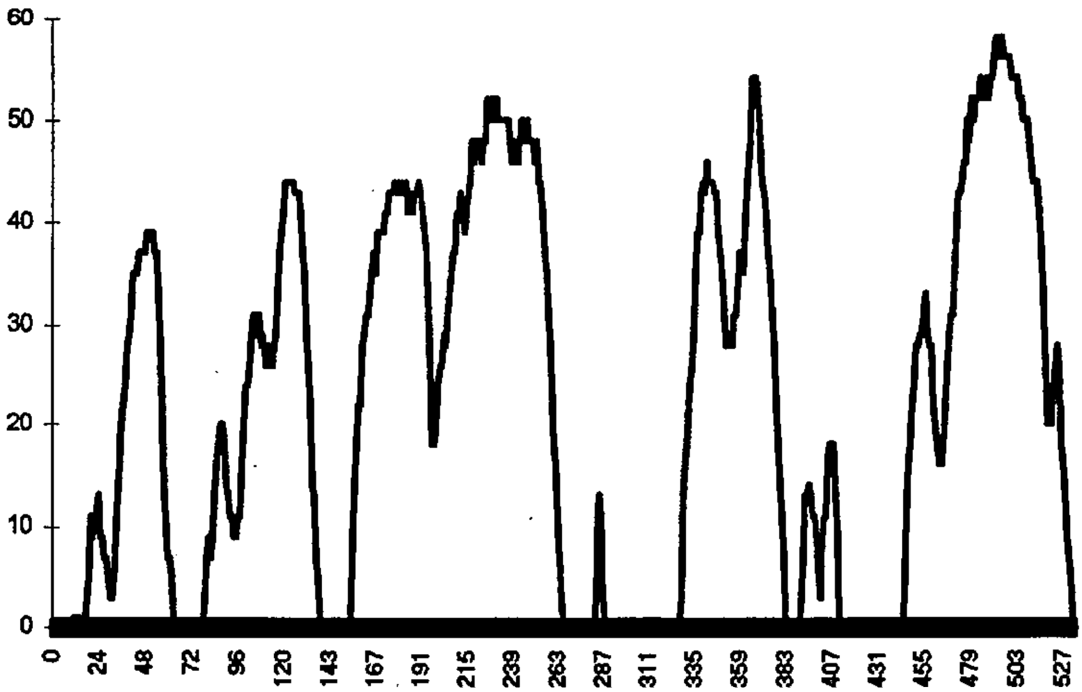
Proceedings from the International Workshop on Vehicle Driving Cycles



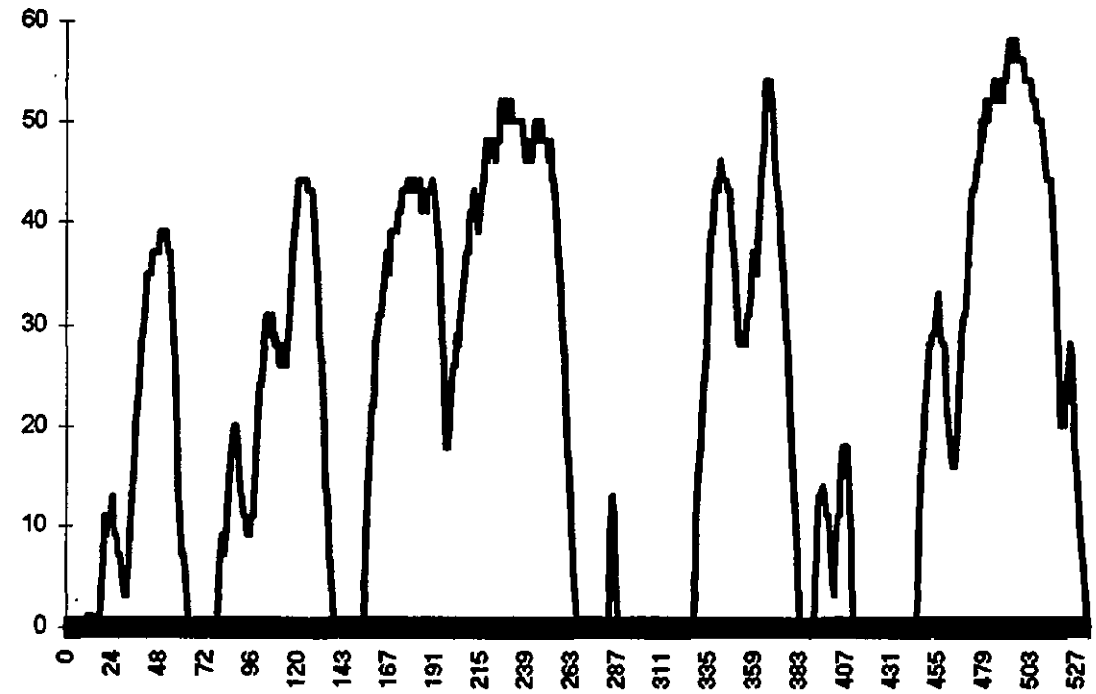
Held at the
Government of Canada Conference Centre
Ottawa, Canada

April 6-7, 1995

Organized by
Gordon Taylor, *Instrumental Solutions*

Sponsored by
Environment Canada
Transport Canada
Natural Resources Canada

COMPTE RENDU DE L'ATELIER INTERNATIONAL SUR LES CYCLES DE CONDUITE DES VÉHICULES



organisé par
Gordon Taylor, *Instrumental Solutions*

etparrainé par
Environnement Canada
Transports Canada
Ressources naturelles Canada

au Centre de conférences du Gouvernement du Canada
à Ottawa

les 6 et 7 février 1995

International Workshop on Vehicle Driving Cycles:

Measurement, Analysis and Synthesis

Government of Canada Conference Centre, Ottawa, CANADA

WORKSHOP PROGRAM

Monday, February 6

Session 1: European Programs

Review of Research on Vehicle Use & Operating Conditions, Michel Andre, INRETS, Lyon, France
Driving Cycle Generation, Jonathan Cohen, Systems Applications International, San Rafael, CA

Session 2: Measurement and Analysis

Characterization of Traffc & Driving Cycle Development, Michel Andre, INRETS, Lyon, France
Torque & Speed Distributions of Commercial Vehicles, Heindrich Steven, FIGE GmbH, Aachen, Germany

Session 3: U.S. Federal Test Procedure Review

Customer Vehicle Driving Surveys, Dennis Fett, Chrysler Corp., Auburn Hills, MI and Glen Heiser, Ford Motor Company, Dearborn, MI
EPA's Augmented FTP Cycle, Jim Markey, US EPA, Ann Arbor, MI

Session 4: California's Driving Analysis Projects

Facility Based Driving Cycles, Larry Larson, California Air Resources Board, Sacramento, CA
Vehicle Activity Monitoring, Augustus Pela, California Air Resources Board, Sacramento, CA

Tuesday, February 7

Session 5: Current Field Studies

Development of an On-board Emission Measurement System, Costa Kaskavaltzis, Ontario Ministry of Transportation, Toronto, ON
Development of Vehicle Driving Cycles for Bangkok, Sandeep Kishan, Radian Corporation, Austin, TX
Using GPS for Speed and Grade Measurement, Ted Younglove, CE-CERT, Riverside, CA
The Atlanta Project, Michael Rogers, Georgia Institute of Technology, Atlanta, GA

WORKSHOP COORDINATOR

Gordon Taylor, ***Instrumental Solutions***, Ottawa, ON

SPONSORS

Environment Canada, Transportation Systems Division
Natural Resources Canada, Transportation Energy Division
Transport Canada, Road Safety & Motor Vehicle Directorate

Atelier international sur les cycles de conduite des véhicules : mesure, analyse et synthèse

Centre de conférences du Gouvernement du Canada, Ottawa

PROGRAMME DE L'ATELIER

Le lundi 6 février

1^{er} séance : Programmes européens

Revue des recherches sur l'utilisation et les conditions de fonctionnement des véhicules, Michel André, INRETS, Lyon (France)
Établissement de cycles de conduite, Jonathan Cohen, Systems Applications International, San Rafael (Californie)

Séance numéro 2 : Mesure et analyse

Caractérisation de la circulation et établissement de cycles de conduite, Michel André, INRETS, Lyon (France)
Répartitions du couple et du régime moteur des véhicules commerciaux, Heindrich Steven, FIGE GmbH, Aachen (Allemagne)

Séance numéro 3 : Revue des méthodes d'essai de l'EPA des États-Unis

Enquêtes auprès de la clientèle sur la conduite des véhicules, Dennis Fett, Chrysler Corp., Auburn Hills (Michigan) et Glen Heiser, Ford Motor Company, Dearborn (Michigan)
Augmentation du cycle suivant les méthodes d'essai de l'EPA, Jim Markey, EPA, Ann Arbor (Michigan)

Séance numéro 4 : Projets californiens d'analyse de la conduite

Cycles de conduite fondés sur les équipements, Larry Larson, California Air Resources Board, Sacramento (Californie)
Surveillance de l'activité des véhicules, Augustus Pela, California Air Resources Board, Sacramento (Californie)

Le mardi 7 février

Séance numéro 5 : Études actuelles sur le terrain

Conception d'un système de bord de mesure des émissions, Costa Kaskavaltzis, ministère ontarien des Transports, Toronto (Ontario)
Établissement de cycles de conduite des véhicules pour Bangkok, Sandeep Kishan, Radian Corporation, Austin (Texas)
Utilisation du GPS pour mesurer la vitesse et la déclivité, Ted Younglove, CE-CERT, Riverside (Californie)
Le projet d'Atlanta, Michael Rogers, Georgia Institute of Technology, Atlanta (Géorgie)

COORDONNATEUR DE L'ATELIER
Gordon Taylor, *Instrumental Solutions,* Ottawa (Ontario)

PARRAINS
Environnement Canada, Division des systèmes de transport
Ressources naturelles Canada, Division de l'énergie reliée aux transports
Transports Canada, Direction générale de la sécurité routière et des véhicules automobiles

Workshop on Vehicle Driving Cycles

Executive Summary

Environment Canada, Transport Canada and Natural Resources Canada all are involved in the development of regulatory framework for vehicles and in the analysis of the impact of vehicle usage. This Workshop was sponsored by the Departments as part their activities in developing an overall plan to collect better information on vehicle demographics and assess the technology and analytical techniques that are being used in other countries for vehicle surveys. The Workshop was also aimed at transferring this information to Canadian companies and developing better networking between researchers in the area. The Workshop was attended by over 64 researchers and analysts with approximately half of the attendees non- Canadian. Almost all of the non-Canadian attendees were from the U.S. (France and Germany were also represented). The organizations represented included Government program officers, research laboratories, universities and consulting engineering firms.

The measurement and characterization of vehicle use is an essential element in the development of testing procedures and regulations of vehicles and for the accurate estimation of emissions inventories. Whether the objective is the analysis of vehicle emissions, energy, and safety, it is impossible to develop a mathematical representation of driving without substantial amounts of data from vehicles in real-world driving conditions.

In the past few years, a number of regulatory development activities in Europe and North America have lead to a number of vehicle surveys. At the same time, advancements in electronics have allowed an increased amount of data to be collected at ever decreasing costs. The problem that is now presenting itself, is how this mass of data should be analyzed and further, how driving cycles should be developed from this statistical database. It is a complex mathematical challenge to come up with a sampling and statistical reconstruction approach which will provide a good replication of driving from a variety of viewpoints, such as emissions, energy, noise and safety.

This two day Workshop focussed on the experience to date of a variety of researchers in measuring driving and on the mechanics of creating driving cycles from raw data, specifically with emission characterization work in mind.

The Workshop was opened by a overview paper by **Michel André** from **INRETS** who had undertaken the work on behalf of the European Union's COST program (European Co-operation in the field of Scientific and Technical Research). His work found a variety of methods being used to collect activity and vehicle operational data in Europe, Scandinavia, North America and Australia. Data were collected through questionnaire surveys (travel diaries or recall), during compulsory vehicle inspections (odometer), traffic studies (road side and floating vehicle), and on-board measuring equipment. His presentation provided a topology of parameters against measurement method and some comments on the development of driving cycles from the collected data.

Jonathan Cohen from **Systems Applications International** reviewed his work on developing statistical methods for deriving driving cycles from vehicle data which had been undertaken for light duty vehicles with the USA and for the heavy duty vehicles for Transport Research Lab (UK) as part of a European initiative. The method involves dissecting the speed trace data into modal segments and then developing a probability model of modal segment progression. The driving cycle is then constructed using a series of statistical rules and smoothing of connected segments (mean speed, mean torque, duration, initial/final speed). Data on the summary cycles developed for the heavy duty vehicles were presented in terms of density plots of normalizes RPM and torque.

Michel André of **INRETS** presented his work on driving cycle development which has been based on monitoring driving of some 151 vehicles over the last decade in France and other parts of Europe. The statistical methods developed used factor analysis and principal component techniques based on sequences (stop to stop portions of the trip) . The cycles are synthesized using stochastic progression rules obtained from analysis of the raw data for each of a series of sequence types. The method uses actual speed trace segments obtained from a "library" compiled from the raw data. The method also uses a post classification of the driving into four classes of road structure and volume (congested urban, free-flow urban, road traffic, motorway). The latest work (DRIVE-modem project) has developed a driving cycle which represents light duty vehicle driving consisting of a series of 14 cycles totalling 36 km and 90 minutes of driving.

German research and development of a heavy duty engine test cycle was discussed by **Hienz Steven** from **FIGE**. They analyzed speed and torque data was analyzed from 26 heavy duty vehicles operating in Germany. The mathematical presentation of these data was in the form of distribution plots of the percentage of total time at various normalized engine speed and engine torque (percentage of maximum or rated in each case) ranges. The engine torque information was obtained by correlation to injector rack position. The data were compared with both the current EU and EPA testing regulations and indicated that on-road driving was significantly different than either of these tests and also between various duty cycle groups (buses, urban trucks, long distance trucks, etc.). A series of six road type classifications were proposed to adequately cover the range of vehicle operations: motorway, rural main roads, rural two lane roads, suburban main roads, urban main roads with >300 m between stops, and urban roads with short distances between stops. An actual test speed/torque trace was constructed by selecting typical segments from data representing the six road classes and blending them into a new composite cycle that has been proposed as a replacement for the current ECE test cycle (13 mode).

Dennis Fett (Chrysler) and **Glen Heiser (Ford)** described the data collection and results of a instrumented vehicle survey of 293 vehicles in Baltimore and Spokane in 1992. Two types of instrumentation were used: a three channel (road speed, engine speed, and MAP) and a six channel recorder system (road speed, engine speed, MAP, A/F, throttle position, and engine temperature). The participants' vehicles were instrumented and then driven for a one week period. The data collected was compared to the existing Federal Test Procedure driving cycle primarily by speed/acceleration distribution comparisons. The field data collected indicated significantly higher power and speed operating states than that in the FTP. Presentations of the comparison of the data to a number of other test cycles was also provided.

EPA's analysis of the Baltimore/Spokane survey data was presented by **Jim Markey** of the Ann Arbor Laboratories. The work was undertaken as a regulatory review requirement by the U.S. Congress and the notice of proposed rule making had just been published the week before this Workshop. The Baltimore data along with data collected in Los Angeles by CARB was used for the synthesis of new augmentations to the current FTP cycle. The approach was to use micro-trip data and build a trace that matched the in-use distributions of speeds and accelerations. Other limitations incurred in developing the cycle were discussed. A prime factor was identified as a need to constrain the overall duration of test so that the cost and testing burden could be minimized. The mathematical method used was a quasi-random method employing a "seed" microtrip and an incremental selection of the subsequent micro-trip segments. The new cycles assessed represented a start sequence, high speed/accel ,remnant cycle and CARB cycle. A five minute additional test cycle was proposed to address driving behaviour that is not represented in the current FTP.

The development of **CARB**'s facility type specific emission factors and models was the subject of **Larry Larson**'s presentation. The model development is aimed at creating a method to estimate the emission rates from the roadway at various levels of congestion and facility type. As emission rates are non-linear with respect to speed, a simple factoring of FTP-based emission factors will not provide as accurate an estimate as a more modal model. Using chase car data, speed/accel characteristics for a variety of road structures were developed. The data collected was lacking in a direct measure of road congestion level and cross-linkage to link data on the road network. However, a clearly different driving cycle was seen on freeways compared to arterial roads. The data was segmented by driving "snippets" by road characteristics (length, structure, congestion) and cycles were created using stochastic methods to link snippets and event data. The analysis has created seven cycles for freeway traffic and three cycles for arterial roads. The cycles define a driving pattern at various ranges of congestion and have significantly different statistics one to another and compared to the FTP Bag 2. Further work is expected to provide better linkages to the physical network. To obtain better traffic density data and speed data, and to collect other data on a link basis that can be used for selecting the most representative cycle.

Augustus Pela from **CARB** discussed their work on monitoring driving activity. This effort is a follow on to the driving cycle data collection projects of EPA and CARB. It is intended to expand the statistical accuracy of data on driving activity and collect data on time, distance, speeds, and if possible, location or facility type. Phase 1 which is methodology report has been completed in draft and will be the basis for a Phase 2 large scale data collection effort to start later in 1995. The data are expected to provide more details on the soak cycles, duty cycles and temporal and spatial difference in driving between northern and southern California.

Kosta Kaskavaltzis with the **Ontario Ministry of Transportation** discussed their development of an instrumented vehicle capable of measuring emissions in real-time. The system is installed in a flexible fuel 1991 Lumina and uses the sensor inputs from the vehicle to calculate mass flow (MAP+ fuel flow) and merges this data with the real-time concentration data from HC, CO, CO_2 and NO analyzers. The vehicle has had correlation tests completed using a CVS dyno cell and the data presented indicated good correlation between the two measurement systems. The vehicle will be used for consumer driving data collection and to do verification tests of Ontario's I/M pilot program. Further research into the measurement of grade, better NO/NOx sensors and the effects of methanol blends is planned.

Sandeep Kishan provided an overview of work that **Radian Corp.** is undertaking in Bangkok aimed at developing and emission control program. They have used the three parameter data loggers developed for the EPA program to instrument 15 cars and 10 motorcycles. The data collected were compared to the Baltimore/Spokane database and indicated a much lower speed distribution for cars and a more similar speed distribution for motorcycles in Bangkok. The datasets were compared using speed/acceleration distribution plots (Watson plots) which appear to be the most commonly used statistical measure. The project in Bangkok will develop a control program including test cycle development for passenger cars and motorcycles. More vehicles will be instrumented and it is hoped that diesels can be monitored for PM10 emissions in the future.

Ted Younglove from the **University of California at Riverside's College of Engineering - Centre for Environmental Research and Technology** (CE-CERT) presented information on their experience in using Global Positioning System (GPS) hardware to provide location, speed and grade information on vehicle use. The data collected by GPS was compared to information supplied by the vehicle's on-board data system (a Ford Taurus with a Ford Research Console (RCON) installed). The comparison of speed indicated a very good correlation, with acceleration correlation somewhat poorer. The GPS was also able to provide a better measure of road grade than the RCON unit. Discussion of the problems of GPS included the high price for high resolution equipment, linking to GIS databases, the loss of signal during driving (bridges, buildings, etc.). The largest issue was the cost of post-processing the real-time data to GIS data to correlate driving with road facility type.

The extensive emission modelling effort in the Atlanta area was discussed by **Mike Rogers** from **Georgia Tech**. This program includes measurement of driving by instrumentation, remote sensing of emissions and the development of integrated emissions and transportation models. He reviewed the sources of data that they compiled to characterize driving including correlation of individual driver technique differences such as throttle roughness. They have started to develop a vehicle performance model based on normalized road or engine power which in turn could be related to emission rates, especially for enrichment events. The objective of the work was to develop a modal based model that allowed for modular enhancement and modification and used data that was typically available or able to be collected with reasonable levels of effort and cost.

Summary Observations:

1. The work presented at the sessions represented the state-of-the-art vehicle data collection and analysis projects from several countries.

2. The recent activity can be segmented into two major areas of interest:
    1. development of in-use driving cycles for the regulation of vehicle emissions and fuel consumption, and
    2. the analysis of driving to develop improved estimates of the impacts (emissions primarily) of vehicle use.

    In both areas, the understanding and accuracy is restricted by the relatively limited number of vehicles that have be monitored to date, and the length of time they have been observed.

3. All the work presented at the Workshop, was based the cycle development on post analysis of continuous (1Hz) data obtained from the monitored vehicles. While other parameters were collected in many of the studies, only time and distance (speed/acceleration) were used for the development of the light duty vehicle test and modelling cycles.

4. In developing representative cycles, there appears to be some degree of consensus that the process consists of :
   - segmentation of the speed trace data into modes of operation,
   - statistical aggregation these modes by frequency and by progression probability, and
   - stochastic reconstruction cycles using typical snippets of actual driving trace.

   There are a number of approaches for this segmentation and reconstruction. However, they are all derived from the original trace data using relatively simple distribution matrices of speed and acceleration. This may lead to an ability to process data real-time on the vehicle and thus reduce the size of data files that need to be collected.

5. A number of the studies had the purpose of locating the driving by the type of road structure characteristics (road class, grade, link, etc.) and there would appear to be a number of projects underway or in the planning stages, which will attempt to merge emission models with transportation planning and engineering models (traffic flow and demand models). As these studies are completed, better analyses of the emission impact of congestion and traffic control facilities and structures will be possible. Methods for classifying congestion or linking to road volume information in real-time were mentioned as being lacking in this research area.

6. The measurement of engine power is a significant problem in most studies and is usually estimated by relating engine speed and manifold pressure (or injector position in diesels). It should be possible to obtain direct measurement of engine output from a number of the computer control systems installed as original equipment by the manufacturers. Effort should be placed on documenting the type and locations of imbedded signals that are available from the variety of vehicles on the road at present, in order to decrease the cost of instrumentation.

7. The measurement of road grade was another parameter that a number of researchers had tried to collect. GPS appears to provide a good measure of grade and speed but has a high unit cost and will frequently suffer from signal loss. The testing and selection of inexpensive grade measurement systems (e.g., atmospheric pressure) could assist the research community in providing a more complete instrumentation package.

8. The largest restriction in the work appears to be the limited number of vehicles from which data has been collected. If the sample size is to be increased, lower cost instrumentation techniques will be needed as well as the development of mathematical techniques to reduce the amount of continuous data collected (or improved post processing methods). In this regard, the requirement for collecting location information along with performance data is a significant issue for which there was no clear consensus.

Overall the Workshop, appeared to highly successful in presenting the current activities and analysis techniques in measuring vehicle usage. The network of researchers has been strengthened which should lead to more cooperation between programs and individuals in the future. A repeat of this type of gathering will be warranted within the next two years as studies currently underway or planned are completed.

ATELIER SUR LES CYCLES DE CONDUITE DES VÉHICULES

Sommaire

Environnement Canada, Transports Canada et Ressources naturelles Canada participent tous à la mise au point d'un cadre de réglementation pour les véhicules et à l'analyse des répercussions de l'utilisation des véhicules. Ces ministères ont parrainé l'atelier dans le cadre de leurs activités de conception d'un plan global pour collecter de meilleures données sur la démographie des véhicules et pour évaluer les technologies et les techniques analytiques auxquelles on a actuellement recours dans d'autres pays afin de réaliser des enquêtes sur les véhicules. L'atelier visait aussi à communiquer ces données à des entreprises canadiennes et à développer de meilleurs réseaux entre les chercheurs qui travaillent dans le domaine. Plus de 64 analystes et chercheurs ont participé à l'atelier; environ la moitié des participants à ce dernier n'étaient pas Canadiens. Presque tous les participants qui n'étaient pas Canadiens venaient des États-Unis (la France et l'Allemagne y étaient aussi représentées). Les organisations qui y avaient délégué des représentants incluaient des services gouvernementaux, des laboratoires de recherche, des universités et des cabinets d'ingénieurs-conseils.

Il faut absolument mesurer et caractériser l'utilisation des véhicules afin d'élaborer des méthodes d'essai et des dispositions réglementaires pour les véhicules et afin d'évaluer avec précision les volumes des émissions. Qu'il s'agisse d'analyses des émissions, de la consommation d'énergie ou de la sécurité des véhicules, il est impossible d'établir un modèle de représentation mathématique de la conduite automobile sans disposer d'énormes quantités de données collectées à partir des véhicules dans les conditions réelles de conduite.

Ces dernières années, l'élaboration d'un certain nombre de règlements en Europe et en Amérique du Nord a entraîné la réalisation d'enquêtes sur les véhicules. Les progrès en électronique ont, en même temps, permis de collecter plus de données à des coûts de moins en moins élevés. Le problème qui se pose aujourd'hui consiste à déterminer comment on devrait analyser cette masse de données et à déterminer également comment il faudrait s'y prendre pour définir des cycles de conduite au moyen de cette base de données statistiques. Il s'agit là d'une tâche mathématique complexe qui nécessitera une méthode d'échantillonnage et de reconstruction statistique qui puisse fournir une bonne reproduction de la conduite dans une foule d'optiques, comme celles des émissions, de la consommation d'énergie, du bruit et de la sécurité.

L'atelier, qui a duré deux jours, a été axé sur l'expérience acquise jusqu'ici par une multitude de chercheurs qui s'emploient à mesurer la conduite et sur la mécanique de l'établissement de cycles de conduite au moyen de données brutes, surtout sous l'angle des recherches sur la caractérisation des émissions.

L'atelier a débuté par un aperçu des recherches de **Michel André**, de l'INRETS, qui les avait entreprises pour le compte des responsables du programme COST (Coopération européenne dans le domaine de la recherche scientifique et technique) de l'Union européenne. M. André a constaté dans le cadre de son travail qu'on utilise bien des méthodes différentes pour

collecter des données sur l'activité et le fonctionnement des véhicules en Europe, en Scandinavie, en Amérique du Nord et en Australie. On a collecté des données au moyen d'enquêtes par questionnaire (carnets de route ou rappel), durant des inspections obligatoires de véhicules (des compteurs kilométriques) et à l'aide d'études sur la circulation (en bordure de route et en véhicule flottant) et d'équipement de bord servant à effectuer des mesures. M. André a présenté dans son exposé une topologie des paramètres pour définir une méthode permettant de mesurer la conduite et a formulé des commentaires sur l'établissement de cycles de conduite au moyen des données collectées.

Jonathan Cohen, de Systems Applications International, a passé en revue ses recherches sur l'élaboration de méthodes statistiques pour définir des cycles de conduite à partir de données sur les véhicules, recherches qu'il avait entreprises dans le cas des véhicules légers avec les États-Unis et dans celui des véhicules lourds pour Transport Research Lab (du Royaume-Uni) dans le cadre d'un projet européen. Sa méthode suppose la dissection des données sur la courbe des vitesses en segments modaux, puis la conception d'un modèle probabiliste de la progression de ces segments. Elle suppose ensuite l'établissement du cycle de conduite à l'aide d'une série de règles statistiques et d'un lissage des segments reliés (vitesse moyenne, couple moyen, durée et vitesse initiale/ finale). M. Cohen a présenté ses données sur les cycles sommaires définis pour les véhicules lourds sous forme de tracés de densité des régimes et des couples normalisés.

Michel André, de l'INRETS, a fait part de ses recherches sur l'établissement de cycles de conduite, qui ont reposé sur la surveillance de la conduite de quelque 151 véhicules au cours des dix dernières années en France et dans d'autres régions d'Europe. Les méthodes statistiques qu'il a élaborées faisaient appel à l'analyse des facteurs et aux techniques des composantes principales fondées sur les séquences (les parties d'un déplacement entre les arrêts). M. André synthétise les cycles à l'aide de règles stochastiques de progression établies à partir d'une analyse des données brutes pour chaque série de types de séquences. Sa méthode fait appel à des segments de la courbe des vitesses réelles obtenus à partir d'une «bibliothèque» compilée en se servant des données brutes. Sa méthode fait aussi appel à une classification postérieure de la conduite en quatre classes suivant l'ouvrage routier et le débit (urbain-encombré, urbain-fluide, trafic routier et autoroute). M. André a défini dans le cadre de ses plus récentes recherches (le projet de modem du programme DRIVE) un cycle de conduite. Ce cycle, qui représente la conduite de véhicules légers, se compose d'une série de 14 cycles totalisant une distance de 36 km et une durée de 90 minutes.

Heindrich Steven, de FIGE, a traité des travaux de recherche et de développement réalisés en Allemagne en rapport avec un cycle d'essai de moteurs de grande puissance. On y a analysé des données sur les régimes et les couples collectées à partir de 26 véhicules lourds utilisés sur les routes allemandes. La présentation mathématique de ces données revêtait la forme de tracés de répartition du pourcentage du temps total à différents niveaux du régime et du couple moteur normalisés (le pourcentage au régime maximal ou nominal et au couple maximal ou nominal dans chaque cas). On a collecté de l'information sur le couple moteur par corrélation avec la position des supports des injecteurs. On a comparé les données aux règles actuelles régissant les essais de l'UE et de l'EPA et observé que la conduite sur route était bien différente de l'un et l'autre de ces essais et aussi entre divers groupes de cycles d'utilisation (autobus, camions urbains, camions longue distance, etc.). On a proposé six classifications relativement aux types de routes pour englober adéquatement la gamme de celles qu'empruntent les véhicules : les autoroutes, les routes rurales principales, les routes rurales à deux voies, les routes principales de banlieue, les routes urbaines principales où la distance entre les arrêts est de plus de 300 m et les routes urbaines où la distance entre les arrêts est courte. On a établi une courbe réelle des régimes et des couples d'essai en choisissant des segments typiques à partir de données représentant les six catégories de routes et en les intégrant à l'intérieur d'un nouveau cycle composite qu'on propose pour remplacer le cycle d'essai actuel de la CEE (13 modes).

Dennis Fett (de Chrysler) et **Glen Heiser** (de Ford) ont décrit la collecte de données et les résultats d'une enquête effectuées en 1992 à l'aide de 293 véhicules équipés d'instruments à Baltimore et à Spokane. On y a utilisé deux types de systèmes : un système d'enregistrement automatique à trois voies (pour la vitesse de croisière, le régime et la pression absolue dans la tubulure d'admission) et un système d'enregistrement automatique à six voies (pour la vitesse de croisière, le régime du moteur, la pression absolue dans la tubulure d'admission, la proportion d'air et de carburant, la position du papillon et la température du moteur). On a équipé d'instruments les véhicules des participants, qui les ont ensuite conduits pendant une semaine. On a comparé les données collectées au cycle de conduite actuellement établi pour la méthode d'essai de l'EPA surtout en comparant la répartition des vitesses et des accélérations. Les données collectées sur le terrain ont révélé des états de fonctionnement pour la puissance et la vitesse plus élevés que dans la méthode susmentionnée. MM. Fett et Heiser ont aussi dans leur exposé comparé les données à un certain nombre d'autres cycles d'essai.

L'analyse effectuée par l'EPA des données de l'enquête réalisée à Baltimore et à Spokane a été présentée par **Jim Markey**, des laboratoires d'Ann Arbor. À noter qu'il s'agissait d'une exigence formulée aux termes de l'examen de la réglementation par le Congrès américain et que l'avis de projet de réglementation avait été publié la semaine même précédant l'atelier. Les données collectées à Baltimore et celles rassemblées à Los Angeles par le CARB ont servi à la synthèse de nouveaux ajouts au cycle actuellement établi pour la méthode d'essai de l'EPA. La méthode consistait à utiliser des données sur des microdéplacements et à construire une courbe mariant les répartitions en usage des vitesses et des accélérations. Les présentateurs ont traité d'autres limites qui sont apparues lors de l'établissement du cycle. Ils ont défini que l'un des principaux facteurs à considérer était la nécessité de restreindre la durée globale d'un test de façon à pouvoir réduire au minimum son coût et le fardeau des essais. La méthode mathématique utilisée était une méthode quasi probabiliste faisant appel à un microdéplacement «initial» et à une sélection différentielle des segments subséquents du microdéplacement. Les nouveaux cycles évalués représentaient une séquence de démarrage, un cycle de vitesses et d'accélérations élevées et le cycle du CARB. On a proposé un cycle d'essai additionnel de cinq minutes pour étudier le comportement en matière de conduite qui n'est pas représenté dans l'actuelle méthode d'essai de l'EPA.

L'exposé de **Larry Larson** portait sur l'établissement de facteurs et de modèles d'émissions propres aux types d'installations du CARB. L'établissement de modèles vise à concevoir une méthode d'évaluation des taux d'émission à partir de la route à différents niveaux d'encombrement et suivant le type d'équipement ou d'installation. Étant donné que les taux d'émission ne sont pas linéaires par rapport à la vitesse, une factorisation simple des facteurs d'émission fondés sur la méthode d'essai de l'EPA ne peut fournir une estimation aussi exacte qu'un modèle plus modal. À l'aide de données obtenues à partir d'automobiles suiveuses, on a défini les caractéristiques des vitesses et des accélérations pour une foule d'ouvrages routiers. Les données collectées ne suffisaient pas à mesurer directement le niveau d'encombrement et d'interliaison pour relier les données au réseau routier. On a cependant constaté un cycle de conduite manifestement différent sur les autoroutes par rapport aux voies à grande circulation. Les données ont été segmentées par «fragments» de conduite suivant les caractéristiques d'une route (sa longueur, sa structure et son encombrement) et on a établi des cycles à l'aide de méthodes stochastiques pour relier les fragments et les données sur les événements. L'analyse a permis d'établir sept cycles pour la circulation sur les autoroutes et trois cycles pour celle sur les grandes voies de circulation. Les cycles définissent un profil de conduite à différents niveaux d'encombrement et donnent des statistiques grandement différentes d'un à l'autre et comparativement au «Bag 2» de la méthode d'essai de l'EPA. On devrait réaliser d'autres travaux pour établir de meilleurs liens avec le réseau physique, pour obtenir de meilleures données sur les densités de la circulation et les vitesses et pour collecter suivant les liens d'autres données qui pourront servir à sélectionner le cycle le plus représentatif.

Augustus Pela, du CARB, a traité de son travail de surveillance de la conduite qui fait suite aux projets de collecte de données sur les cycles de conduite de l'EPA et du CARB. Ce travail vise à accroître la précision statistique des données sur la conduite et à collecter des données sur le temps, la distance, les vitesses et, si possible, l'emplacement ou le type d'équipement ou d'installation. On a achevé la rédaction de l'ébauche du rapport de la méthodologie utilisée, qui constituait la première phase du travail et qui servira de fondement à la phase 2, celle de la collecte sur une grande échelle de données; cette phase doit débuter plus tard en 1995. Les données devraient fournir plus de détails sur les cycles d'imbibition, les cycles d'utilisation et les différences temporelles et spatiales en matière de conduite entre le nord et le sud de la Californie.

Kosta Kaskavaltzis, du ministère ontarien des Transports, a traité de la mise au point par ce dernier d'un véhicule équipé d'instruments permettant de mesurer en temps réel les émissions. Le système en question, qui est installé à bord d'un véhicule polycarburant Lumina 1995, fait appel aux données des capteurs du véhicule pour calculer le débit-masse (la pression absolue dans la tubulure d'admission + le débit - carburant) et fusionne ces données avec les données sur la concentration en temps réel provenant d'analyseurs des HC, du CO, du CO_2 et du NO. On a fait effectuer au véhicule des essais de corrélation à l'aide d'une capsule dynamométrique de mesure à volume constant; les données présentées montraient l'existence d'une bonne corrélation entre les deux systèmes de mesure. Le véhicule servira à collecter des données sur les habitudes de conduite des consommateurs et à effectuer des essais de vérification du programme pilote de surveillance et d'entretien de l'Ontario. On prévoir effectuer des recherches plus poussées sur la mesure de la déclivité, de meilleurs détecteurs de No et de NOx et les effets des mélanges de méthanol.

Sandeep Kishan a livré un aperçu du travail que Radian Corporation réalise actuellement à Bangkok et qui vise à mettre sur pied un programme de lutte contre les émissions. L'entreprise a utilisé les consignateurs de données à trois paramètres mis au point pour le programme de l'EPA afin d'équiper d'instruments 15 voitures et 10 motocyclettes. Elle a comparé les données collectées à celles de la base de données rassemblées à Baltimore et à Spokane et a fait état à Bangkok d'une répartition des vitesses beaucoup plus faible pour les voitures et d'une répartition des vitesses plus similaire pour les motocyclettes. Elle a comparé les ensembles de données à l'aide des tracés de répartition des vitesses et des accélérations (les tracés de Watson), qui semblent la mesure statistique la plus couramment utilisée. Le projet réalisé à Bangkok conduira à la conception d'un programme de lutte contre les émissions, y compris à l'établissement d'un cycle d'essai pour les voitures particulières et les motocyclettes. On y équipera d'instruments davantage de véhicules et on espère pouvoir à l'avenir y contrôler les émissions de PM 10 des diesels.

Ted Younglove, du Centre for Environmental Research and Technology du Riverside College of Engineering (CE-CERT) de l'Université de la Californie, a livré un exposé sur l'expérience de son établissement dans l'utilisation du matériel du système de positionnement global (GPS) pour fournir de l'information sur l'utilisation des véhicules se rattachant à l'emplacement, à la vitesse et à la déclivité. On y a comparé les données collectées à l'aide du GPS à celles fournies par le système de données installé à bord d'un véhicule Ford Taurus sur lequel a été installé un pupitre de recherche de Ford (RCON). La comparaison des vitesses a révélé une très bonne corrélation dans leur cas et une corrélation quelque peu moins bonne dans le cas des accélérations. Le GPS a aussi permis de mieux mesurer la déclivité des routes que le RCON. M. Younglove a traité des problèmes posés par le GPS, y compris le prix élevé du matériel à haute résolution, la liaison avec les bases de données du système d'information géographique et la perte du signal durant la conduite (à cause des ponts, des édifices, etc.). Le problème le plus important était le coût du post-traitement des données en temps réel suivant les données du système susmentionné pour établir une corrélation entre la conduite et le type d'équipement routier.

Mike Rogers, du Georgia Institute of Technology, a traité du vaste programme de modélisation des émissions dans la région d'Atlanta. Ce programme vise entre autres à mesurer la conduite à l'aide d'instruments, à détecter à distance les émissions et à élaborer des modèles intégrés des émissions et des transports. M. Rogers a passé en revue les sources de données que son établissement a compilées pour caractériser la conduite, ce qui incluait la corrélation des différences entre les techniques des conducteurs, comme l'actionnement avec rudesse du papillon. Son établissement a commencé à concevoir un modèle de la performance des véhicules fondé sur la puissance motrice et la puissance de croisière normalisées, ce qui, en retour, pourrait être relié aux taux d'émission, surtout en cas d'enrichissements. La recherche avait pour but de concevoir un modèle modal destiné à permettre des améliorations et des modifications modulaires et faisant appel à des données généralement disponibles ou pouvant être collectées, sans que cela ne nécessite des efforts et des coûts déraisonnables.

