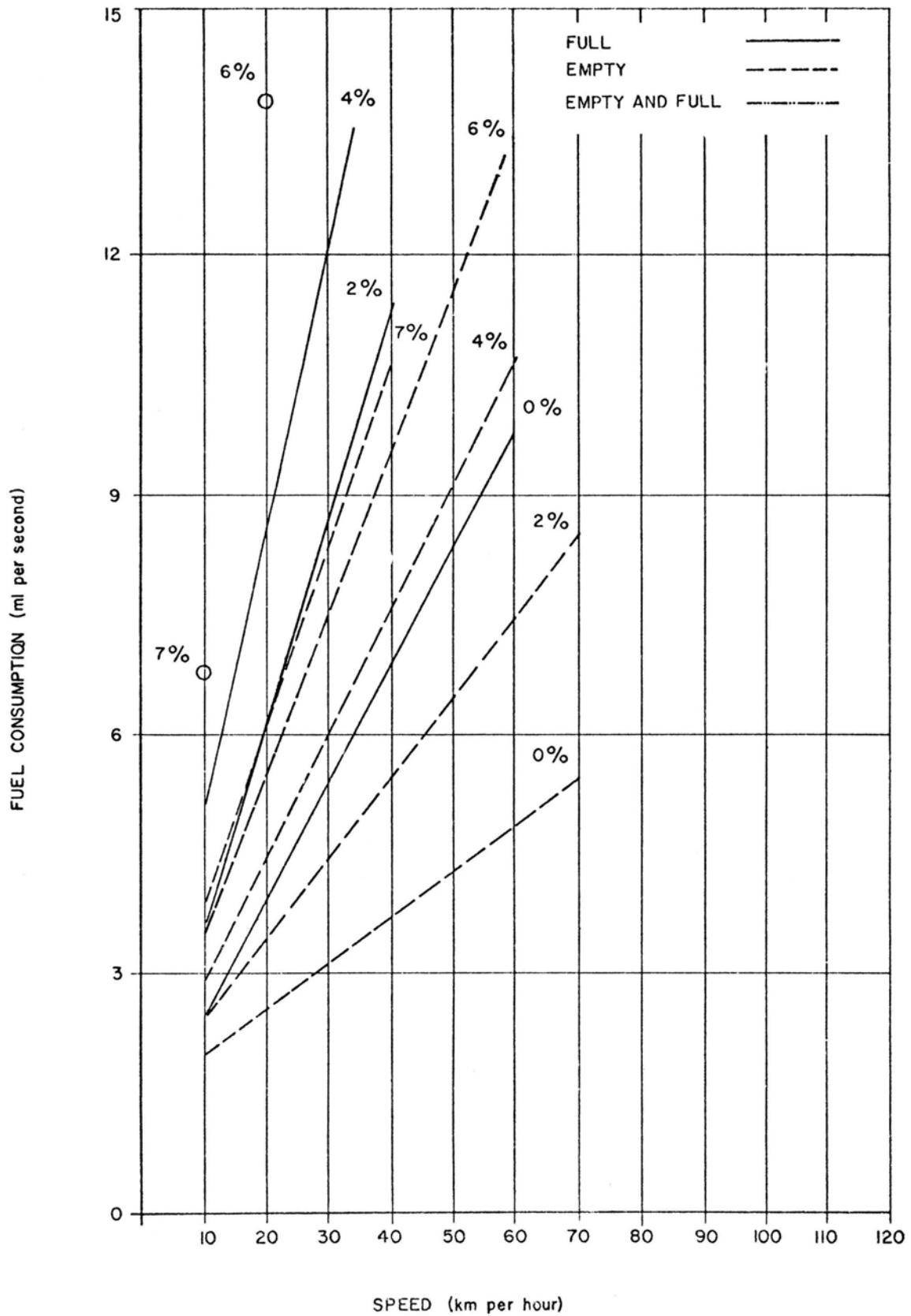Paved Grades Between Zero and Seven Percent

29

Figure 13 - Fuel Related to Speed for a Full and Empty
Scania Operating on Positive Paved Grades
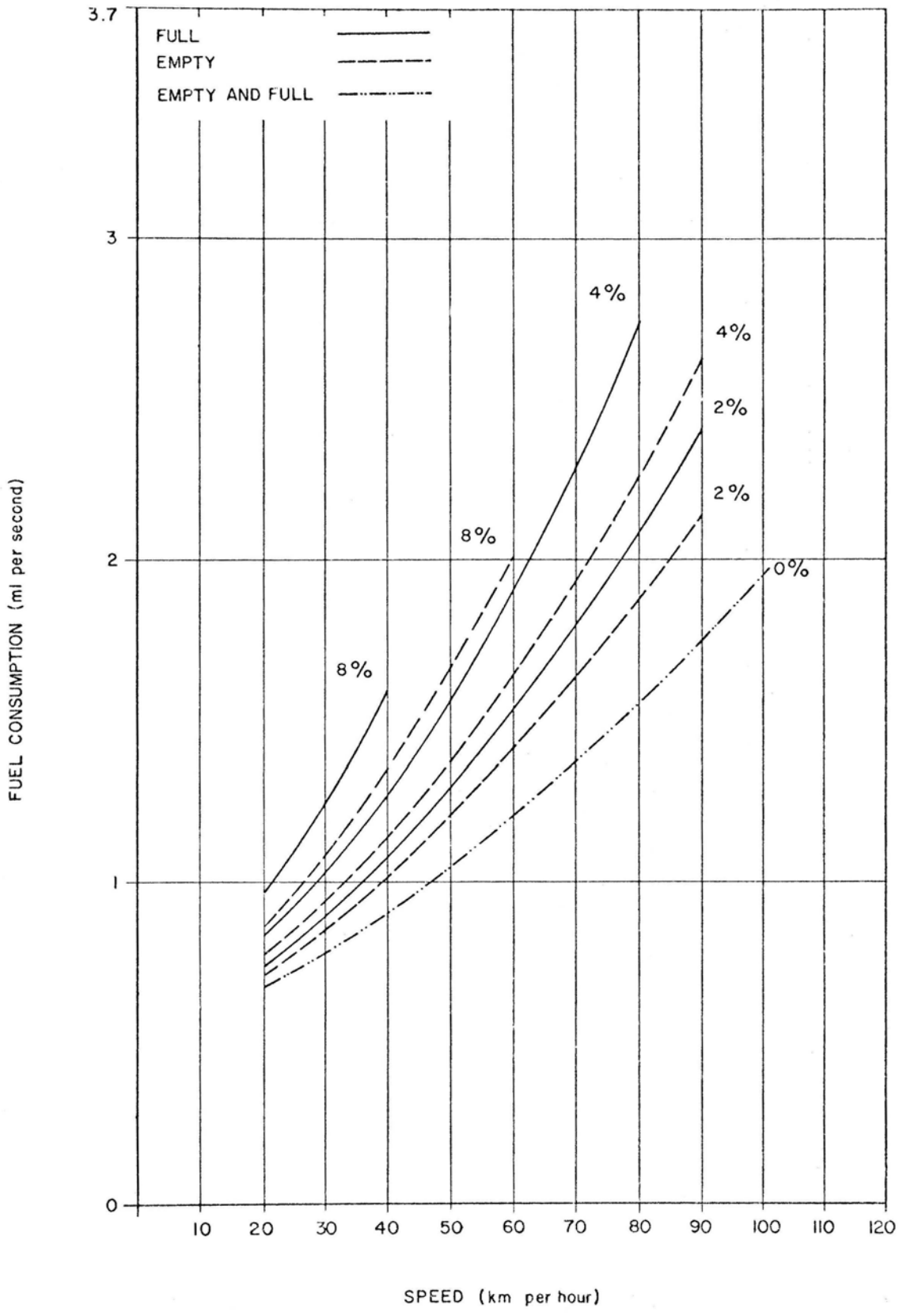Between Zero and Seven Percent

30

Figure 14 - Fuel Related to Speed for a Full and Empty
Volkswagen 1300 Operating on Positive Unpaved
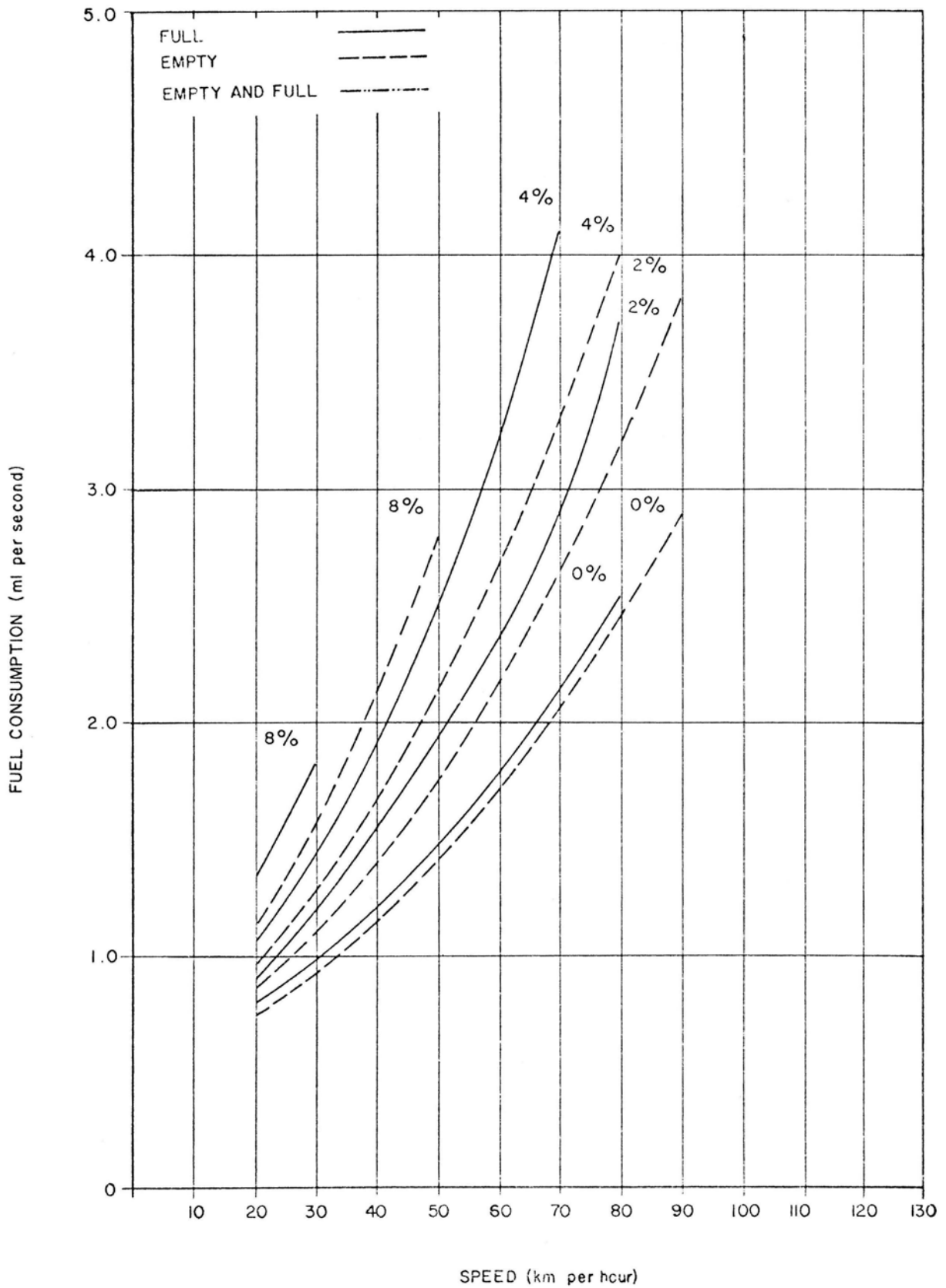Grades Between Zero and Eight Percent