Résumé des observations

1. Les travaux présentés lors des séances représentaient les projets de collecte et d'analyse de données sur les véhicules à la fine pointe de la technologie de plusieurs pays.

2. On peut fragmenter les récents travaux en deux principaux domaines d'intérêt :
   1. la définition des cycles de conduite en usage pour la réglementation des émissions des véhicules et la consommation de carburant; et
   2. l'analyse de la conduite pour établir de meilleures estimations des répercussions (surtout des émissions) de l'utilisation des véhicules.

Dans les deux cas, le nombre relativement limité de véhicules qui ont jusqu'ici été observés et la période de temps durant laquelle ils l'ont été restreignent la compréhension et la précision des résultats.

3. Tous les travaux présentés à l'atelier reposaient sur la définition de cycles à partir d'une analyse postérieure de données continues (1Hz) obtenues à l'aide des véhicules observés. Même si on a rassemblé d'autres paramètres dans nombre des études, on n'a utilisé que le temps et la distance (vitesse / accélération) pour l'établissement des cycles d'essai et de modélisation des véhicules légers.

4. Pour ce qui est de l'établissement de cycles représentatifs, on semble dans une certaine mesure s'entendre pour dire que le processus consiste :

   - en une segmentation en modes de fonctionnement des données sur la courbe des vitesses;
   - en un regroupement statistique de ces modes par fréquence et par probabilité de progression; et
   - en une reconstruction stochastique des cycles à l'aide de fragments typiques de la courbe de conduite réelle.

   Il existe un certain nombre d'approches ou de méthodes pour réaliser cette segmentation et cette reconstruction. Toutes sont cependant dérivées des données de la courbe de départ et font appel à des matrices relativement simples de répartition des vitesses et des accélérations, ce qui peut permettre de traiter les données en temps réel sur les véhicules et de réduire ainsi la taille des fichiers des données qu'il faut collecter.

5. Un certain nombre des études visaient à établir la corrélation entre le cycle de conduite et les caractéristiques de l'ouvrage routier (la classe d'une route, la déclivité, la liaison, etc.); il semble en outre qu'il y ait un certain nombre de projets en cours ou à l'étape de la planification qui auront pour objet de fusionner des modèles des émissions avec des modèles de planification et d'ingénierie des transports (des modèles de l'écoulement de la circulation et de la demande de trafic). À mesure que ces études s'achèveront, on pourra mieux analyser les répercussions des émissions des installations et des ouvrages de contrôle de l'encombrement et de la circulation. On a mentionné que les méthodes de classification de l'encombrement ou de liaison avec l'information en temps réel sur le débit de la circulation faisaient défaut dans ce domaine de recherche.

6. Mesurer la puissance motrice pose un problème dans le cadre de la plupart des études; on évalue généralement cette puissance en établissant la relation entre le régime du moteur et la pression d'admission (ou la position des injecteurs dans les diesels). Il devrait être possible de mesurer directement la puissance motrice à partir d'un certain nombre des systèmes de gestion par ordinateur installés à l'usine par les constructeurs. On devrait s'efforcer de documenter le type et les emplacements des signaux intégrés dont on dispose à l'heure actuelle à partir d'une foule de véhicules qui empruntent les routes afin de réduire les coûts d'instrumentation.

7. La déclivité des routes est un autre paramètre sur lequel un certain nombre de chercheurs ont essayé de collecter des données. Le récepteur GPS semble permettre de bien

mesurer la déclivité et la vitesse, mais son coût unitaire est élevé et il perd souvent le signal. La mise à l'essai et la sélection de systèmes peu coûteux de mesure de la déclivité (par pression atmosphérique, par exemple) pourraient aider les chercheurs à établir une trousse d'instrumentation plus complète.

8. La limitation la plus importante à l'intérieur des travaux semble être le nombre restreint de véhicules à partir desquels des données sont collectées. Si la taille des échantillons doit augmenter, il faudra disposer de techniques d'instrumentation moins coûteuses et concevoir des méthodes mathématiques pour réduire la quantité de données continues collectées (ou de meilleures méthodes de post-traitement). Sous ce rapport, la nécessité de collecter des données sur les emplacements parallèlement à des données sur la performance ou le rendement constitue un point important sur lequel on ne s'entend pas clairement.

Globalement, l'atelier a semblé avoir très bien réussi à faire connaître les recherches et les techniques d'analyse qui visent actuellement à mesurer l'utilisation des véhicules. Le réseau des chercheurs en a été renforcé, ce qui devrait mener ultérieurement à une plus grande collaboration entre les responsables des programmes et les gens. Il y aura lieu de répéter ce genre de réunion au cours des deux prochaines années à mesure que les études actuellement en cours ou prévues seront achevées.

List of Workshop Attendees

Andre,Michel
INRETS,Research Engineer
109 Avenue Salvador Allende,Bron,Cedex,69675
011-33-72-36-2473

Ayres,John
Environment Canada,Project Manager
1179 Rue Duburry,Montreal,QU,H3B 3H9
514-496-6858

Ballentyne,Vera
Environment Canada,In-use Vehicles
13 th Floor, 351 St. Joseph Blvd.,Hull,QU
K1A 0H3,
819-953-9967

Barton,Raymond,ADI Limited,Manager, Ottawa Office,
5 - 2100 Thurston Drive,Ottawa,ON,K1G 4K8
613-737-9344

Berelle,Carol
Environment Canada,Fuels Section
13 th Floor, 351 St. Joseph Blvd.,Hull,QU,K1A 0H3
819-953-1141

Bond,Brian,Transport Canada
13th Floor, 344 Slater St.,Ottawa,ON,K1A 0N5
613-990-1953

Boucher,Denis
Transport Canada,Senior Engineer
13th Floor, 344 Slater St.,Ottawa,ON,K1A 0N5
613-990-1953

Bourbeau,Andre
Natural Resources Canada,Energy Data Analyst
17th Floor, 580 Booth St.,Ottawa,ON,K1A 0G1,
613-995-7307

Carr,Barry
ZEV Technologies,National Sales Manager
Syracuse,NY
315-635-5345

Clark,Nigel
West Virginia University,Professor
357 Engineering Science
Building,Morgantown,WV,26506-6106
304-293-3111

Clark,Jude
Electric Transportation Associates.
11213 Ashbrook Place,Avondale,AZ,85323
602-877-9002

Cohen,Jonathan
Systems Applications International
101 Lucas Valley Rd.,San Rafael,CA,94903
415-507-7191

Doku,Dan
Volvo Cars of North America,Emissions Engineer
RockLeigh,NJ
401-768-7300

El-Herraoui,Moin
Carelton University,Graduate Student
Ottawa,ON,,

Fett,Dennis
Chrysler Corporation,Test & Development Engineer
800 Chrysler Dr. East,Auburn Hills,MI,48326-2757
810-576-5588

Fraser,Royden
University of Waterloo,Associate Professor
200 University Avenue West,Waterloo,ON,N2L 3G1
519-888-4764

Garbak,John
U.S. Dept of Energy
1000 Independence Ave. SW, EE332,Washington,DC,20585,

Goguen,Steve
U.S. Dept of Energy
1000 Independence Ave. SW, EE332,Washington,DC,20585,

Groblicki,Peter
General Motors,Sr. Staff Research Scientist
30500 Mound Rd., Box 9055,Warren,MI,48090-9055
810-986-1610

Gullon,Allan
218 Twyford St.,Ottawa,ON,K1V 0V9
613-738-0712

Heiser,Glen
Ford Motor Co.,Technical Standards Engineer
The American Road,Dearborn,MI,48121-1899
313-248-8010

Jaques,Art
Environment Canada,Head, Inventory Development, GHE
351 St. Jospeh Blvd.,Hull,QU,K1E 0H3
819-994-3098

Kaskavaltzis,Costa
Ont. Min. of Transportation,Research Engineer
3rd Floor, Central Building,Downsview,ON,M3M 1J8
416-235-5014

King,Lionel
Sypher:Mueller International,Manager
Suite 500,Ottawa,ON,K2L 1C4
613-236-4318

Kishan,Sandeep
Radian Corporation,Project Engineer
P.O. Box 201088,Austin,TX,78730-1088
512-454-4797

Larson,Larry
California Air Resources Board,Statistician
2020 L St.,Sacramento,CA,95814
916-322-3988

Lee-Gosselin,Martin
University Laval,Professor
1624 Pavilion Felix Anton-Savard,Ste Foy,QU,G1K 7P4
418-656-2578

MacLean,Greg
University of Ottawa,Manager, EV Programs
33 Mann Avenue,Ottawa,ON,K1N 6N5
613-564-6818

Markey,Jim,Environmental Protection Agency,FTP Study
2565 Plymouth Road,Ann Arbor,MI,48105
313-668-4534

McBean,Peter
Chrysler Canada,Engineer
PO Box 1621,Windsor,ON,N9A 4H6
519-973-2730

McDuff,Glen
Environment Canada,Co-op Student
13 th Floor, 351 St. Joseph Blvd.,Hull,QU,K1A 0H3
819-953-1141

McKain,David
West Virginia University,Engineering Scientist
357 Engineering Science
Building,Morgantown,WV,26506-6106
304-293-3111

Miller,Bob
US Navy
560 Center Dr., ESC 432/RM,Port Hueneme,CA,93043-4328
805-982-3590

Miller,Eric
Univ. of Toronto,Professor
35 St. George St.,Toronto,ON,M5S 1A4
416-978-4076

Peerenboom,William
American Trucking Association,Vice President
2200 Mill Road,Alexandria,VA,22314-4677
703-838-1863

Pela,Augustus
California Air Resources Board,Engineer
2020 L St.,Sacramento,CA,95814
916-323-8525

Penney,Terry
National Renewable Energy Laboratory,
Manager, Hybrid Vehicle Program
1617 Cole Blvd.,Golden,CO,80401-3393
303-275-3654

Philpot,Sharon
Environment Canada,Engineer, Transportation Systems
13 th Floor, 351 St. Joseph Blvd.,Hull,QU,K1A 0H3
819-994-1643

Reilly-Rowe,Peter
Natural Resources Canada,Assistant Director
17th Floor, 580 Booth St.,Ottawa,ON,K1A 0G1
613-996-6001

Riechers,Mark
National Renewable Energy Laboratory,Senior Project
Engineer
1617 Cole Blvd.,Golden,CO,80401-3393
303-275-4413

Robinson,Russ
Environment Canada,Head, Transportation Systems
13 th Floor, 351 St. Joseph Blvd.,Hull,QU,K1A 0H3
819-953-1601

Rogers,Michael
Georgia Institute of Technology
School of Earth & Atmospheric
Sciences,Atlanta,GA,30332-0340
404-853-3094

Schingh,Marie
Natural Resources Canada,Advisor, Alternate Fuels
17th Floor, 580 Booth St.,Ottawa,ON,K1A 0G1
613-995-8401

Sotirakas,Cris
Protectair,Shop Manager
294 Billings Cres.,Newmarket,ON,L3Y 7Z2
416-497-3547
Steven,Heinrich
FIGE GmbH,Manager,Technologiepark,Herzogenrath,D-52134
011-49-2407-2089

Suski,Victor
American Trucking Association,Technical Specialist
2200 Mill Road,Alexandria,VA,22314-4677
703-838-1846

Taylor,Gordon
Instrumental Solutions,President
190 Bronson Ave.,Ottawa,ON, K1R 6H4
613-237-1565

Wang,Michael
Argonne National Laboratories,Research Scientist
Argonne,Il
708-252-2819

Washington,Simon
Univ of California (Davis),
Institute for Transportation Studies
Davis,CA,95616-8762
916-752-8460

Webb,Cynthia
Southwest Research Laboratories
6220 Culbera Dr.,San Antonio,TX,78228
210-522-5873

White,Charles
National Renewable Energy Laboratory,Research Associate
1617 Cole Blvd.,Golden,CO,80401-3393
303-275-4426

Williams,Peter
Natural Resourses Canada,Project Engineer
7th Floor, 580 Booth St.,Ottawa,ON,
613-99

Young,Michael
Ministry of Environment and Energy,
Transportation Issues Advisor
Room 133, Central Building,Downsview,ON,M3M 1J8
416-235-5136

Younglove,Ted
Univ of California (Riverside),Senior Statistician
CE-CERT, Riverside,CA,92521-0425
909-781-5047

Review of Research on Vehicle Use & Operating Conditions

Michel Andre
INRETS, Lyon, France

A review of Researches dealing with Vehicles Uses and Operating conditions, and derived Driving Patterns or Driving Cycles

M. ANDRÉ

INRETS - Laboratoire Energie Nuisances, Case 24, 69675 Bron Cedex - France

The main objective of the European COST[1] action 319 (estimation of pollutant emissions from transport) is to coordinate research activities in the field of transport-related pollution. As a part of this project, a survey is currently conducted, concerning the European and non-European researches dealing with statistics on vehicles uses and operating conditions.

The aim is to collect the information and statistic data available, to study the methods and equipment used, and also the methods applied to characterize operating conditions and to build up test cycles.

A questionnaire in two parts was sent to a number of European and non European experts. The first part addressed experiments dealing with Vehicle use : vehicle types, tools used (survey, on-board measurements, etc...), information collected, and methodology. The second part concerned the use of the data collected : driving cycles or model development, and the method used for analysing the data.

A total of 23 experiment results have been received yet, relating to Passenger Cars, Duty Vehicles, in urban or non urban areas. On-Board recording, Surveys, Video, etc..., were used. Various parameters were monitored such as trip characteristics, speeds, engine parameters, vehicule usage, etc... Recordings were continuously performed or pre-processed (histogram, average, etc...). The data were used either to derive Driving Cycles, or to build-up models. A short overview and a typology of these studies are presented in this paper.

Key-words : Driving Cycle, Driving behaviour, Driving patterns, Actual Uses, Engine Operating Conditions, Passenger Cars.

1. Introduction : What is COST 319 ?

Cost (European Co-operation in the field of scientific and technical research) groups 23 European states (members of the European Union or not). Activities performed as part of the Cost programme address research issues of common interest, considering their international character (oceanography, environment, etc...) or in the aim of harmonizing regulations (telecommunications, transport, etc...). They are funded at a national level and only states interested in such researches take part into the programme. These are mainly "concerted actions" for co-ordinating national projects (existing or proposed), organized by management committees. European funding is limited to some punctual actions and for operating of the management committees. Public authorities, public and private research institutes and centres take part into this programme. The tasks involved are complementary to a number of European research programmes (ESPRIT, RACE, BRITE, EURAM, etc...).

The COST 319 project (estimation of pollutants from transport) was implemented in 1993 and includes 15 European countries (see box below).

---

[1] COST: European co-operation in the field of scientific and technical research

European co-operation in the field of scientific and technical research (COST)

COST 319 : estimation of pollutant emissions from transport

Concern over the environmental effects of pollutant emissions from transport has increased to such an extent that it is now one of the main constraints on transport developments. The growth in concern parallels the increased significance of transport as a source of air pollution that is a direct consequence of the greater and greater mobility characteristic of modern societies. It is now estimated, for example, that road transport produces more than half the man-made emissions of oxides of nitrogen and volatile organic compounds, and a quarter of carbon dioxide in the European Community.

Research types : Because of its large and increasing importance, there is considerable research that addresses the problems of transport and the environment. This research and development activity can be categorised broadly under two headings : studies to measure the current situation and to forecast future conditions and studies to develop and evaluate solutions. Typical research in the first category is the measurement of vehicle emission rates or the investigation of the links between economic growth and transport activity. The second category includes topics as diverse as improvements in vehicle technology, better traffic management and the development of environmentally targetted transport policies.

International and interdisciplinary collaboration : While it is clear that there is a strong international element to these problems, most research is carried out at a national level. Furthermore, collaboration between the various important research disciplines is also rare : thus, there are engineers who know intimately the emission characteristics of vehicles and ways to improve them, traffic experts familiar with modern management techniques, and economists and policy makers capable of developing the best ways to promote and sustain a transport system that is environmentally more acceptable. It is necessary, though, to bring together all of this knowledge and expertise since progress cannot be optimum if it is concentrated in one single area.

A COST action : for these reasons, a proposal has been made for COST action 319. Its basic objective is to coordinate research activities in the field of transport derived pollution. A simple, though fundamental precept to the proposal is that pollutant emissions may be expressed by the formula :

$$E = e \cdot a$$

where
E is the amount of emission,
e is the emission rate per unit of activity,
a is the amount of transport activity.

This is fundamental to the type of researches that are necessary : measurement and forecasting requires a knowledge of both transport activity and activity related emission rates, and must determine the links and functional relationships between them, while research on solutions must aim to reduce one or other, or both, of these factors.

The diversity of participants : This COST action was initially proposed by delegates from Finland and Sweden, and contributions have been made by experts of Austria, Belgium, Finland, France, Germany, Greece, Italy, Sweden and the United Kingdom, mainly in the field of road vehicle emissions. The collaboration should be geographically enlarged to *Eastern Europe*, and by scientists from other essential areas such as *transport operations, planning, economics and policy, and for modes other than road transport.*

Three axes : The work plan envisages the formation of three sub-groups, whose work would be coordinated by a management committee and periodic plenary meetings, with the following research areas :
- *Emission factors and functions*: quantification of pollutant emissions and studies of the factors that influence them,
- *Transport characteristics*: the operations of the transport sector and how they are affected by technical, social, policy and economic factors,
- *Tool harmonization and development:* study and evaluation of procedures to assess and reduce transport's environmental impacts.

The expected duration of the action is four years, but it is possible that the group's work will lead to a longer-term need to adapt and maintain its findings as knowledge improves and as changes take to vehicles and to transport infrastructure, operations and policies.

Further information: R. Mayet, Commission Européenne - 200 rue de la Loi - BU 31 5/34 - B-1049 Bruxelles, fax (32) 2 296 37 65, tel (32) 2 296 46 77, R. Joumard, INRETS (F), fax (33) 72 37 68 37, tel (33) 72 36 24 77.

The aim is to analyse the research methods and the results obtained, to make a synthetical review of the available data, and to coordinate research on emissions of regulated and non regulated pollutants and fuel consumption by transport. It concerns :

- data collection on unit emissions of present and future vehicles and engines, on driving behaviour, statistics of different vehicle fleets, passenger and freight transport, and vehicle use ;
- the analysis and synthesis of the baseline data in order to derive appropriate dependencies and guide-line methodologies to be applied for multi-purpose evaluations ;
- the production of estimations of amount of emitted pollutants at local, national and international levels, the assessment of transport policies, traffic management, efficiency of new technologies.

All the transport modes (road, air, train, etc ...) are taken into account, including the non polluting ones (walking, bicycles) and off-road vehicles.

The identification of the gaps in the knowledge of the emission behaviour of different transport sub-groups is among the major targets of the working group. This will enhance the specification, coordination and support of research activities in these fields. As an example, the coordination of the experimental work for the emissions of trucks and buses (under way now in many European laboratories) is of particular importance, since these vehicles are dominant in some pollutant cases (i.e. NOx and particulates), which are not well known and demand high research investments (much higher than for passenger cars).

The COST action 319 is structured around 4 working groups and 21 sub-groups (Table 1), within the responsability of co-ordinators which are specialists in this research field. In a first step, this demultiplying organization, associated with a co-ordinating and executive structure, led to launch a series of surveys among all European specialists related to data and model availabilities, and the methods used. The following step will consist in collecting data, comparing them and drawing-up conclusions which will constitute an European database for transport-related pollutant emissions. Various inventory tools will be tested in a large scale, including the checking of the final model by airborne measurement systems.

Table 1: COST action 319 structure "estimation of pollutant emissions from transport"

0	**COST319, Coordination A, B, C, D**		**B**	**Traffic Characteristics**	
A	**Emission Factors and Functions**			B1	Traffic management
	A1	Engine Maps		B2	Driving behaviour
	A2	Instantaneous Vehicle Emissions		- B2a	Simulation models
	A3	Average Vehicle Emissions		- B2b	Measures and measurement methods
	- A3a	Hot emission factors for PC		B3	Traffic composition
	- A3b	Cold start emissions		B4	Mobility : factors analysis and models
	- A3c	Evaporative emissions			
	- A3d	Gradient influence	**C**	**Inventorying Tools**	
	- A3e	Light duty vehicles			
	- A3f	Heavy duty vehicles		C1	Bottom-up Approach
	- A3g	Motorcycles		C2	Top-down Approach
	A4	Future Veh. & Life Cycle Emissions			
	- A4a	Alternative fuels	**D**	**Non road Transport**	
	- A4b	New vehicle technologies		D1	Inland and maritime transport
	- A4c	Life cycle emissions		D2	Air transport

2. Driving behaviour, measurements and measurement methods

Among the various topics addressed by the COST action 319 , topic B is a description of the vehicle traffic and mobility indicators, and a sub-topic more particularly concerns driving behaviours, i.e the way the vehicles are driven (use and operating conditions).

Two basic types of information are involved:

- Detailed data on vehicle parameters such as vehicle speed, engine speed, gear ratio, thermal conditions etc, for different types of vehicle (passenger car, truck, bus, motor-cycle, etc.), for different types of operation (freight transport, public passenger transport, etc.), by geographical location (city, rural, different countries, etc.). Data may be obtained by measurement or from simulation models.
- More general information on trips, such as trip distributions as a function of variables like journey purpose, duration, time of day, time of year, frequency and duration of stops. These data are usually available from surveys of vehicle users.

The following Research Topics were contemplated within this sub-topic:

- To investigate equipement and methodologies available for measuring vehicle operations, to assess and improve them, if necessary;
- To investigate the availability of information on journeys in Europe, to collect and evaluate the information

2.1. The survey

A survey was carried out to prepare an inventory of measured data on driving behaviour, together with a review of the methods used for the measurements, and the methods used to derived Driving Patterns or Driving Cycles.

A questionnaire included 2 parts :

- information concerning experiments dealing with Vehicle use : vehicles concerned, tools used (survey, on-board measurements, etc...), information collected, and methodology;
- the use of the data collected : driving cycles or model development, and the method used for data analysis.

It was sent to 60 people: 45 participants of COST 319, concerned with or known to be interested in the topic addressed, and 15 other people known for having experience in this field: in Europe, Canada, the USA and Australia.

First, the answers obtained allowed the listing of new permanent contacts in Ireland, Spain and Hungary, in Italy and the USA. Thirteen directly usable answers were received, representing 23 individual sheets or questionnaires, each one corresponding to one experience.

2.2. Synthetic review

Among the reported cases, 16 involved experiments with on-board equipment, 6 were the results of questionnaire surveys, and 2 used other traffic analysis techniques.

Ten experiments involved only passenger cars, 6 only duty vehicles, and 7 did not make any distinction. Eight experiments were carried out in urban areas, 3 in extra-urban areas and 10 covered both areas.

Finally, for 15 cases, data were recorded continuously, among which six were recorded in the distribution or average speed forms, etc... In 18 cases, the experiment resulted in the building-up of test cycles or "typical data" (driving patterns).

Note: in the following sections, only experiments reported during this survey are dealt with. A number of other cases published are not taken into account.

3. Experiment overview and typology

There is a great variety of tools for collecting information (of various types) related to driving behaviours (questionnaire surveys, on-board equipment, etc...). The method applied seems to be the most significant differentiating factor in these experiments (in particular as far as objectives, vehicle numbers, etc..., are concerned). Therefore, it is proposed to analyse the investigation fields, the methods and means implemented, the data collected and the interest of the data obtained as part of the COST action 319, for each experiment type.

3.1. Questionnaire surveys

Surveys using questionnaires or interviews are sometimes associated with a diary to be filled in for each trip. These are periodically updated. A low number of such cases are reported in the answers, since the experts contacted most often work in organizations concerned with environmental issues. But, in practice, this type of survey is performed in most countries.

Often referred to as "national surveys" or "transport surveys", they involve a significant number of vehicles or households.

- 20000 households, 43000 individuals et 120000 trips in 1989 in Switzerland for example (Ref. 11[1]), recorded through a questionnaire including questions about the trips of the day,

- 7600 subjects in Sweden (Ref. 19),

In both cases, these were surveys about people's mobility (including all transport modes).

- 55000 private cars in Spain in 1989 (Ref. 18), recorded through an interview survey performed in various sites alonside roads, in extra-urban areas.

There is a great number of varied data recorded during these surveys which are of direct interest for COST 319: number of vehicles available per household, annual mileage, vehicle occupancy rates, trip lengths, transport systems commonly used, trip purposes (commuter trips, etc...) and especially space distribution (comparing geographical areas, urban and rural areas, road types, etc...), time distribution (day time, week days, week-ends, evolution with seasons and years), according to people's categories (male, female, age, socio-professional categories), according to trip purposes (commuting trips, recreational activities, etc...) and the vehicles (type, age, fuel, etc...) used for trip performance.

Data relating to vehicle use number, trip length, and even estimated fuel consumption can yield very approximate values if based on the respondent's answers only. Undoubtedly, they are more reliable in the case of diary surveys, provided the consumption is recorded between each refuelling operation within a week period..

Representativity and a very large coverage (area, vehicle types, subject categories, etc..) are probably the main assets of such a type of survey. It would be very usefull to make a review of the surveys currently performed by specialists in each country, and to check whether the data are not already gathered or federated at a European level.

3.2. Surveys during compulsory vehicle inspection

With the implementation of "compulsory technical inspection", a periodic monitoring of the vehicle use conditions has been made possible. Two cases can be mentioned:

---

[1] References: see the literature review at the end of the paper.

- in Switzerland, the cantonal authorities as well as inspection centres, recorded data over 93000 vehicles, all types being considered (2500 heavy vehicles, 3500 small duty vehicles, 6000 cycles), between 1991 and 1992, (Ref. 8). Annual mileages were thus assessed precisely (from the first putting into operation of the duty vehicles, from the last inspection relating to pollutant emissions of passenger cars).

- In Sweden (Ref. 20), an analysis was systematically performed between two successive years of vehicle inspection (between 1987 and 1991).

In both cases, a very accurate distribution of the mileages recorded was obtained as a function of the area, vehicle age (which appears to be a significant factor of annual mileage reduction), the technical vehicle characteristics (engine capacity, mass, etc...), and according to the vehicle categories (passenger cars, minibuses, cycles, duty vehicles, trucks, trailer trucks), which are essential information for obtaining a reliable inventory of pollutant emissions. It should be noted that the data recorded during these surveys are limited (annual mileage, and if appropriate, vehicle condition), but they could be complemented by additional survey stages related to mobility.

In this field too, with the progressive implementation of technical inspection procedures in Europe, it should be useful to define the bases and a single method for data collection, which would allow the rapid drawing-up of a very reliable and accurate database on the evolution of vehicle mileages and their distribution as a function of the European areas.

3.3. Traffic analysis

The use of systems aimed at counting the vehicles and calculating their speeds allows the speed assessment of a great number of vehicles locally.

In Sweden, measurement campaigns were performed annually and comparative studies were carried out (63 measurement spots on countryside roads in 1991, in 5 or 6 periods over the year, i.e 46 000 vehicles, 1 800 trucks and 430 buses). The systems were used to differentiate the main vehicle classes and the different types of road. The 1990 and 1991 data analysis shows a significant increase in speeds for all types of road (Ref. 21).

In Switzerland, the use of video equipment, associated with the use of the vehicle registration file, allowed a more precise identification of the vehicle characteristics (Ref. 12). This study concerned duty vehicles only over 20 road sections in extra-urban areas.

The main objective of this last study was to better know the traffic structure (per vehicle categories), as a function of the road types, which is a significant information too for COST 319. Owing to the punctual character of measurement spots, measuring speeds does not constitute an very interesting approach to vehicle operating conditions.

3.4. On-board measuring equipment

For this survey, half of the answers related to experiments performed using on-board equipment (12 cases, plus 4 "hybrid" cases described hereafter). The purposes of most experiments were related to pollutant emissions, which explains the predominance of these cases among the answers recorded, but , in any case, this does not mean that the previously mentioned types of study have been performed more rarely.

Most studies led to the construction of driving or test cycles, or the determination of input data for simulation models related to vehicle operation, associated with a pollutant emission model, if required.

Two great families of experiments are to be observed.

3.4.1. Measurements in pre-determined sites

A series of sites had been previously defined (road or route selection, etc...), where instrumented vehicles had to be driven. The quality of the data recorded was highly dependent on the quality of the road pre-selection.

In these cases, the vehicles often were "laboratory" instrumented vehicles driven by operators or their drivers. Driving instructions could have been associated such as "follow the vehicle flow" (floating vehicle) or "follow the vehicle before" or any vehicle at random (car chase). The advantage of such a method is to associate vehicle operating conditions to prescribed road types and to traffic conditions that can be simultaneously observed (traffic conditions, but also pavement conditions, weather conditions, etc...).

Among all the existing cases, let mention:

- Germano-Swiss experiments (Ref. 3, 4, 9 , 10) on passenger cars and duty vehicles, and namely a large scale study into vehicle operating conditions and emissions over 20 motorway sections of about 40 km long, representative of the German network (Abgas-Grossversuchs, Ref. 4), with 30 instrumented vehicles, over 600 000 km recorded; the development of typical cycles and emission measurements as a function of the vehicle types and road gradient conditions.

- more limited experiments in Greece, in Thessalonica (1 instrumented vehicle, over 1 500 km recorded, Ref. 5), or in Austria, in Graz (1 instrumented vehicle, over 3 000 km, Ref. 22), and in Finland where 4 instrumented vehicles, monitored on various urban road types, allowed the drawing-up of 56 typical cycles, used for simulating emissions in the town (Ref. 2).

3.4.2. Measurements under free-use conditions

No site had been previously selected. Vehicles could be privately-owned passenger cars used by their drivers for their own purposes. Traffic conditions were not known except from the analysis of recorded vehicle own data (speeds, accelerations, etc...). One of the advantages of this method is that it also provides information about actual vehicle use conditions (trip lengths, times, etc...). The selection of the vehicle types and owners significantly contributed to the representativity of the recorded data.

In a number of cases, the complex instrument use required the presence of an operator. Thus, this enabled to simultaneously record additional explicative information (traffic conditions), with the risk of disturbing the driver and thus modifying his behaviour and of increasing the complexity of the experiment management. This was made possible for duty vehicles since their use could be planned, but would have been more difficult for privately-owned vehicles, since their uses could not be predicted and there was a great variety of them.

Among all these studies, let quote:

- the experiments conducted in France over 55 privately-owned vehicles (70 000 km recorded, Ref. 14), and similar experiments being carried out over 48 commercial and small duty vehicles, some trucks and buses (Ref. 16).

- experiments performed as part of the European DRIVE-modem research programme, in France, Great Britain and Germany, with 60 privately-owned vehicles, representing the vehicle fleets of the three countries (73 000 km, 8000 trips recorded, 1600 days of vehicle monitoring, Ref. 13). Data obtained from this project currently constitute a reference database about use and operating conditions of passenger cars in France. They also were used to build-up urban test cycles, to measure instantaneous pollutant emissions of 150 European cars, and to develop a model of emissions.

- Germano-Swiss experiments over 30 duty vehicles (of which 5 in Switzerland, Ref. 17), with a recording duration for each vehicle ranging from 4 to 24 hours. The presence of an operator during these experiments enabled to bring additional information elements (on-board equipment mass, traffic conditions, road types, etc...). These recordings are being used to develop a new engine test cycle for duty vehicles. In addition, data recorded on a 32-ton truck in Great Britain (Ref. 23) are being used too.

Finally, a large scale experiment over 150 buses and articulated buses in Budapest, continuously monitored over a 2-month period, exlusively using a monitoring equipment for "commercial" vehicle uses (speed measurements and passenger counting, Ref. 6) is also to be mentioned.

3.5. Hybrid methods

Studies applying to complementary methods should be added to those previously described:

- in Italy, an experiment was performed using a vehicle equipped with a data logging system and a video camera to record traffic conditions (Ref. 1),

- experiments associating on-board measurement systems and the implementation of new strategies of traffic light control (two experiments in France - Ref. 15 - and similar experiments in Sweden),

- Experiments carried out in Australia, during which on-board measurements were performed after having characterized and selected homogeneous urban areas ('urban ecology" concept - Ref.7), from factors describing the land use (urban density, housing density, distance to the town centre), transport systems (urban surface/public transport availability ratio, trip distribution between various transport systems), congestion (in kilometres . vehicles) and socio-economic conditions (earnings, average number of vehicles, etc...),

- and in the same spirit, the studies previously mentioned, which associated a preliminary study or survey aimed at pre-selecting sites, as well as the study into operating conditions on motorways in Germany, using traffic sensors and video equipment in addition to on-board measurement systems (Ref.4).

3.6. Measured parameters

The parameter types measured and the types of study involved are summarized in Table 2. As regards the parameters measured on vehicles, it should be noted that, among the studies mentioned, some parameters were recorded only exceptionnally: exhaust gas temperature in order to better assess catalyst efficiency (Ref. 1), engine torque, which is an essential operating parameter measured only for duty vehicles (Ref. 10, 16, 17, 23). Furthermore, the methods used (sensors, data logging frequency, etc...) to measure a same parameter could significantly vary. Therefore, comparing the data collected during two different experiments is made very difficult.

Overlapping ranges between the various types of study can also be noted;

- between surveys and on-board measurements as related to trip information, even if representativity levels were not the same (some thousands vehicles in the survey cases, some tens for on-board measurements);

- between traffic measurements and on-board measurements, when the latter were used for analysing traffic conditions from the analysis of speed data and other indicators.

For all these reasons, the development of light , low cost on-board systems of easy use, even installed in series on the vehicles, could allow extending the scope of such a method.

Finally, it should be observed that the number of vehicles involved is roughly inversely proportional to experiment complexity (and cost), since the cost is related to a number of parameters on the one hand (torque for example), and to the vehicle types on the other hand (heavy duty vehicles).

Table 2: Typology of the parameters measured as a function of the study cases.

Trip behaviour		
Annual mileage	surveys at vehicle inspections	
Weekly or daily mileage (duration and number of trips)	surveys	
Trip description (length, duration)		
Engine operating conditions		on-board measurements
Engine speed		
Load conditions		
Thermal conditions		
Exhaust gas temperature (catalyst)		
Engine torque		
Vehicle speeds		
Miscellaneous external conditions	traffic analysis	
Traffic conditions		

3.7. Developing driving cycles from on-board measurement data

One of the characteristics of a great number of previous studies was the development of test cycles. One of the major issue often met was the definition and the selection of "characteristic" variables describing speeds (and accelerations).

Some original methods, most often using advanced statistical tools, were drawn up to build-up cycles, whose description would significantly exceed the scope of this paper. In addition, most documents are not available yet or have not been analysed in detail. For the purposes of illustration, let mention the broad lines of these different methods:

- point by point cycle simulation, respecting the speed and measured acceleration distribution or the probability cross matrix (two-way contingency matrix, Ref. 4, test cycles on motorways in Germany for example, a test method which has been contemplated in Australia),

- splitting the speed curve between vehicle successive stops prior to analysis performance. Such a method can be followed by various analyses:

- In Greece (Ref. 5), sequences between stops were divided linearly into three segments (acceleration, steady speed, deceleration), and analysed according to the 5 following parameters: duration, stop duration, average acceleration (constant), average deceleration (constant), average steady speed. They were then classified into three equivalent groups, graduated as a function of speed levels. Average characteristics for each group were reference data for typical sequences or they could be further used to build-up a prescribed cycle.

- In Italy (Ref. 1), and for the DRIVE-modem programme (Ref. 13), a sequence typology was drawn-up by factorial analysis. Cycles were built-up first using a transition (or succession) probability matrix of the various sequence types on the one hand, and trip typology (as a function of trip composition, duration, etc...), also defined by classification on the other hand.

- Cycle building-up was often performed from real recordings (and not by simulating the speed vs time curve), selected for their representativity as a function of a number of criteria (even by comparing the average characteristics of a simulated curve perfectly meeting the representativity requirements, but for which simulation biasses the instantaneous real use character). This is the case for the previous Italian and DRIVE-modem experiments, as well as for the Australian experiments (Ref. 7).

- In Finland, the best parameters for describing driving cycles were defined using stepwise linear regression to explain pollutant emissions and fuel consumption (Ref. 2).

- In Germany and Switzerland (Ref. 3), relationships were sought for by variance analyses between the various types of pre-selected roads and the driving characteristics. An analysis using a classifying method would allow the identification of typical driving behaviours, as related to each road type, to be further used to calculate pollutant emissions.

- Finally, as regards duty vehicles, studies aimed at constructing cycles were most often based on the cross distributions of engine rotation speed/torque, in order to select the most representative operation points. They were then reproduced on a stationary engine test bench. Nevertheless, studies have been performed recently to build-up transient cycles from measurement data obtained during the Germano-Swiss and English studies (Ref. 17 and 23).

3.8. Additional comments

In the previous studies, it should be observed that:

- the experiments have rarely be performed at an international level, except co-operations between Germany, Austria and Switzerland and those developed as part of some European projects;

- very few data is available concerning duty vehicles;

- most experiments, even limited ones (over 1 or a few vehicles), have been performed by academic laboratories and not by official institutions.

3.9. Conclusions and prospects

This survey showed that most concerns are similar in all the European countries and that there is a great variety and complementarity of the tools implemented: surveys, surveys on the occasion of vehicle technical inspections, on-board measurements. Original and interesting techniques are mentioned: "traffic analyzer", video.

In the aim of harmonizing procedures at a European level, necessary to develop databases for assessing pollutant emissions related to transport, it is required to:

- for each country, review typical surveys highlighted in this work, and in particular surveys concerning mobility and surveys performed during vehicle technical inspections, which will enable to accurately determine the distribution of the kilometers covered, as a function of the area studied, the vehicle characteristics (age, category, type, engine capacity, mass, etc...), which are essential features for drawing up a reliable inventory of pollutant emissions. In this aim in view, contacts must be established with specialists from each country involved and it will be required to check whether data have not been already gathered or federated at a European scale.

- with the implementation of procedures for vehicle technical inspection in Europe, define the bases and method for data collection which would allow the rapid development of a reliable and accurate database relating to vehicle mileage evolution and their distribution as a function of the European areas studied, and, if required, the performance of complementary mobility-related surveys.

More specifically, as regards on-board measurements, the methods and equipment used should be thoroughly studied in order to define standard measurement parameters and methods. Objective clarification (which are the actual needs to better know vehicle operating and use conditions, which are the purpose of test cycles, the gaps, the data use limits, etc... ?) could enable setting the bases for developing large scale procedures of data collection, using low-cost, simplified equipment, some sort of an "observatory of vehicle operating conditions in Europe".

Analysis methods used for constructing driving cycles must be compared to enable a mutual enrichment by multiple considerations (statistic tools, relevance of a number of analyses, representativity, limits of data extrapolation, etc...).