31

Figure 15 - Fuel Related to Speed for a Full and Empty
Kombi Operating on Positive Unpaved Grades
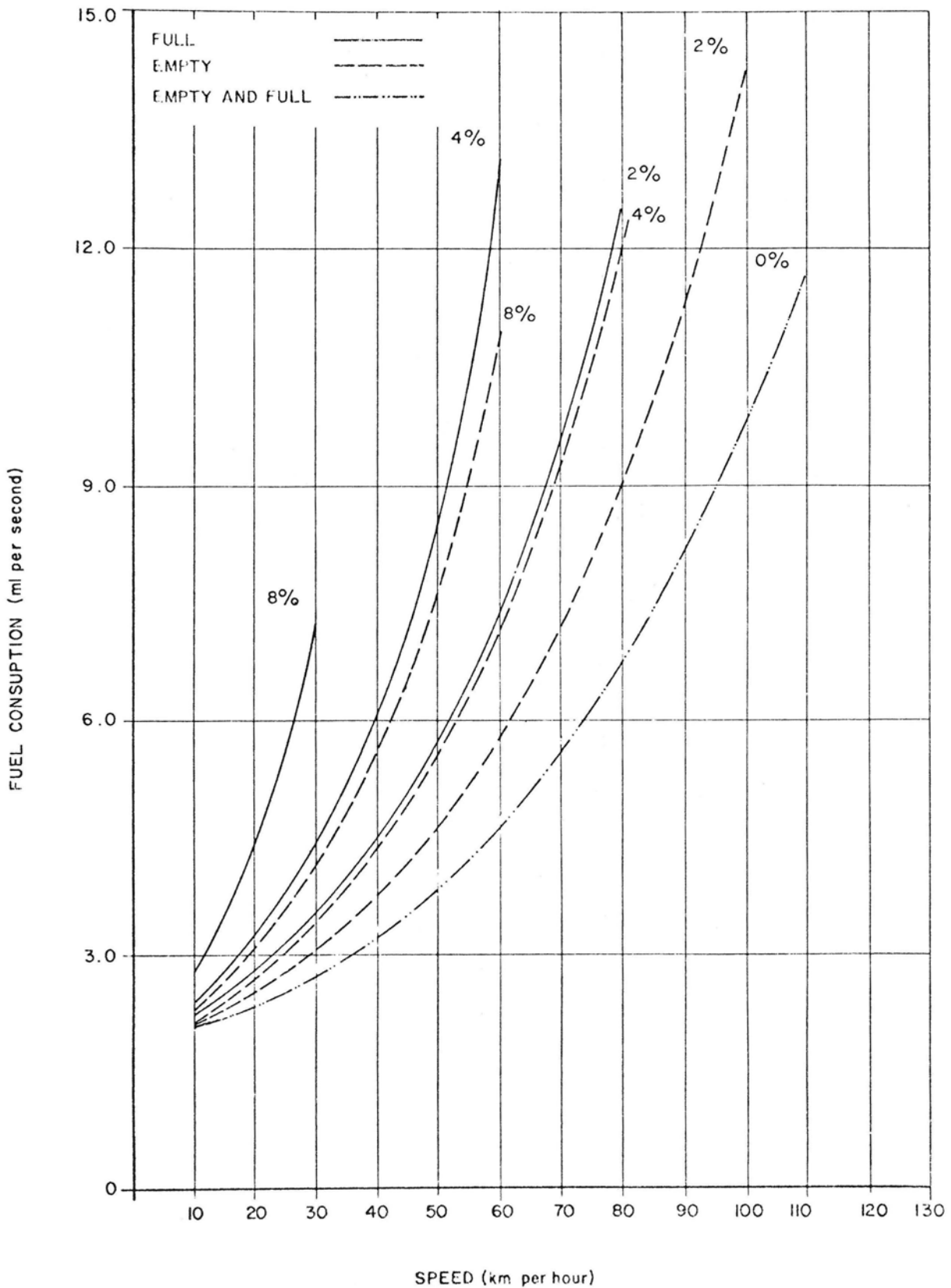Between Zero and Eight Percent

32

Figure 16 - Fuel Related to Speed for a Full and Empty
Ford 400 Operating on Positive Unpaved
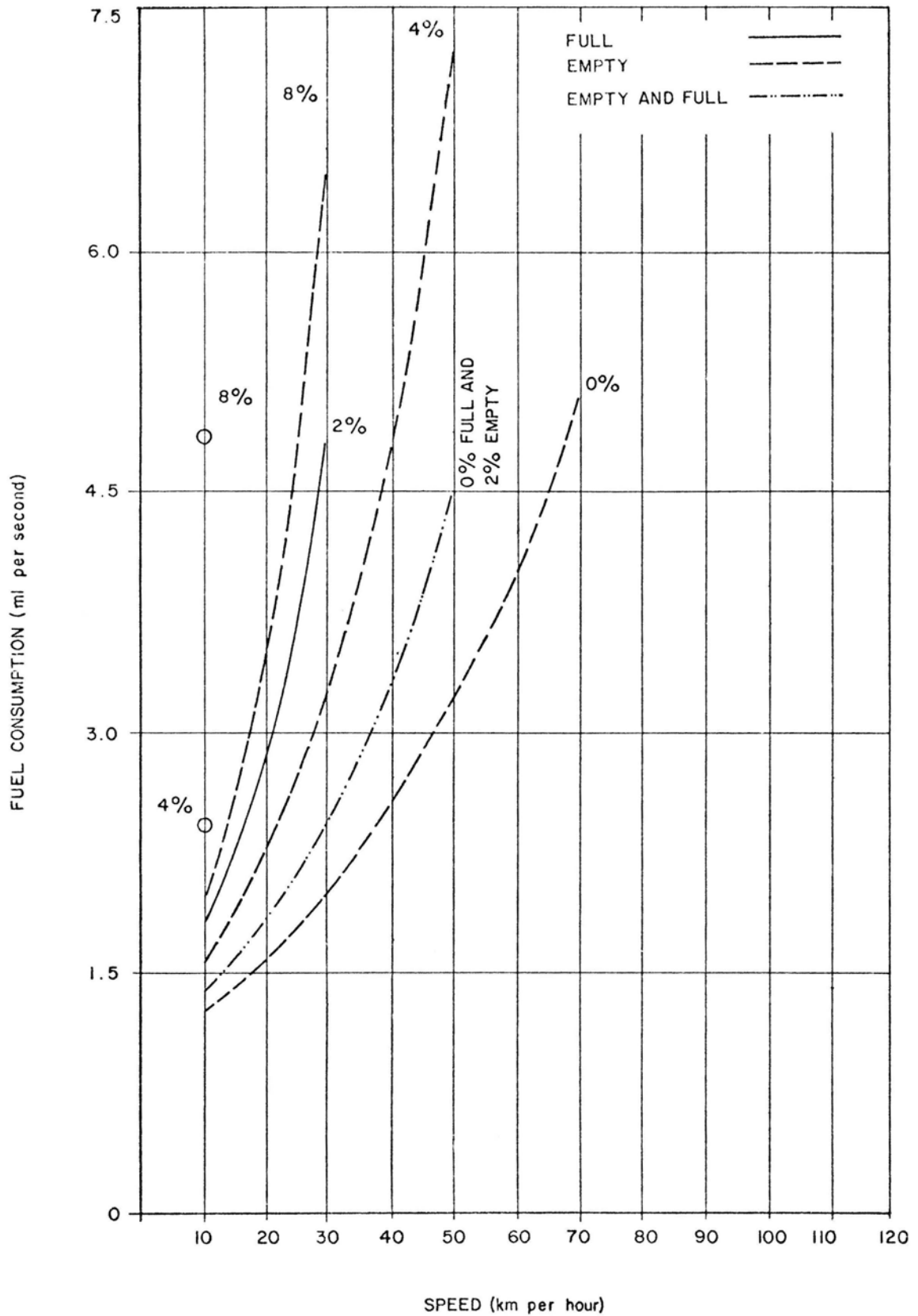Grades Between Zero and Eight Percent

33

Figure 17 - Fuel Related to Speed for a Full and Empty
Mercedes Benz 1113 Operating on Positive
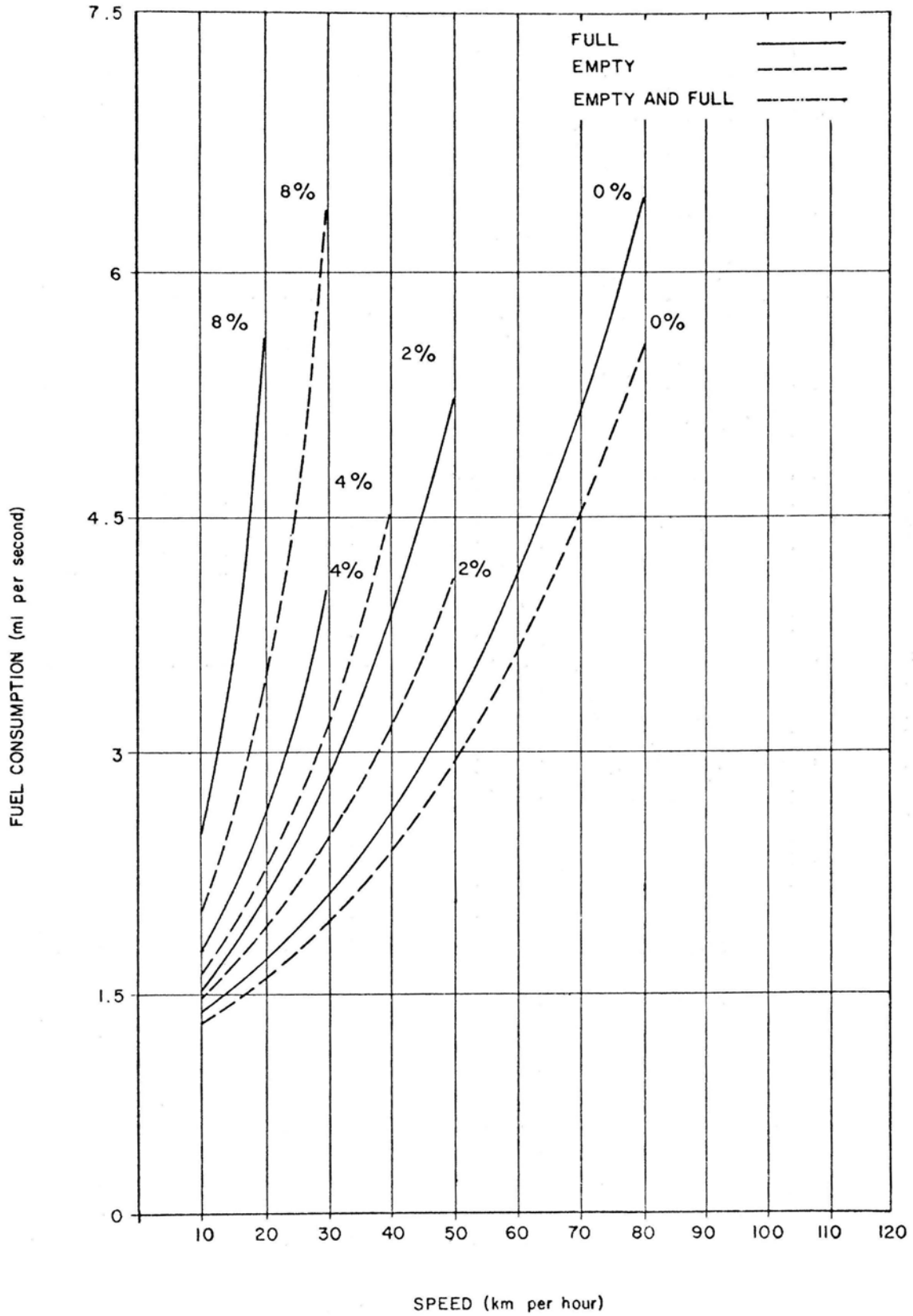Unpaved Grades Between Zero and Eight Percent

34

Figure 18 - Fuel Related to Speed for a Full and Empty
Mercedes Benz 0-362 Bus Operating on Positive
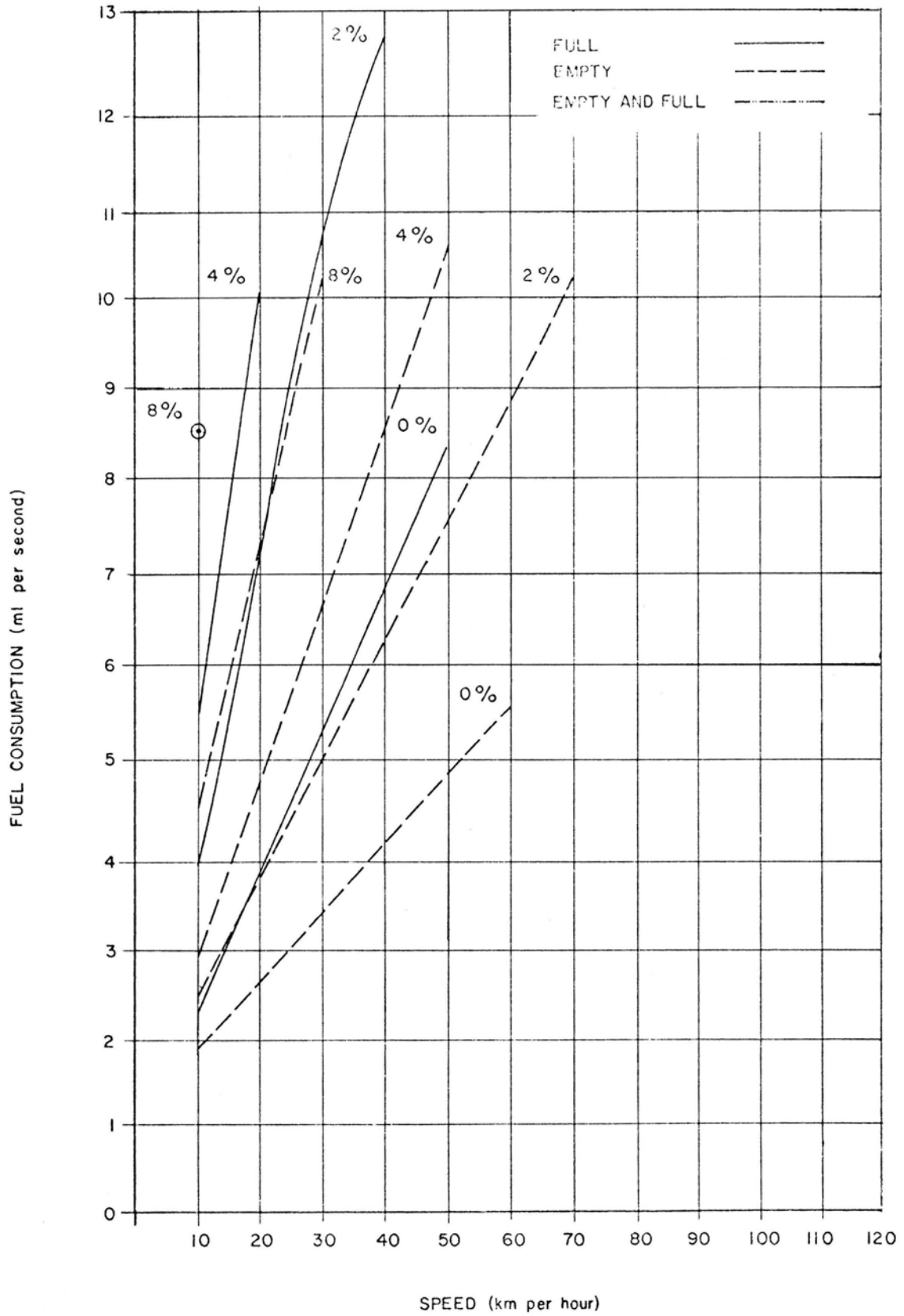Unpaved Grades Between Zero and Eight Percent

35

Figure 19 - Fuel Related to Speed for a Full and Empty
Scania Operating on Positive Unpaved Grades
Between Zero and Eight Percent

36

TABLE   5   -   FUEL CONSUMPTION REGRESSION EQUATION FOR NEGAT-
IVE GRADES

Volkswagen and Kombi Unpaved

$$F = -.87 + (1+1.88(C + .5)(e^{(-.214\ G)}))\ .009\ V$$

$$S = .04$$

Volkswagen and Kombi Paved

$$F = -1 +(1+(.065 + .042\ C)(e^{(-.016\ G^2)})+.003(3-G)C)\frac{L}{}\ .107\ V$$

$$S = .07$$

Ford-400 Unpaved

$$F = \frac{1.77}{(1+G)^{.5}}\ -1 +(1+e^{(.814 + .07(L+1)^2(.827-G))})\ .0178\ V$$

$$S = .56$$

Ford-400 Paved

$$F = \frac{1.91}{(1+G)^{.5}}\ -1 +(1+e^{(1.38 + .1(L+1)^2(1.26-G))})\ .01\ V$$

$$S = .27$$

MB-1113 Unpaved

$$F = \frac{1.264}{(1+G)}\ -1 +(1+e^{(.597 + .253(L+1)^2(.684-G))})\ .02\ V$$

$$S = .11$$

MB-1113 Paved

$$F = \frac{1.09}{(1+G)}\ -1 +(1+e^{(.519 + .213(L+1)^2(1.08-G))})\ .0181\ V$$

$$S = .14$$

Scania Unpaved

$$F = \frac{2.068}{(G+1)^{.5}}\ (e^{(1.765 + .522(L+1)(.863-G))})\ .0091\ V$$

$$S = .36$$

Scania Paved

$$F = \frac{2.343}{(G+1)^{.5}}\ (e^{(.879 +(L+1)(.79-G))})\ .0086\ V$$

$$S = .14$$

where C = Class,   1=Volkswagen,   2=Kombi
      G = Grade in percent
      V = Velocity in km per hour
      L = Load   0=Empty   1=Full
      F = Fuel in ml per second
      S = Standard error of the equation

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Scania data. In general all of the equations reflect an increase in fuel consumption per second with increasing speed. The speed influence reverses itself for the Scania operating on negative grades.

On the negative unpaved sections the influence of speed reverses for grades of four percent. At the four-percent level, the empty vehicle consumes more than the laden vehicle and increasing speed causes decreasing fuel consumption. On the negative paved sections, the influence of speed reverses for grades of two percent. At the two-percent level, increasing speed causes decreasing fuel consumption, and the empty vehicle consumes more than the laden vehicle. Table 5 contains the equations for the trucks for negative grades. Each of the functions is a nonlinear form with the exception that the Scania equation is intrinsically linear. Figures 20 through 28 present the equations for fuel consumption on negative grades in graphical form.

Summary of FC-1 Analysis - Eighteen regression models are presented. They are the result of preliminary analysis of 20,000 steady-state fuel-consumption measurements. The equations are not in final form since the analysis reflects only a portion of the overall steady-state fuel-consumption experiment. The preliminary analysis using nonlinear regression techniques offered a range of possible regression models. However, further refinements and modifications are required on the equations. For lack of actual analysis time, many possible improvements could not be accomplished. Certain problems with high coefficient correlations and large coefficient errors have not been satisfactorily eliminated from some of these preliminary nonlinear equations. Such problems should be addressed before any of the functions are utilized for predictions.

Fuel Consumption on Curves (FC-3)

It has been demonstrated in previous literature (Sawhill, Ref. 2) that small radius curves can significantly affect fuel
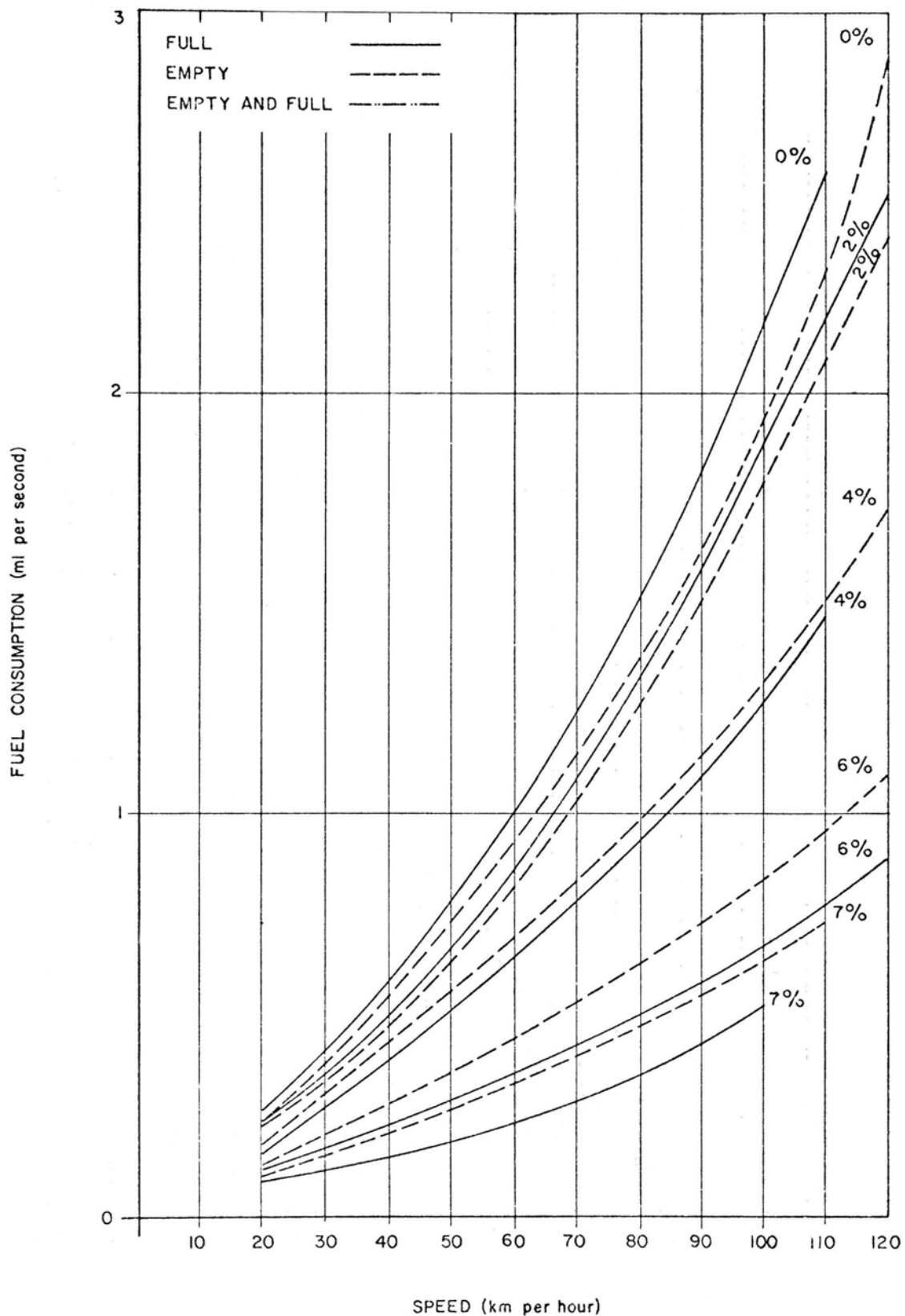
Figure 20 - Fuel Related to Speed for a Full and Empty
Volkswagen 1300 Operating on Negative Paved
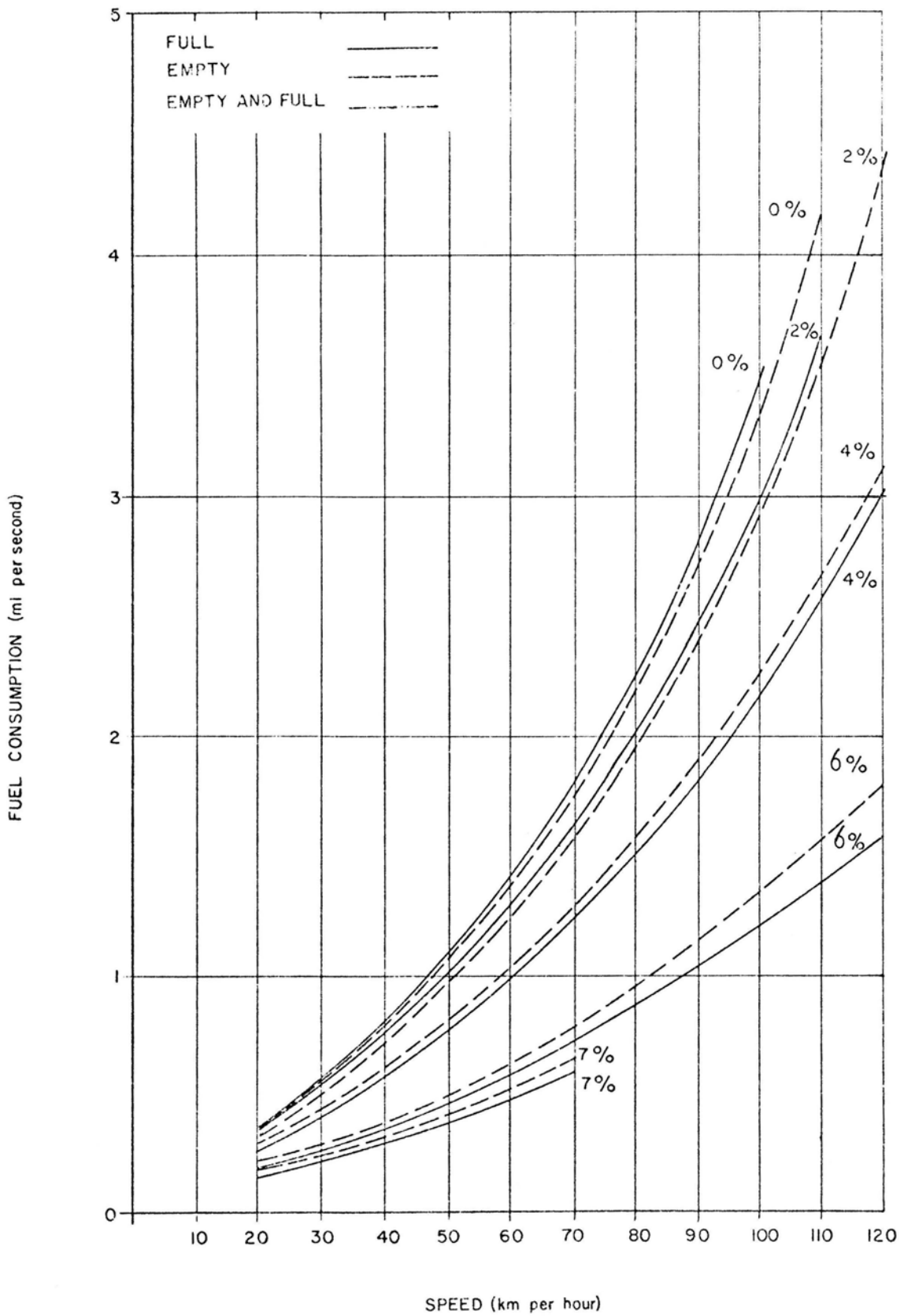Grades Between Zero and Seven Percent