Eventually, this first synthetical analysis must be extended through analysing new cases resulting from new contacts and from the review of an abundant literature.

Bibliography (or contacts)

Several references corresponding to a same study are numbered:6.1, 6.2, etc...for example

1.1 M. Rapone & coll., "Automobile mission profile", FISITA Congress Beograd 1986, paper 865101, pp. 3.227-3.234, Beaograd

1.2 L. Dela Ragione, V. Gillio, V. Luzar, M. Rapone, "Characterization of urban driving cycles by means of basic statistical analysis: a preliminary approach", Poster session, 3rd Int. Symposium "Transport and Air Pollution", Avignon, France, 6-10 June 1994

2 Report(s) in finnish - Matrex Oy, Helsinki, Finland

3.1 Study on Representative Car Drivers Behaviour on Urban and Rural Roads, Heusch/Boesefeldt GmbH Aachen, in coop. with TÜV-Rheinland Cologne

3.2 Evaluation of Measurement of trips to the Driving Behaviour of Passenger Cars, Air pollutant Emission of road traffic in Switzerland 1990-2000, doct 4a, Heusch/Boesefeldt GmbH Aachen

3.3 Determination on Representative Driving Pattern of Passenger Cars with Cluster Analysis; Air pollutant Emission of road traffic in Switzerland 1990-2000, doct 10, Heusch/Boesefeldt GmbH Aachen

4 Final Report about the Exhaust Gas Large Scale Test (Abgas-GrossVersuch)

5.1 "Time dependence of traffic emissions in the Urban area of Thessaloniki", The Science of Total Environment, Elsevier, Vol. 134(1993), pp 273-288

5.2 "Driving pattern development of an urban area", paper presented at the "Traffic induced Air Pollution International Conference", in Graz, 1992

5.3 "Actual Traffic emissions inThessaloniki on one hour and one year basis", presented at the 7th EUMAC Workshop

5.4 "Determination of the time and area distribution of the emissions production and fuel consumption due to the traffic in the area of Thessaloniki", Final Report submitted to the "Thessaloniki Planning Organization", March 1991 (two volumes in Greek language)

6.1 Statistical evaluation of operation data of city buses, Nauka i Motorna Vozila 89, (Sciencs & Motor vehicles 89), JU.M.V. Proceedings, Belgrad, 1989, pp. 8913101.1-8913101.5, Borbély G., Békefi Z., Keresztes A.

6.2 Analyse von Betriebsarten der Nutzfahrzeuge. Wissenschaftliche Berichte, Technische Hochschule Zwickau (Wissenschaftliche Tagung des Sektion Kraftfahrzeugtechnik, 1989, pp 103-110), Borbely G., Fekete T.

7.1 Kenworthy et al., The ecology of urban driving 1 - Methodology, Transportation Research, 26A, pp 263-272

7.2 Kenworthy et al., The ecology of urban driving 2 - Driving cycles across a city: their validation and implications, Transportation Research, 26A, pp 273-290

7.3 Lyons, T.J., B. Alimoradian, P.W.G. Newman, 1987, A truck driving cycle for Perth. NERDDC End of Grant Report, Transport Research Paper 5/87, Murdoch University, 29pp

7.4 and about 30 other publications

8 PIFA 1991, GVF report Nr 202, Febr 1993

9 "Fahrverhalten von Personenwagen in der Schweiz", BUWAL Report Nr 10, Luft, 1994

10 Report in preparation

11 "Verkehrsverhalten in der Schweiz", GVF Report Nr 6, 1991

12 "Zusammensetzung des Verkehrs nach Fahrzeug-Typen", BUWAL Report Nr 14 (B+S), Berne, Juin 1993

13 Actual car uses and their operating conditions as emission parameters; derived urban driving cycles, M. ANDRÉ, R. JOUMARD, A.J. HICKMAN, D. HASSEL, , The Sciences of the Total Environment, Elsevier Science Publishers BV., Amsterdam, 146/147 (1994), pp 225-233.

14 In Actual Use Car Testing : 70,000 Kilometers and 10,000 Trips by 55 French Cars under Real Conditions, M. ANDRÉ -. S.A.E. Technical Paper Series N° 910039 - ISSN 0148 - 7191, 10p., 1991.

15 Usages et Conditions de Fonctionnement, des Petits Véhicules Utilitaires, Méthode de mesure au moyen de capteurs embarqués, (EUREV - PVU), M. ANDRÉ, J.P. ROUMÉGOUX, R. VIDON, C. PRUVOST, P. TASSEL, Rapport INRETS -LEN N° 9408, Mars 1994, 71 pp
16 Assessment of the energy and environmental impact of a trafic monitoring in Niort, M. André, R. Vidon, P. Tassel, rapport du projet THERMIE/NIORT 93/91 FR - Evaluation de l'impact énergétique de la modification du plan de régulation des feux à Amiens, au moyen de véhicules instrumentés, M. André J.P. Roumégoux, D. Olivier, C. Pruvost, Rapport INRETS-LEN, N° LEN9407, Février 1994, Bron, France, 121p.
17.1 H. Steven, Engine torque and Speed distributions of commercial vehicles and its consideration in emission measurement accordng to the EC Directives 38/77/EEC, res ECE Regulation R49 - Report N° 104 05 316, Final Report, Jan 1994
17.2 H Steven, Das Fahrverhalten von Nutzfahrzeugen in der Schweiz, Bundesamt für Umwelt, Wald und Landschaft, Sept 1993
18 statistics reports, DG CARRETERAS - MOPTIMA, Madrid, Spain
19.1 Resvareundersökningen 1984/85, T11SM8701
19.2 VTI Meddelande 717, by Per Herrikson
20 "Arligg hörstrückur skuttude ur Bilprovningens dutusas", T149 1994, VTI
21 VTI reports : M660, M627, M610, M617, M589 (each year report)
22.1 Pischinger R.: Eine Methode zur Berechnung des Kraftstoffverbrauches von Kraftfahrzeugen aus dem Geschwindigkeitsverlauf, XX FISITA Congress, SAE 845114, 1984
22.2 Wegerer M.: Ermittlung von Kennfelden zur Berechnung des Abgasemissionen und des Kraftstoffverbrauches von PKW, Hrsg. Pischinger R., Mittelungen des Inst. für Verbrennungskraftmaschinen un Thermodynamik, Heft Nr 51, 1989
22.3 Almbauer R., Pucher K., Sturm P.J.: A computer program for determining Traffic Emissions, in Zanetti (Ed.), Computer techn. in Environnemental Studies III, Springer Verlag, 1990
22.4 Sturm P.J.: Determination of Motor Vehicle Emissions as a function of Driving Behaviour, in the Emission Inventory, Pasadena, 1993, AWMA Pittsburg, 1994
23 no reports at present, TRL, Crowthorne, UK

Appendix 1 : Global description of the studies

	Pass.cars Duty veh	Urban /extra-urban	Pays	On-Board Survey	Continu Histogr	Number Vehicles	Driving cycles	Models	
1	P	U	Italy	OB	C	1	DC	M	
2	P	U	Finland	OB	C	4	DC	M	
3	P	U	Germany Switzerl.	OB	C	3	DC		
4	P	Ex	Germany	OB	C	15	DC		
5	P	U	Greece	OB	C	1	DC		
6	DV	U	Hungary	OB	H/A	150		M	
7	P/DV	U	Australy	OB/S	C		DC		
8	P/DV		Switzerl.	at Inspection	H/A	94000	DC		
9	P	U/Ex	Switzerl.	OB	C	?	DC		
10	DV	U/Ex	Switzerl.	OB	C	?	DC		
11	P/Oth		Switzerl.	S	H/A	20000	DC		
12	DV	Ex	Switzerl.	Video	H/A	?	DC		
13	PC	U/Ex	F/FRG/UK	OB	C	58	DC	M	
14	PC	U/Ex	France	OB	C	55	DC	M	
15	PC	U	France	OB	C	4			Traffic Managnt
16	DV	U/Ex	France	OB	C	48			In progress
17	DV	U/Ex	Germany Switzerl.	OB	C	30	DC		
18	P Van	Ex	Spain	S	?	55000	DC		
19	P/DV	U/Ex	Sweden	S	H/A	7600			
20	P/DV	U/Ex	Sweden	at Inspection	H/A	48230			
21	P/DV	U/Ex	Sweden	Traffic analyser	Time gaps		?	M	
22	P	U	Austria	OB	C	1	DC		
23	DV	U/Ex	UK	OB	C	1	DC		

Types of information recorded

	On-Board / Survey	Trips descript.	Veh. Speed	Engine speed	Engine load	Thermal cond.	Gearbox	vehicle use	other
1	OB	1	1	1		1	1		
2	OB	1	1	1	1	1	1		
3	OB		1						
4	OB		1						
5	OB	1	1						
6	OB	1	1				1		
7	OB/S		1						
8	at Inspection							1	annual mileage
9	OB		1						
10	OB		1	1	1	1			
11	S	1						1	
12	Video								traffic condition
13	OB	1	1	1		1	1	1	
14	OB	1	1	1		1	1	1	
15	OB		1	1			1		
16	OB	1	1	1	1	1	1	1	
17	OB	1	1	1	1		1	1	
18	S	1						1	
19	S	1						1	
20	at Inspection								annual mileage
21	Traffic analyser		1						traffic condition
22	OB	1	1	1			1		
23	OB	1	1	1	1		1	1	

Driving Cycle Generation

Jonathan Cohen
Systems Applications International, San Rafael, CA

DRIVING CYCLE GENERATION

Jonathan Cohen

Systems Applications International
San Rafael, California

International Workshop on Vehicle Driving Cycles
Ottawa, Canada

6 February 1995

95004|001

SUMMARY

Purpose: Create short driving cycles to represent in-service sec by sec data

Generic Algorithm

- Divide in-service sec by sec data into modal segments
- Cycle = sequence of randomly selected modal segments
- Match cycle summary statistics to in-service data

Applications

- Light duty driving cycles (vehicle speed)
- Heavy duty driving cycles (% engine speed, % engine torque)
- Using segment summary data to generate cycles

LIGHT-DUTY DRIVING CYCLES

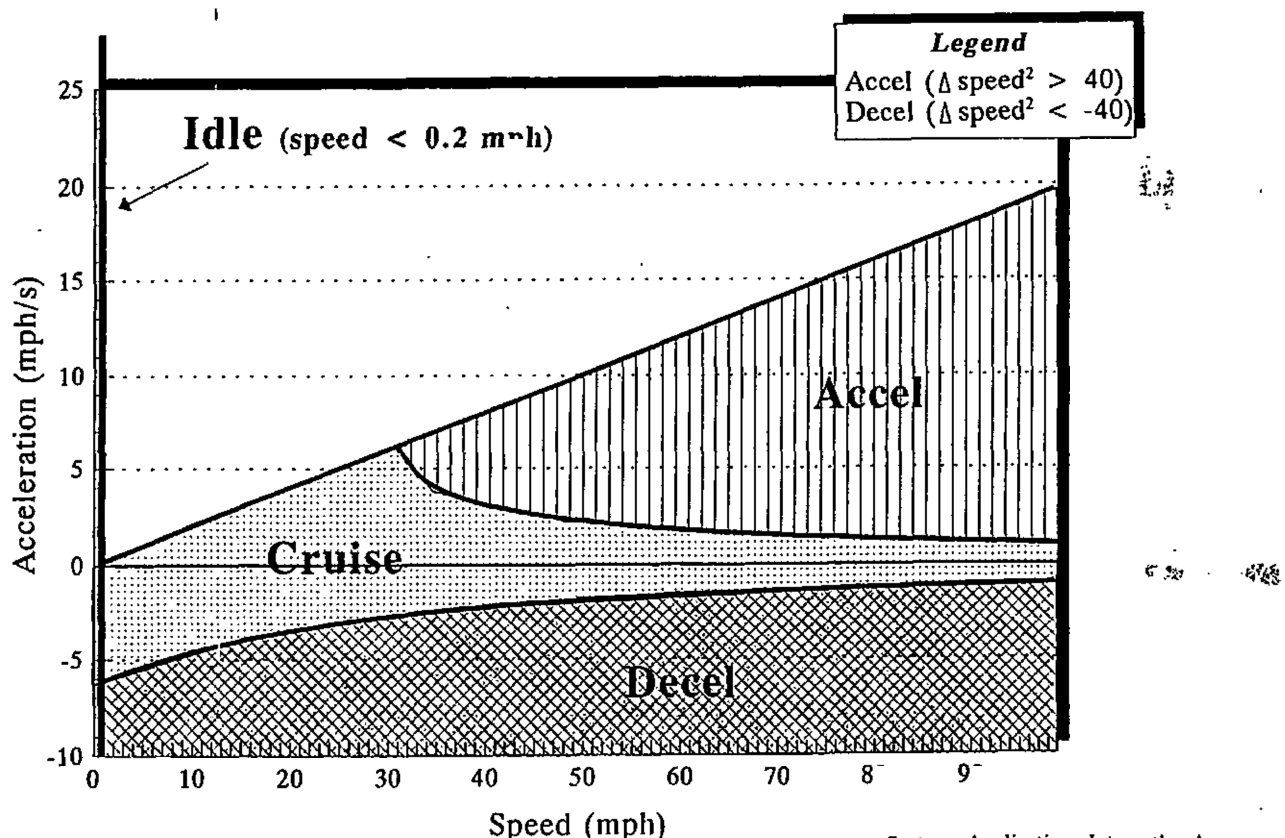
For EPA OMS

Software Development Only

- Modal segment definition
- Cycle algorithm
- Cycle statistics

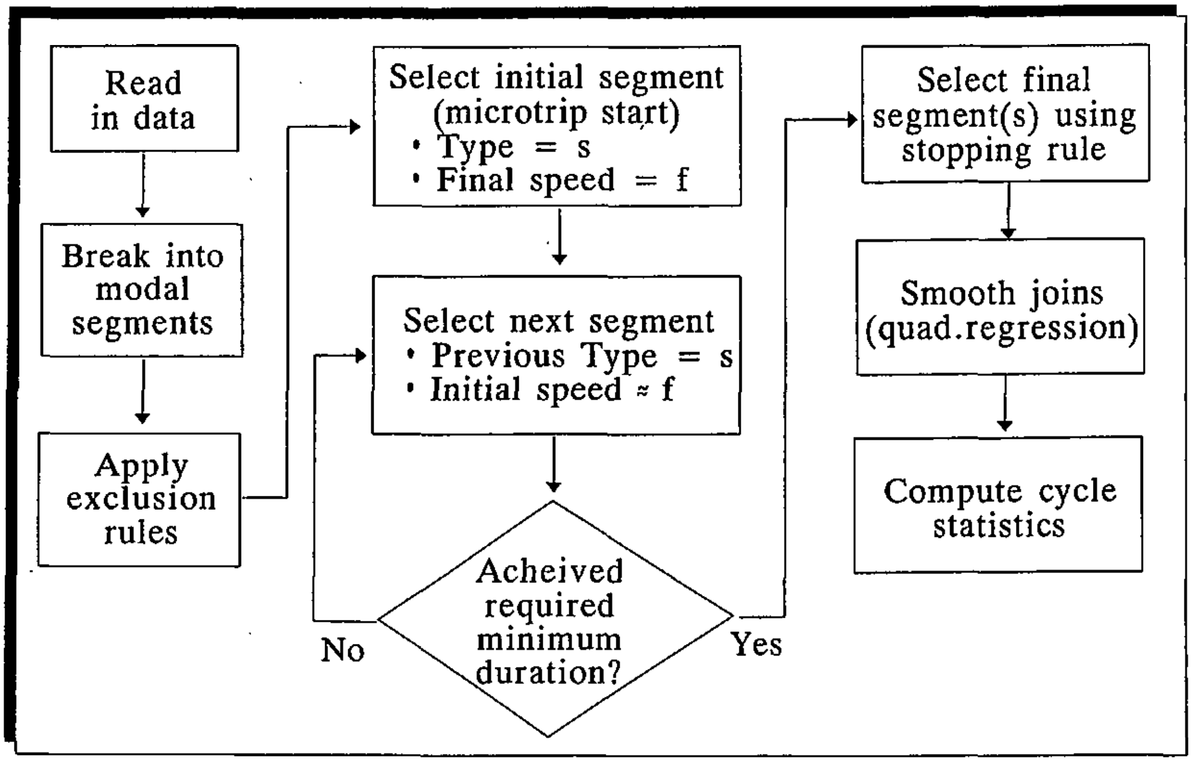
Systems Applications International

SPEED BASED MODAL SEGMENTS

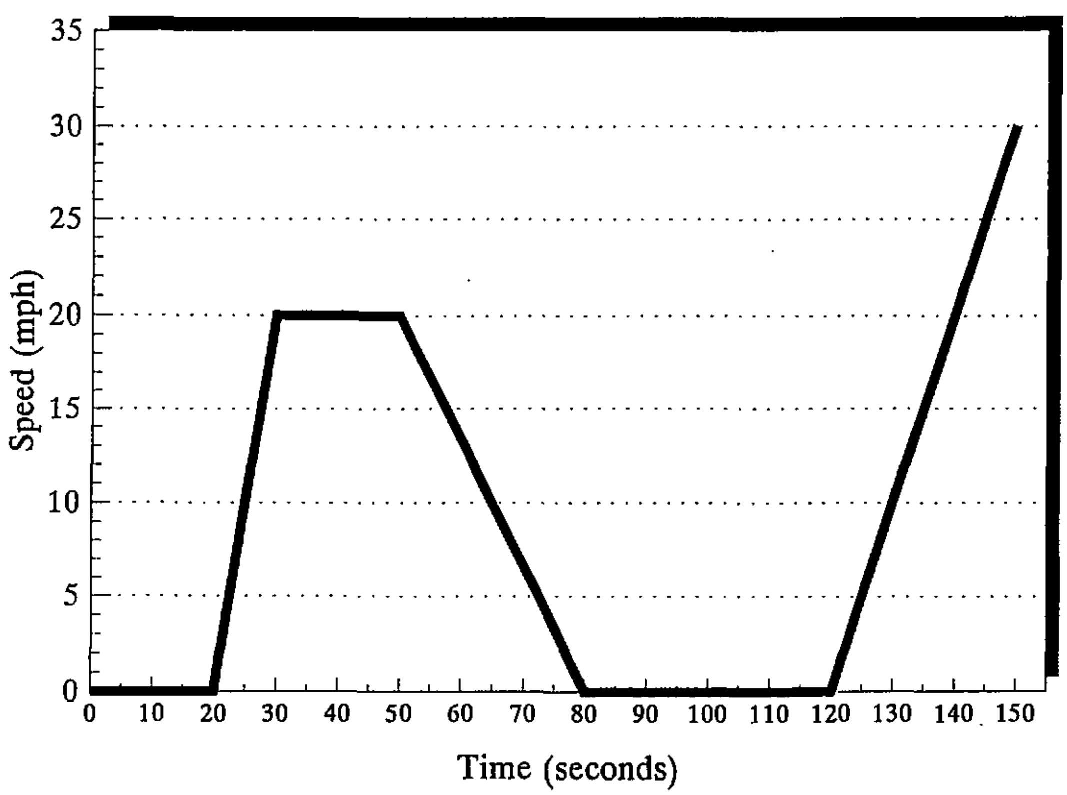


Systems Applications International

CYCLE GENERATION ALGORITHM
Light Duty



MODAL SEGMENTS SELECTION



CYCLE STATISTICS
Light Duty

Time Based
- Mean speed, pos. speed
- Mean pos. accel, neg. accel
- Mean specific power (Δ speed^2/acc > 0)
- % idle, cruise, accel, decel
- Speed distribution
- Accel distribution

Micro-Trip Based
- Mean duration, distance
- Mean speed, pos. speed
- Mean % idle
- Mean stops/idle time per mile
- Mean specific power

Modal Segment Based
- Average mean speed for cruise
- Average mean speed for accel
- Average mean speed for decel
- Average mean accel for accel
- Average mean decel for decel
- Average duration for idle

SUM OF DIFFERENCE STATISTICS
Light Duty

For Ranking Acceptable Cycles

SD_1 Time-based: speed, accel
SD_2 Time-based: speed, accel, Δ accel
SD_3 Modal segment based: mean speed, mean accel, duration

Example:

$$SD_1 = \text{Total} \left| \begin{array}{l} \text{Fraction of cycle at speed s, accel a} \\ \text{-Fraction of data at speed s, accel a} \end{array} \right|$$

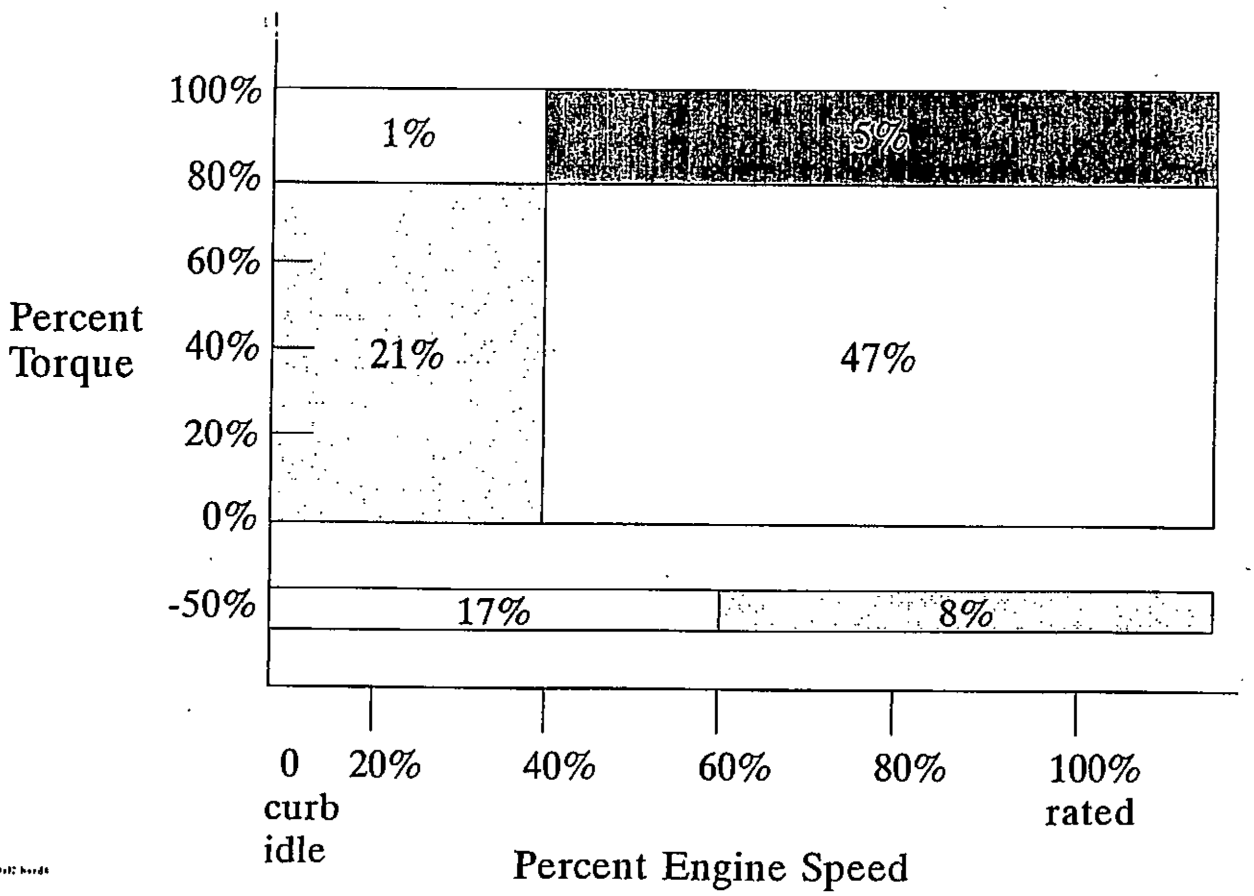
Summed over speed, accel ranges

HEAVY DUTY DRIVING CYCLES

For TRL, British Dept. of Transportation, EU

- Modal segment definition
- Cycle algorithm
- Cycle statistics

MODAL SEGMENT BLOCKS



IN-SERVICE DATA CONVERSION

Curb idle = lowest rpm

Rated rpm = highest rpm at which maximum power occurs

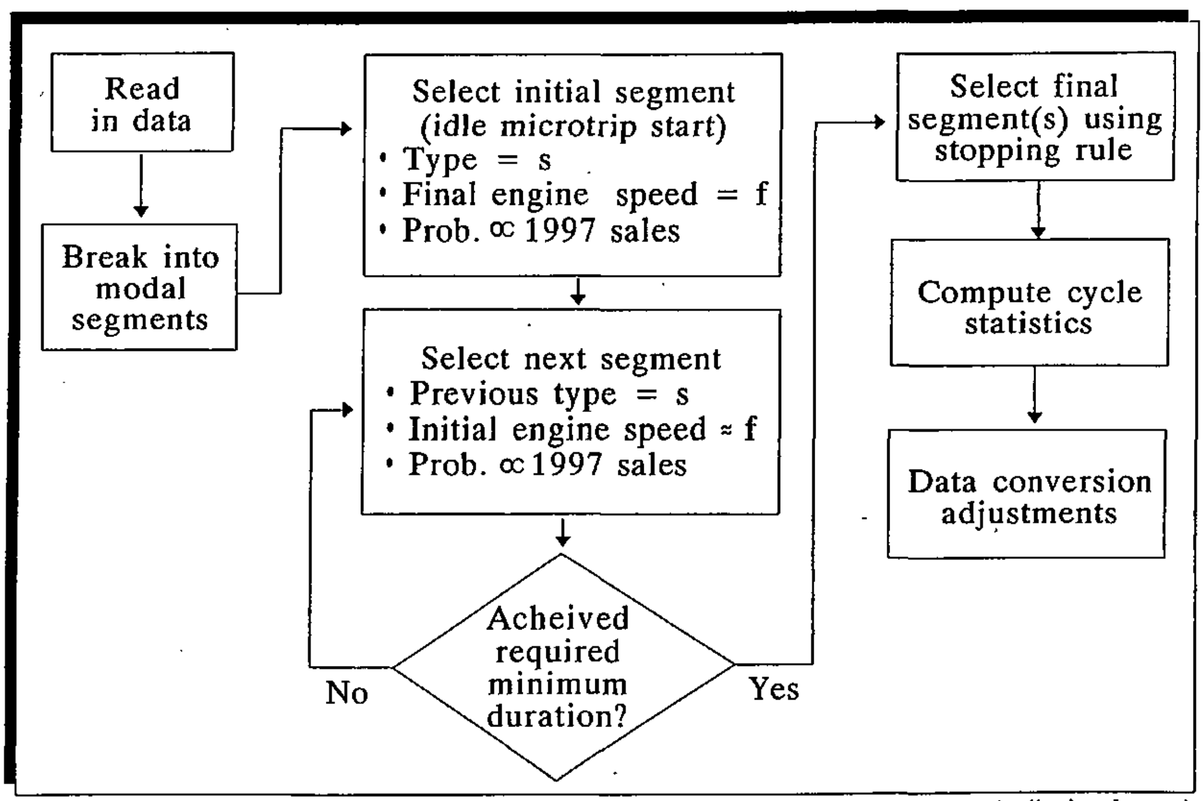
$$\% \text{ rpm} = \frac{\text{rpm - curb idle}}{\text{rated rpm - curb idle}} \times 100\%$$

$$\% \text{ torque} = \frac{\text{torque (Nm)}}{\text{maximum torque for rpm bin (Nm)}} \times 100\%, \text{ non-motoring}$$

or -50%, motoring

Systems Applications International

CYCLE GENERATION ALGORITHM
Heavy Duty



Systems Applications International

CYCLE STATISTICS
Heavy Duty

Time Based

Description	Units	In-Service Data	20 Min. Cycle	50 Min. Cycle	U.S. Transient Cycle
Total duration (unweighted)	secs	788646	1207	3024	1199
Mean speed	%	50.54	52.28	51.86	41.50
Mean positive torque	%	33.85	29.49	34.78	28.30
Percentage time in low spd, low torq	%	21.35	21.54	18.88	47.71
Percentage time in high, low	%	46.70	51.12	46.33	24.41
Percentage time in low, high	%	1.00	0.17	2.15	1.50
Percentage time in high, high	%	5.46	5.22	4.23	11.09
Percentage time in low, motoring	%	17.33	12.76	19.11	5.34
Percentage time in high, motoring	%	8.27	9.20	9.29	9.92
Mean absolute change in speed	%	3.14	4.60	5.04	2.44
Mean absolute change in torque	%	8.22	9.05	9.54	5.32

CYCLE STATISTICS
Heavy Duty

(continued)

Segment Based

Description	Units	In-Service Data	20 Min. Cycle	50 Min. Cycle	U.S. Transient Cycle
Total number of segments		69976	113	305	115
Mean Speed					
Mean speed in low spd, low torq	%	11.36	12.27	10.29	2.92
Mean speed in high, low	%	70.29	68.85	74.61	85.50
Mean speed in low, high	%	14.09	7.95	5.00	20.62
Mean speed in high, high	%	73.40	74.11	66.17	82.58
Mean speed in low, motoring	%	29.52	28.41	20.09	29.06
Mean speed in high, motoring	%	73.00	75.41	73.99	82.57
Mean Torque					
Mean torque in low spd, low torq	%	12.96	9.15	12.70	6.17
Mean torque in high, low	%	32.70	28.53	32.74	39.18
Mean torque in low, high	%	91.04	95.61	92.04	83.29
Mean torque in high, high	%	89.05	92.00	87.36	89.14
Mean torque in low, motoring	%	-46.97	-48.56	-47.17	-43.01
Mean torque in high, motoring	%	-48.43	-48.55	-47.60	-47.23

Segment Based

Description	Units	In-Service Data	20 Min. Cycle	50 Min. Cycle	U.S. Transient Cycle
Mean Duration					
Mean duration in low spd, low torq	secs	13.56	13.68	11.42	30.11
Mean duration in high, low	secs	16.58	15.43	13.47	9.45
Mean duration in low, high	secs	6.89	2.00	16.25	2.57
Mean duration in high, high	secs	7.12	7.00	5.33	8.87
Mean duration in low, motoring	secs	8.95	7.33	8.38	3.37
Mean duration in high, motoring	secs	6.49	5.05	5.30	5.17

Micro-Trip-Based

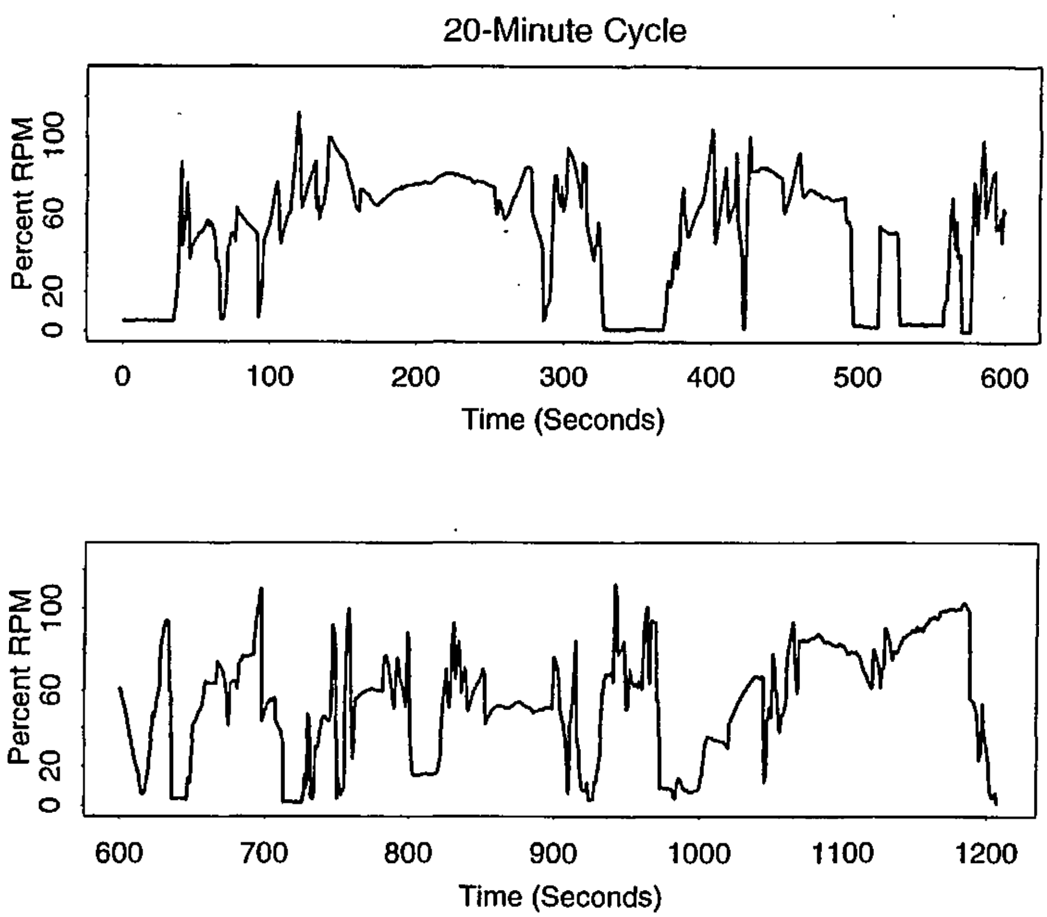
Description	Units	In-Service Data	20 Min. Cycle	50 Min. Cycle	U.S. Transient Cycle
Total number of microtrips	secs	5953	21	38	27
Mean microtrip duration	%	112.15	57.48	79.58	44.41
Mean microtrip mean speed	%	22.45	29.08	27.40	17.18
Mean Microtrip mean pos. torque	%	18.36	18.15	18.55	14.19

OTHER SUMMARY STATISTICS

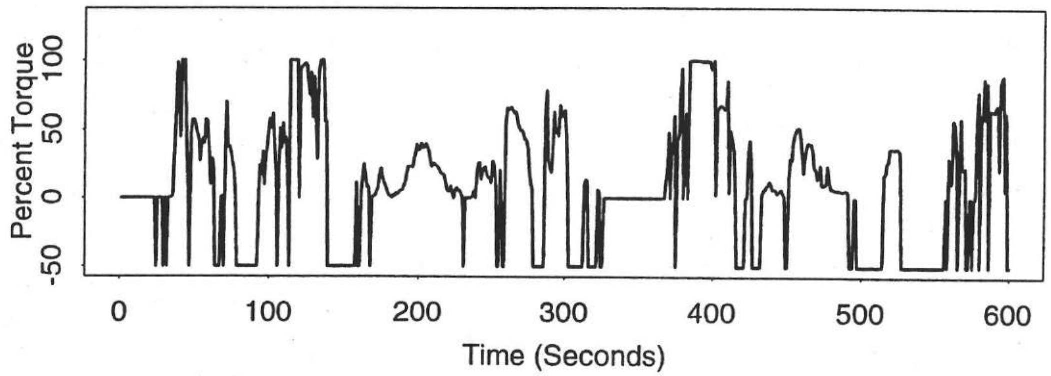
- % speed distribution
- % torque distribution
- % Δ speed distribution
- % Δ torque distribution
- Time-based sum of differences: speed, torque
- Modal segment based sum of differences: mean speed, mean torque, duration

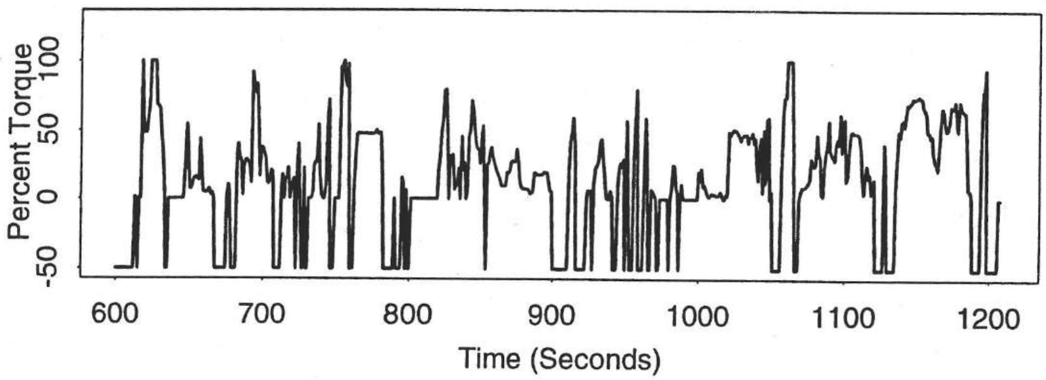
Systems Applications International

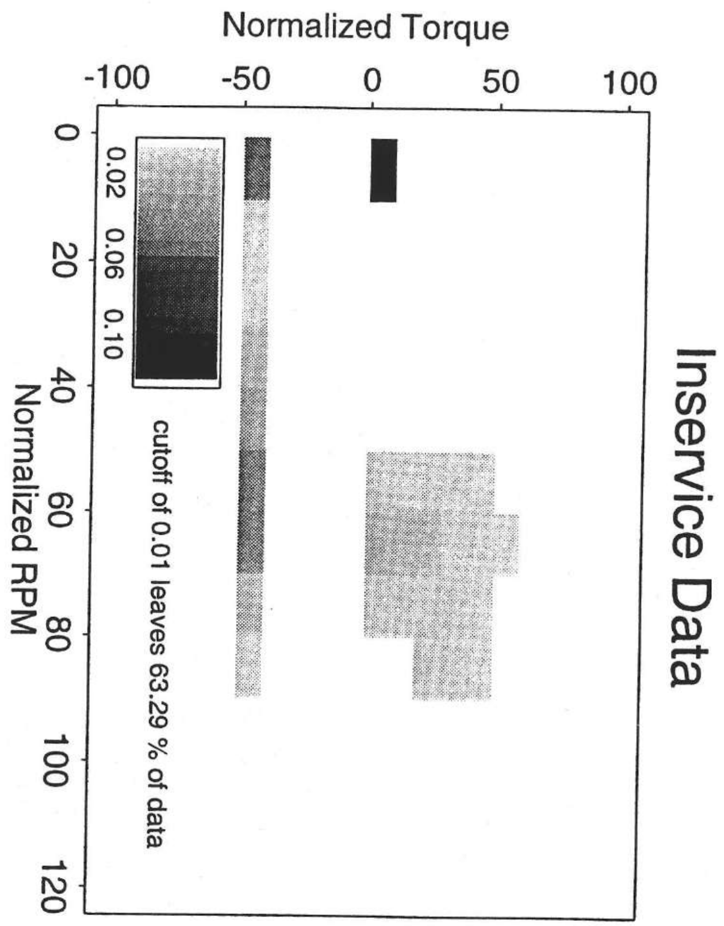
93004.015

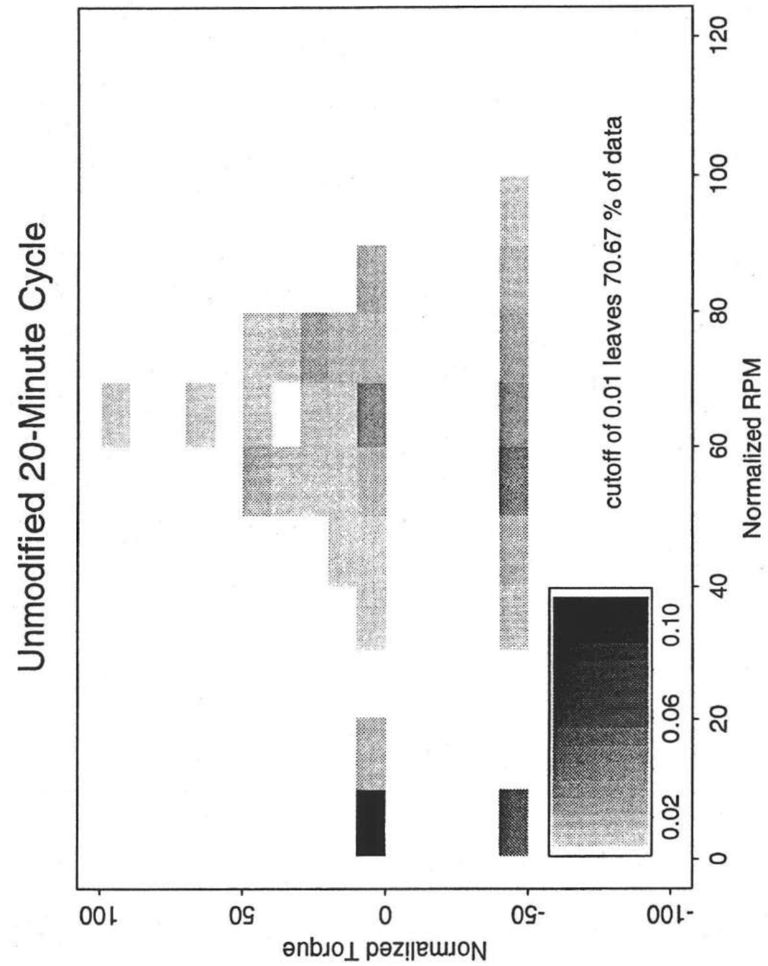


20-Minute Cycle









SEGMENT SUMMARY DATA ALGORITHM

- On-board computer does not keep all sec by sec data

- Keeps modal segment summary statistics only (segment type, mean speed/torque, etc.)

- Generate "collapsed" cycle defined by segment summary statistics

- Compute cycle/data summary statistics

- Then expand collapsed cycle:

  - Select matching segments from sec by sec data base, or
  - Devise software to create modal segments with required properties

SEGMENT SUMMARY STATISTICS NEEDED

Heavy Duty Example

For Cycle Generation

Accumulate by modal segment:

- Mean speed
- Mean torque
- Duration
- Initial/final speed

For generating sec by sec sequences to match segment summary statistics,

For computing cycle statistics

Accumulate by vehicle:

- Vehicle number, type
- Sum |Δspeed|, sum |Δtorque|
- Time in each 10% speed/torque range
- Time in each 10% Δspeed/Δtorque range

CONCLUSION

- Modal segment based approach to cycle generation
- Cycle = random sequence of modal segments
- Should be better than micro-trip approach since micro-trips contain multiple emissions modes, leading to redundancy
- Cycles can be generated and validated using modal segment summary data only
- Generation/validation software available for
  - Light duty driving cycles (vehicle speed based)
  - Heavy duty driving cycles (engine speed and torque based)

Characterization of Traffc & Driving Cycle Development

Michel Andre
INRETS, Lyon, France

Characterization of the traffic conditions and Driving Cycles development using real-world driving measurements

M. ANDRÉ
INRETS - Laboratoire Énergie Nuisances, Case 24, 69675 Bron Cedex - France

with the participation of
TRL - Vehicles & Envir. Div., Crowthorne, Berkshire - RG 116AU - United Kindom
TÜV Rheinland, Zentralabteilung Verkehrs- und Transporttechnik, PF 101750, 5000 Köln 1, RFA (Germany)

Abstract

A better knowledge of vehicle usage and of vehicle and engine operating conditions is highly required when defining realistic test conditions for measuring pollutant emissions or fuel consumption on a test bench, for validating laboratory results, for modelling or drawing-up national or local inventories of pollutant emissions.

With the aim of defining typical vehicle real-world operating conditions, a database on actual vehicle use has been built-up within the EEC research program, DRIVE[1] - *modem*[2]. An experimental study was carried out by INRETS in France, TÜV-Rheinland in Germany and TRRL in Great Britain, using 58 privately-owned vehicles, equipped with a data-acquisition system to record their operating conditions. Vehicles were driven for their normal uses by their owners. Over 8,200 trips and 73,000 kilometers were monitored, during which the vehicle speed, engine speed, temperatures and other variables were recorded at one second time intervals.

The data obtained provided a wide image of normal European driving, and were used to characterize traffic conditions and to derive representative driving cycles. Traffic conditions have been characterized through splitting recorded speed profiles into "kinematic sequences", between successive stops. Factorial analysis and classifying techniques enabled the characterization of these sequences and linking of the different sequence types. Realistic driving cycles were then drawn-up by recombining real sequences, randomly selected in accordance with the results of the statistical analyses. These cycles represent the European traffic conditions and driving patterns, while taking into account the influence of the vehicle type, driver's behaviour and geographical location, as well as the detailed records of engine operations.

Beyond these experiments, the method used to record vehicle operating conditions is widely discussed and is extended to duty vehicles. Tools and methods developed for constructing test cycles are described.

Key-words : Driving Cycle, Driving behaviour, Driving patterns, Actual Uses, Engine Operating Conditions, Passenger Cars

Introduction

Vehicle-related pollutant emissions and fuel consumption are dependent on a number of factors: vehicle technology, vehicle conditions (tuning quality, age), fuels used, etc... "External" conditions should also be taken into account: traffic, geographical and weather conditions, vehicle usage (short or long trips, use frequencies, transported loads, urban structure, roads travelled), and eventually the drivers'behaviour (gentle or "aggressive" driving, driver's attitude as related to speed limitations, gearbox and choke uses, etc..). All these conditions have repercussions on vehicle and engine operating conditions: experienced speeds, accelerations, engine speeds, engine

---

[1] DRIVE: Dedicated Road Infrastructure for Vehicle Safety in Europe - EEC research program - DG XIII
[2] modem : Modelling of Emissions and Fuel Consumption in Urban Areas - DRIVE Project V1053.- by TRRL (UK), TÜV-Rheinland (FRG), CEDIA (B), INRETS (F)

power, thermal conditions, etc...

Most of the emissions recorded on a vehicle (or engine) test bench for obtaining a better data representativity must be performed under most realistic conditions, in particular according to prescribed speed versus time curves (driving cycles). But vehicle running conditions in real-world uses - which are required to define test conditions - are badly known.

The knowledge of such conditions is also required to draw-up an inventory of transport-related pollutant emissions or to assess the impact of regulatory measurements or innovative technologies from the measurement results obtained. These data are also needed as input data in models aimed at simulating operating conditions.

In order to determine a database of vehicle real use and operating conditions, a number of experimental studies were performed with privately-owned vehicles, equipped with data acquisition systems. In France, such studies were performed at INRETS in 1983 and 1989 (Eurev [1] study, Ref. 1 and 2), over 35 and 20 privately-owned cars. A European experiment based on the same method was conducted in 1990 as part of an EEC research programme, the DRIVE-*modem* programme (Ref. 3 and 4). It was aimed at modelling vehicle pollutant emissions and fuel consumption under urban traffic conditions, according to instantaneous operating parameters. This study was performed jointly by INRETS in France, TÜV-Rheinland in Germany and TRRL in Great Britain. Studies related to duty vehicles have already been performed (in Germany, Switzerland, Great Britain, etc...) or are being conducted (in France, etc...).

1. Data collection relating to vehicle use conditions - Method

The basic principle selected was the observation of vehicle use and operating conditions under real-world driving conditions. Privately-owned cars, driven for their normal purposes by their owners (usual driver, common usages), were equipped with sensors and off-line data acquisition systems to record main operating parameters at instant-time intervals, which were not requiring the action of an operator or the driver. Measurement campaign must be performed over time periods, geographical areas and conditions which are sufficiently diversified and representative to take into account "external" conditions at best (geographical and weather conditions, varieties of behaviours, etc...).

1.1 The "black box" principle

A perfect reliability of the equipment used, sufficient equipment capacities (off-line operating range, recording capacity), a fully automated system and the unavailability of additional explicative information (specific conditions met, road types, etc...) are required when applying such a principle. The driver's action (for coding information for example) is not advisable: tests demonstrated that such information is not reliable, and in addition, this is a constant reminder of vehicle monitoring for the driver, which may to lead to changes in his behaviour (speeds experienced, etc...). The presence of an operator or an investigator on-board would simplify material issues and guarantee the reliability of additional information, but would certainly have an incidence on the driver's behaviour. This alternative cannot be contemplated for private cars, owing to the use unpredictability and trip distribution with time. It can only be used for duty vehicles whose usage is better pre-defined.

1.2 Private vehicles

Instrumenting private vehicles to be operated by their drivers is not a satisfactory alternative. This may lead to an increased use of the vehicle, to "unusual" operating conditions and suppress the vehicle-related variability aspect (wide spread of the vehicle manufacturing features yielding various consumption and emission results).

Due to the great variety of existing vehicles and their use conditions (privately-owned cars, rental cars, commercial vehicles, taxis, light or heavy duty vehicles, specific vehicles, etc...), these are divided into vehicle families. Furthermore, the parameters to be considered could vary substantially as a function of the vehicle type: for example, the transported load is a prevailing element for heavy vehicles, while the impact of such a feature and even more its variation range are relatively limited for passenger cars (vehicle occupancy, luggage volume, etc..).

The primary objective is to develop a statistically representative database, i.e the most common vehicle types are studied in a first step (special vehicles such as "sports cars" or up-market cars can be discarded). In the same way, it is recommended to not consider very rare use cases (trailer towing, etc...), provided that such uses are actually marginal.

Owing to the relatively high equipment and monitoring costs, the number of test vehicles is relatively low. Therefore, greater precautions should be taken for the purposes of representativity and variety. In order to obtain a relatively good representation of the vehicle fleet involved, at least the following criteria to determine the vehicle distribution are to be considered for selecting the sample: geographical distribution, fleet structure, and drivers'characteristics.

1.3 Geographical distribution

The geographical vehicle location is certainly one of the most important parameters conditioning the usage types and vehicle operating conditions: urban or rural areas, uplands or lowlands, hot or cold climatic areas. For duty vehicles, very specific use conditions should be observed for borderline areas as related to freight transport or on main communication roads.

1.4 Structure of the vehicle fleet

The great variety of the vehicles is related on the one hand to technology (carburetion or injection petrol-engined vehicles, diesel-engined vehicles, equipped with catalysts or not, etc...) which varies from one manufacturer or model to another, on the other hand to technology changes (20 years of technology changes can be observed over the operating fleet of passenger cars and duty vehicles). In the same way, vehicles have been subject to various regulations as a function of the design year (in particular as regards pollutant emissions). An evolution in operating conditions should be expected with vehicle wear degree and age, and in particular a reduced use intensity. Finally, the "vehicle calling" is a fundamental parameter: the use of a taxi or rental car certainly differs from the use of a private car; duty vehicle types (tank vehicle, flat semitrailer, panel delivery truck, open semitrailer, trailer, etc...), transported goods types , the use type (from deliveries in urban areas to long-distance transport, etc...), and the company operation pattern (independent or sub-contracted companies), have an impact on the vehicle operating conditions.

As for passenger cars, the following parameters were selected for defining the vehicle sample: technological features (petrol, Diesel, injection engines, catalyst), the vehicle make and model (including foreign manufacturers), the manufacturing year (and associated regulations), the total mileage already covered.

Duty vehicles were studied according to the following classification: commercial vehicles and small duty vehicles (including vehicles derived from technologies specific to passenger or commercial vehicles), commercial or heavy vehicles, and road passenger transport vehicles (buses and coaches). For each family, a sample was determined as a function of the technology used, the vehicle make and model, age and mileage, and according to the "calling" or the transport usage type (delivery, etc...) and the company type.

Considering the previously mentioned items requires a preliminary study for characterizing and describing the vehicle fleet, its geographical distribution, its uses from national statistical data (registration, traffic data, etc...).

Test sets	Number of cars tested	Number	test locations	Car models	Years
France (passenger cars)					
1983-85	35	6	urban / non-urban	7	1979-81
1989-90	20	2	urban / non-urban	2	1989-90
Total	55	8	urban / non-urban	9	
Commercial & Light					
Duty vehicles 1994-95 (ref.5)	40	4	urban / non-urban	9	1989-92
Duty vehicles & buses 1995	8	2	urban / non-urban	2	1989-92
DRIVE modem (pass. cars,1990)					
Germany	19	2	urban	5	1982-89
France	21	2	urban	5	1980-89
Great-Britain	18	2	urban	7	1981-89
Total	58	6	urban / 3 countries	13	

Table 1 : fields of different French and European sets of measurements

1.5 Driver-related selection

Owing to the driving behaviour incidence, the vehicles must be selected as a function of their drivers, the age and sex of the main driver, their social and personal conditions, etc... This requires the knowledge of the drivers' profiles, which signifcantly vary with vehicle models, motorization, etc... (e.g, small car users are generally females, young or retired people).

1.6 Which parameters should be measured?

A number of measurement campaigns related to pollutant emissions (Ref. 6) demonstrated the role of the following parameters: speeds and accelerations experienced, engine speeds used, engine thermal conditions. Pollutant emissions can significantly vary with speed by 1 to 5 over usual speed ranges, they can be increased by a factor 2 as a function of the acceleration rate; cold start emissions can be very significant. For duty vehicles, the engine torque - which is substantially dependent on the load transported, road gradient, etc... - has a prevailing role.

Therefore, access to such data during measurement campaigns related to vehicle usages is essential. More generally, main issues can be grouped as follows:

- *vehicle usages (and commercial activity)*: times, durations, distances travelled, stop numbers and durations (delivery, etc...) volume/weight transported etc...

- *travelling vehicle:* speeds experienced, accelerations, stops at road intersections, congestions, etc...; road characteristics (gradients and geographical areas, urban or rural fabric, weather conditions, etc...), traffic conditions, etc...

- *engine operating conditions*: engine speeds and loads, thermal conditions (cooling, lubricating, exhaust gas and intake air temperatures), start-up, etc...

- operation of *engine auxilliary equipement:* gearbox, clutch, electrical power consummed and generated (alternator, battery and network), operating conditions of a turbocompressor, if any, and of the engine cooling fan, etc...

As regards passenger cars, the following parameters were selected: date and time for each trip, distance travelled at each second time interval - from which were derived the vehicle speed and acceleration data - engine rotation speed, throttle opening or injection control position for indicating the engine load, fuel consumption, engine water and oil temperatures, ambient air temperature, the uses of a number of auxilliary equipement such as wipers (an indicator of weather conditions), brakes (an indicator of traffic conditions), choke (a determining factor regarding emissions and fuel consumption). Calculating the transmission ratio from vehicle and engine speed data would enable the determination of the gear ratio engaged.

Concerning duty vehicles, measurement data such as the total vehicle mass and road profile (gradients), the torque transmitted by the transmission shaft (the engine torque and the rotation speed being required set data for engine testing on a bench) must be considered additionnally.

1.7 Sensor and equipment selection

Owing to severe environmental conditions (vibrations, high or negative temperatures, electromagnetic disturbances), measurement equipment must be carefully selected. Sensors and electronic instruments specifically designed for car uses (distance, speed, consumption, temperature, etc...) have the advantage of being highly reliable and low-cost equipment, to the detriment of measurement accuracy. Such an accuracy may nevertheless be sufficient in a number of cases. But, when torque measurements on a rotative shaft, potentionmeter pickoffs or accelerometers are concerned, high cost and high accuracy "laboratory" sensors must be used.

The distance travelled, car speed and acceleration were measured using a fairly cheap optoelectronic speed/distance transducer, fitted to the speedometer cable and giving out 8 or 10 pulses a revolution. One pulse is about 20 cm, that means an instantaneous speed accuracy of 0.7 km/h. This accuracy is better when integrating on a few measurements. More recently, fiber-optical sensors and reflectors, Hall effect and toothed wheel (gear) sensors have been implemented to increase measurement accuracy.

The fuel consumption was measured using a fuel flow meter. The selected sensor uses an accurate positive displacement flow sensor containing oval gears which gives a low pressure drop. A degassing chamber ensures that air and vapour bubbles do not affect the measurement. For petrol vehicles, an electrical signal was taken from the low tension connection to the ignition system, to measure engine speed. For diesel cars, an optical device was used to measure the revolution of a suitable rotating engine component.

In order to assess the engine load, a magneto-strictive non-contacting torque sensor was looked for. But, at that time, such a sensor was not available. The throttle position for carbureted engines, and the position of the injection pump command for diesel and injection engines were measured as load indication, using angular or linear position sensors. For duty vehicles, the torque is measured by strain gauges placed on the transmission shaft or on a universal (or cardan) joint. The signal is transmitted using a transceiver, and the gauge power supply is provided by an antenna. The mass transported by the vehicle is measured from the strain of 2 opposite suspension devices, using 2 potentiometer pickoffs.

Brake, choke and wipers uses were recorded from the corresponding electrical information. Water temperature was measured within a pipe of the engine cooling circuit by means of a T branch adaptation, and the oil temperature sensor was mounted with the oil pressure sensor of the engine, by means of a mechanical adaptation. Air temperature was measured at the rear of the car, opposite to the exhaust pipe.

Many signals from the sensors require conditioning in order that they provide satisfactory input to the data logger, and also in order to provide some functions: power supply, signal filtering, delay time, etc.... Conditioning was performed by a conditioner (under the bonnet), which centralized all the cables from the sensors to the data logger (in the boot).

1.8 On-board data acquisition system

The on-board data acquisition system ("SYMADE") was developed at INRETS. The last version is characterized by compact over-all dimensions and limited electric power consumption (200 mA, 12 volts). In addition, the application program (system resident) which is written in language C is liable to be developed. Sixteen analog channels, 16 logic channels and 5 counting channels can be parametrized (from 0.03 to 10 Hertz). Data acquisition is coupled with an external contact (vehicle contact). Data is stored on a PCMCIA FlashCard (up to 20 Megabytes). Parametrization, dialogue and data transfer are achieved using a PC compatible portable micro-computer.

All the parameters measured were recorded continuously. Therefore, from basic data, it was made possible to detect and discard any abnormality due an equipment dysfunctioning (sensors, logger or even the vehicle). Interactions between the various measured parameters could be analysed, as well as their characteristics as a function of various external conditions. Lastly, constructing driving cycles from kinematic values (speeds, accelerations) could be performed from data provided in the chronological mode only. For studies which did not require a parameter monitoring with time, a data logger fitted with a data pre-processing system would provide a number of advantages: size reduction (less storage capacity required), longer monitoring periods.

1.9 Miscellaneous considerations

The whole recording equipment should not provide a significant disturbance to the vehicle operation, uses, and for the driver himself. In this aim, the equipment should be as compact and as well-integretad as possible. The features of each model for adapting sensors (mechanical or electrical ones) vary and a preliminary study is required for each model involved. Universal features should be sought for to minimize these pre-study stages.

A monitoring period of about one month would limit the impacts of the variations observed over a week period, during holidays, etc... Considering seasonal effects would require vehicle monitoring over various periods of year. During the monitoring periods, inspections are provided every 10 to 15 days to check the appropriate operation of the equipment (and to prevent and minimize losses in case of failure), and to collect the data recorded. The time required for installing the equipment on a vehicle is about 1 day for a passenger car and 3 days for a duty vehicle, with a high performance team.

Previous experiments conducted in France and in Europe on passenger cars demonstrated that samples including about some tens vehicles (20 vehicles as a minimum), would provide a relatively good approach. The cost of the whole equipment (logger and sensors) is about 120 000FF (20 000 US$).

In addition, the drivers' participation is not always acquired: a compensation can be proposed, and some precautions should be taken for their being confident. Some socio-professional catagories (workers for whom buying a car is a great investment) can be hardly reached, some others (teachers, free lance workers) can be very easily reached. It seems very hard to motivate owners of up-market vehicles. Finally, should material problems arise, the equipment is brought into attack immediatly, and a quick servicing and support is highly recommended.

2. Measurements performed on privately-owned vehicles, DRIVE-*modem*

Experiments performed on private cars as part of the European DRIVE-*modem* programme are addressed below. Vehicles were selected in or near 6 European cities: London and Derby for Great Britain, Cologne and Krefeld for Germany and Marseille and Grenoble for France. These were selected owing to the great variety of urban conditions observed: large or medium conurbations, northern or southern cities, uplands location. The study was aimed at describing in-operation vehicle fleets in each country, as a function of the vehicle popularity, technology (engine capacity; power; petrol, diesel or injection motorization, catalyst use, etc..), age, usage types (urban, rural), and mileage. Thirteen models manufactured from 1980 to 1989 were selected: Citroën BX 19 Diesel, Renault 5, Ford Fiesta, Peugeot 205 and Renault 21 in France, Vauxhall Cavalier, Austin Metro, Ford Granada/Sierra, Ford Escort/Fiesta Diesel, Peugeot 205, VW Golf GTI and Vauxhall Cavalier in Great Britain, and VW Golf, VW Golf Diesel, Opel Corsa, Renault 21 and Audi 100 in Germany.

First, the vehicles were selected by random sampling of owners' addresses for the chosen models, in the involved areas and then, from a number of representativity and diversity criteria. Vehicles were monitored over a 1-month period (2 vehicles simultaneously in each country). A total of 58 vehicles were tested successfully. The instantaneous data obtained corresponds to 73 300 km recorded over 1 700 hours (i.e on average 1 200 km over 27 hours per vehicle). The recordings allowed the analysis of 8 200 trips from vehicle start-up to vehicle stop (i.e 140 trips per vehicle):

trip lengths, durations, vehicle speeds, and also the number of stops at intersections, the maximum speeds reached, accelerations, etc... versus time distribution. Information about daily use frequencies (use number, durations and daily distances) and use variations with days was get from the 1580 days of vehicle monitoring (about 26 days per tested vehicle).

Table 2: Summary of the experimental study (DRIVE-*modem* data)

	number of vehicles	monitoring duration (days)	number of trips	driving duration (h)	distance (km)
Germany	19	556	3 124	642	33 020
France	21	638	3 243	670	24 680
Great-Britain	18	384	1 861	376	15 590
Total	58	1 580	8 228	1 690	73 280

Table 3: Average trip characteristics through the different studies (DRIVE-*modem* data)

	Average length (km)	Average duration (min.)	Average speed (km/h)	Stop frequency (stop/km)
Germany	10.6	12.3	51.4	0.47
France	7.6	12.4	36.8	0.84
Great-Britain	8.4	12.1	41.5	0.59
Total	8.9	12.3	43.4	0.62

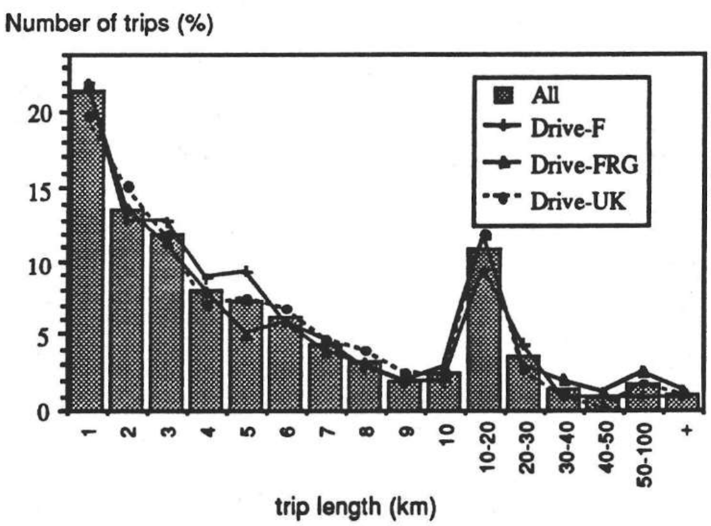


Figure 1: Distribution of trip lengths and comparison between the different measurement stages.

Driving patterns are relatively different in the three countries: trip average lengths range from 7.6 to 10.6 km, average speeds range between 37 and 51 km/h, intermediate stop frequencies (intersections, congestions, etc...) vary from 0.5 to 0.8 stop per kilometre travelled (Table 3). Despite these discrepancies, a great similarity can be observed between trip lengths (Fig. 1). The significant number of very short vehicle uses is particularly remarkable. Thus, according to the measurement stages, 20 to 22% of the trips do not exceed 1 kilometre (12% do not exceed 500 meters). Globally, 1 trip in 2 (47 to 48% according to the stages) does not exceed 3 km. Trips exceeding 10 km represent 17 to 22% of the total number; 4 to 7% exceed 30 km.

3. Characterizing traffic conditions and building-up driving cycles

3.1 Method

Realistic driving cycles, representative of various traffic conditions, were developed from kinematic analyses in order to measure pollutant emissions on a test bench.

The method consisted in analysing the vehicle speed curve as a function of time, and of determining the standard characteristics of this curve as a function of the traffic conditions. Each trip was considered as a series of 'kinematic sequences' (the speed/time curve between successive stops). It was assumed that traffic conditions for an individual sequence were relatively homogeneous, but they could be very heteregeneous during the whole trip, giving a succession of varied sequences.

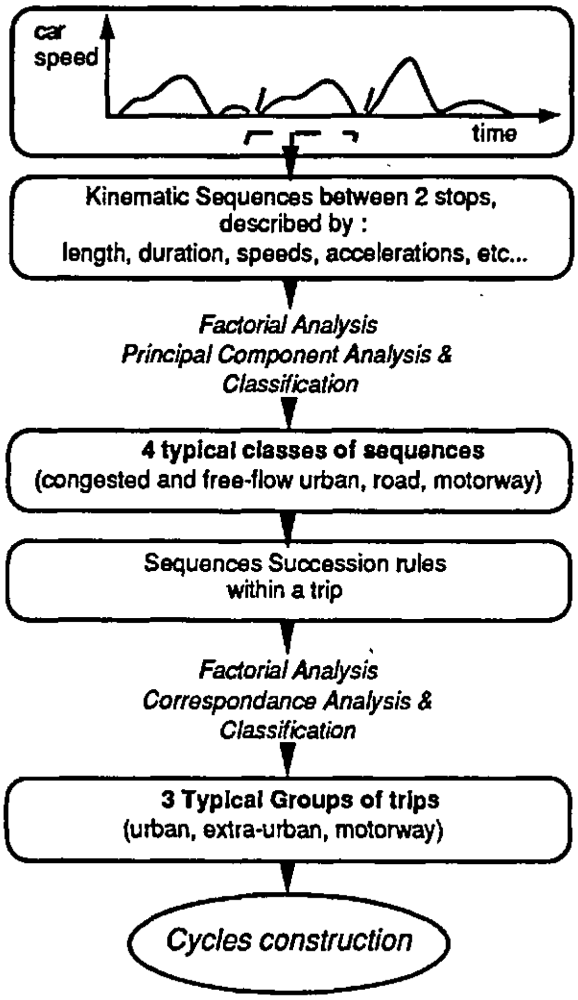


Fig. 2: summary of the analysis

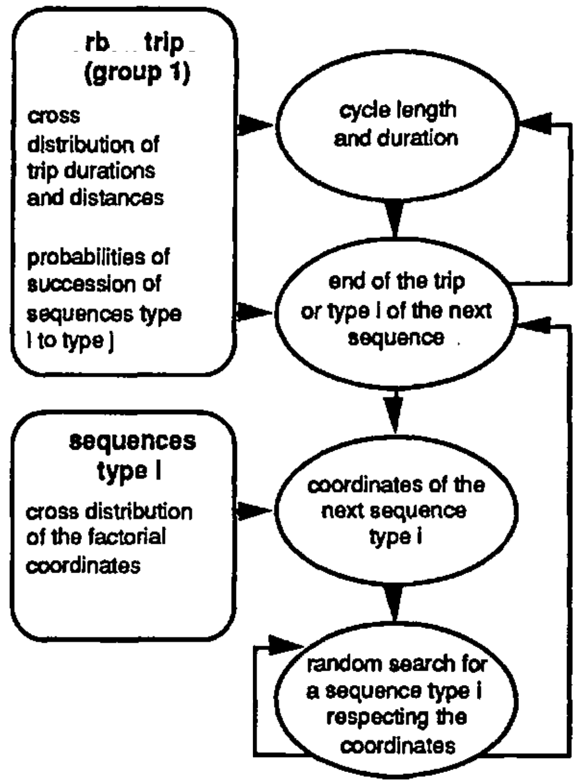


Fig. 3 : flow chart of the driving cycles building-up

This method, initially designed for and applied to French data, has been used to develop test cycles ("Inrets" cycles, Ref. 7) which are relatively homogeneous from a kinematic standpoint and distributed according to various levels of average speed. To reproduce more realistic traffic conditions, these notions of homogeneity and distribution have been discarded and replaced by the consideration of linking probabilities of sequence types over a prescribed trip. These techniques were used to construct a test cycle related to a duty vehicle (garbage truck, Ref. 8) and then to build-up *modem* urban cycles (DRIVE-*modem* data, Ref. 5).

After the characterization of the kinematic sequences, and the specification of each trip in terms of kinematic sequences, duration, and length, it was possible to build-up Driving Cycles representative of the actual driving conditions (Fig. 2). In addition, an algorithm was developed to determine the gearbox ratios to be used for test cycles as a function of the vehicles to be tested, while being representative of the variety of drivers'behaviours.

3.2. Characterizing traffic conditions

The sequences were described by a number of variables taking into account traffic and vehicle operating conditions. All the sequences obtained and associated variables were then analysed by factorial analysis methods to identify the parameters which best described the variability of traffic conditions, to determine whether separate classes of identical sequences exist and to check the consistency of the class distribution thus obtained.

A sequence included a period with the car stopped at idle, followed by a driving period. The sequence at the end of the trip therefore consisted only of an idle period, and was different from the other sequences. In this case, the idle period was not a time spent waiting before continuing with a driving period, and there was no distance travelled during the sequence. For this reason, the trip-end sequences were analysed separately from other types.

From the initial analysis and other reported studies, 20 interesting variables were distinguished :
- describing the sequence size: distance travelled, stop duration, driving duration;
- describing the speeds used: running speed (excluding stops), maximum speed reached; standard deviation, Kurtosis skewness coefficients, 20% and 80% percentiles of instantaneous speed distribution;
- describing the accelerations used: same shape coefficients and percentiles as those defined for the speed;
- various indicators of the disturbed speed character: distances between two accelerations, 2 decelerations, etc...

The test site, the vehicle model, the test date and time and other qualitative data were used as additional variables for this analysis.

3.3. Description of the sequences and interactions between the variables

A total of 49,714 kinematic sequences was obtained from the 8228 trips recorded in the survey. Of those, 5930 were trip-end idle sequences that did not include a driving period. The average number of sequences per trip was 6.5, including the trip-end sequence. The sequences obtained are short : 1.52 km on average, but 45% are less than 250 metres, 77% less than 1 km. The average duration is 2.1 minutes. Duration at stop is 0.4 min. per sequence on average; it is less than 15 sec. for 53% of the sequences and less than 30 sec. for 78% .

Principal Component Analysis (P.C.A) is based on the matrix of correlations between the variables. It is used to understand the links between the variables, and to identify a limited number of new variables or main axes, which are linear combinations of the initial variables. In that way, a smaller set of main variables is determined that gives the best statistical representation of the sequences and their variability. In this study, the P.C.A. led to the identification of 5 main axes which explained 83% of the sequence sample variance. These main axes and their relationships with the initial variables are :

- Axis 1 describes the speeds used during the sequences: average speed, maximum speed and speed distributions are highly correlated with this axis. The sequence size (distance travelled, duration) is also well described. This axis compares long sequences at high speed with short sequences at low speed. It accounts for 47% of the sample inertia or variance, and is therefore very significant.

- Axis 2 gives the variability of the accelerations recorded: the standard deviation and acceleration distributions are strongly correlated. It compares sequences spent at relatively stable speeds with those including frequent accelerations. Axes 1 and 2 account for 63% of the sample variance.

- In addition to these first two axes relating to speed, distance and acceleration, Axis 3 describes the speed distributions. It compares sequences whose speed distribution is skewed towards high speeds with those whose speed distribution is skewed towards low speeds.

- Axis 4 distinguishes size and speed and compares the sequences as a function of their size for a same speed level or vice versa. Size and speed are correlated on axis 1, but opposed on this axis.

- Lastly, axis 5 represents the duration of the sequence idle period ; this variable does not depend on the others, which shows that the idle period (intersection, congestion) is not really connected with the subsequent driving period.

3.4 Classification of the sequences

Classification techniques are aimed at classifying the sequences into well-differentiated classes, in which the sequences are very similar (in terms of their factorial coordinates defined by the P.C.A., or the initial variables describing them), in order to obtain very distinctive classes. Therefore, a significantly different sub-group, if any, can be identified, or an optimum partition can be reached for a relatively continuous set. The method consists in a Dynamic Cluster Classification, followed by Hierachical Classification, and consolidating iterations to improve the classification (Ref. 9).

These procedures enabled the identification of 4 classes corresponding with well differentiated traffic conditions. A partition into a higher number of classes only slightly increases the quality of the results (expressed by the ratio of the inertia between classes to the total inertia , i.e the heterogeneity between the classes studied). These 4 classes and their average properties are shown in Table 4.

Classes 1 and 2 represent urban traffic conditions and comprise relatively short sequences (90 and 500 meters respectively, on average), at low speeds (8 and 23 km/h). Class 1 represents congested conditions, where the vehicle flow is constrained by the traffic, while Class 2 seems to represent free flowing traffic between two intersections with free acceleration followed by braking (Fig. 4).

Class 3 corresponds with suburban or extra-urban traffic. The average duration in class 3 is 5 min. at an average speed of 51 km/h. This class, however, contains sequences whose length and duration vary considerably (the variation in length is 0.5 to 62 km). Finally, class 4 contains a small group of sequences typical of motorway (or main road) driving conditions. The sequences are longer than in the other cases (6 to 460 km, average 58 km) and are driven at higher speeds (93 km/h on average).

It should be noted that this classification does not give a full and reliable identification of the geographical location or the type of road on which a sequence occurred. Congested traffic sequences may well have been recorded on busy motorways, but they will be included in class 1 (congested urban) rather than class 4 (motorway and main road) because of their speed and duration characteristics. Similarly, high speed sequences (assigned to classes 3 or 4) may have been recorded in urban areas, etc...

There is considerable disparity between the classes in term of their total contribution to the whole set of sequences (see also Table 4): urban sequences (classes 1 and 2) comprise 81% of the total number of sequences, but account for only 18% of the total distance travelled and 42% of the travel duration. By contrast, only 1% of sequences was classified as motoway sequences (class 4), but they account for 33% of the total distance driven. In the same way, class 1 sequences (congested urban) represent 2% of the total distance driven but use more than 7% of the total fuel; class 4 sequences represent 33% of mileage, but use 26% of fuel.

3.5 Succession of the different types of sequence within trips

The previous section allowed the definition of 4 typical classes of kinematic sequences. To characterize realistic traffic conditions, it is important to take into account the probabilities of the 4 sequence classes linking, within a whole trip. Thus, the trips were described by the frequencies of each sequence type succession, and were analysed by the correspondence method yielding a trip classification. These analyses are roughly similar to those used to analyse the sequences.

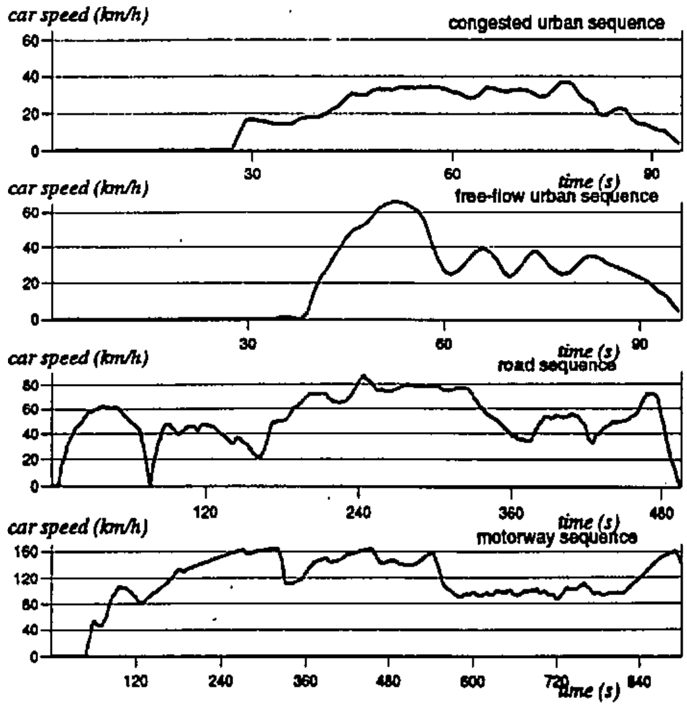


Figure 4 : typical sequences from urban, road and motorway classes (from top to bottom)

Table 4: Description of the 4 kinematic classes, i.e. the traffic conditions

	1 - congested urban traffic	2- free-flow urban traffic	3 - road traffic	4 - motorway traffic	total
number of sequences (%)	35	46	18	1	43783 seq.
% of mileage	2.2	15.7	49.6	32.6	66463 km
% of consumption	7.3	24.0	42.6	26.1	
length (km)	0.09	0.5	4.2	57.7	1.5
duration (min)	0.8	1.4	5.0	37.4	2.1
average speed (km/h)	8	23	51	93	43
nb. of accelerations/km	24	3	0.8	0.2	1
consumption (l/100km)	25.1	12.0	7.1	6.4	7.7

The final classification enabled the identification of three well differentiated trip families or groups. The average properties of the three types of trip, and their composition in terms of kinematic sequences, are given in Table 5. The probabilities of the successions of sequence types are illustrated for urban (Table 6) and motorway trips (Table 7).

Urban trips include a great number of class 1 and 2 sequences (on average 5.8 urban sequences) and have very low probabilities of road or motorway traffic conditions ; these trips have an average length of 4.4 kilometres, and an average speed of 29 km/h.

Road trips mainly include class 3 sequences (road traffic conditions) ; the average length is about 10 km, travelled at 44 km/h. Lastly, the third group of 264 trips have a higher probability of motorway conditions (1.2 motorway sequences ; these trips are long (75 km on average), travelled at high speed (80 km/h on average), and represent typical motorway uses.