39

Figure 21 - Fuel Related to Speed for a Full and Empty
Kombi Operating on Negative Paved Grades
Between Zero and Seven Percent

40

Figure 22 - Fuel Related to Speed for a Full and Empty
Ford 400 Operating on Negative Paved Grades
Between Zero and Seven Percent

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Figure 23 – Fuel Related to Speed for a Full and Empty
Mercedes Benz 1113 Operating on Negative
Paved Grades Between Zero and Six Percent

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Figure 24 – Fuel Related to Speed for a Full and Empty
Scania Operating on Negative Paved Grades
Between Zero and Seven Percent

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Figure 25 - Fuel Related to Speed for a Full and Empty
Volkswagen and Kombi Operating on Negative
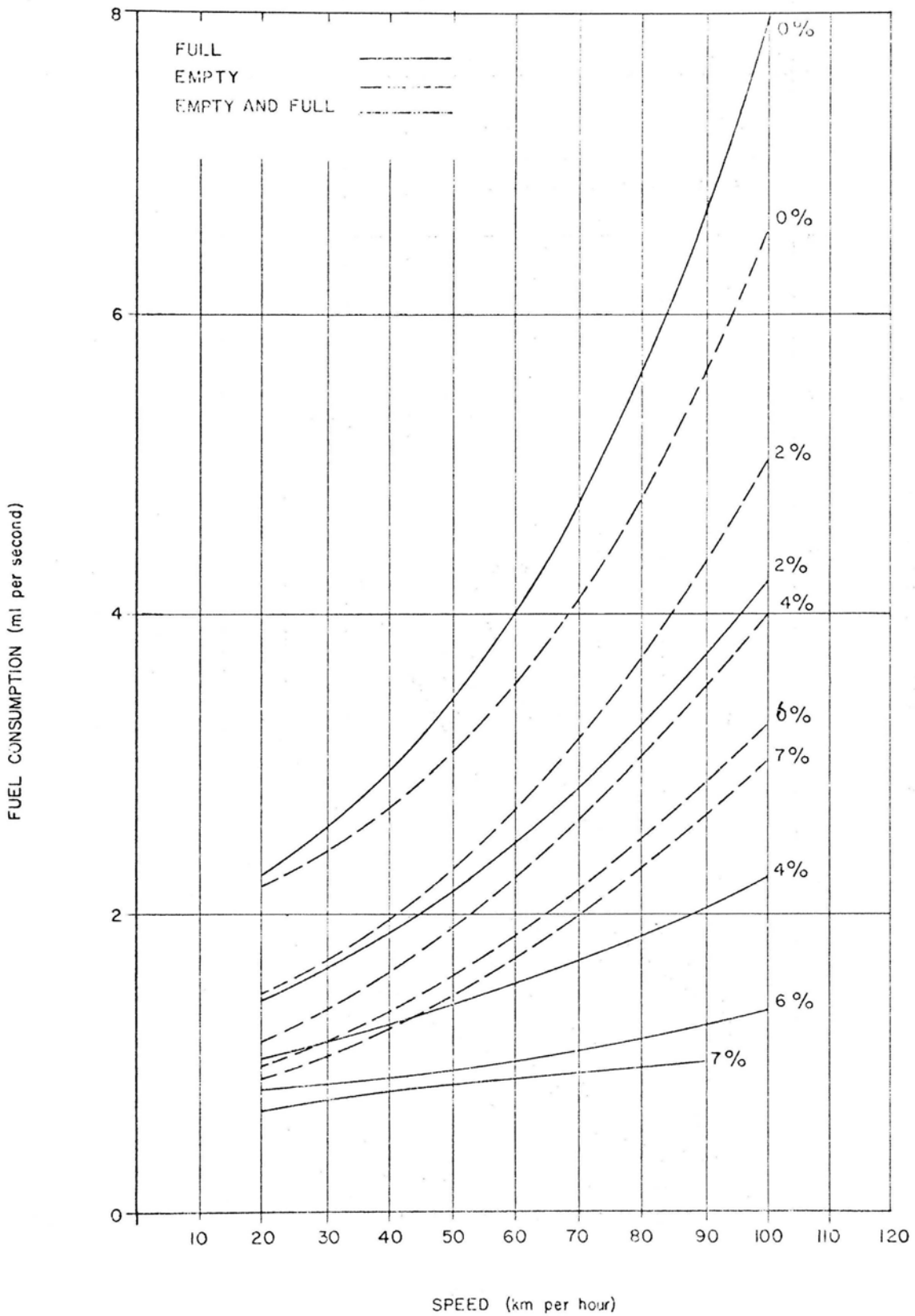Unpaved Grades Between Zero and Eight Percent

44

Figure 26 - Fuel Related to Speed for a Full and Empty
Ford 400 Operating on Negative Unpaved Grades
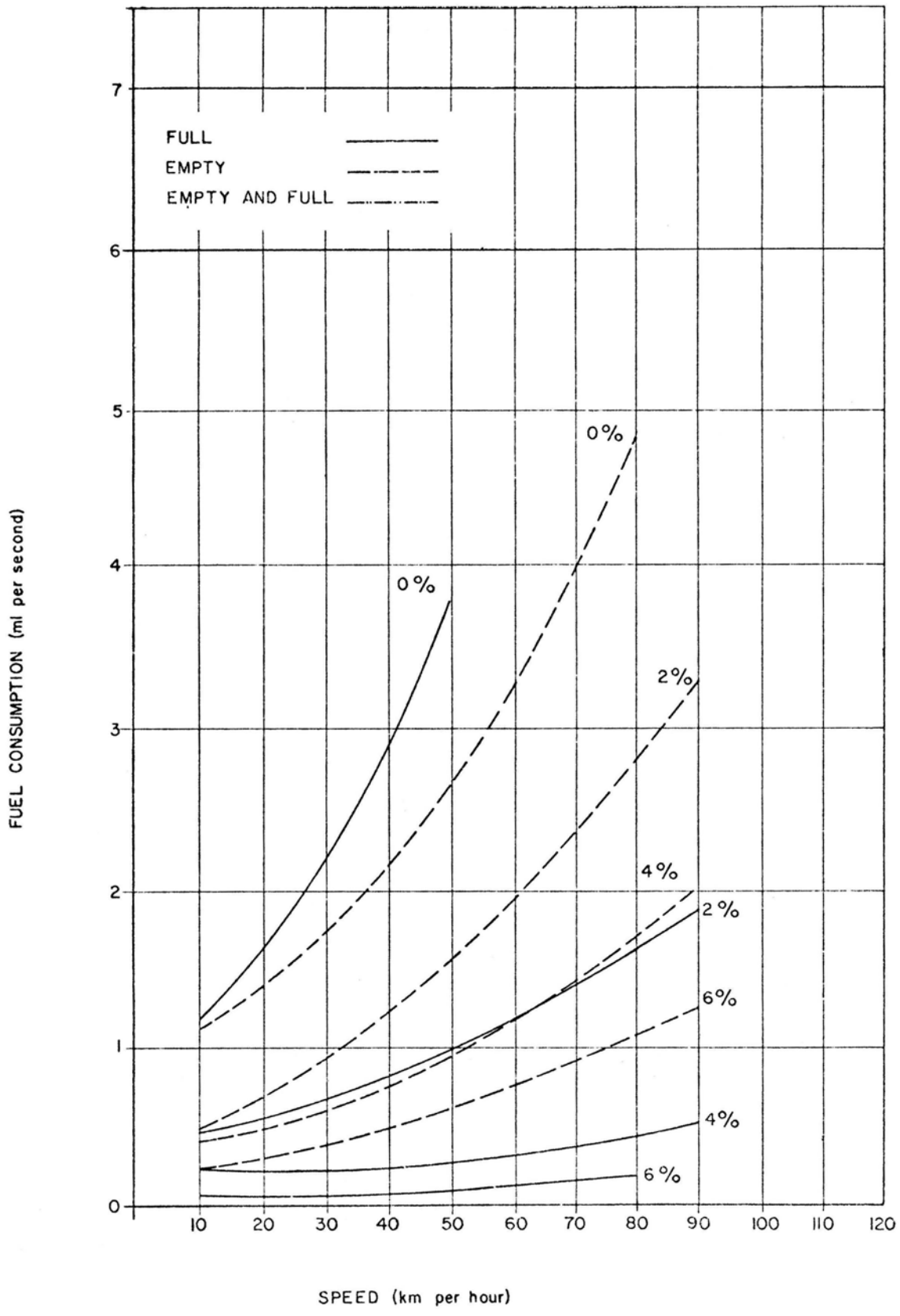Between Zero and Eight Percent