The respective share of each trips group is as followed: urban trips represent 61% of the total number of trips, and 31% of the mileage ; road trips represent 35% of the total number, and 39% of the mileage ; motorway trips correspond to 3.4% only, but 30% of the total mileage. This classification enables test cycles to be to built-up to represent typical driving conditions for each group of trips.

Table 5 : comparison of trip groups obtained by classification

	group 1 urban trips	group 2 road trips	group 3 motorway trips	total
Number of trips	4714	2693	264	7672
Mileage (km and share in %)	20727 (31%)	25726 (39%)	20009 (30%)	66463
Average length (km)	4.4	9.6	75.8	8.7
Average duration (min)	9.0	13.1	56.7	12.1
Average Speed (km/h)	29.3	44.0	80.2	43.1
Average number of sequences of each type per trip				
- class 1 (congested urban)	2.6	0.9	1.7	2.0
- class 2 (free-flow urban)	3.2	1.8	2.0	2.7
- class 3 (road conditions)	0.5	1.9	1.5	1.0
- class 4 (motorway conditions)	0.01	0.003	1.2	0.05
total	7.1	5.4	7.1	6.5

Table 6 : probabilities of the successions of each sequence type within urban trips

type of sequence / final initial /	congested urban sequence	free-flow urban sequence	road sequence	motorway sequence	Idle sequence	End of the trip
beginning of the trip	6,0	6,0	0,4	0,0	0,0	0,0
congested urban sequence	15,8	9,2	1,4	0,0	5,0	1,0
free-flow urban sequence	9,1	21,2	3,3	0,0	4,2	1,6
road sequence	1,6	3,0	0,7	0,0	0,4	0,1
motorway sequence	0,0	0,0	0,0	0,0	0,0	0,0
Idle sequence	0,0	0,0	0,0	0,0	0,0	9,7

Table 7 : probabilities of the successions of each sequence type within motorway trips

type of sequence / final initial /	congested urban sequence	free-flow urban sequence	road sequence	motorway sequence	Idle sequence	End of the trip
beginning of the trip	4,6	3,4	1,5	2,8	0,0	0,0
congested urban sequence	7,5	4,1	2,7	2,7	3,2	0,6
free-flow urban sequence	3,1	8,8	5,4	4,0	1,8	0,9
road sequence	2,9	4,9	4,4	4,3	1,5	0,4
motorway sequence	2,7	2,8	4,5	1,0	3,2	0,7
Idle sequence	0,0	0,0	0,0	0,0	0,0	9,7

3.6 Building-up driving cycles

The previous steps have allowed the characterization of driving conditions into four classes, and the classification of trips into three typical groups. The statistical results were then used to build-up representative driving cycles within each trip group. The following paragraphs concern in particular the development of urban driving cycles, representative of the 1st trip group.

A driving cycle was drawn-up according to the following rules (Fig.3):

- the cycle duration and distance were determined at random to repeat the observed cross distribution of durations and distances established for the urban trips (Group 1) ;
- the sequence type (Classes 1 to 4, or idle sequence, or end of the trip) was simulated by random sampling in accordance with the observed succession probabilities for the appropriate type of trip (Table 6) ;
- for a prescribed sequence type, sequences were selected randomly from the data-base of recorded sequences in the required class; they were chosen to correspond approximately with the distribution of factorial coordinates for the class (roughly duration, distance, speed and acceleration distributions) ;
- the cycle generation, sequence by sequence, was continued until the selection of linked sequences conformed with the cycle duration and distance previously determined ;
- the resulting cycle consists of a succession of recorded sequences, i.e the actual speed versus

time curves. It does not result from a point by point simulation.

A set of simulated cycles is thus representative of urban trip durations and distances and of the varied urban traffic conditions. Within the DRIVE-modem project, a set of 14 urban driving cycles was generated which together gave a comprehensive representation of the observed urban driving conditions. The cycles have a total duration of 90 minutes and a distance of 36 kilometres (Fig. 5).

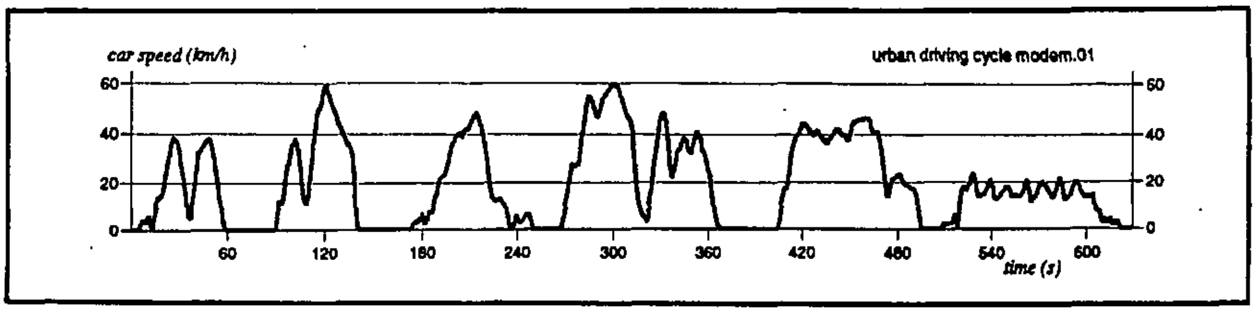


Figure 5 : One of the 14 generated urban driving cycles (curve speed versus time)

3.7 Gear ratio changes

The speed profile does not entirely define a driving cycle. Gearbox use has to be defined. In most driving cycles, the gear ratios are imposed for all the tested vehicles (ECE15 cycles, etc...), though in some cases they are left to the discretion of the driver. The first method undoubtely favours some vehicles, depending on their characteristics. It is also not realistic that a low-power vehicle and a small sports vehicle are driven in the same manner. Selection of gears by the driver does not allow the comparison of the results obtained from different vehicles driven by different drivers with their own way of driving. This method also supposes that the driving style of professional drivers is relatively constant, and neglects the great variety of driving styles.

The principle used in this work, is to determine gear changes during a cycle so that they conform with those observed in normal driving. This solution is able to provide different patterns of gear changes for different types of vehicle and is more representative of actual driving. It was assumed that the gear ratio was mainly determined by the engine speed and the power demand. At each instant through the cycle, a gear change event and its nature depended on the initial ratio, the initial engine speed, the acceleration demand and the probabilities, under those conditions, of a different gear being selected.

These probalities have been established through the gear ratio distributions observed during the on-road data collection, during which engine speed, acceleration and gear ratio were recorded for different types of vehicle. Accelerations and recorded engine speeds were converted into non-dimensional forms by dividing them respectively by the engine speed at maximum power, and by the vehicle specific power. These non-dimensional values were then used for the determination of a distribution or table of occurence as a function of the non-dimensional acceleration and engine speed, initial and final gear ratios from drivers' behaviour data, and later for the simulation of the gear ratios for each vehicle to be tested on the chassis dynamometer, taking into account the technical characteristics of this vehicle. This table was established considering urban driving only, to simulate correctly the gear ratios under urban conditions. When the procedure was applied to the selection of gears during a driving cycle, the final gear ratio was determined randomly, taking into account the initial values of acceleration, engine speed and the gear engaged, and the probabilities associated with possible changes.

Conclusions

The acquisition of a good knowledge of vehicle use and operating conditions - which is highly required for defining realistic test conditions using a test bench - has been made possible with the use of on-board data acquisition systems installed on privately-owned vehicles, provided some precautions had been taken. Experiments performed on a number of vehicles yielded data which highlighted vehicle usages and operating conditions. Eventually, these studies enabled the development of statistical methods and tools for constructing representative test cycles of traffic conditions and therefore the realistic measurement of vehicle-related pollutant emissions and fuel consumption on a chassis dynamometer.

ACKNOWLEDGEMENTS: The European DRIVE-modem research program was jointly carried out by TRRL in Great Britain, TÜV-Rheinland in Germany and INRETS in France, with the financial support of the EEC, Directorate General XIII.

REFERENCES

[1] Experimental Study on the Actual Uses of the Cars (EUREV), M. ANDRÉ, S.A.E. Technical Paper Series N° 890874 - ISSN 0148 - 7191, 7p., 1989.

[2] M. André, In Actual Use Car Testing: 70,000 Kilometers and 10,000 Trips by 55 French Cars under Real Conditions. SAE. Techn. Paper Ser. N°910039, 10p., 1991.

[3] M. André, A.J. Hickman, T.J. Barlow, D. Hassel and R. Joumard, DRIVE-*modem*, Modelling of emissions and consumption in urban areas: Measurements of the Driving Behaviour and the Vehicle Operations in Actual Uses - Method, Dec. 1989, INRETS report, NNE 8905, 129 p., Bron, France.

[4] M. André, R. Joumard, A.J. Hickman, D. Hassel, DRIVE-*modem*, Modelling of emissions and consumption in urban areas: Realistic Driving Cycles for passenger cars, September 1991, INRETS report: Len9105, 29 p., Bron, France.

[5] Usages et Conditions de Fonctionnement, des Petits Véhicules Utilitaires, Méthode de mesure au moyen de capteurs embarqués, (EUREV - PVU), M. ANDRÉ, J.P. ROUMÉGOUX, R. VIDON, C. PRUVOST, P. TASSEL, Rapport INRETS -LEN N° 9408, Mars 1994, 71 pp

[6] H.S. Eggleston, D. Gaudioso, N. Gorissen, R. Joumard, R.C. Rijkeboer, Z. Samaras and K.H. Zierock: CORINAIR working group on emission factors for calculating 1990 emissions from road traffic - vol. 1: methodology and emission factors. CEC report, contract B4-3045(91)10PH, Brussels, 116p., 1991

[7] M. MAURIN, J.P. CRAUSER - The kinematic sequences, an atomistic approach to automobile travel and the effects of traffic - Rech. Transp. Sécurité, Revue de l'INRETS, English Issue N° 5, June 1990, Arcueil, France.

[8] D. Pillot, M. André, R. Vidon, C. Pruvost, Cinématique typique d'un véhicule Benne à Ordures Ménagères (BOM), Rapport Inrets-Len, Déc. 1990, Bron, France.

[9] (Software : SPAD - systeme portable d'analyse des données, see for example: *Multivariate Descriptive Statistical Analysis, Lebart, Morineau, Warwick, 1984*)

Torque & Speed Distributions of Commercial Vehicles,

Heindrich Steven
FIGE GmbH, Aachen, Germany

Report

Engine Torque and Speed Distributions of Commercial Vehicles and its Consideration in Emission Measurement According to EC Directive 88/77/EEC resp. ECE Regulation R 49

by

Heinrich Steven

assisted by

Jerzy Bachurski
Wolfgang Enz
Klaus Günther Kirstein
Dirk Schneider
Ellen Skrzipczyk

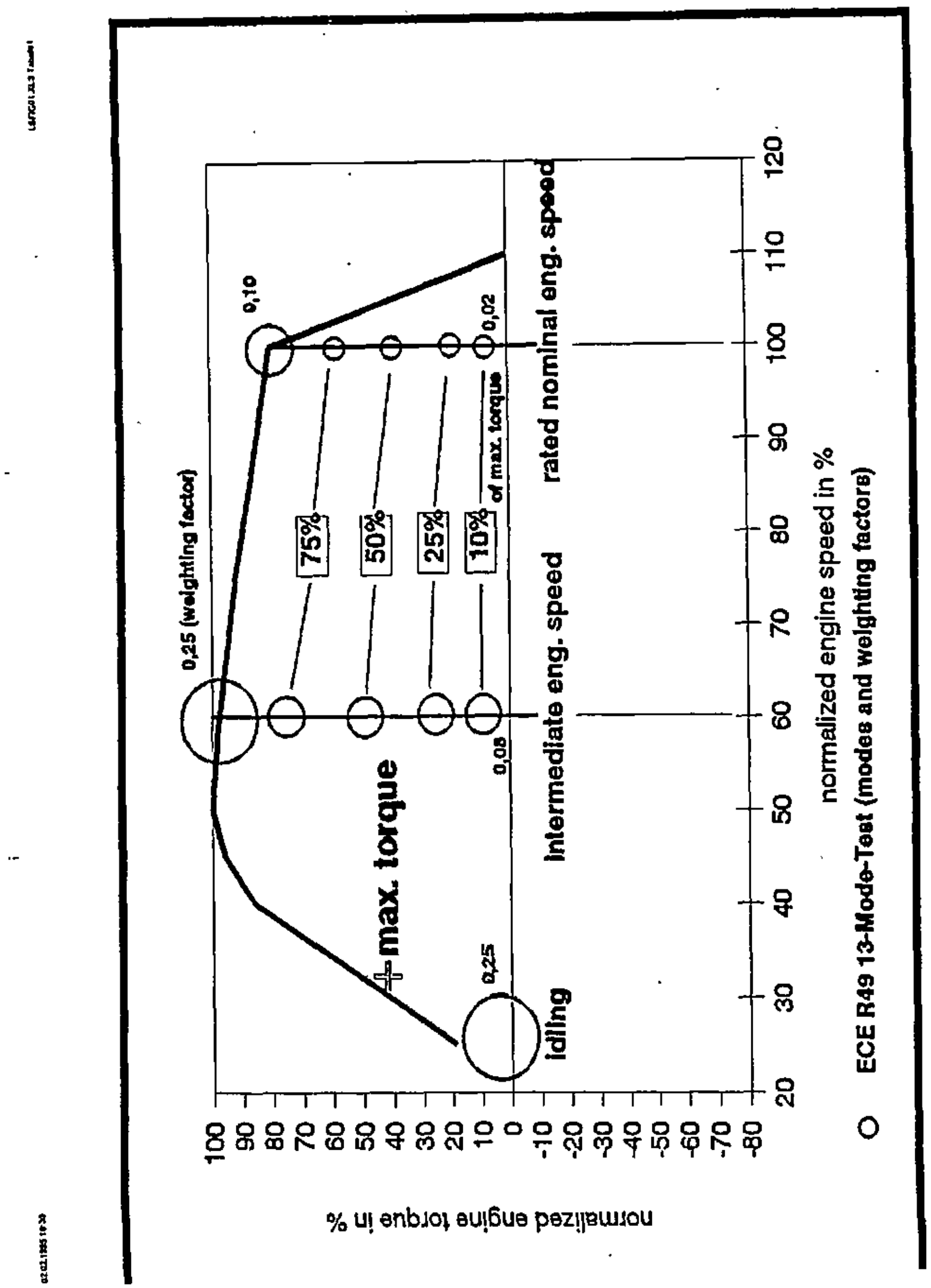
FIGE GmbH
Forschungsinstitut Geräusche und Erschütterungen

Kaiserstr. 100
D 52134 Herzogenrath (near Aachen)

Report No. 104 05 316

Commissioned by the Federal Environmental Agency, Berlin

January 1994



Project Tasks

The tasks of the project may be characterized by the following questions:

1. **Are the operating modes included in the ECE R 49 13-mode test still representative for modern HGV diesel engines in urban traffic?**

2. **Are the operating modes in the 13-mode test equally representative for all engine classes?**

3. **To what extent must operating modes representing traffic outside built-up areas be included in the test method?**

4. **To what extent and in what way must dynamic operating modes be taken into account in determining the pollutant emissions?**

12.02.1995 11:14 LBTAB01A.XLS 1

lo.	Rated Eng. Power in kW	Engine Capacity in cm^3	Owner	Area of Use	Manu-facturer	Vehicle Type	Vehicle Body	Engine Type	Speci-fications	No. of Gears	Rated Eng. Speed in 1/min
	124	5638	municipal authority	Aachen and environs	Mercedes	1217 AK	all wheel / tipper	OM 353	R6 L	5	2800
	184	14517	food distributor	Cologne and environs	Mercedes	1425 S	semitrailer train	OM 422	V8 S	12	2300
	125	5917	food distributor	Cologne and environs	Mercedes	1617 C	box	OM 366 A	R6 L	8	2600
	224	11000	FIGE	Aachen and environs	Scania	R 112 MA	semitrailer train	DS 1115	R6 LL	10	2000
	159	10888	food distributor	Cologne and environs	Mercedes	2222	box	OM 421	V6 S	8	2300
	137	6550	beverage manufacturer	Aachen and environs	MAN	17.192	box	D 0826 TF	R6 L	6	2600
	159	10888	beverage manufacturer	Aachen and environs	Mercedes	1622	platform / trailer	OM 421	V6 S	6	2300
	125	5917	municipal authority	Herzogenrath	Mercedes	1617	container	OM 366 A	R6 L	6	2600
	100	5917	haulage contractor	Aachen and environs	Mercedes	814	box	OM 366	R6 S	5	2800
	153	11309	municipal authority	Düsseldorf and environs	Mercedes	1722	container	OM 441	V6 S	12	1800
	169	6871	beverage manufacturer	Aachen and environs	MAN	18.232	box / trailer	D 0826 LF02	R6 LL	8	2400
	198	9973	municipal authority	Düsseldorf and environs	MAN	26.272 F	container	D 2865 LF02	R5 LL	16	2000
	265	11967	beverage manufacturer	Munich and environs	MAN	24.362	box / trailer	D 2866 LXF	R6 LL	12	2200
	213	11884	beverage manufacturer	Munich and environs	MAN	24.291	box / trailer		R6 LL	13	2200
	362	14618	haulage contractor	Aachen and environs	Mercedes	1748 LS	semitrailer train	OM 442 LA	V8 LL	16	2100
	277	13798	haulage contractor	Aachen and environs	IVECO	190-36PT	semitrailer train	8210.42	R6 LL	16	1800
	92	6560	haulage contractor	East Berlin and environs	IFA	W50	box	4VD 14,5/12	R4 S	5	2300
	50	3972	haulage contractor	East Berlin and environs	IFA	Robur	box	4VD 12,5/10	R4 S	5	2600
	33	1997	municipal authority	East Berlin	IFA	Multicar M25	container	4VD 8,8/8,5	R4 S	4	3000
	142	10350	public transport	East Berlin	Ikarus	280.02	articulated bus	Raba - MAN	R6 U	6	2100
	142	10350	public transport	East Berlin	Ikarus	260.02	city bus	D2156 HM 6U	R6 U	6	2100
	68	3972	food distributor	Aachen and environs	Mercedes	609	box	OM 364	R4 S	5	2800
	177	11884	public transport	Aachen and environs	MAN	SG 242	articulated bus	D 2866 UH	R6 LL	5 (automatic)	2200
	150	11334	public transport	Aachen and environs	MAN	SL 202	city bus	D0826 LUH	R6	4 (automatic)	2200
	137	6596	public transport	Aachen	van Hool	A 508	small city bus	MAN	R6L	4 (automatic)	2600
	157		public transport	different cities	MAN	SL 202	city bus	d0826 LUH	R6 LL	4 (automatic)	2400

1a.1 : Technical data of commertial vehicles (Germany)

V.-No.	Max. Eng. Torque in Nm	ngine Speed from to in 1/min	in 1/min	Tyre Dimensions	Vehicle Weight in kg	Payload in kg	Gross Vehicle Weight in kg	Trailer Weight in kg	Power to Vehicle Weight ratio in kW/t	Power to gross Vehicle Weight ratio in kW/t	Axle Transmission Ratio
1	490	1600		10 R 22.5	6195	7105	13300		20,02	9,320	5,920
2	932	1200		11 R 22.5	6050	8450	30500	7800	13,29	6,030	4,750
3	560	1400		11 R 22.5	8150	7850	16000		15,34	7,810	5,220
4	1235	1300		12 R 22.5	7020	9890	40000	7200	15,75	5,600	3,500
5	784	1200		12 R 22.5	10400	13600	24000		15,29	6,630	3,920
6	620	1200	1500	275/70 R 22.5	6990	10010	17000		19,60	8,060	5,260
7	784	1200		11 R 22.5	7250	8300	28000	3620	14,63	5,680	4,750
8	560	1400		11 R 22.5	8500	8500	17000		14,71	7,350	5,910
9	402	1400		225/75 R17.5	4820	2670	7490		20,75	13,350	3,910
10	834	1000	1500	12 R 22.5	8000	10000	18000		19,13	8,500	5,220
11	792	1200	1500	295/80 R 22.5	7320	10680	30000	3620	15,45	5,630	4,110
12	1130	1000	1400	12 R 22.5	11000	13000	24000		16,00	8,250	5,260
13	1500	1200	1400	12 R 22.5	10260	13740	40000	4500	17,95	6,630	4,040
14	1200	1200	1400	12 R 22.5	10060	13940	40000	4300	14,83	5,330	4,200
15	2000	1000	1600	315/80 R 22.5	7380	9620	40000	10200	20,59	9,050	3,450
16	1765	1000		315/80R22.5	7560	8440	40000	7050	18,96	6,930	3,080
17	422	1350		8.25R20	5500	4150	9650		16,73	9,530	5,360
18	216	1800		6.50-20	2900	2900	5800		17,24	8,620	5,170
19	108	2300		6.70-13C	1970	1150	3120		16,75	10,580	7,500
20	697	1300		11.00R20	12500	10000	22500		11,36	6,310	6,190
21	697	1300		11.00R20	9100	6900	16000		15,60	8,880	6,190
22	266	1400	1600	205/75R16	3365	2235	5600		20,21	12,140	3,727
23	865	1300		11/70R22.5	14700	12900	27600		12,04	6,410	5,920
24	780	1300		11/70R22.5	10000	7600	17600		15,00	8,523	4,638
25	630	1500		305/70R19.5	7800	4500	12300		17,56	11,140	5,640
26	780	1300		11R22,5	9960				15,76		6,727

ıle 1a.2 : Technical data of commertial vehicles (Germany)

Measuring Methodology

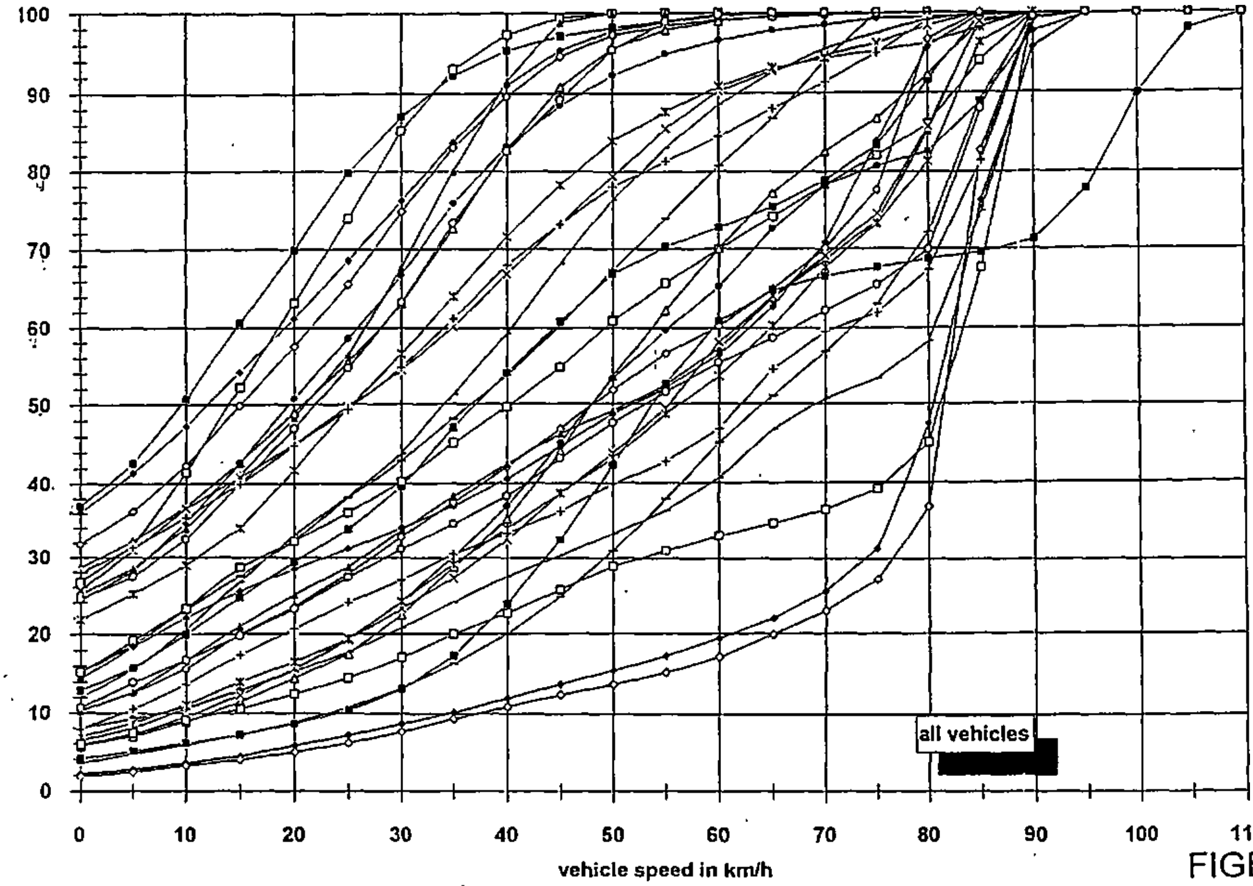
The measuring system was devised to take account of the following operating parameters:

- road speed
- engine speed
- torque at the cardan shaft

The following parameters were inferred by calculation from the above-mentioned measured variables:

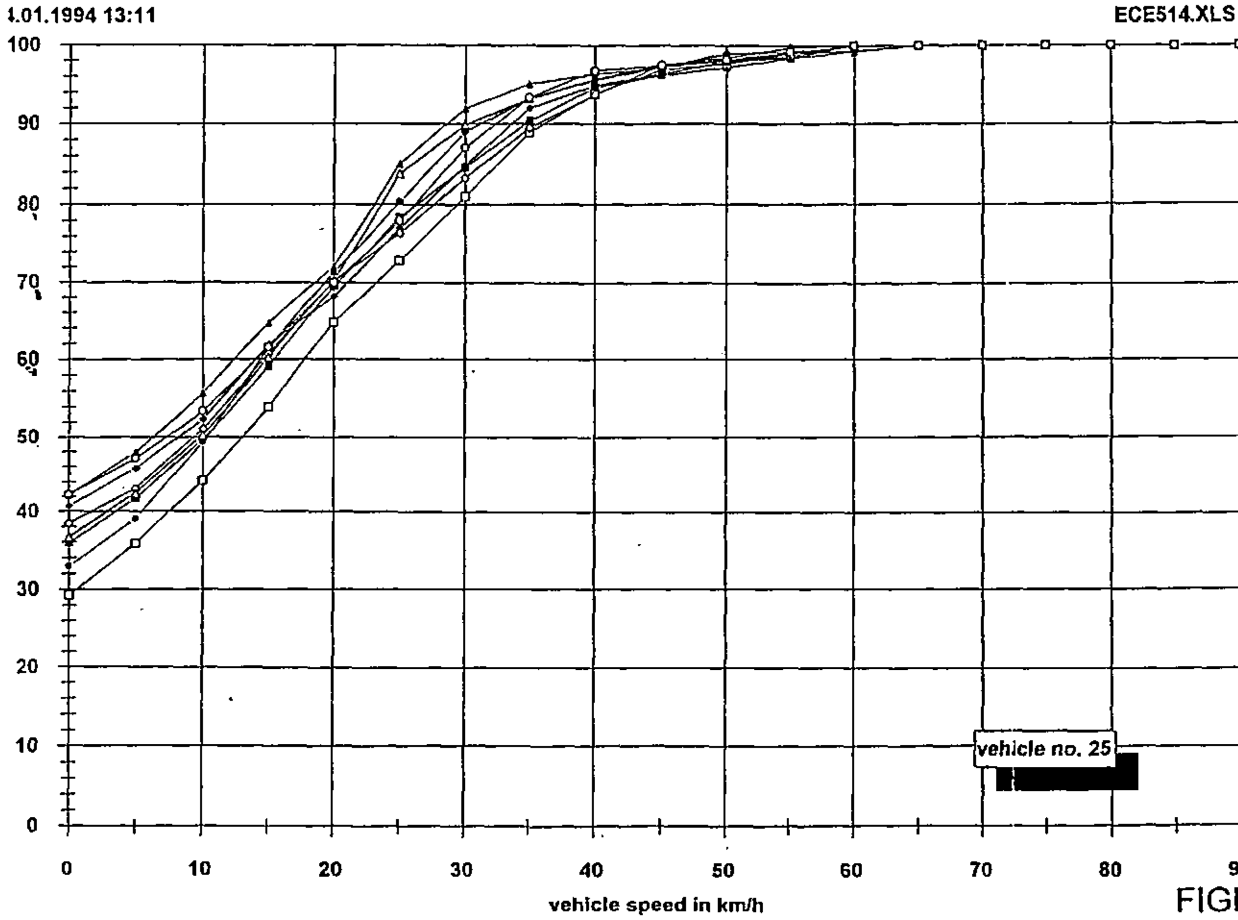
- acceleration
- engine power
- engine torque
- changes in engine speed over time
- changes in torque over time

1.01.1994 13:05 ECE516.XLS 1

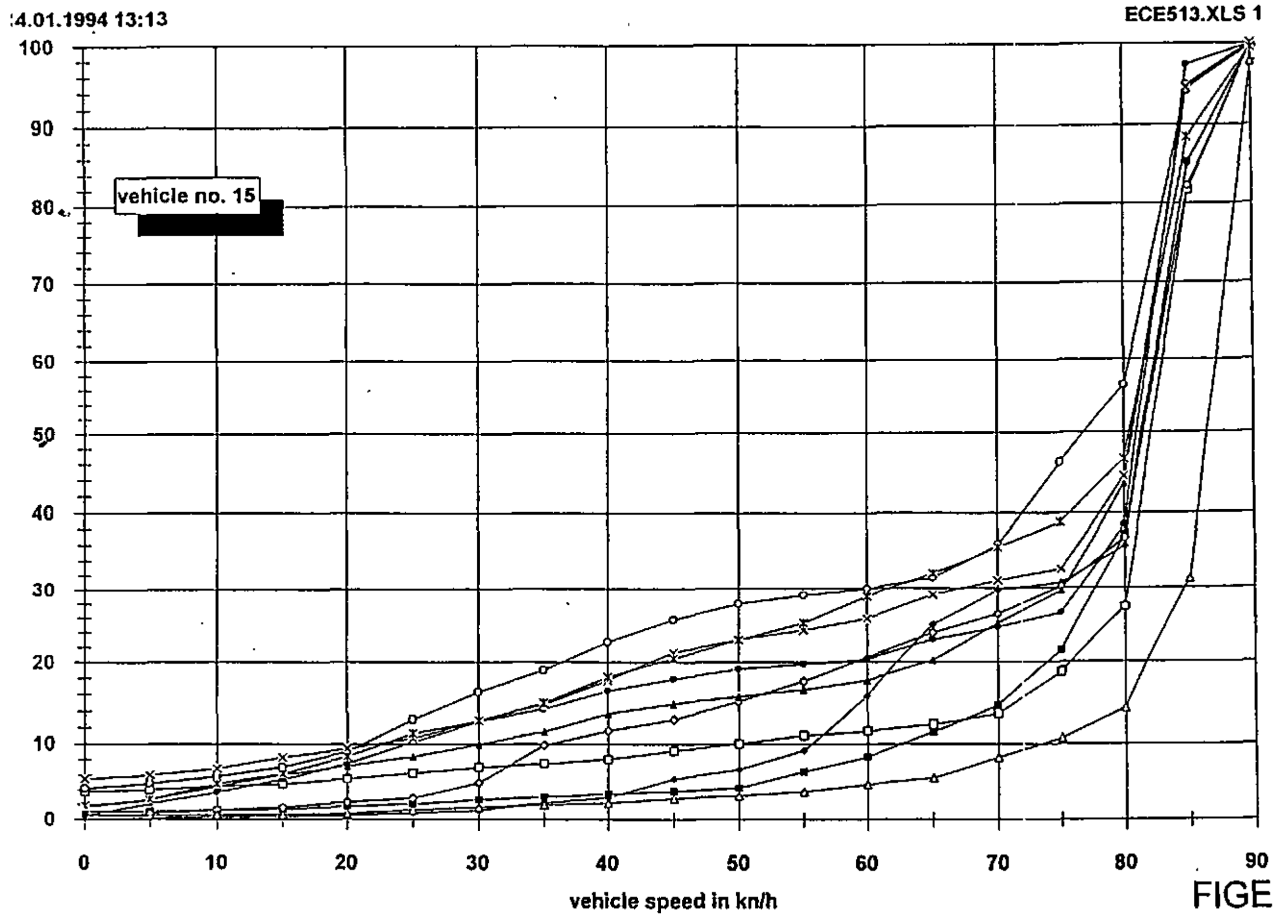


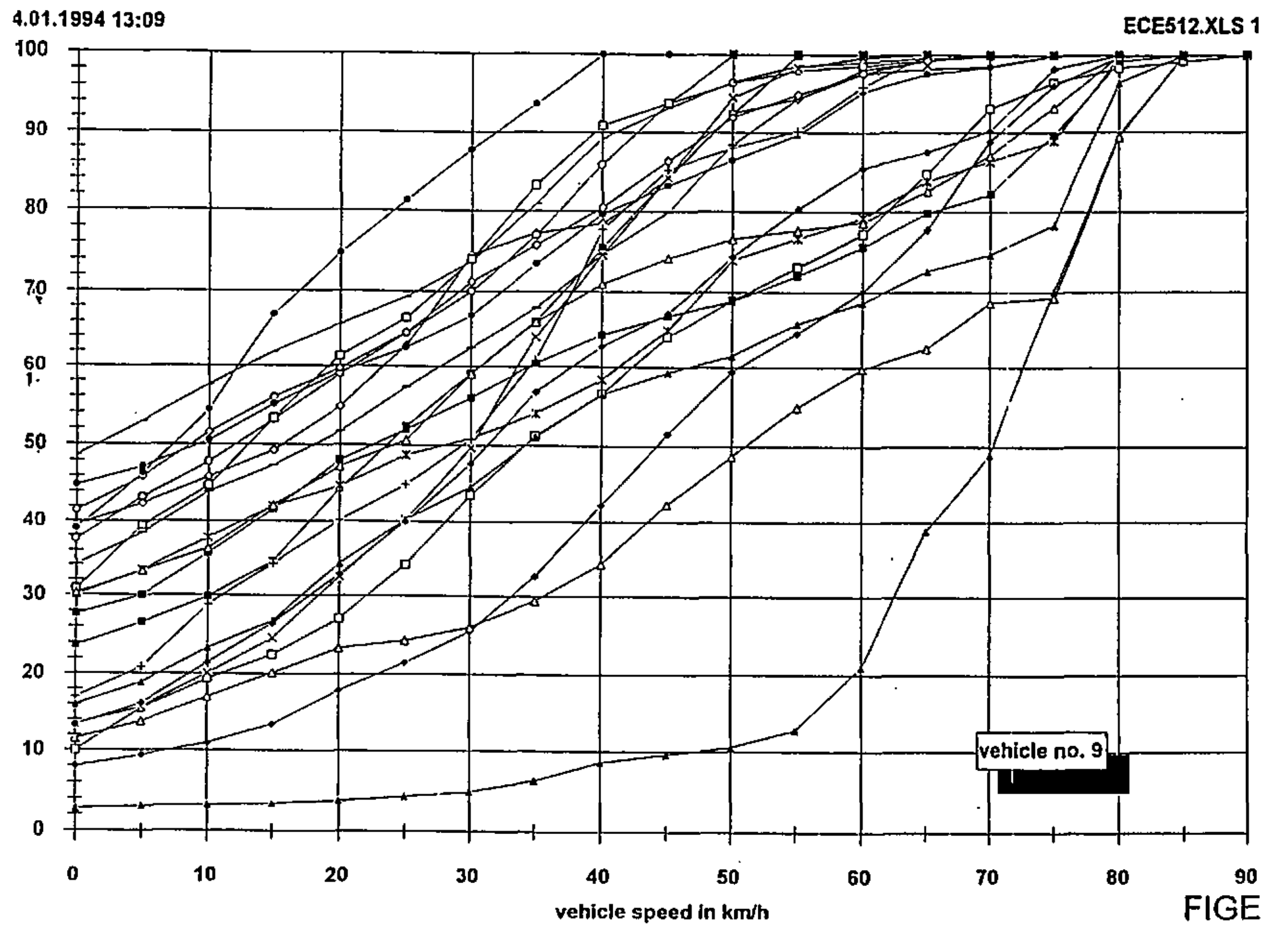
FIGE

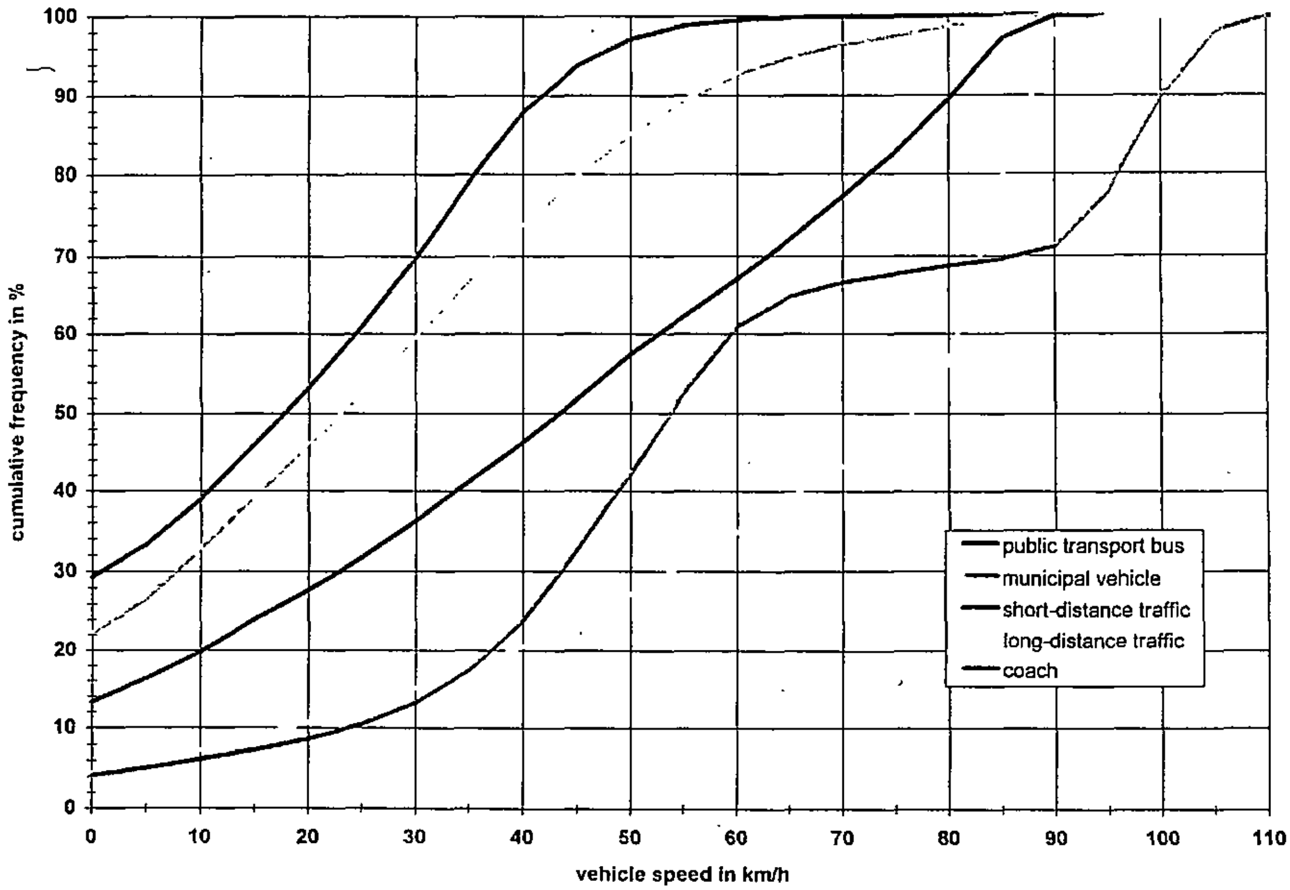
4.01.1994 13:11 ECE514.XLS 1



FIGE


:4.01.1994 13:13
ECE513.XLS 1
vehicle no. 15
[redacted]
100
90
80
70
60
50
40
30
20
10
0
0 10 20 30 40 50 60 70 80 90
vehicle speed in kn/h
FIGE


4.01.1994 13:09
ECE512.XLS 1
100
90
80
70
60
50
40
30
20
10
0
vehicle no. 9
[redacted]
0 10 20 30 40 50 60 70 80 90
vehicle speed in km/h
FIGE



Average speed

- local public transport buses: < 20 km/h
- municipal vehicles: < 30 km/h
- local traffic: ≤ 40 km/h
- long-distance traffic: > 60 km/h

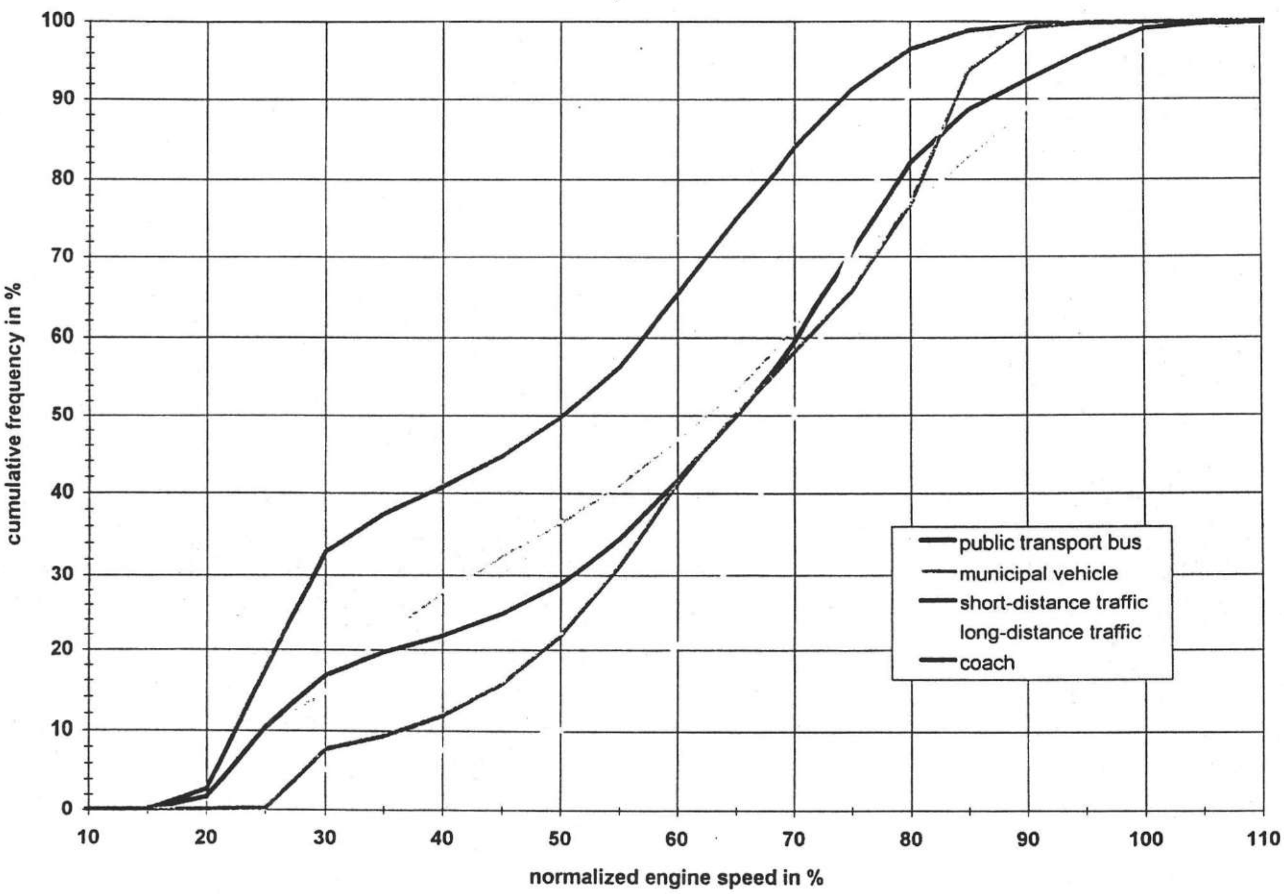
Stop component

- local public transport buses: 30 % (29,3 %)
- municipal vehicles: 22 % (22,2 %)
- local traffic: 13 % (13,2 %)
- long-distance traffic: < 5 % (4,4 %)

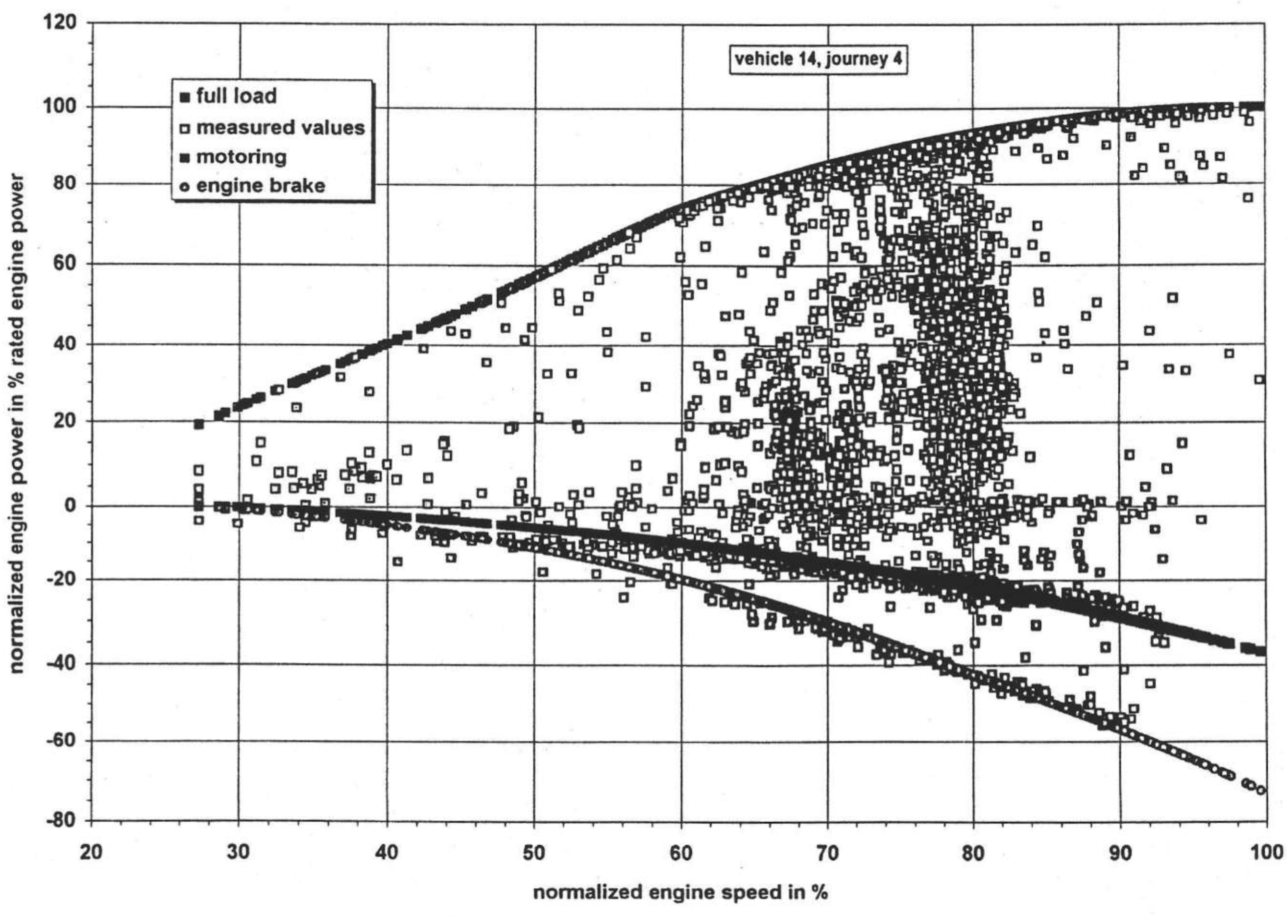
Idling component

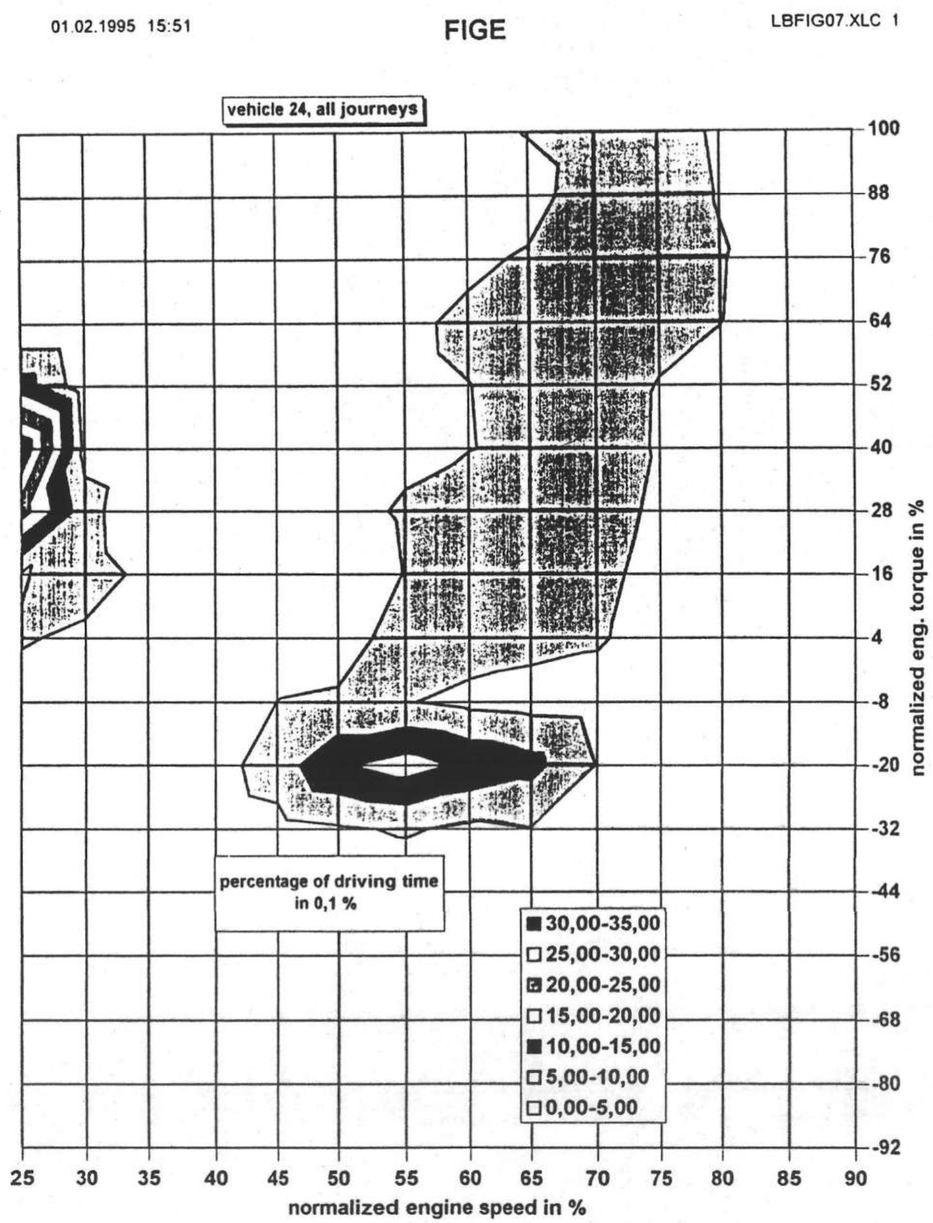
- local public transport buses: 30 % (30,8 %)
- municipal vehicles: 25 % (25,2 %)
- local traffic: 15 % (15,3 %)
- long-distance traffic: 5 % (5,0 %)

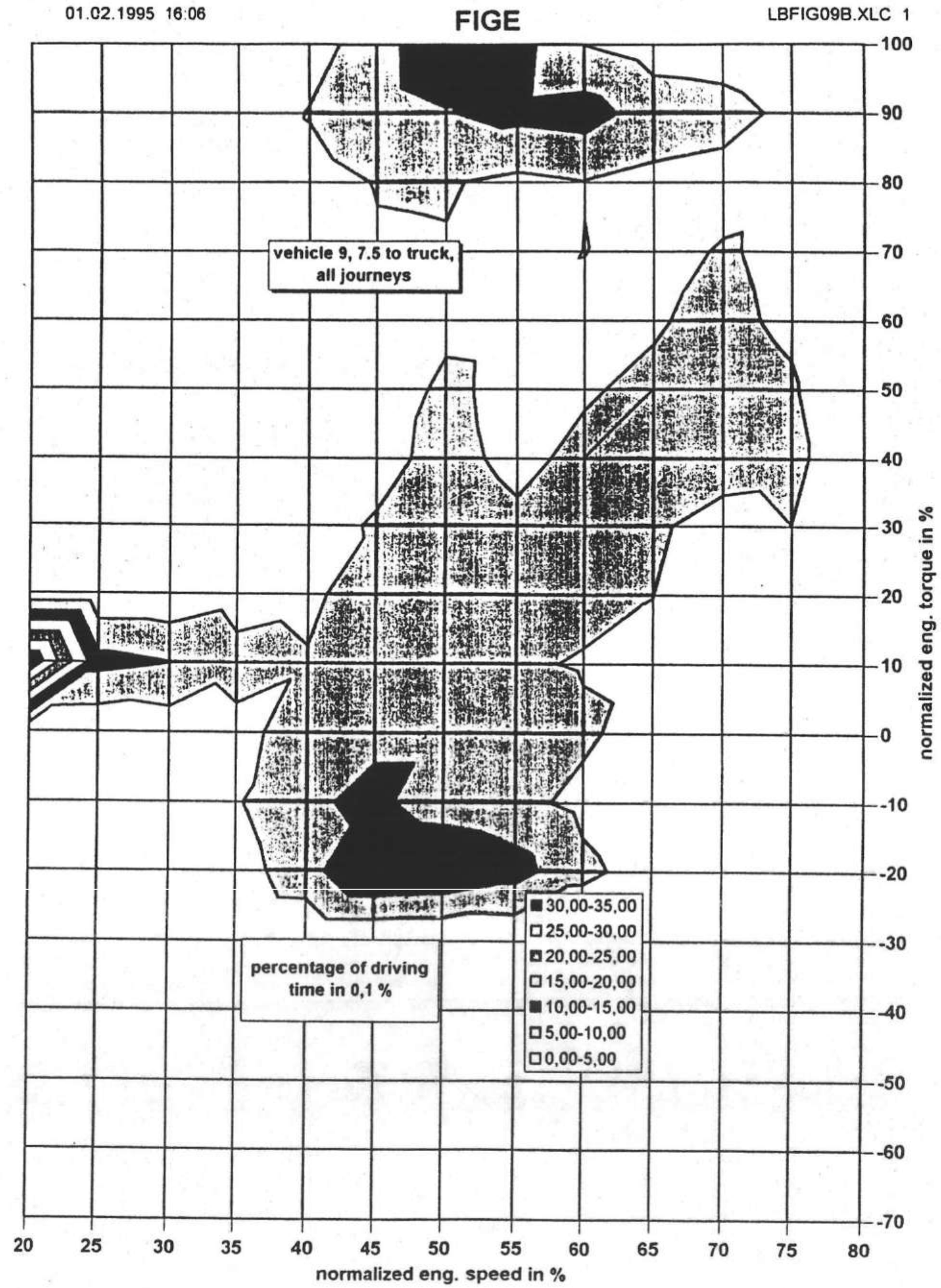
02.02.1995 10:06 FIGE LBFIG03.XLC 1



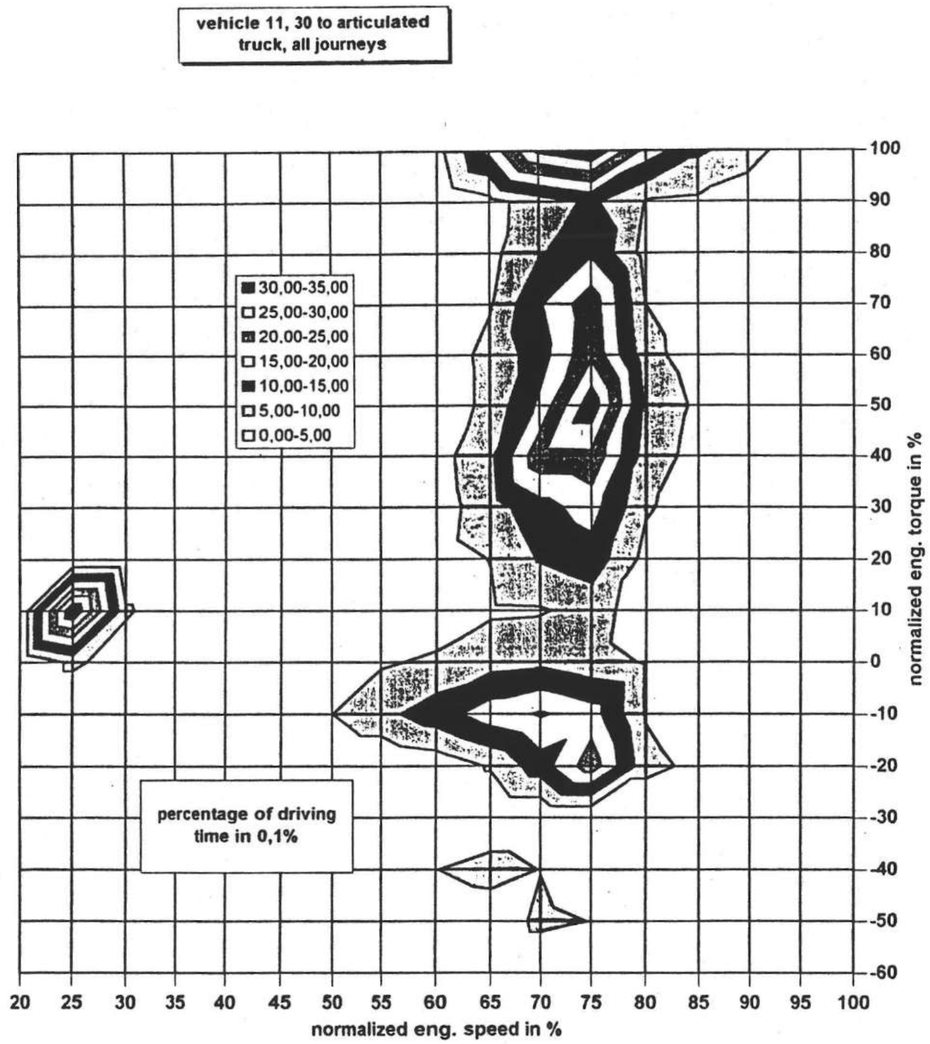
01.02.1995 14:46 FIGE LBFIG06.XLC 1



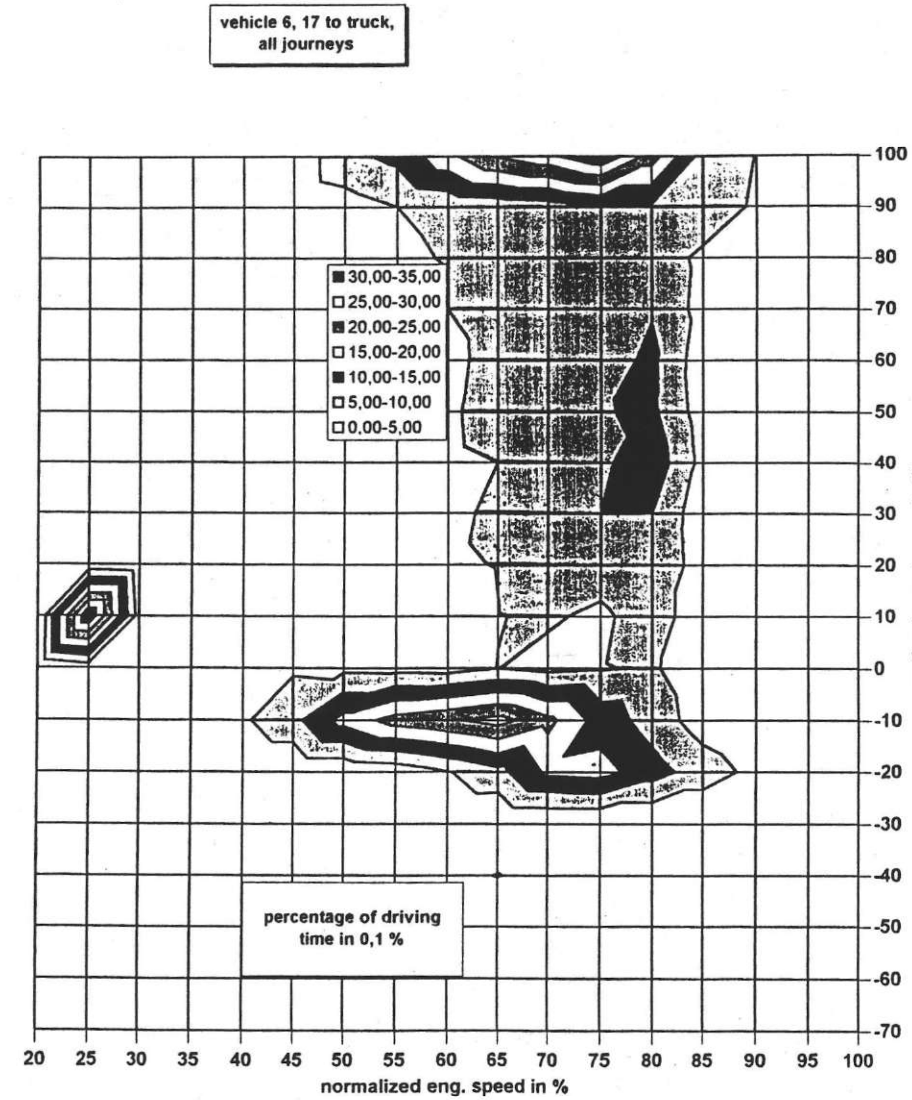

01.02.1995 15:51
FIGE
LBFIG07.XLC 1
vehicle 24, all journeys
percentage of driving time in 0,1 %
30,00-35,00
25,00-30,00
20,00-25,00
15,00-20,00
10,00-15,00
5,00-10,00
0,00-5,00
100
88
76
64
52
40
28
16
4
-8
-20
-32
-44
-56
-68
-80
-92
normalized eng. torque in %
25
30
35
40
45
50
55
60
65
70
75
80
85
90
normalized engine speed in %


01.02.1995 16:06
FIGE
LBFIG09B.XLC 1
vehicle 9, 7.5 to truck, all journeys
percentage of driving time in 0,1 %
30,00-35,00
25,00-30,00
20,00-25,00
15,00-20,00
10,00-15,00
5,00-10,00
0,00-5,00
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
normalized eng. torque in %
20
25
30
35
40
45
50
55
60
65
70
75
80
normalized eng. speed in %

01.02.1995 16:40 **FIGE** LBFIG09E.XLC 1



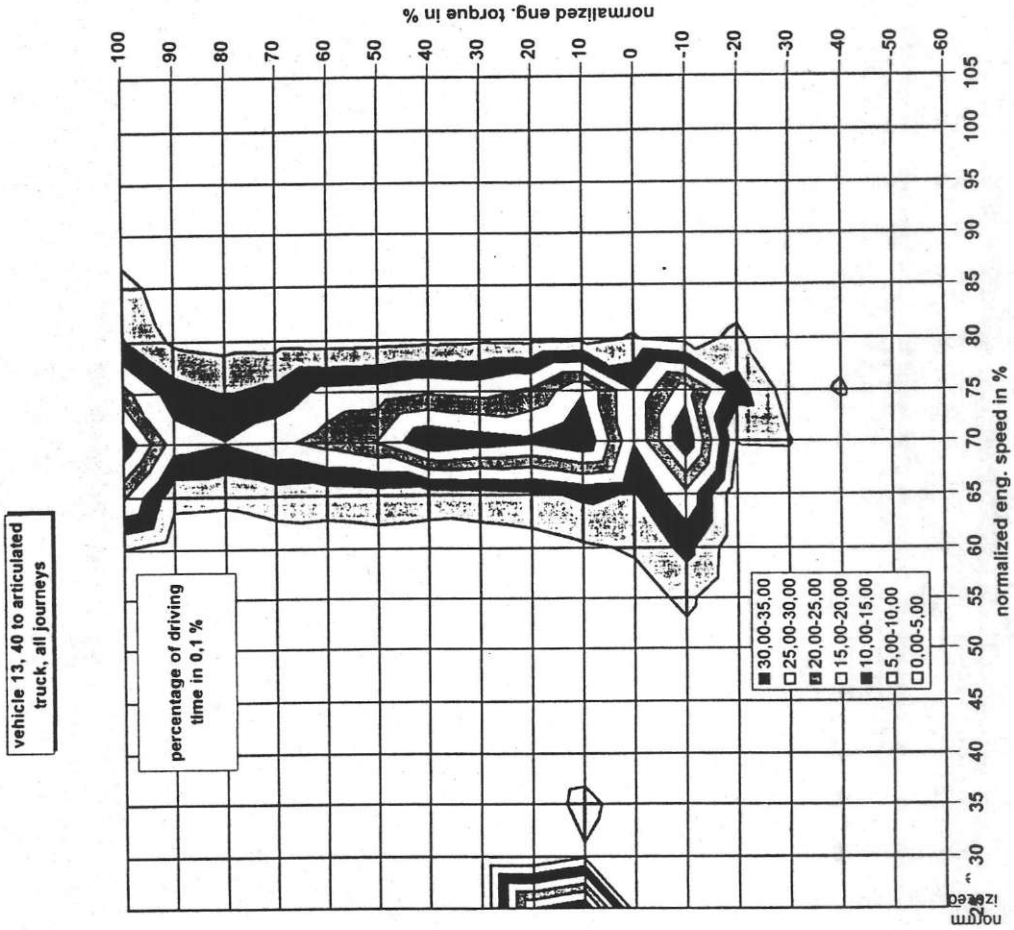
01.02.1995 16:23 **FIGE** LBFIG09C.XLC 1