45

Figure 27 - Fuel Related to Speed for a Full and Empty
Mercedes Benz 1113 Operating on Negative
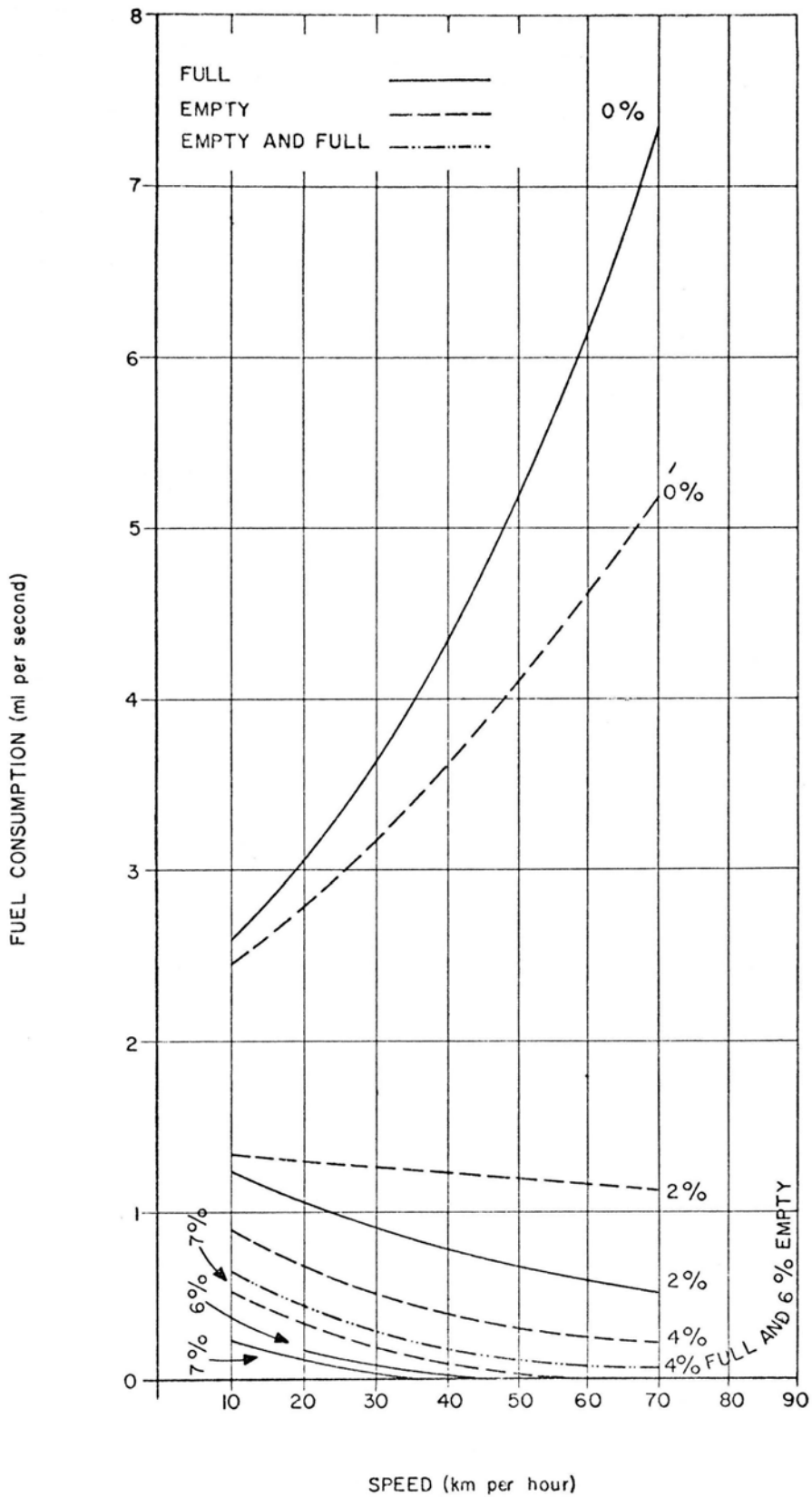Unpaved Grades Between Zero and Eight Percent

46

Figure 28 - Fuel Related to Speed for a Full and Empty
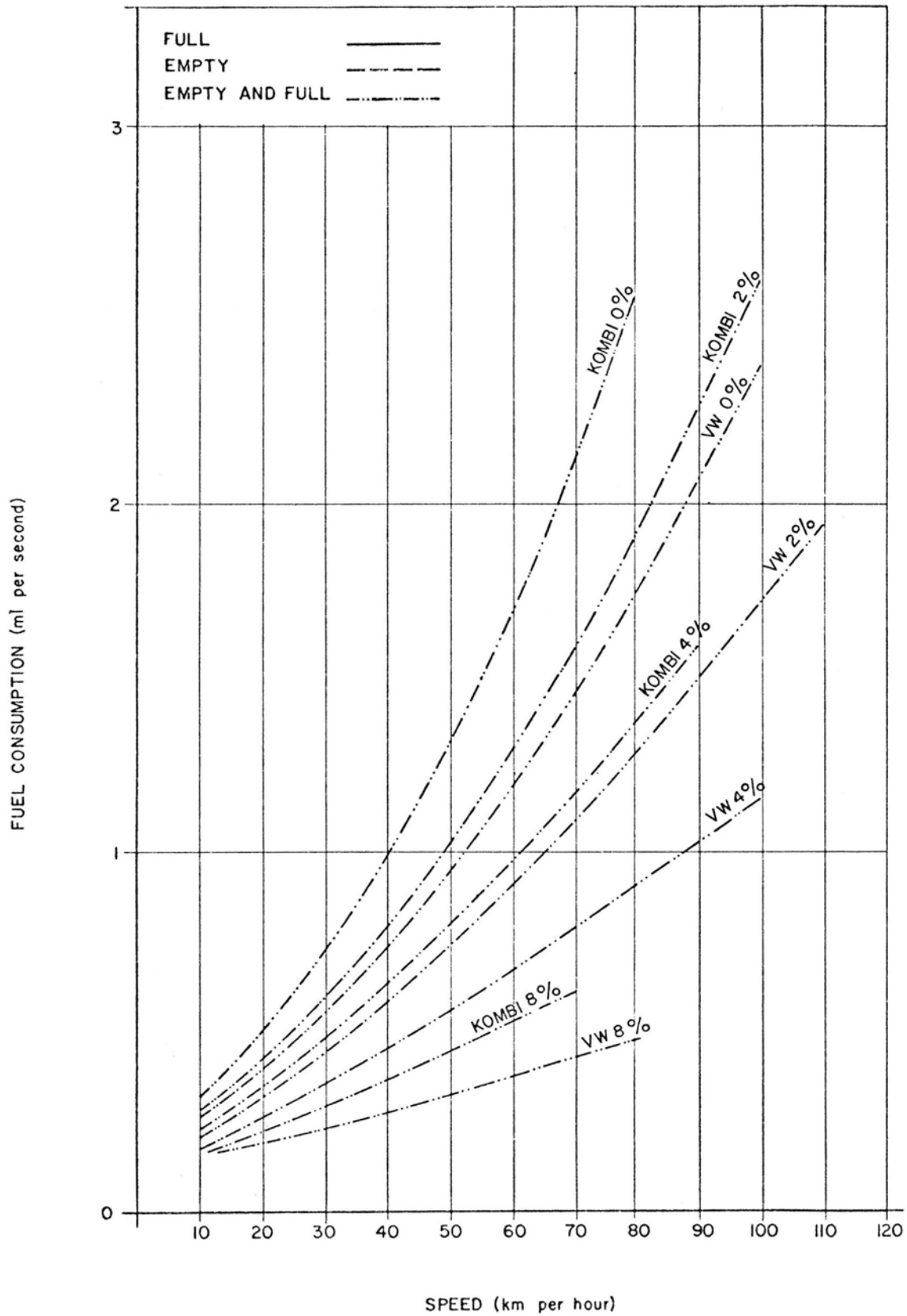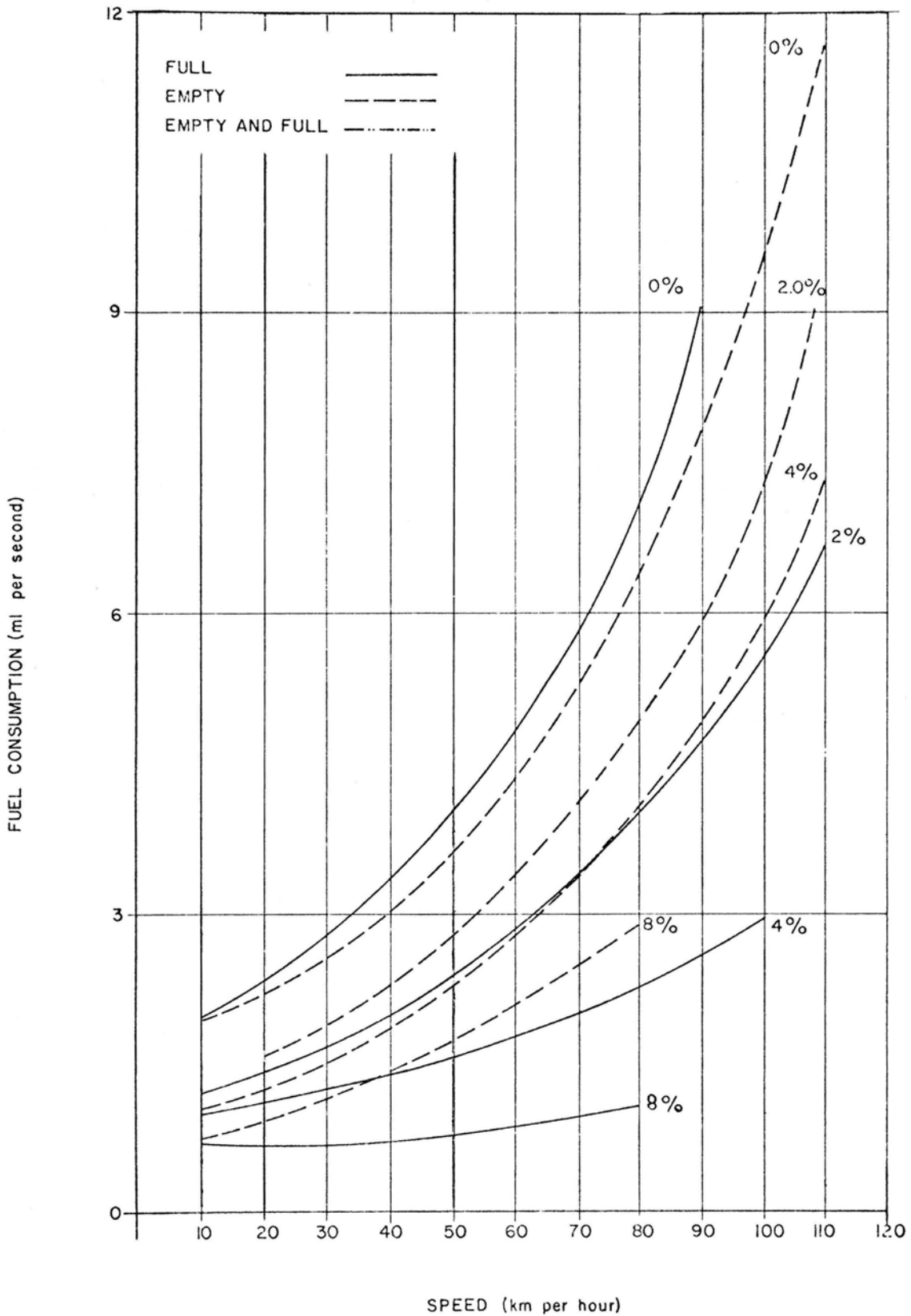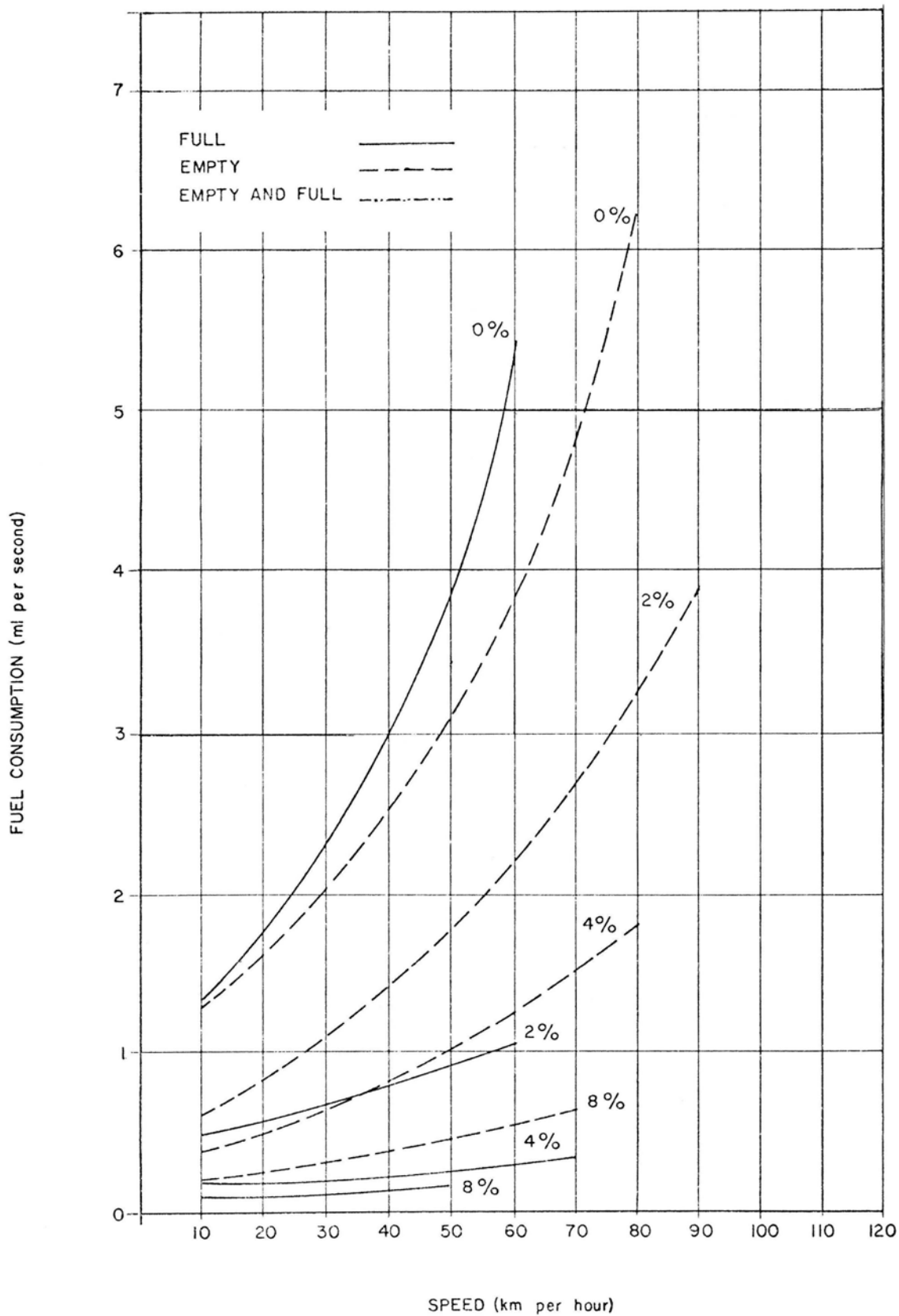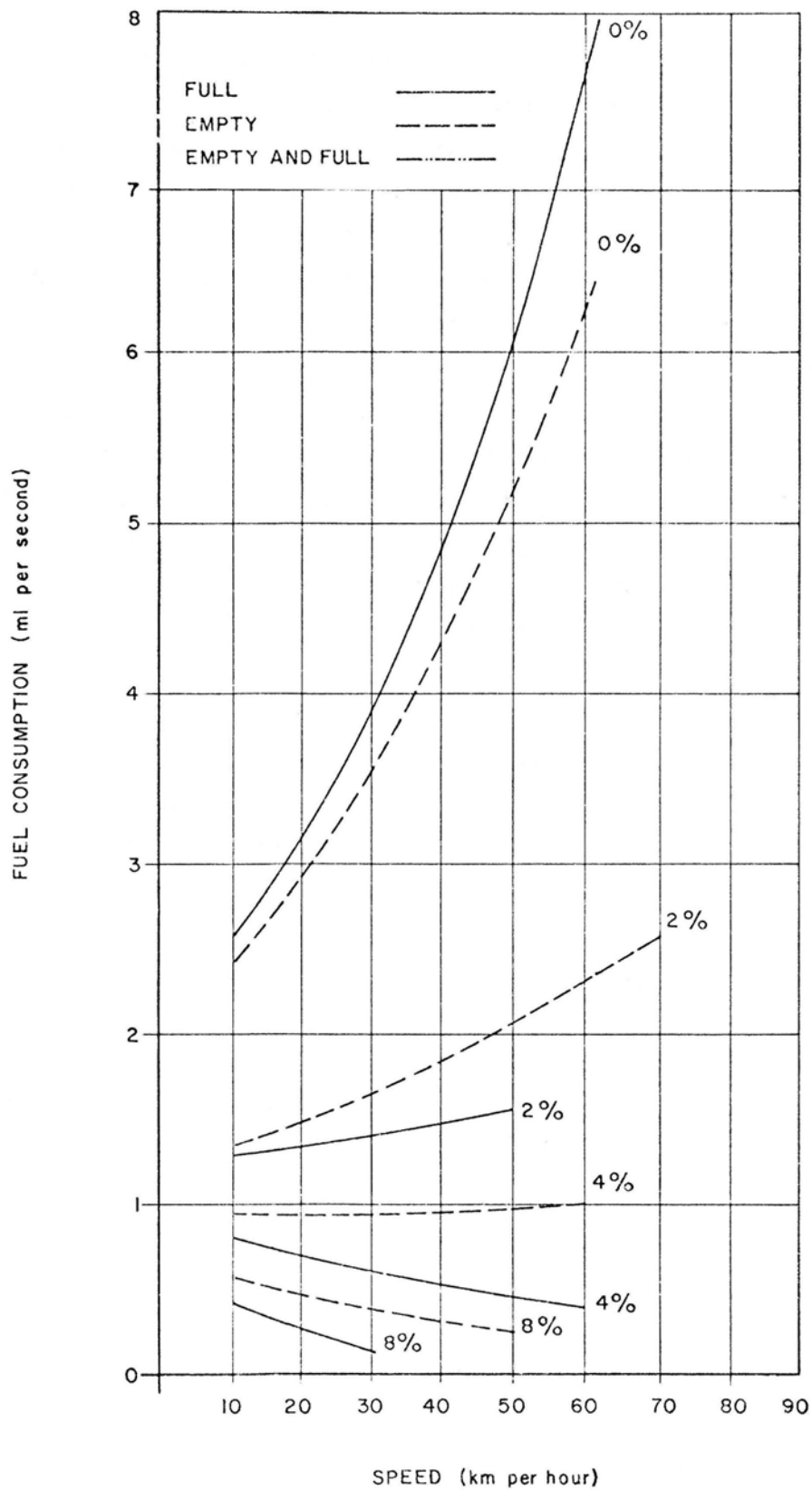Scania Operating on Negative Unpaved Grades
Between Zero and Eight Percent

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consumption. The purpose of this experiment is to examine the effects of extreme curvilinear alignment on fuel consumption. Eight test vehicles provided the data collected on the two 8% gravel sections. Test runs were made in both directions in the empty and laden condition. Since one of the sections was a tangent and the other had a very small radius curve, fuel consumption differences could be compared between the two horizontal curvature extremes.

It is difficult to make firm conclusions about the results of the analysis-of-variance procedures because of the limited degrees of freedom in the error term and because of the inference restrictions. The experiment cannot be viewed as a definitive study of the effect of horizontal curves on grades. However, within the scope of this experiment, the effect of horizontal curves appears to be minimal. Since this test was conducted using extreme conditions of horizontal curvature and grade, and for these conditions the largest mean difference in fuel consumption was only 3%, it may be concluded that it is not economical to experiment further on the effects of curves on fuel consumption. Therefore, the satellite study to further investigate the effect of horizontal curves on fuel consumption, FCS-2, will not be conducted.

FUEL CONSERVATION

In the process of evaluating the state of the art in the area of fuel-consumption experiments, several factors were identified which should be considered in establishing fuel conservation policies.

The information reviewed originated in other countries, and has been collected and summarized by project staff. It may be placed in two basic categories: studies to develop unit costs savings of motor vehicle operation, and those that may be described as cost effectiveness studies.

Since the highway transportation system is unique for each country, some difficulty arises when trying to transfer this

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information across international boundaries. This is particularly true for cost effectiveness studies since they are dependent on the transportation demand pattern. Cost effectiveness studies are the result of computing total costs or savings for a given strategy based on an estimated transportation demand level, and unit costs or savings information.

On the other hand, because there are some common denominators in all transportation systems, the unit costs studies may have a certain amount of international application. Therefore, emphasis is placed on reviewing unit costs or savings studies, but cost effectiveness studies are cited to give examples of the potential impact of various petroleum conservation programs.

In order to affect the amount of petroleum required for transportation it is necessary to alter one or more of the three components of the transportation system. These components are 1) the vehicle, 2) the roadway and 3) the user.   To alter the petroleum requirement, one may use technological, legal, or economic means, to reduce the demand for transportation, or increase the efficiency of the transportation system.

User Considerations

In general, the highway user's attitude about transportation convenience must be altered in order to affect petroleum conservation. Examples of changing user attitudes include:

    a) encouraging the use of car pooling and mass transit for routine trips such as going to and returning from work;

    b) encouraging use of reduced speeds on rural roads,

    c) encouraging people to walk on short trips (less than 2 km), rather than drive; and

    d) encouraging truck operators to switch off the motor when stopping for more than six minutes.

Cost effectiveness studies of these types of fuel conservation measures have been performed in the United States and are shown in Table 6 as an example of the amount of savings which

TABLE 6 — COST EFFECTIVENESS OF VARIOUS USER PROGRAM FOR PE-
TROLEUM CONSERVATION IN THE UNITED STATES (Ref. 3)

Option	Fuel Savings as Percent of Direct Transport Energy		Likelyhood of Achievement
	1980	1990	
CAR POOLING			
47% Participation	1.9	1.5	Medium
70% Participation	4.9	3.8	Low
SPEED LIMIT			
(88 km/h)			
Cars	1.2	0.9	High
Trucks	0.5	0.6	High
BETTER VEHICLE MAINTENANCE	0.7	0.6	Low
IMPROVED DRIVING HABITS	2.4	1.9	Medium
URBAN TRAFFIC FLOW	0.4	0.9	High

can be obtained. Since user attitudes are probably different
in the United States and Brazil, the figures given in the table
cannot be used here. However, a study of the situation in Bra
zil would probably show   high potential savings through the
use of these measures.

Vehicle Considerations

It is well accepted that through technological means, the
efficiency of the modern passenger and cargo vehicle may be
greatly increased. Table 7 is a summary of methods which have
shown potential for saving fuel. Care must be taken when ap-
plying these results to Brazilian conditions. For example,
generally the savings shown by reducing aerodynamic drag of
trucks is based on a study of trucks with enclosed trailers.
Since this type of trailer is not predominant in Brazil, the
fuel saving potential in this case will be different.

Table 8 gives an example of the potential energy conserv-
ation available in the United States for various methods of in
creasing the efficiency of vehicles.