02.02.1995 09:26

FIGE

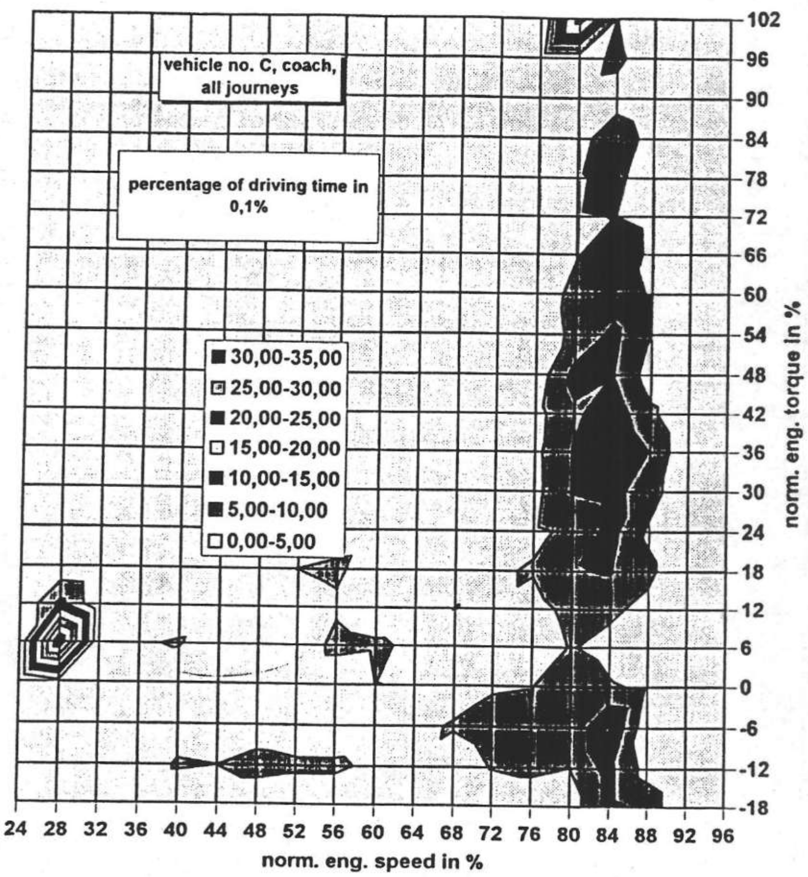
LBFIG10B.XLC 1



02.02.1995 10:55

FIGE

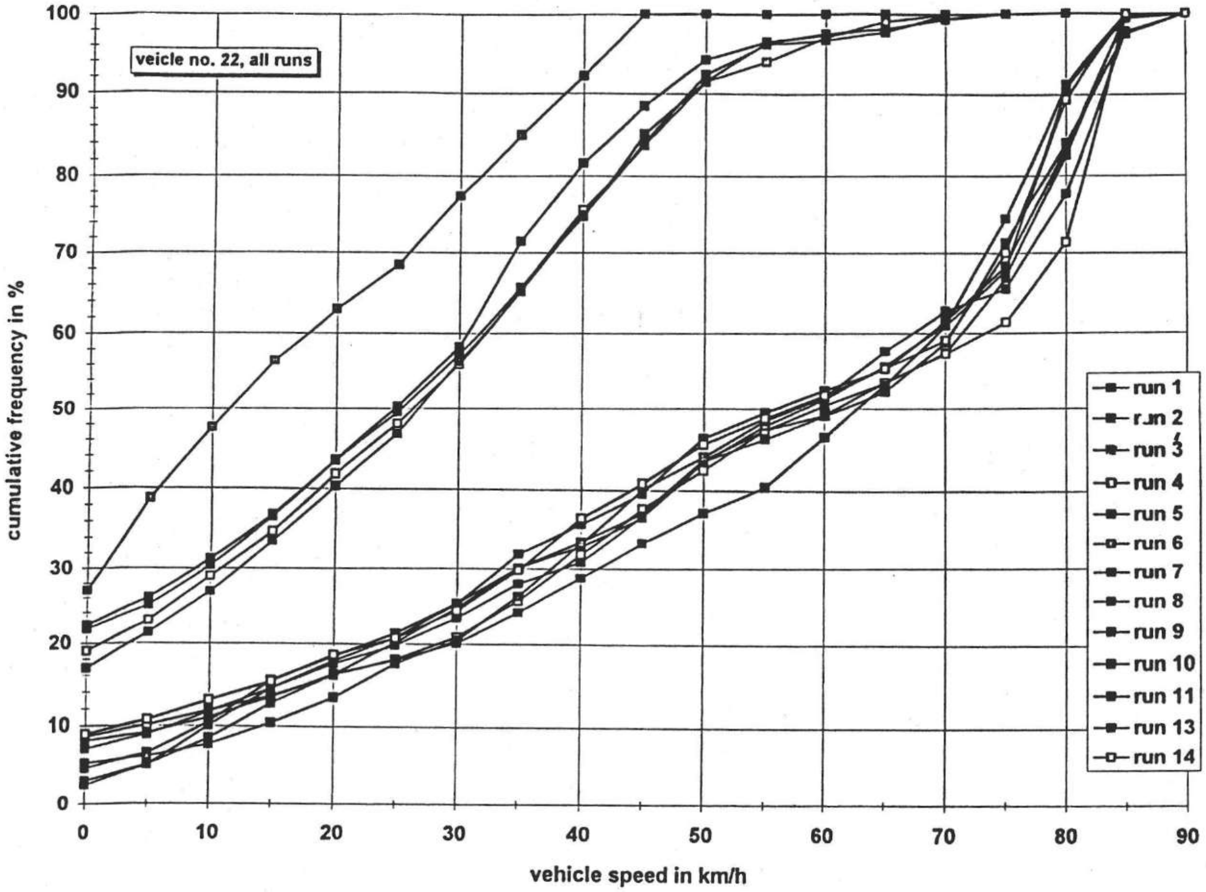
LBFIG11.XLC 1



02.02.1995 10:58

FIGE

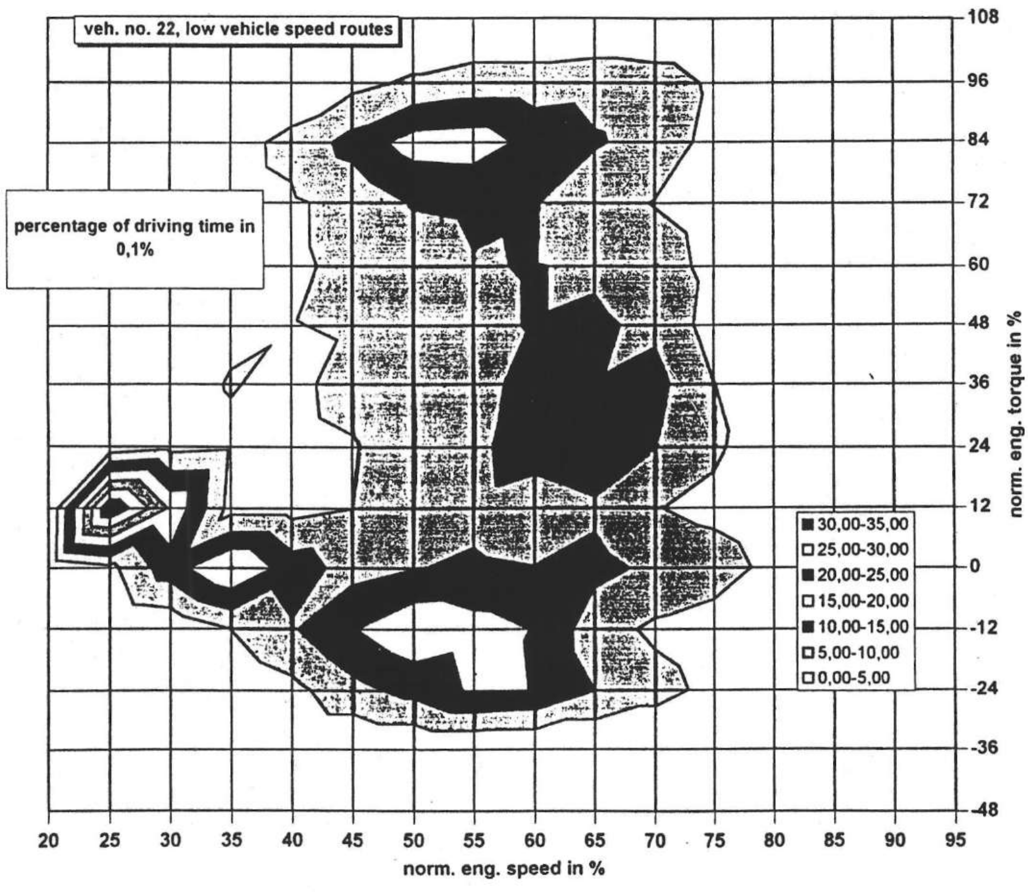
LBFIG12.XLC 1

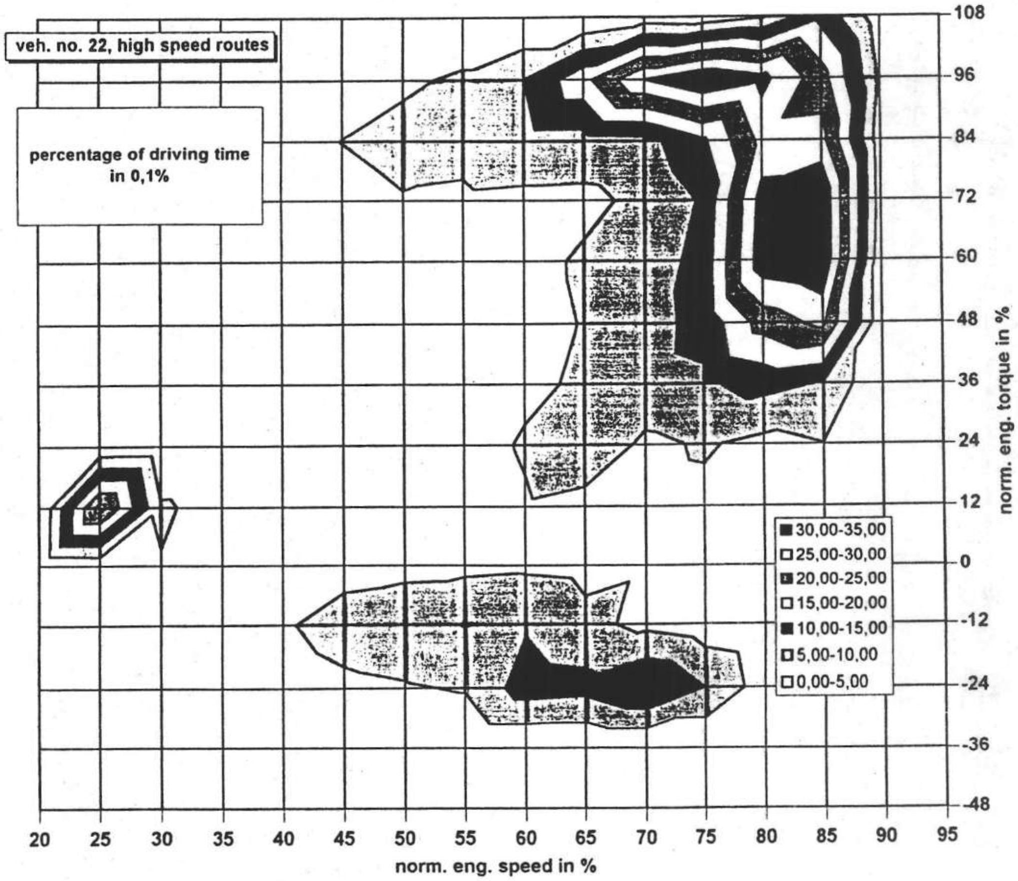


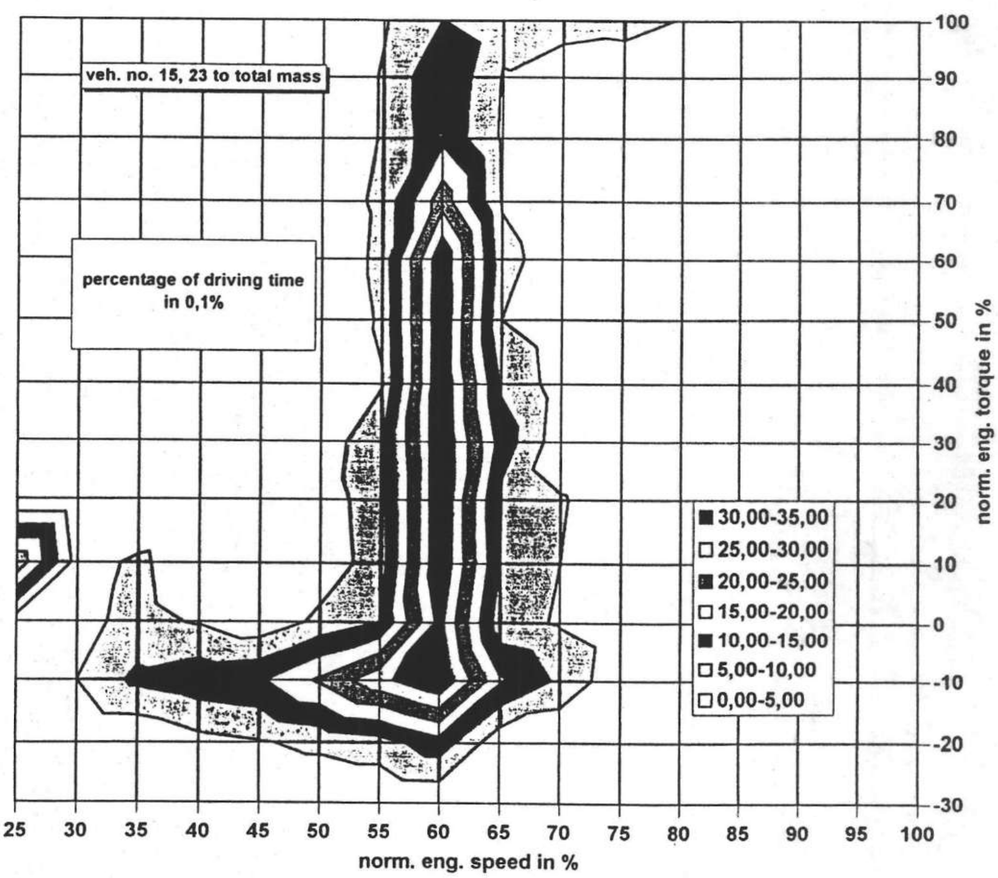
01.02.1995 15:01

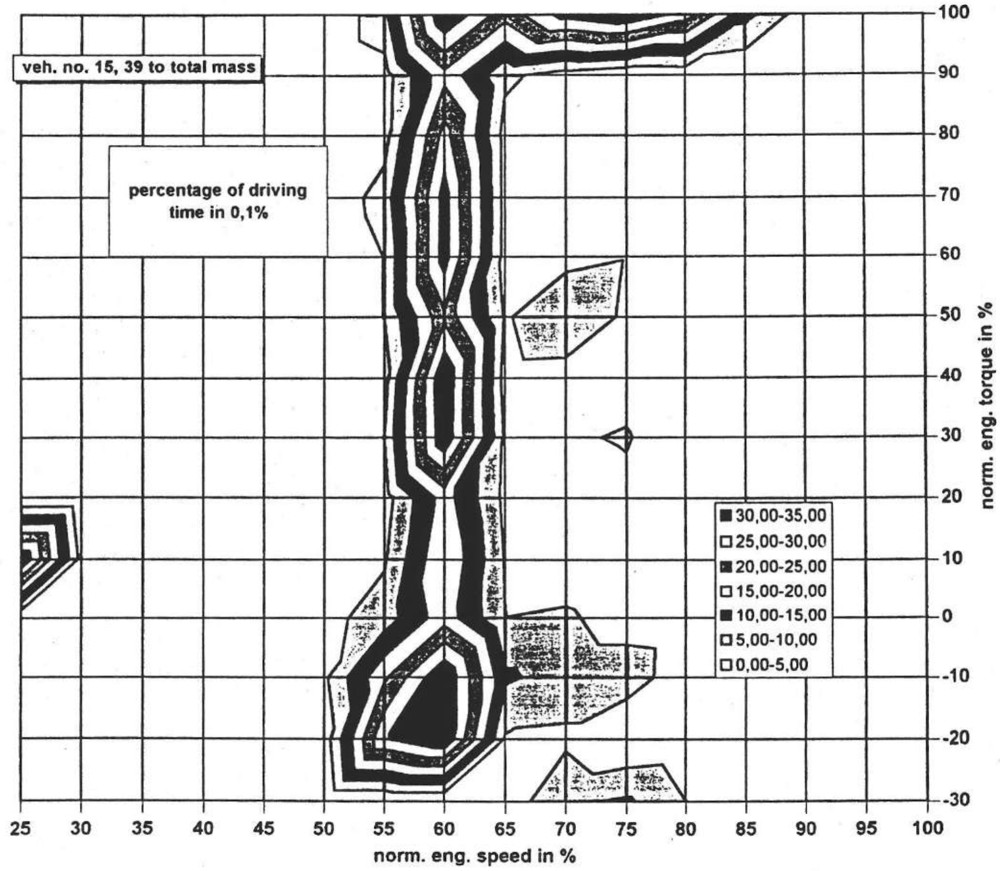
FIGE

LBFIG13A.XLC 1




veh. no. 22, high speed routes
percentage of driving time in 0,1%
30,00-35,00
25,00-30,00
20,00-25,00
15,00-20,00
10,00-15,00
5,00-10,00
0,00-5,00
108
96
84
72
60
48
36
24
12
0
-12
-24
-36
-48
norm. eng. torque in %
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
norm. eng. speed in %


veh. no. 15, 23 to total mass
percentage of driving time in 0,1%
30,00-35,00
25,00-30,00
20,00-25,00
15,00-20,00
10,00-15,00
5,00-10,00
0,00-5,00
100
90
80
70
60
50
40
30
20
10
0
-10
-20
-30
norm. eng. torque in %
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
norm. eng. speed in %



The structure of the engine-speed/torque distribution may be characterized by the following four most frequently occupied ranges:

preferred relative engine speeds in the full-load range

preferred relative engine-speeds in the sub-load range

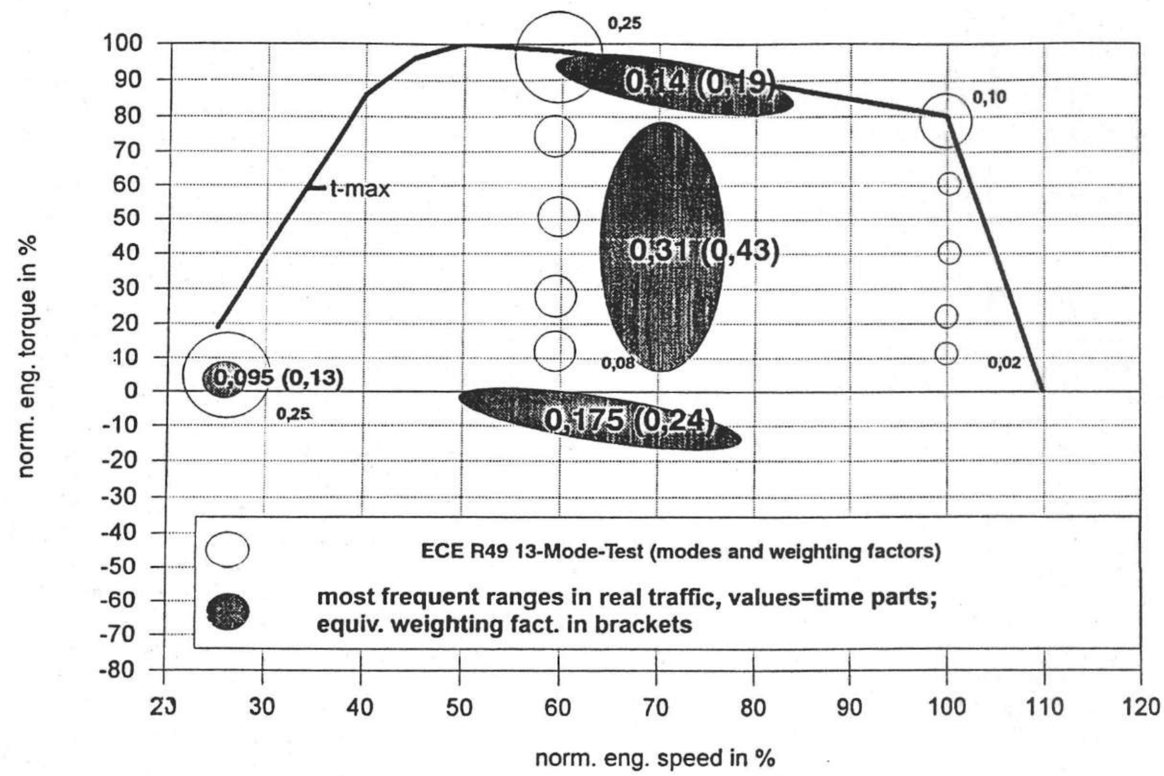
preferred relative engine speeds in the motoring range (motoring curve)

idling range

vehicle category	public transport buses	municipal vehicles	short distance transport	long distance transport	average short/long
idle speed in % of time	**32,0**	**23,0**	**13,5**	**5,5**	**9,5**
full load in % of time eng. speed range in %	**4,0** 55-75	**13,0** 65-100	**15,0** 58-84	**13,0** 65-82,5	**14,0** 60-82,5
partial load in % of time eng. speed range in % most frequent eng. speed in %	**23,0** 55-75 65,0	**13,5** 67,5-77,5 73,0	**20,0** 70-77,5 73,5	**42,5** 66-75 71,5	**31,0** 70-77,5 72,5
negative torque in % of time eng. speed range in %	**14,5** 45-70	**21,0** 50-85	**15,5** 49-75	**19,0** 56-77,5	**17,5** 50-75
Total percentage of driving time	**73,5**	**70,5**	**64,0**	**80,0**	**72,0**

Table 10 b: Most frequently used sections of the joint frequency engine speed/torque distributions for different groups of commercial vehicles.

FIGE



The operating points in the 13 mode test should be modified as follows:

1) Full load points

n/s in %	weighting factors
a) 0,30	0,05
b) 0,60	0,06
c) 0,725	0,07
d) 0,85	0,06
e) 1,0	0,05

2) sub load points at n/s = 0,725

T/T_{max} in %	weighting factors
a) 0,25	0,13
b) 0,50	0,12
c) 0,75	0,12

3) Motoring points:

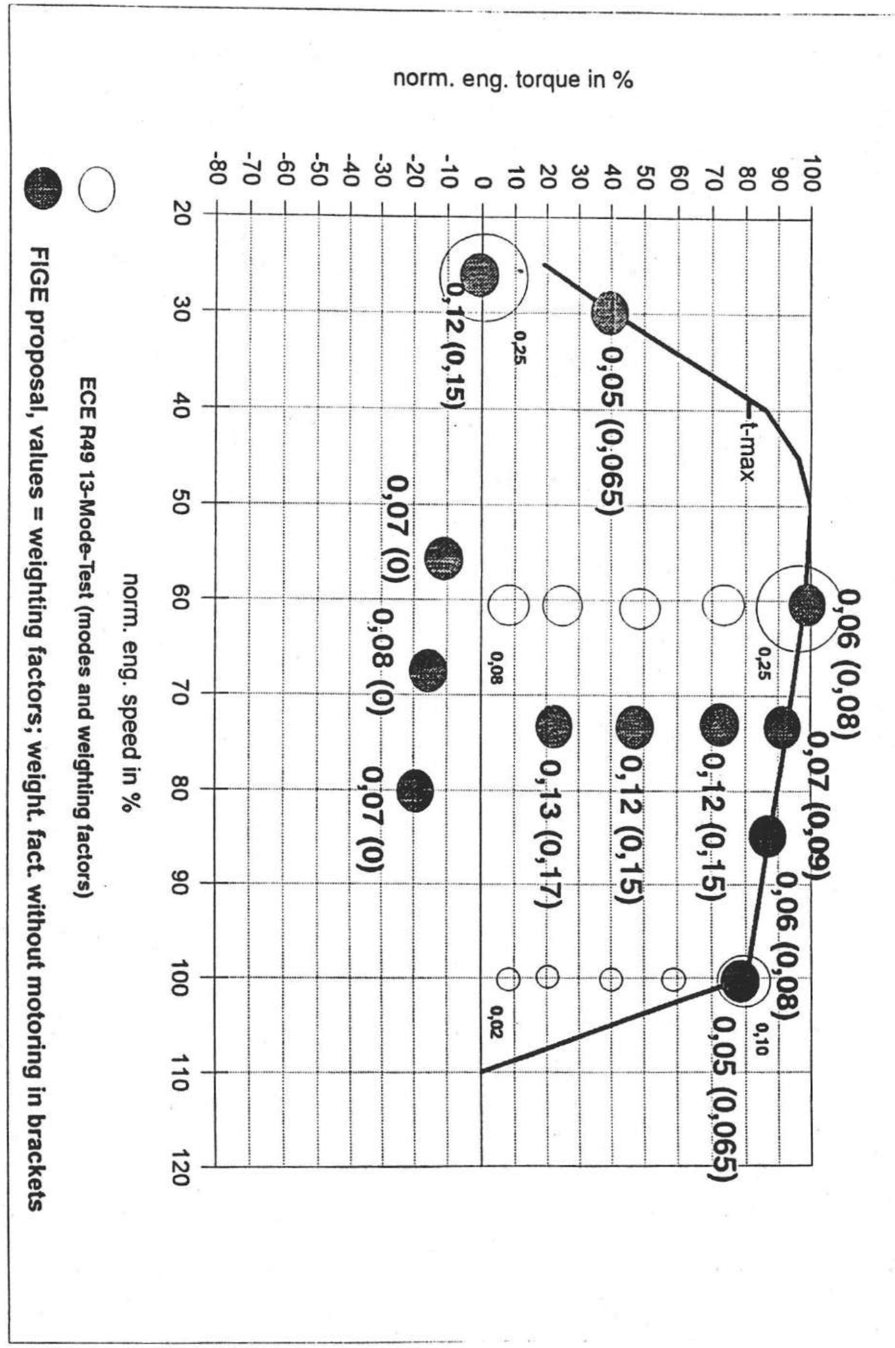
n/s in %	weighting factors
a) 0,55	0,07
b) 0,675	0,08
c) 0,8	0,07

4) idling:

weighting factor

0,12

Measurement of the motoring points requires a more complex test stand technology than has previously been employed. If previous test stand technology were retained, the three motoring points would have to be omitted and the remaining weighting factors increased accordingly.



Trucks			Load conditions:	no load (load percentage 0 to 20%)					partial load					full load (load percentage 80 to 100%)				
			Gradient:	-6%	-3%	0%	3%	6%	-6%	-3%	0%	3%	6%	-6%	-3%	0%	3%	6%
	Road type		Explanations															
1	motorway			Z01420	Z01020+	Z01020	Z01110	Z01210						Z01420	Z01020+	Z01020	Z01130	Z01230
2	main rural		4lane, 3lane, 2lane with add. lane	Z01420	Z02020+	Z02020	Z01110	Z01210						Z01420	Z02020+	Z02020	Z01130	Z01230
3	rural		others	Z01420	Z03020+	Z03020	Z03110	Z01210						Z01420	Z03020+	Z03020	Z03130	Z01230
4	main urban		main streets	Z04420	Z04020+	Z04020	Z04020+	Z01230						Z04420	Z04020+	Z04020	Z04020+	Z01230
5	urban		others, center with long junction dist.	A(Z05010)	A(Z05010)	Z05010	A(Z05010)	A(Z05010)						A(Z05030)	A(Z05030)	Z05030	A(Z05030)	A(Z05030)
6	urban		others, center with short junction dist.	A(Z06010)	A(Z06010)	Z06010	A(Z06010)	A(Z06010)						A(Z05030)	A(Z05030)	Z06030	A(Z05030)	A(Z05030)

Coaches		Load conditions:	no load (load percentage 0 to 20%)					partial load					load percentage 75 %				
		Gradient:	-6%	-3%	0%	3%	6%	-6%	-3%	0%	3%	6%	-6%	-3%	0%	3%	6%
	Road type	Explanations															
7	motorway		n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	Z01420	Z07030+	Z07030	Z07130	Z01230
8	main rural	4lane, 3lane, 2lane with add. lane	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	Z01420	Z08030+	Z08030	Z08030+	Z01230
3	rural	others	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	Z01420	Z03020+	Z03020	Z03130	Z01230
4	main urban	main streets	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	Z04420	Z04020+	Z04020	Z04020+	Z01230
5	urban	others, center with long junction dist.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	A(Z05030)	A(Z05030)	Z05030	A(Z05030)	A(Z05030)
6	urban	others, center with short junction dist.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	A(Z05030)	A(Z05030)	Z0603C	A(Z05030)	A(Z05030)

Public transp. buses		Load conditions:	no load (load percentage 0 to 20%)					partial load					full load (load percentage 80 to 100%)				
		Gradient:	-6%	-3%	0%	3%	6%	-6%	-3%	0%	3%	6%	-6%	-3%	0%	3%	6%
	Road type	Explanations															
9	urban	center, short bus-stop distances	n.v.	n.v.	n.v.	n.v.	n.v.	(Z0904	(Z0904	0904	(Z0904	(Z0904	n.v.	n.v.	n.v.	n.v.	n.v.
10	urban	center, long bus-stop distances	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	10040	1004	10040	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.
11	urban/rural	city to city line	n.v.	n.v.	n.v.	n.v.	n.v.	1144	11040	1104	11040	1124	n.v.	n.v.	n.v.	n.v.	n.v.

Special cycles		Load conditions:	no load (load percentage 0 to 20%)					partial load					full load (load percentage 80 to 100%)				
		Gradient:															
	Road type	Explanations															
12	-	Serpentinen	A(Z12010)	n.v.	n.v.	n.v.	Z12010	n.v.	n.v.	n.v.	n.v.	n.v.	A(Z12030)	n.v.	n.v.	n.v.	Z12030
13	urban	influenced by traffic queue	n.v.	Z13022+	Z13022	Z13022+	n.v.	n.v.	13022	1302	13022	n.v.	n.v.	Z13022+	Z13022	Z13022+	n.v.
	urban	stop and go	n.v.	Z13023+	Z13023	Z13023+	n.v.	n.v.	13023	1302	13023	n.v.	n.v.	Z13023+	Z13023	Z13023+	n.v.
14	motorway	part. influenced by traffic queue	n.v.	n.v.	Z14021	n.v.	n.v.	n.v.	n.v.	1402	n.v.	n.v.	n.v.	n.v.	Z14021	n.v.	n.v.
	motorway	influenced by traffic queue	n.v.	Z14022+	Z14022	Z14022+	n.v.	n.v.	14022	1402	14022	n.v.	n.v.	Z14022+	Z14022	Z14022+	n.v.
	motorway	stop and go	n.v.	Z13023+	Z13023	Z13023+	n.v.	n.v.	13023	Z13023	13023	n.v.	n.v.	Z13023+	Z13023	Z13023+	n.v.

FIGE

The dominant influence on the road-speed curve is the location of the road and its function in the road network. The following categorization is adequate in terms of road speed curves:

1. **Motorway**

2. **Other main roads outside built-up areas (four-lane, three-lane or two-lane with adjoining multi-purpose lanes)**

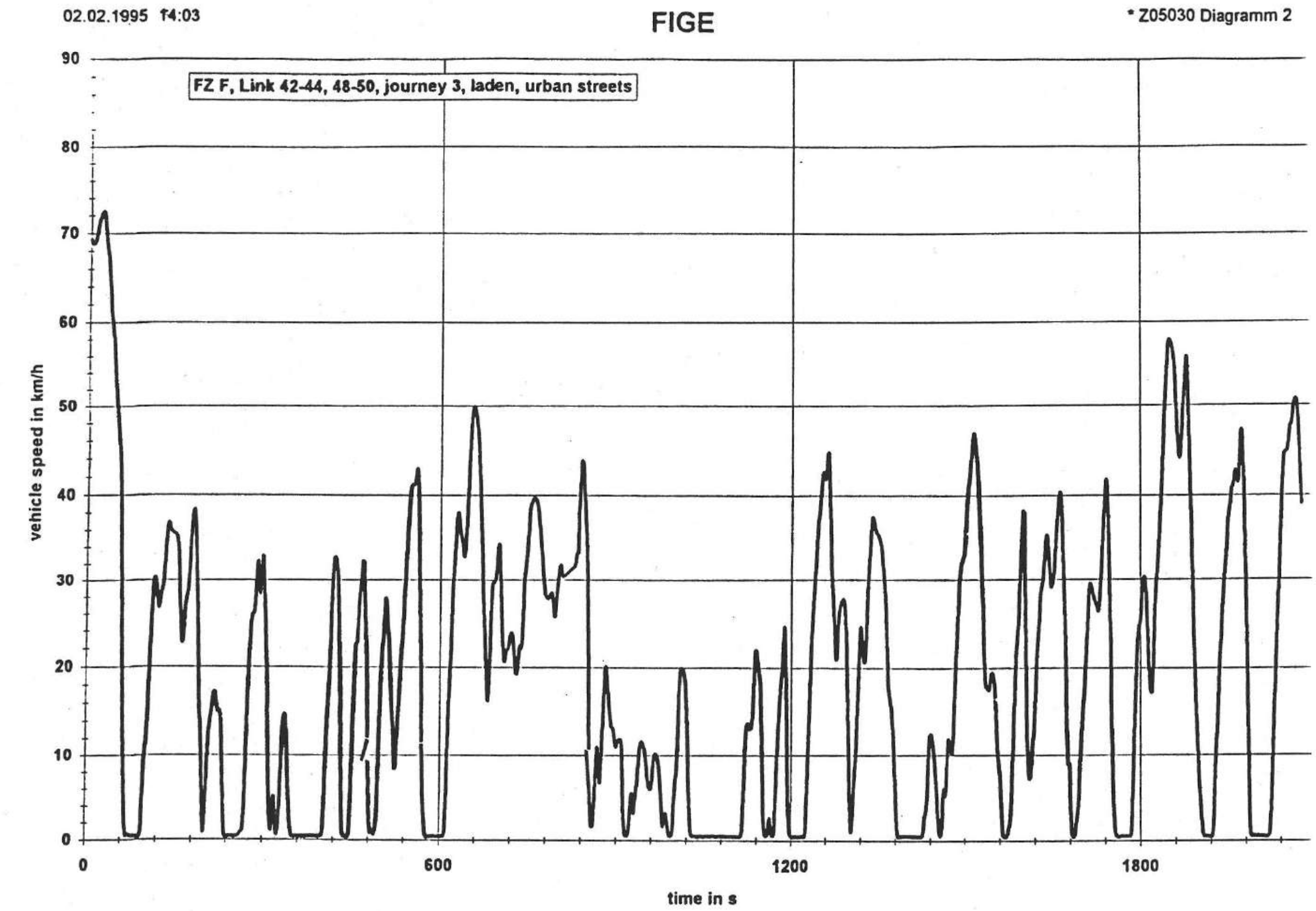
3. **Two-lane roads outside built-up areas**

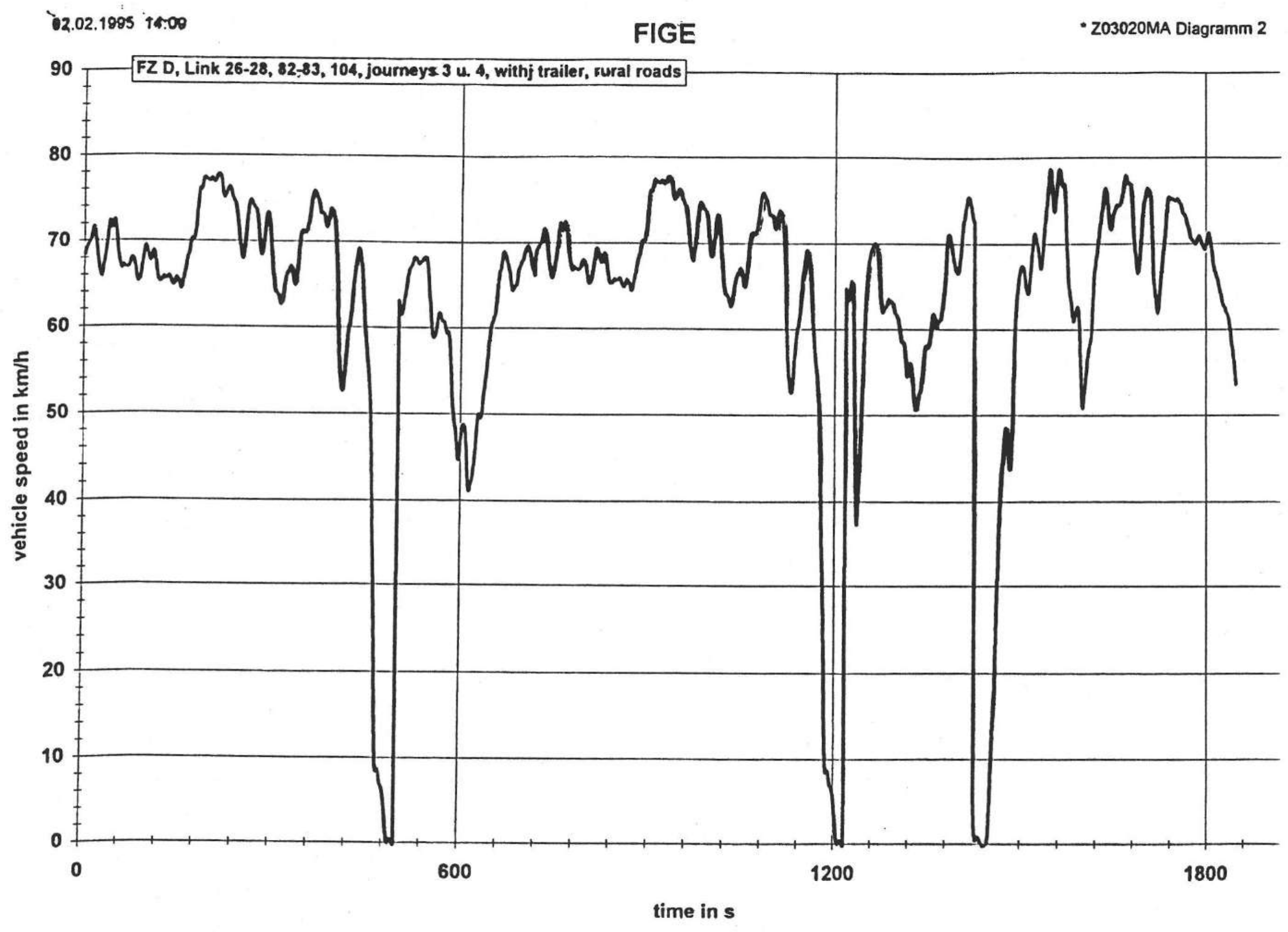
4. **Main roads in built-up areas at the periphery or level-free in town centres**

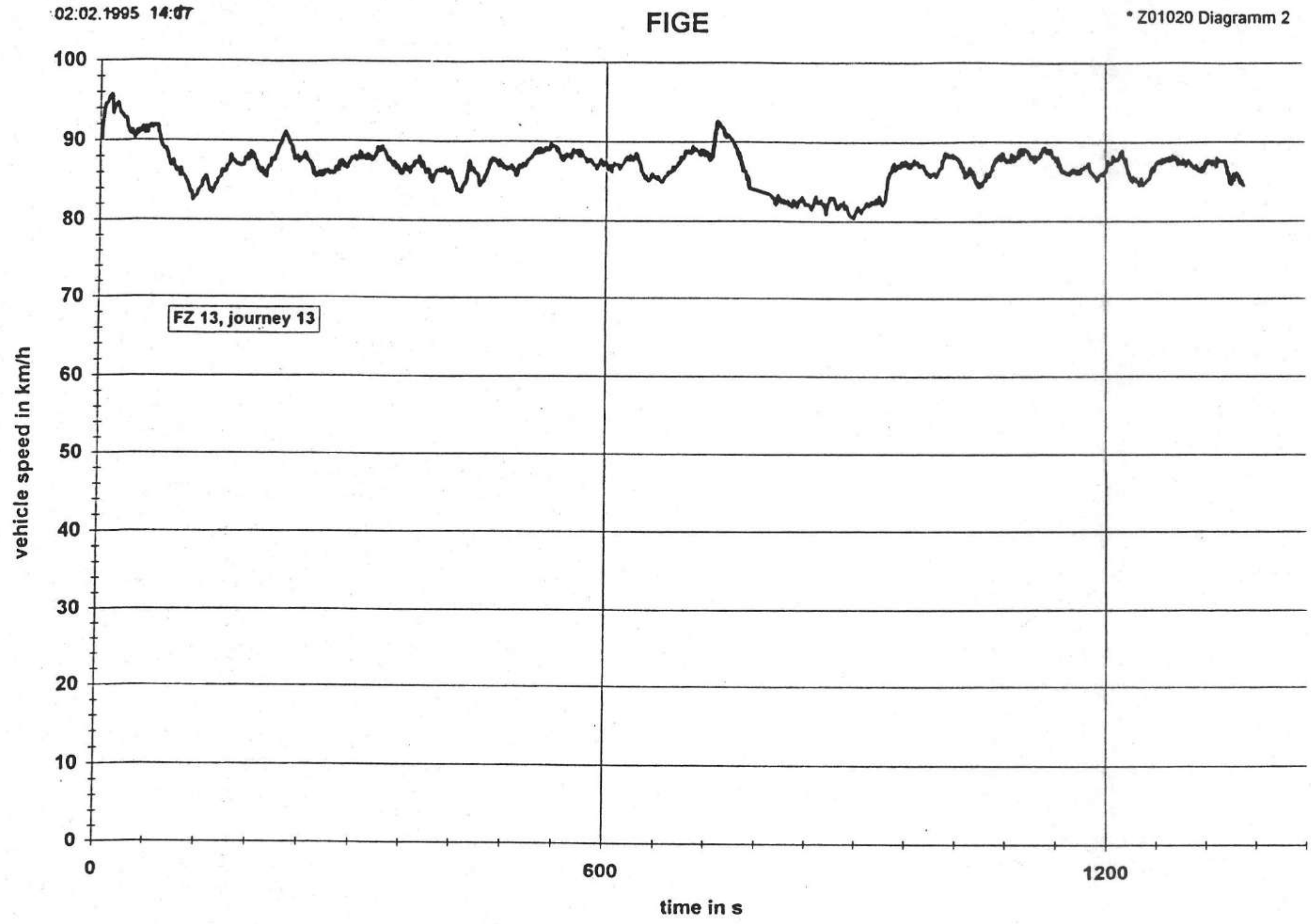
5. **Main roads or traffic routes in town centres with large distances between nodes (> about 300 m)**

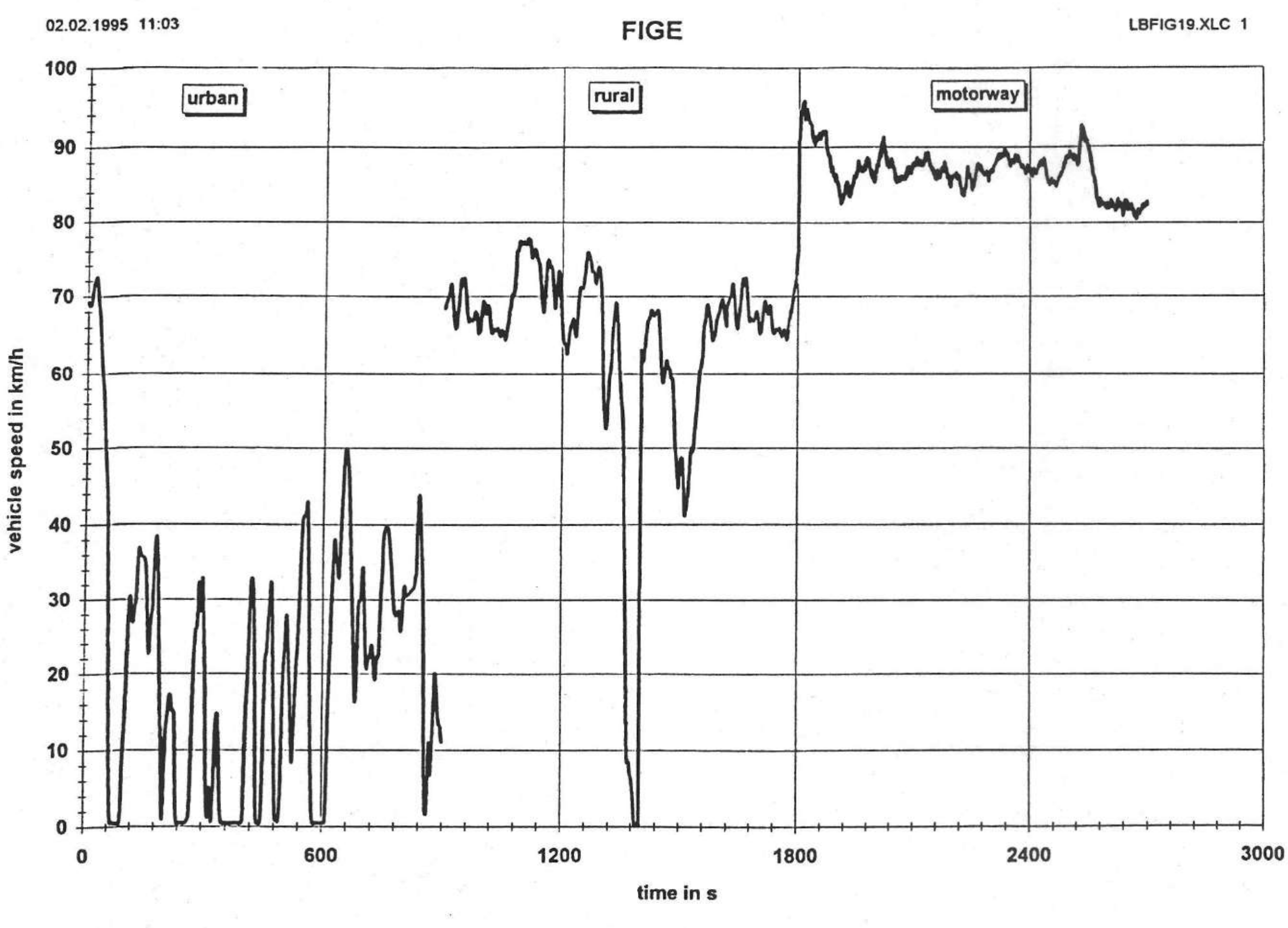
6. **Other traffic routes in town centres with small distances between nodes (< about 300 m).**

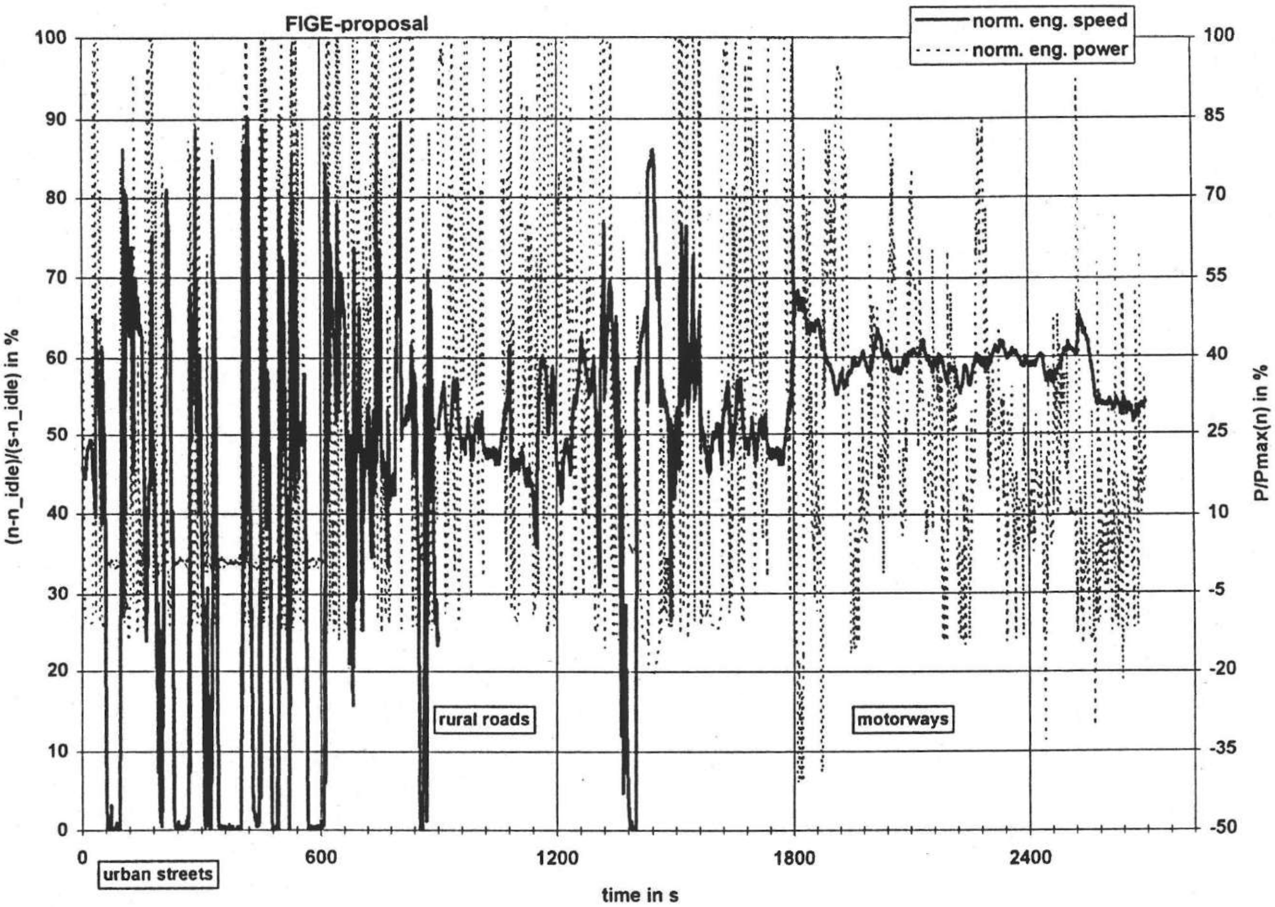
Within road categories defined in this way, there are three remaining parameters which significantly influence the speed curve: the traffic state or more accurately the traffic intensity, the gradient and the ~~amount of traffic carried~~. vehicle load