Roadway Considerations

Petroleum conservation may be obtained through improved
roadway design and planning. The two main areas for potential
savings are improving the traffic flow in urban areas   and
the efficiency of vehicles operating on the roadway by
using more energy-efficient design standards. Examples of tech
niques which may be used for fuel conservation through improved
traffic flow in urban areas include   roadway and street plan-
ning,so that traffic can flow at a constant and possibly optimum
speed for maximum fuel economy, and land use planning along
with an adequate street system to minimize trip distances. Ex-
amples of highway design standards which may be altered to in-
crease the fuel economy of vehicles operating on the roadway
are reduced surface roughness standards, and changes to vertical

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TABLE 7 - EXAMPLES OF PERCENT FUEL SAVINGS RESULTING FROM TECHNOLOGICAL IMPROVEMENTS IN PASSENGER AND CARGO VEHICLES

Means	Vehicle	
	Passenger Cars	Trucks
(1) Aerodynamics	0.0-5.0[a]	0.0-5.0[d]
(2) Fuel System Modifications	5.0-6.0[b]	
(3) Minor Motor Modifications	9-16[b]	3-10[d]
(4) Gears	0.0-7.7[a]	0- 5[d]
(5) Weight	*	
(6) Radial Tires	0.0[b]	0.0-10[d]
(7) Combination of 1 and 4	15[a]	

* Substantial, but no estimate given (Note c).

a. Carr, G. W., et.al., Vehicle Fuel Economy: Effect of Aerodynamics and Gearing, Motor Industry Research Association, Great Britain, February, 1976.

b. Aerospace Corporation, Highway Vehicle Retrofit Evaluation, Phase I, Analysis and Preliminary Evaluation of Results, US Dept. of Commerce, NTIS, PB252554, November 1975.

c. Cunningham, G., Kapadia, R., Hudson, W.R., Summary of Current Information Available on Fuel Consumption, Tech. Memo., The University of Texas at Austin, June 1976.

d. Jack Fawcett Assoc , Truck Fleet Experience with Fuel Economy Improvement Measures, Submitted to the Federal Energy Administration, Washington D.C., June 1976.

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TABLE 8 - EXAMPLES OF COST EFFECTIVENESS OF VEHICLE
IMPROVEMENTS IN THE UNITED STATES (Ref. 3)

Option	Fuel Saving as Percent of Direct Transportation Energy		Likelyhood of Achievements
	1980	1990	
PASSENGER CAR Modest Modification to Passenger Car Motors	8.2	15.0	High
Advanced Technology	8.7	29.4	Medium to High
Advanced Technology and shift to smaller cars	13.3	32.0	Medium to High
Radial Tires	0.5	0.0	High
TRUCK Vehicle Efficiency	3.3	8.7	High

grade standards.

The available data on these methods of producing fuel
conservation are quite scattered.   For example,
Claffey (Ref. 4) reports a 50 percent increase in fuel consump
tion on badly broken and patched asphalt when compared to fuel
consumption on a smooth pavement.   On the other hand, roughness
does not enter into the computations of Hide et al (Ref. 5)when
estimating the fuel consumption of vehicles on paved roads.

Summary

From this brief review on the methods available for conser
ving petroleum used for transportation, it is clear that signif
icant fuel savings can result from carefully planned programs.
However, care must be exercized when applying the information
from other nations to the conditions in Brazil.   The best use
of the available data would be to produce a cost effectiveness
study based upon the demand for transportation in Brazil and
the unit cost or savings studies from foreign sources, adjust-
ed for the transportation system in Brazil.   The accuracy of
such a study will be greatly improved when the results of the
current highway user cost study are available.

AXLE LOADS

Accurate axle-load data are very important in the determi-
nation of pavement performance relationships; therefore, axle-
load distributions and average load equivalency results for the
pavement test sections are being determined from vehicle weigh-
ings measured with portable scales and the weigh-in-motion sys-
tem.

Collection with Portable Scales

Vehicle wheel weights are obtained using two General Elec-
trodynamics Model MD-400 portable scales. A level stretch of
road (grade less than 1 percent) with good sight distance is

selected in close proximity of the pavement section. The scales are then placed on the roadway and one lane is blocked off to permit measurements as shown in Figure 29.

To ensure that all wheels of one axle group are at the same height, wooden spacers (wooden beams the same thickness as the scales) are used before and after the portable scale in a longitudinal direction. The vehicle wheels thus first pass over the wooden spacers and then onto the scales. The two scales are placed so that both weigh one axle at the same time.

At each site, measurements are obtained during a 5-day period, generally from Monday to Friday. Because of safety considerations and to facilitate reading the scales, measurements are only conducted during daylight hours. On roads carrying less than about 800 vehicles per day, vehicles travelling in both directions can be handled with the scales located in one lane. For roads carrying heavier traffic it is necessary to measure only one direction per day, while the other direction is measured on the following day. Vehicles are sampled during peak hours to minimize delays and thereby maintain the goodwill of long-distance haulers. Thus no more than two vehicles are kept waiting at any single time.

Portable Scale Results

The percentage of axles laden above these legal limits were determined by traffic direction at a number of weighing locations.

The legal limits set by DNER which are in force in Brazil are the following:

Single rear axle	10000 kg
Tandem rear axle	17000 kg
Triple rear axle	25500 kg

The frequency of various increments of overloading by location-direction are shown in Figure 30.

From 10 to 35 percent of single rear axles are over-

55

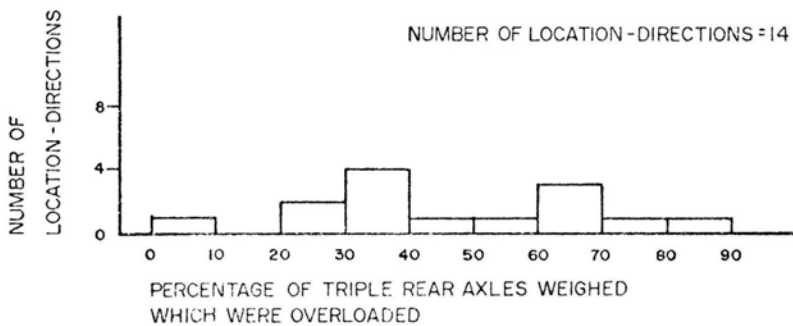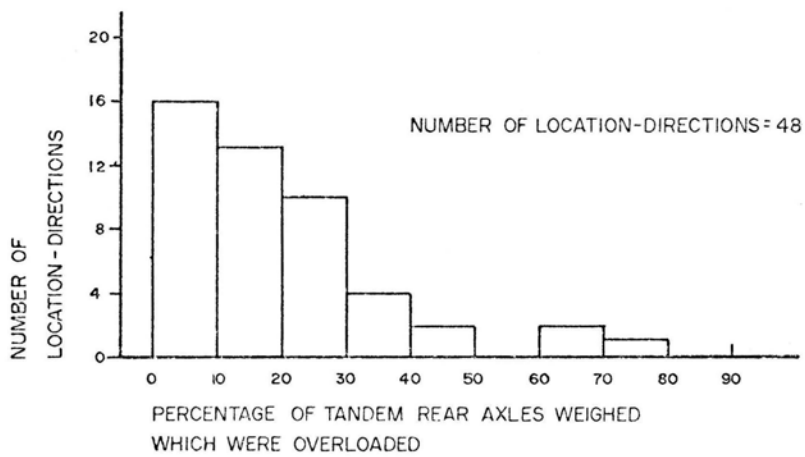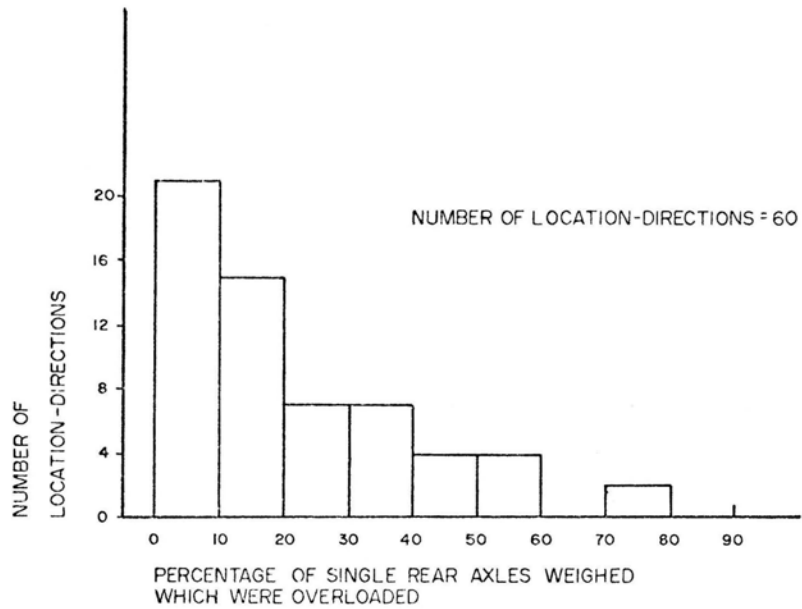Figure 29 - Axle Weighing with Portable Scales

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Figure 30 - Distributions of the Percentage of Rear
Axles Weighed for Vehicle Sample Sizes
Greater than 10.

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laden, depending on the type of road traffic. Some cases have
been recorded in which from 40 to 80 percent of the single rear
axles are overladen. These are associated with the sand, gravel
or ore haul routes. A trend similar to the single rear axles
is apparent for the tandem rear axles on the sand, gravel and
ore routes. The percentage of overladen axles lies between
about 5 and 20. This reduction in the number of overladen ax-
les could be ascribed to the fact that vehicles with tandem
rear axles are generally used for long-haul transport, and con
sequently they would pass at least one of the weigh bridges,
which are located along the main haul routes. Although the
sample sizes of vehicles with triple rear axles are relatively
small, about 30 percent or more are overladen.

Weigh-In-Motion System (WIM)

The WIM system measures vehicle weights while the vehicles
are travelling at normal highway speeds. It uses two transducer
units, which are built into the road in each wheelpath of a
lane, and induction loops which serve as presence detectors and
which also measure vehicle speeds.

The installations are made on tangential sections of road
which have a grade of less than 1 percent, a smooth surface,
and very little transverse deformation, to avoid problems as a
result of dynamic forces. Six installations have been made
similar to the one shown in Figure 30A.

To initiate measurements, the transducers are placed into
the frame and the wires to the control box are fixed to the
transducers, and the computer is connected to the control box.
After completion of testing, the transducers are removed and
replaced by dummy transducers.

Data collected at two WIM sites were analyzed to give a
frequency distribution of axle loads. A computer program,
which uses the magnetic tape as input, uses either the class of
vehicle written onto the tape by the operator, or the axle con
figuration and spacing to distinguish between the different ve
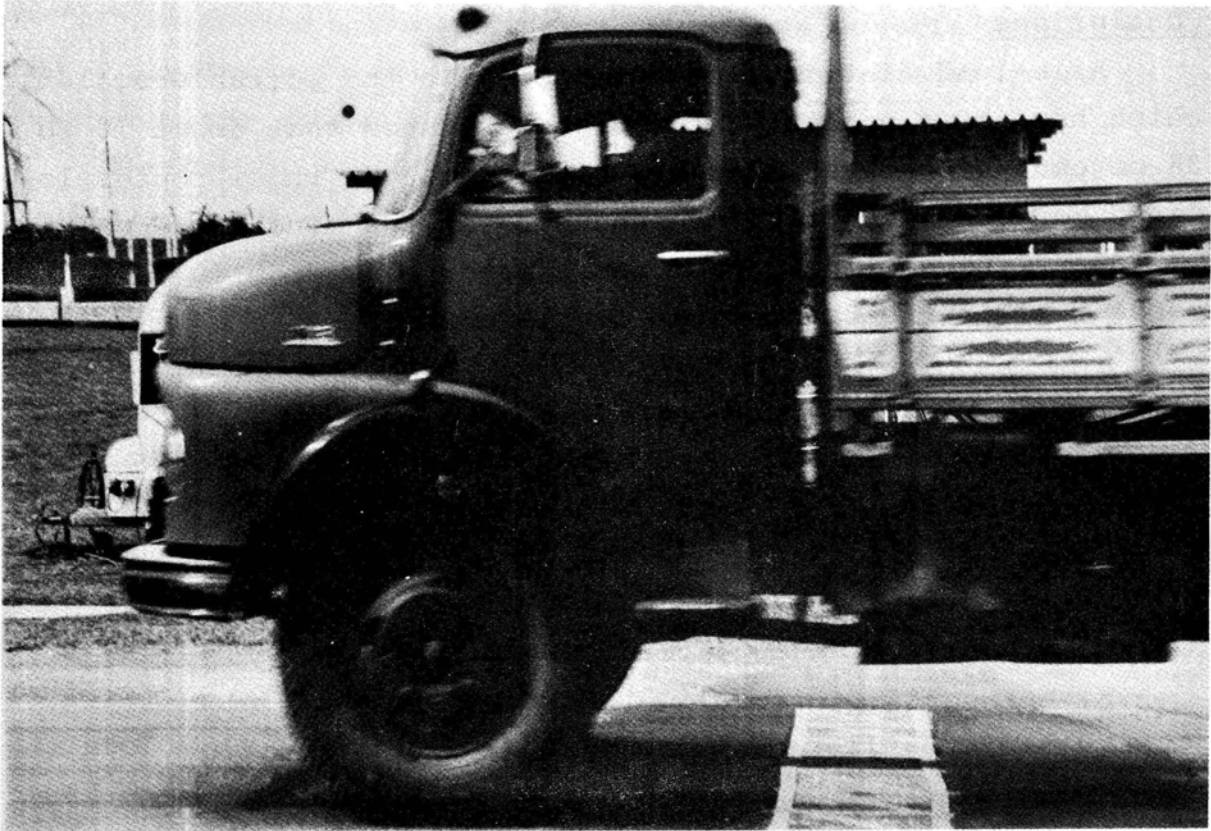hicle classes.

Figure 30A - Vehicle Weighing with Weigh-in-Motion System

A summary of data produced at the two WIM sites again il-
lustrated the severity of overloads. Twenty percent of ap-
proximately 4900 single rear axles were overloaded as were 40%
of some 2000 tandem rear axles card 38% of over 200 triple
rear axles.

Conclusions

Axle-load distribution obtained with the portable scales,
which have been presented for 34 sites, show that about 10 to
35 percent of the vehicles are overladen. On those routes lo-
cated between the gravel or sand pit, or the mine where ore is
mined and the destination of these materials, from 40 to 80
percent of the rear axles are overladen.

MODEL DEVELOPMENT

One of the major activities of the project is the direct adaptation of relationships developed in the project to the latest version of the Highway Design and Maintenance Standards Model (HDM) developed from a combined MIT/TRRL/World Bank effort. Following a number of modifications to this model by the World Bank, it was made available to the project, and is currently operational and being tested in Brazil.

The Brazil version of the model could be directed to any one of a number of planning levels. To illustrate, a subjective scale of sensitivity is shown in Figure 31. At the top end of the scale we show network planning. At this level, the planner wants to establish the character of the links in a state or countrywide analysis. Considered are traffic patterns and benefits resulting when links are added to or improved within the existing network. The number of combinations requiring examination is large, and therefore only the most general evaluation of individual link costs are feasible.

Next we have the selections of alternates, from where it is possible to examine any number of possible paths and roadway standards between two points and select an alternative based on the optimization of a specified value function. In this situation, one expects to evaluate different length routes over different terrain. A moderate level of sophistication is warranted such as predicting earthwork as a function of maximum grades and contour line crossings.

At the project link analysis level, essentially one path is considered. The geometry may be optimized to minimize either construction or total transport costs over the link. One expects a reasonably good description of the terrain, and accuracy sufficient for feasibility estimates of cost.

Finally, a model can be developed to produce essentially final design details suitable for construction plans.

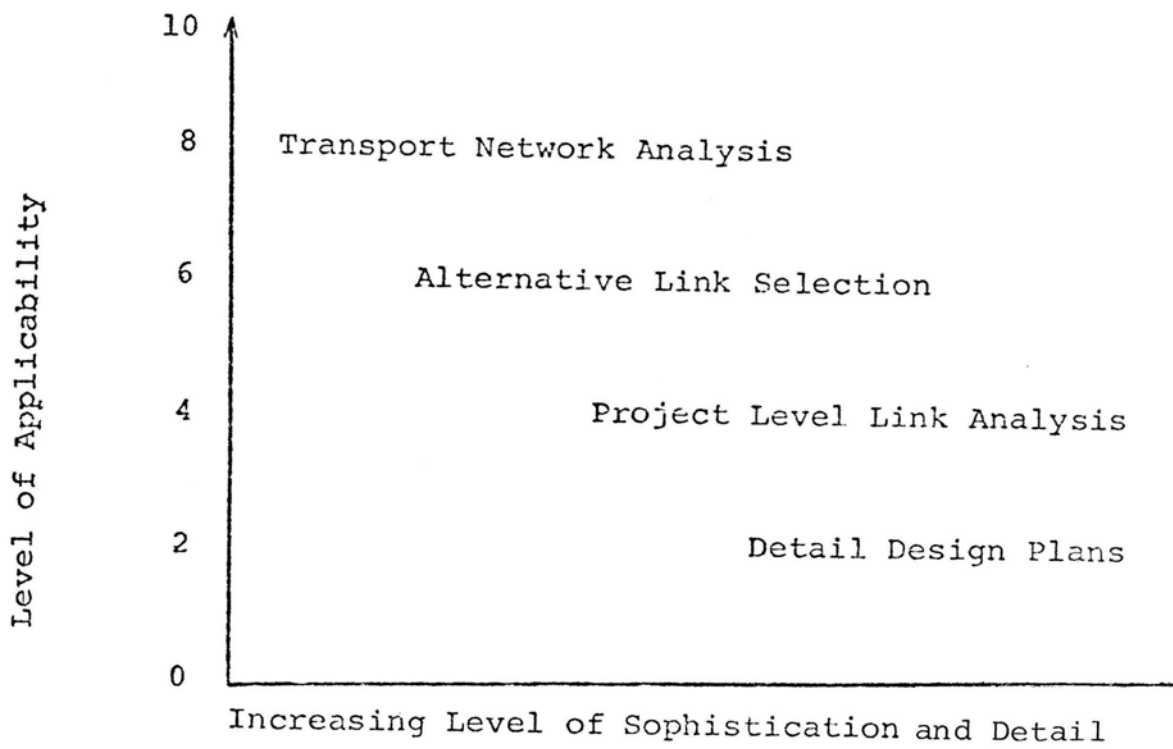The major thrust of the Brazil study is to develop improved

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Figure 31 – Relationship Between Level of Applicability of a Planning Model and the Level of Sophistication Warranted.

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relationships on pavement performance and vehicle operation costs in Brazil. Further, the study has been formulated so that it will be possible to develop routines with details comparable to those used in the TRRL construction subroutines.

Instead of a generalized rise-and-fall index for vertical geometry, plans were formulated to evaluate the influence of in dividual grades on vehicle operation cost. The same was true for horizontal curves. The entire inference space on each experiment was made as wide as possible. A detailed program was outlined to monitor the behavior of pavements receiving two extreme maintenance responses. The objective was to have information at hand to develop relationships which would improve on the sophistication of the maintenance and pavement performance subroutines and the vehicle operating cost routines of the TRRL model.

A construction routine that outputs a description of the roadway link in terms of each grade and horizontal curve is not part of the HDM model, yet the project approach to developing vehicle speed and fuel consumption requires this detail. Also details on terrain will be needed to accomodate a required construction routine.

The HDM model uses average annual daily traffic volumes (AADT). Thus, to handle volume and composition effect on traffic congestion, hourly distributions of traffic by vehicle class are required.

During the conceptualization of this study for the Inception Report (Ref. 6) the TRRL Model was examined as a guide. The level of detail varied considerably within this model, but the construction subroutines were far more sophisticated than either the pavement performance maintenance routines or the user costs routines.

Therefore, it seemed clear that the output of this study would be relationships more detailed and sophisticated than those used in the TRRL pavement and user costs routines, and comparable in detail to the TRRL construction routines.

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Approach

As a result of the work being pursued in Brazil we expect to establish major modifications to some of the relationships used in the existing models. Foremost will be the manner vehicle speeds and fuel consumption are to be handled. Instead of using a single predictor equation for a link or section, we pro pose to simulate the behavior of a vehicle on the study link and develop a continuous speed profile reflecting the impact of changes in vertical and horizontal alignment by vehicle class for given different levels of volume and various vehicle compositions.

Fuel consumption also will be computed in increments and accumulated for every change in speed or mode of operation defined by the speed profile.

The greater number of different classifications of vehicles over a range of loading being studied is expected to produce re lationships covering a wider spectrum of the vehicle stream. Therefore, more classifications of vehicle types will be handled in the model than is currently possible.

A high priority item in this study is the development of information on the utilization rates of vehicles on different roadways. This will have an important impact on determining de preciation rates where almost no information has been developed historically on the influences of the road itself on vehicle utilization.

A completely new set of equations are expected to be devel oped for vehicle maintenance and repair, tire wear and oil consumption, based on the user cost surveys.

New and improved relationships, permitting the impact of various maintenance levels on future pavement performance, are expected to be developed from our pavement performance and maintenance studies.

Thus far, the staff has made very little progress toward actually putting together a Brazil version of the Model. The reason is that higher priority has been assigned to the basic research activities. Each of the three study groups has marsh

alled considerable resources to generate information from which interrelationships on highway construction, maintenance and utilization are to be developed for Brazil. Without these rela tionships, the development of a new planning model is meaning- less. Therefore, it is still necessary to allocate the princi- pal resources of the study to the development of the basic re- lationships needed for the model.

Yet, the final product of this research project will be an operational Highway Investment Model that incorporates the relationships developed during the study. It also will be ne- cessary that the model be documented so that it can be readily modified and updated by Brazilian personnel after the project is complete and the research team is dismantled.

The option to generalize the detailed relationships being developed is always available. However, if the relationships were generalized now, it would not be possible to work back to the detail and sophistication feasible with the data being de- veloped. Therefore, the modeling effort will first be directed towards establishing the detail possible with the data in hand. Next, relationships will be generalized and incorporated into the existing program structure of the HDM. This will represent the first step in adaptation to Brazil conditions. The result- ing model will be called MOBAIR-1 (Modelo Brasileiro para Ava- liação de Investimentos Rodoviários).

Following the initial adaptation process and the creation of MOBAIR-1, further refinements and adaptations will be made. This process will produce subsequent versions of the model, MOBAIR-2, 3 etc. and each new version will attempt to improve the utility of the model to Brazilian needs.

SUMMARY

The research is progressing effectively. Each of the
three principal study groups has refined its field study proce
dures and a comprehensive data collection program is well
underway. The User Cost Surveys Group is generating vehicle
operating-cost data from a wide variety of survey participants
and an average of over 6000 vehicle/months of data covering
different items of user costs are in hand. Detailed inventory
information covering roadway characteristics on over 12000 km
of user surveys routes has been developed by two survey vehi-
cles.

The Road User Costs and Traffic Experiments Group has
identified 22 experiments to be used in developing a determin-
istic model to predict speeds and fuel consumption. Prelimin-
ary equations developed from the fuel data were presented in
this report. A conceptual framework has been developed for a
deterministic model to predict time and fuel consumption, and
various traffic simulation programs are being examined for
use in explaining traffic-composition effects.

The Pavement and Maintenance Studies Group has establish-
ed 116 sections. They have completed roughness, deflection
and condition survey measures on every paved section. Axle-
loading data has been collected on over a third of the sect-
ions and traffic-classification information is currently being
developed.

In summary it can be said that good progress is being made
in the project. Several useful interim results have been de-
veloped and are presented herein.

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