02.02.1995 14:03
FIGE
* Z05030 Diagramm 2
FZ F, Link 42-44, 48-50, journey 3, laden, urban streets
vehicle speed in km/h
90
80
70
60
50
40
30
20
10
0
0
600
1200
1800
time in s

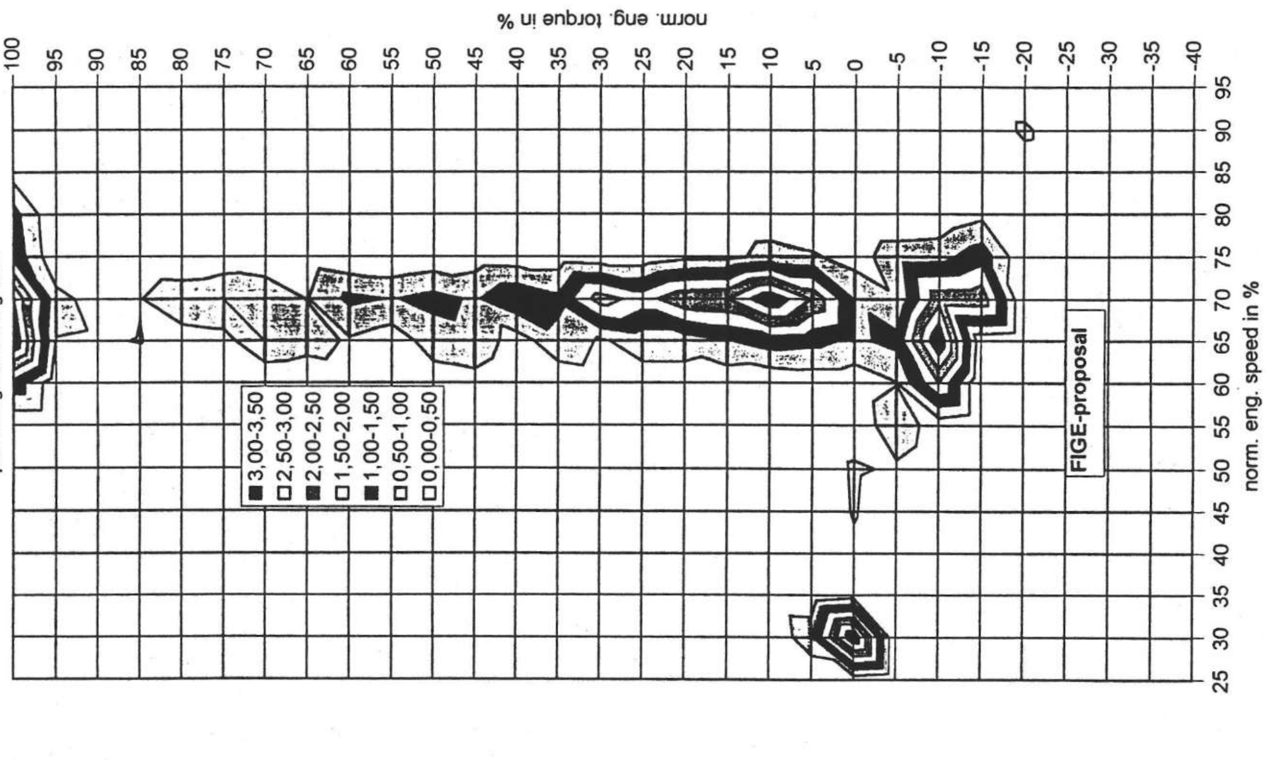

02.02.1995 14:09
FIGE
* Z03020MA Diagramm 2
FZ D, Link 26-28, 82-83, 104, journeys 3 u. 4, withj trailer, rural roads
vehicle speed in km/h
90
80
70
60
50
40
30
20
10
0
0
600
1200
1800
time in s


02.02.1995 14:07
FIGE
* Z01020 Diagramm 2
FZ 13, journey 13
vehicle speed in km/h
100
90
80
70
60
50
40
30
20
10
0
0
600
1200
time in s


02.02.1995 11:03
FIGE
LBFIG19.XLC 1
urban
rural
motorway
vehicle speed in km/h
100
90
80
70
60
50
40
30
20
10
0
0
600
1200
1800
2400
3000
time in s


FIGE-proposal
norm. eng. speed
norm. eng. power
(n-n_idle)/(s-n_idle) in %
P/Pmax(n) in %
time in s
urban streets
rural roads
motorways
0
600
1200
1800
2400
100
90
80
70
60
50
40
30
20
10
0
100
85
70
55
40
25
10
-5
-20
-35
-50

FIGE

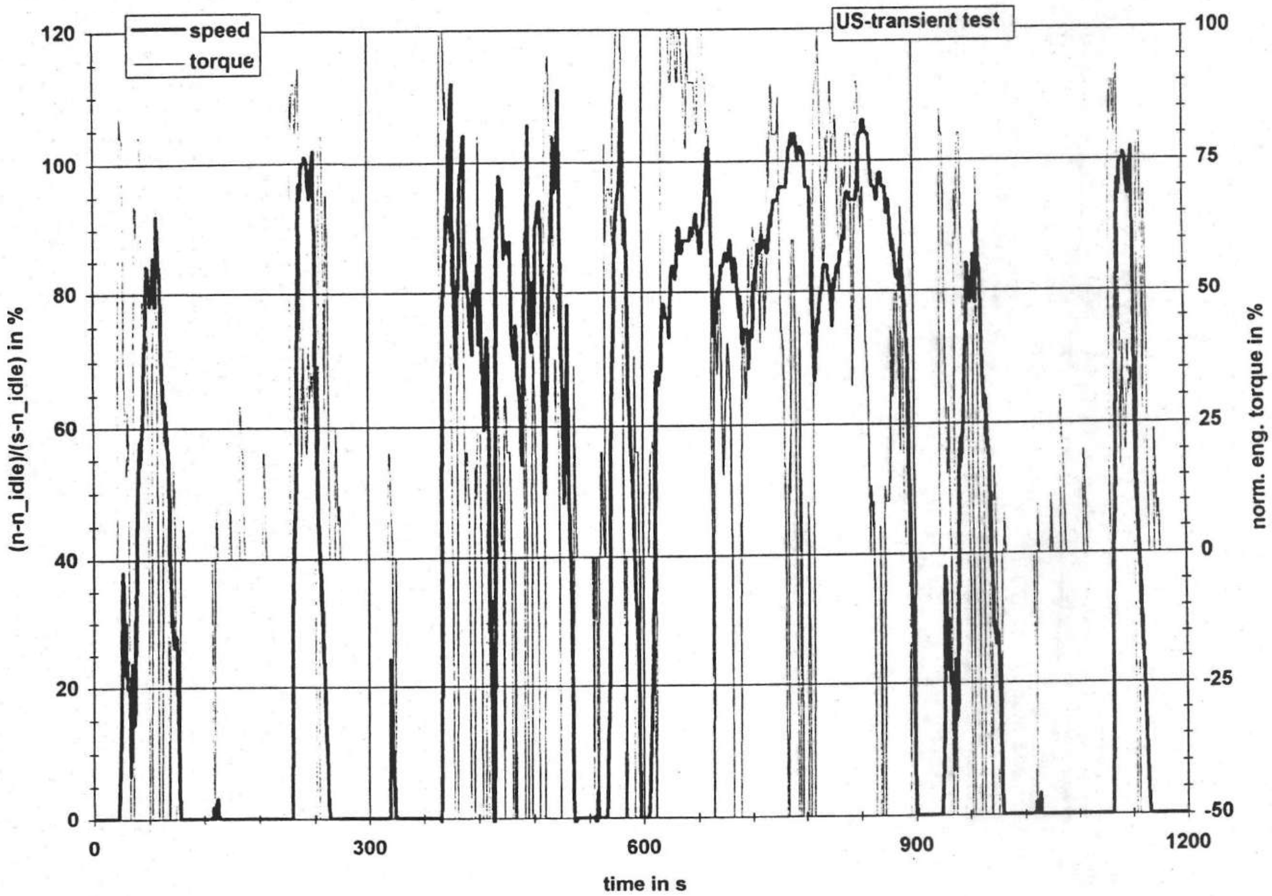

norm. eng. torque in %
norm. eng. speed in %
percentage of driving time
FIGE-proposal
3,00-3,50
2,50-3,00
2,00-2,50
1,50-2,00
1,00-1,50
0,50-1,00
0,00-0,50

FIGE

01.02.1995 14:14

FIGE

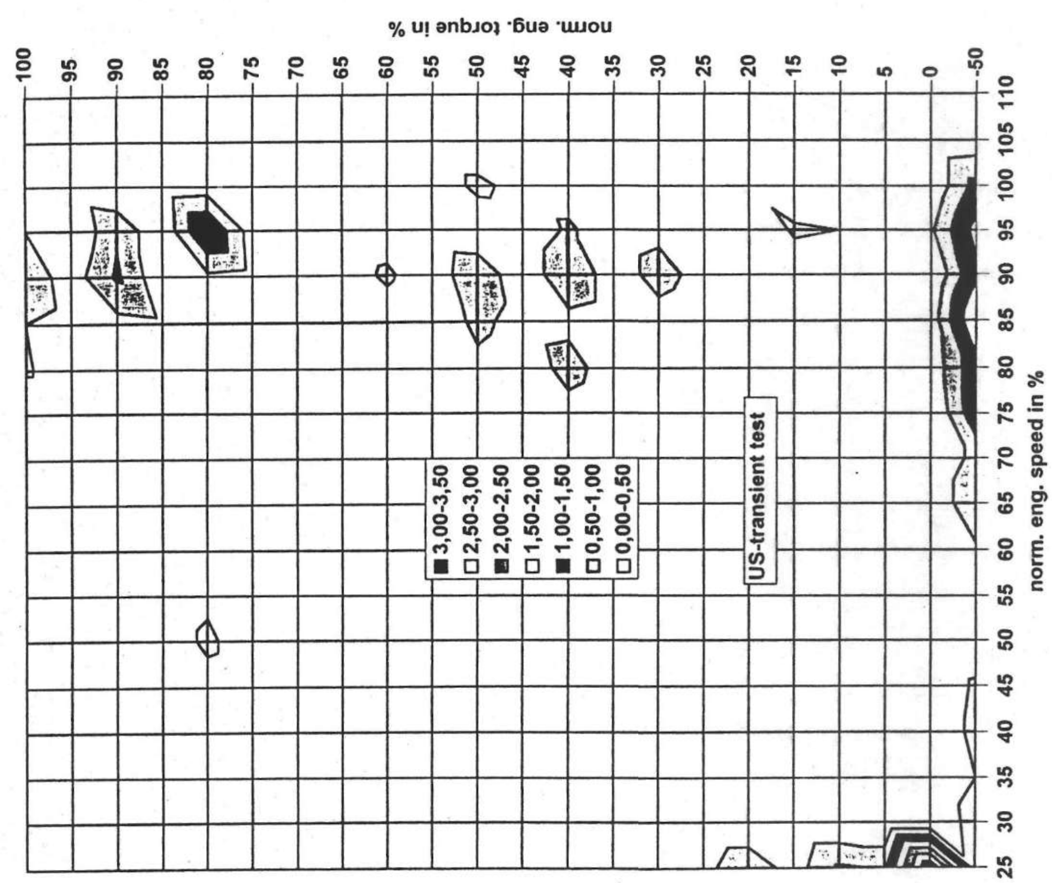
LBFIG23B.XLC 1



LBFIG22.XLC 1

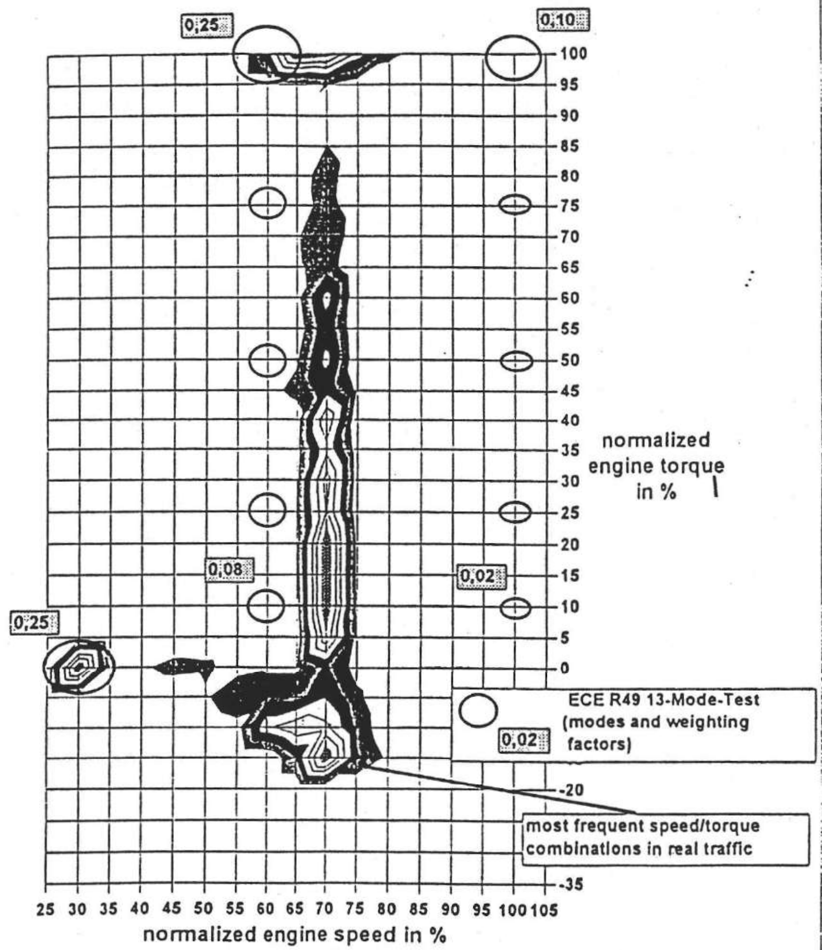
FIGE

01.02.1995 14:00



FIGE GmbH Forschungsinstitut
Geräusche und
Erschütterungen

Sound and Vibrations
Air-pollution
Measuring Systems



Engine Torque and Speed Distributions of Commercial Vehicles in real traffic and its Consideration in Emission Measurement According to EC Directive 88/77/EEC resp. ECE Regulation R49

Customer Vehicle Driving Surveys

Dennis Fett
Chrysler Corp., Auburn Hills, MI
and
Glen Heiser
Ford Motor Company, Dearborn, MI

CUSTOMER VEHICLE DRIVING SURVEY

Spokane, WA and Baltimore, MD

Presented by...

American Automobile Manufacturers Association and Association of International Automobile Manufacturers, Inc.

International Workshop on Vehicle Driving Cycles
February 6th & 7th, 1995
Ottawa, Ontario

CUSTOMER VEHICLE DRIVING SURVEY: Spokane, WA and Baltimore, MD

VEHICLE INSTRUMENTATION — Mr. Dennis W. Fett (Chrysler Corporation)

PROGRAM OVERVIEW

3P DATA ACQUISITION

6P DATA ACQUISITION

DATABASE

DATA ANALYSES — Mr. Glen A. Heiser (Ford Motor Company)

THROTTLE POSITION DISTRIBUTIONS

SPEED DISTRIBUTIONS

ACCELERATION DISTRIBUTIONS

VEHICLE DRIVE CYCLE ANALYSES

PROGRAM OVERVIEW

- A large real-world drive survey database was sought by industry and the regulatory agencies for assisting EPA in its review of the Federal Test Procedure (FTP).
- EPA initiated a program to instrument vehicles and collect manifold absolute pressure, engine RPM and vehicle speed data (3P data collection).
- Industry helped fund additional 3P data collection and launched a program to instrument a smaller subset of newer vehicles for 6P data collection (i.e. 3P data plus three additional parameters: air/fuel ratio, throttle position, and engine temperature).
- Industry conducted a pilot program to prove-out a data acquisition system and to coordinate multi-company involvement.

OVERVIEW (CONT.)

- Each manufacturer supplied "interfaces" that interrogated engine sensor data from the on-board engine control unit (ECU) for the 6P data collection program. Dataloggers and air/fuel ratio meters were purchased separately for the program.
- Radian designed 3P dataloggers and facilitated the 3P and 6P data collection programs simultaneously at field sites. EPA and manufacturer representatives were also present on-site.
- Selection criteria for locations of the survey included factors such as: population, CO and/or Ozone non-attainment, availability of I/M check lanes, and a recent transportation model.
- Spokane Wa. and Baltimore Md. were chosen for the survey sites and the program was conducted Feb - March of 1992.

OVERVIEW (CONT.)

- Specific vehicle owners were asked to participate in the survey as they came through I/M check lanes. Monetary incentives were offered to participants (approximately $100 for 3P participants and approximately $200 for 6P participants).

- Target vehicles for 3P data collection were chosen randomly (based on time of day) and vehicles dated back to the 1970's. Target vehicles for 6P data collection were based on interface availability and vehicles dated between 1989 and 1991.

- Chosen vehicles were required to pass the I/M test and a vehicle screening which essentially verified that the vehicle was in proper working order, the driver is the owner of record and that the vehicle would not be going in for repair or on a long trip during the instrumentation period.

- With 3P data acquisition, approximately 63% of the vehicles solicited were successfully instrumented in Spokane and 36% in Baltimore. For 6P data acquisition, 49% were successfully instrumented in Spokane and 23% in Baltimore.

- Vehicle owners waited at the I/M station as their vehicle was instrumented and function checks were made. 3P systems took approximately 1 hour to install, 6P systems took approximately 2 1/2 hours.

- Owners drove their vehicles with instrumentation for a one week duration.

- Instrumentation was removed at the owner's residence or at the I/M check lane after the collection period and data was downloaded from the dataloggers to floppy disks for data quality checking.

3P DATA ACQUISITION

- 3P dataloggers were designed and fabricated by Radian specifically for this study.
- They measured 5 X 7 X 1.5 inches, circuitry was weather and vibration protected, and they were placed in the engine compartment of the vehicle.
- Each 3P datalogger had storage capabilities of 768Kb of memory.
- Data was stored sec-by-sec. At this rate, a total of 54 hours of engine-on data could be stored.
- Engine parameters measured consisted of engine RPM, manifold absolute pressure (MAP), and vehicle speed.
- Engine RPM was measured by tapping into the ignition system.
- MAP was measured by utilizing a pressure transducer in the datalogger and tapping into any appropriate intake manifold vacuum source.

3P DATA ACQUISITION (CONT.)

- Vehicle speed was measured by any of three methods: A hall-effect transducer attached to the speedometer cable, tapping into the OEM vehicle speed sensor, or attaching magnets and an inductive pickup to the driveshaft.
- Specific speed, RPM or MAP levels triggered the datalogger to sense engine operation and start or end datalogging. Time and date information was collected at each engine startup and shutdown.

6P DATA ACQUISITION

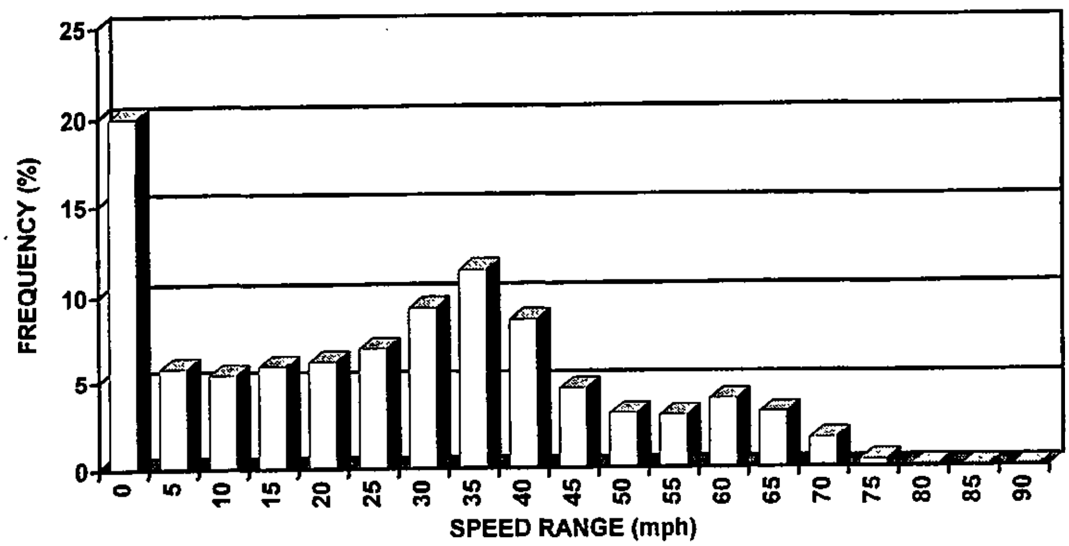
- Campbell CR10 dataloggers.
- Campbell SM716 storage modules (2).
- Most or all of the 6P data acquisition system was packed into rubber containers and placed in the trunk of the vehicle.
- Each 6P datalogger storage system had storage capabilities of 1432Kb of memory.
- Data was stored sec-by-sec. At this rate, a total of 20 hours of engine on data could be stored.
- A specific RPM level triggered the datalogger to sense engine operation and start or end datalogging. A time and date stamp was collected each second.
- Sensor recording was delayed at each engine start to allow for instrument stabilization.
- Engine parameters measured consisted of the 3P data (some manufacturers measured mass air flow instead of MAP), air/fuel measurement, throttle position, and engine temperature.

6P DATA ACQUISITION (CONT.)

- All measurements, with the exception of air/fuel, came directly from the ECU via the manufacturer supplied interface.
- Air/fuel measurements came from exhaust mounted Universal Exhaust Gas Oxygen (UEGO) sensors and controllers that were integrated into the data acquisition system. Both were purchased from NTK.
- UEGO sensors were installed between the catalytic convertor and the muffler. The exhaust system from the rear of the catalyst back was replaced on each vehicle after it was returned by the owner.
- Common data acquisition wiring, connectors, and parameter scaling was utilized for all manufacturers.
- GM utilized their own flight recorder data acquisition system for all GM vehicles and measured parameters in a similar fashion as the other manufacturers.

SPEED DISTRIBUTION

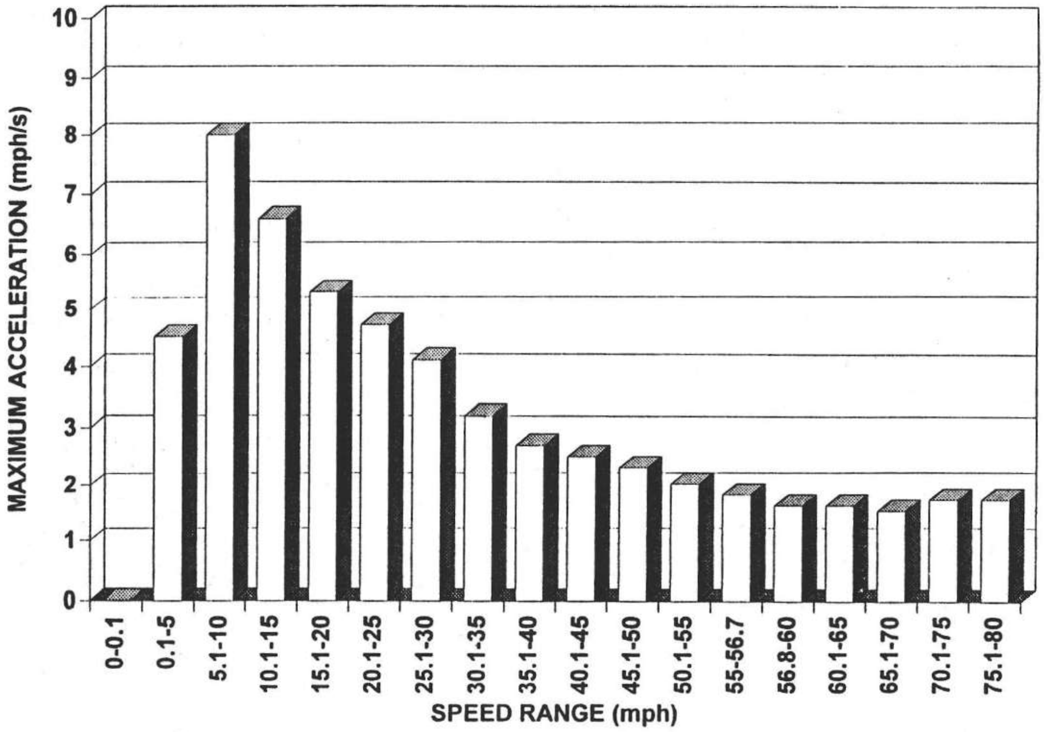
BALTIMORE/SPOKANE



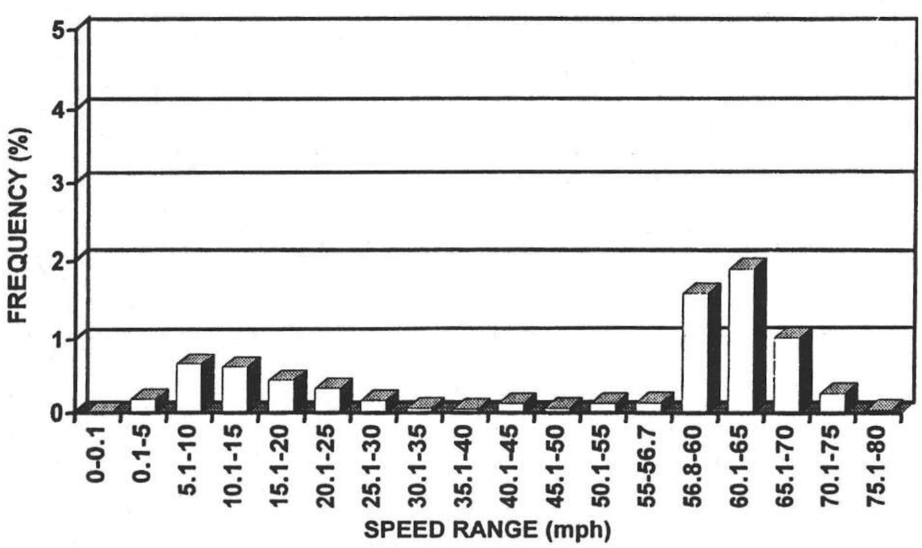
DATABASE

- 293 total vehicles were instrumented.
- 214 vehicles were equipped with 3P dataloggers.
- 79 vehicles equipped with 6P dataloggers.
- After data quality checking was performed, a database was created out of 227 vehicles.
- One week of data collection on 227 vehicles produced 11,886 trips and 7,305,353 seconds of engine operating data.
- On average, each vehicle logged approximately 32,000 sec or approximately 9 hours worth of data in the instrumentation week.

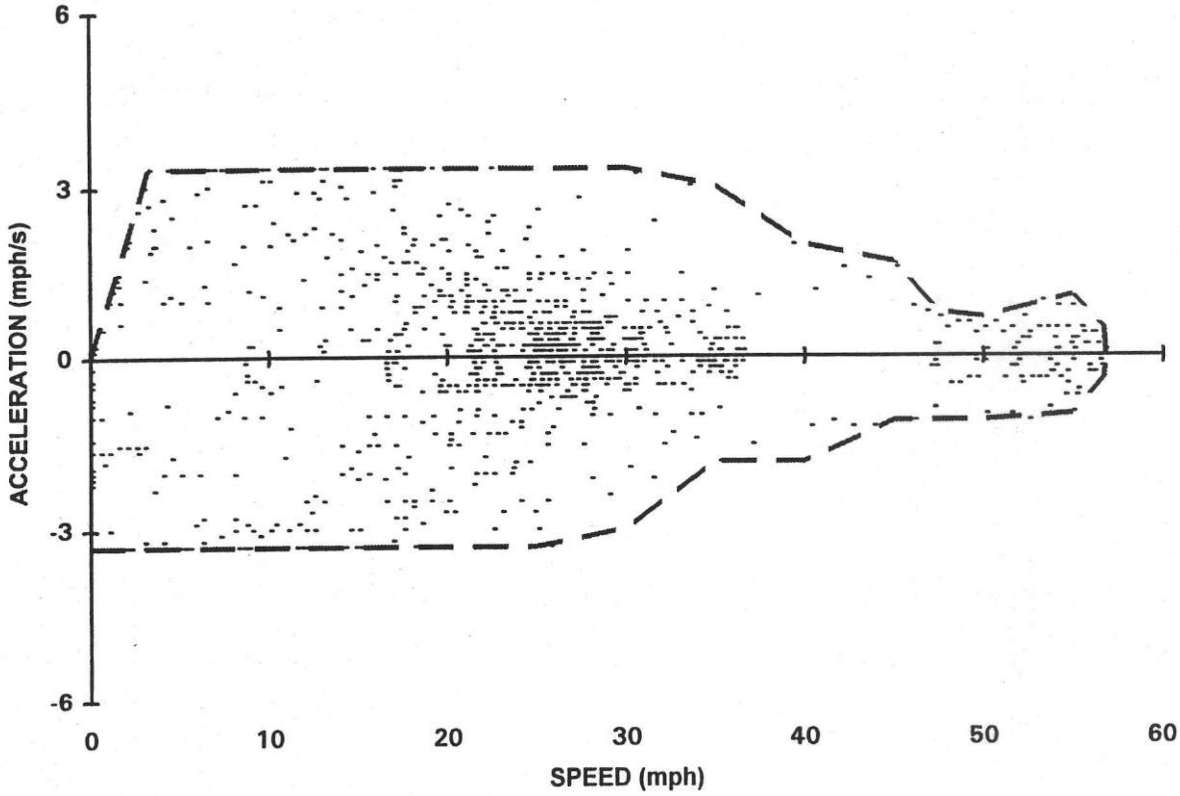
99.5TH PERCENTILE ACCELERATION
BALTIMORE/SPOKANE



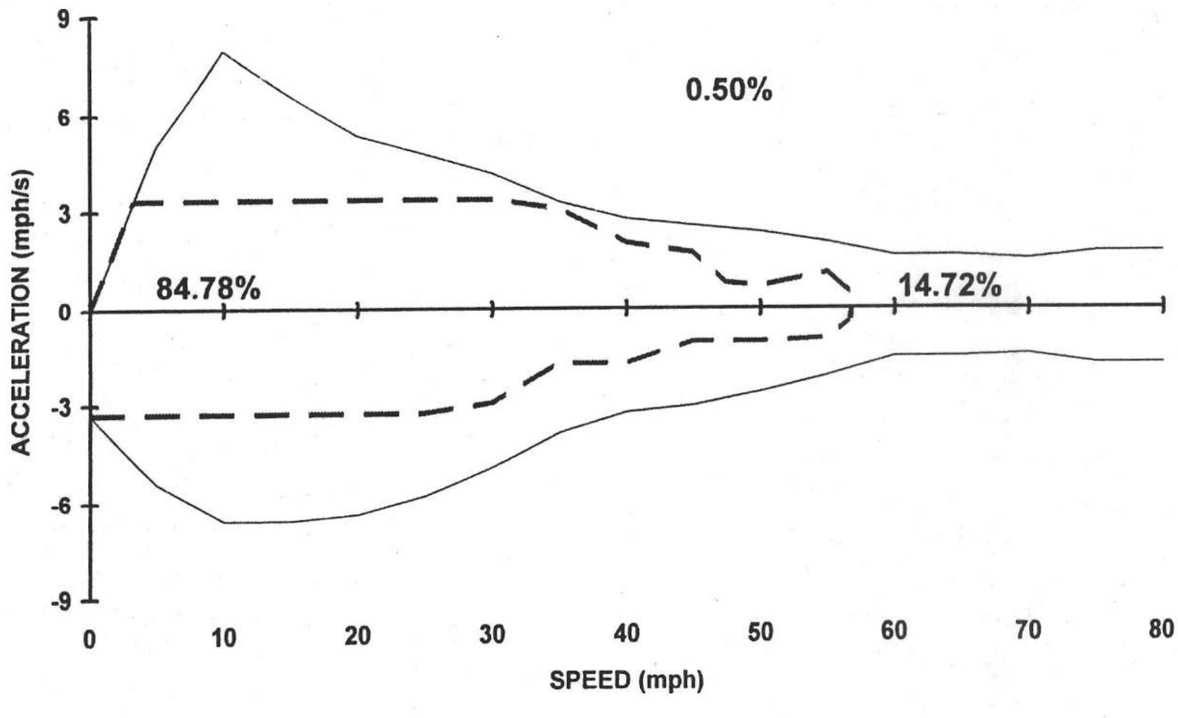
NON-FTP
ACCELERATION FREQUENCY
BALTIMORE/SPOKANE



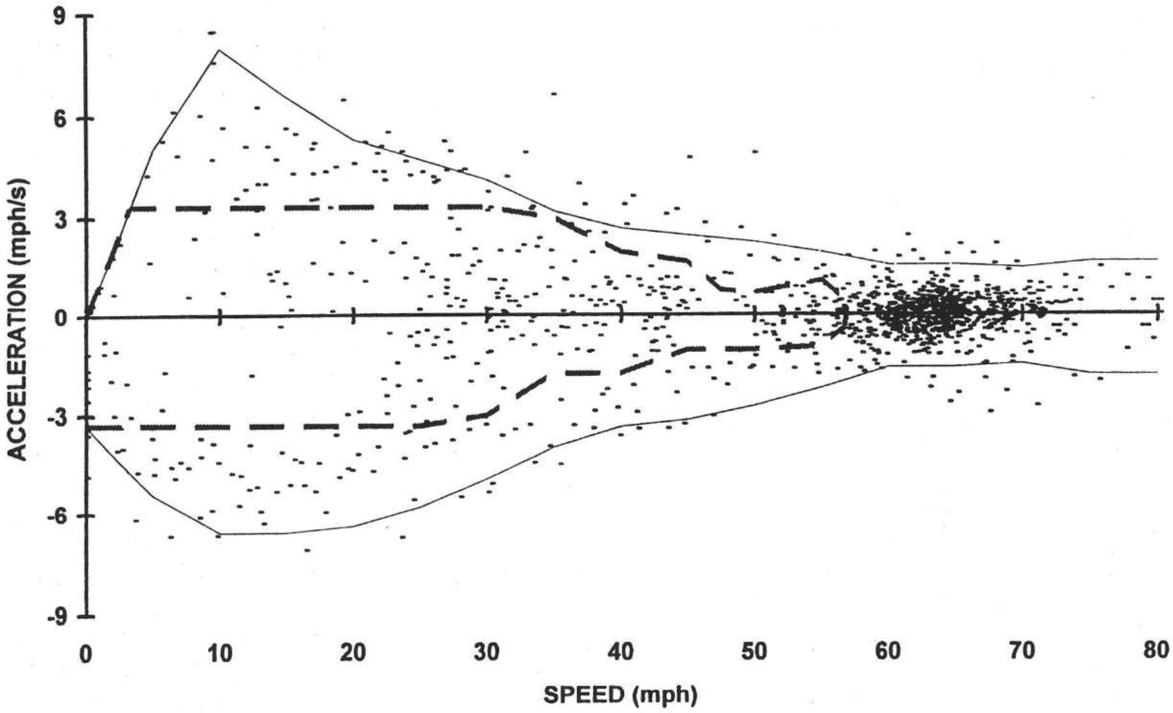
CVS75 SPEED/ACCELERATION DISTRIBUTION
(FTP BAGS 1 AND 2)



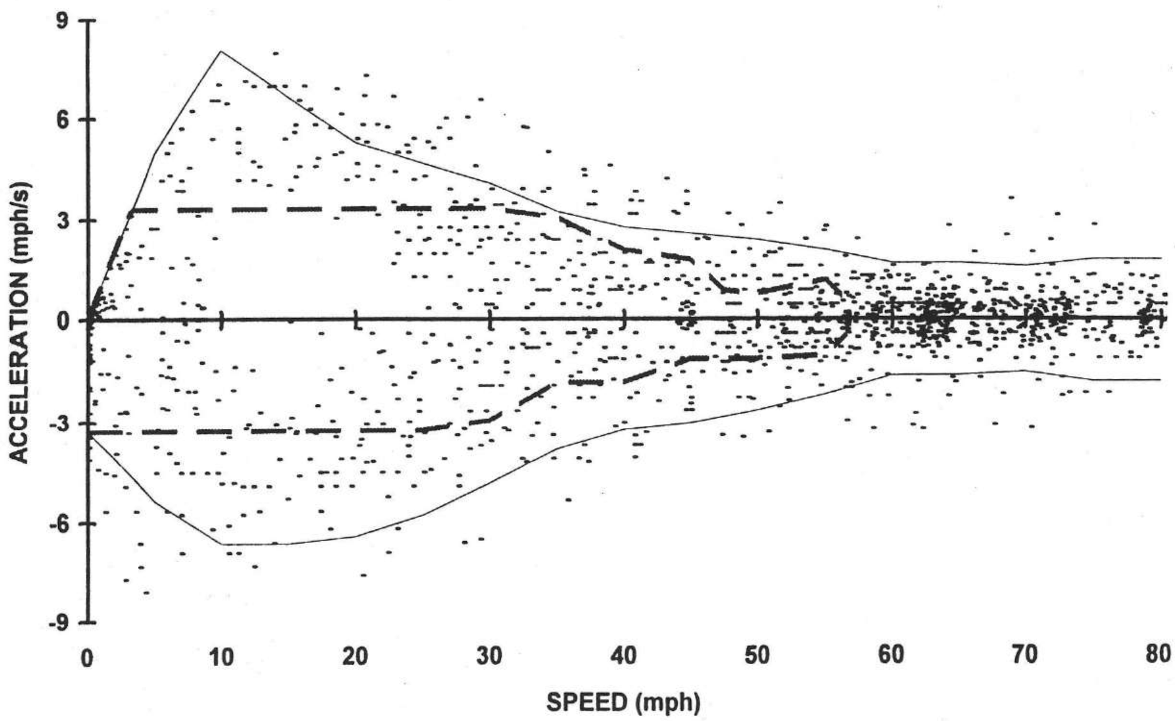
IN-USE SPEED/ACCEL DISTRIBUTION
BALTIMORE/SPOKANE



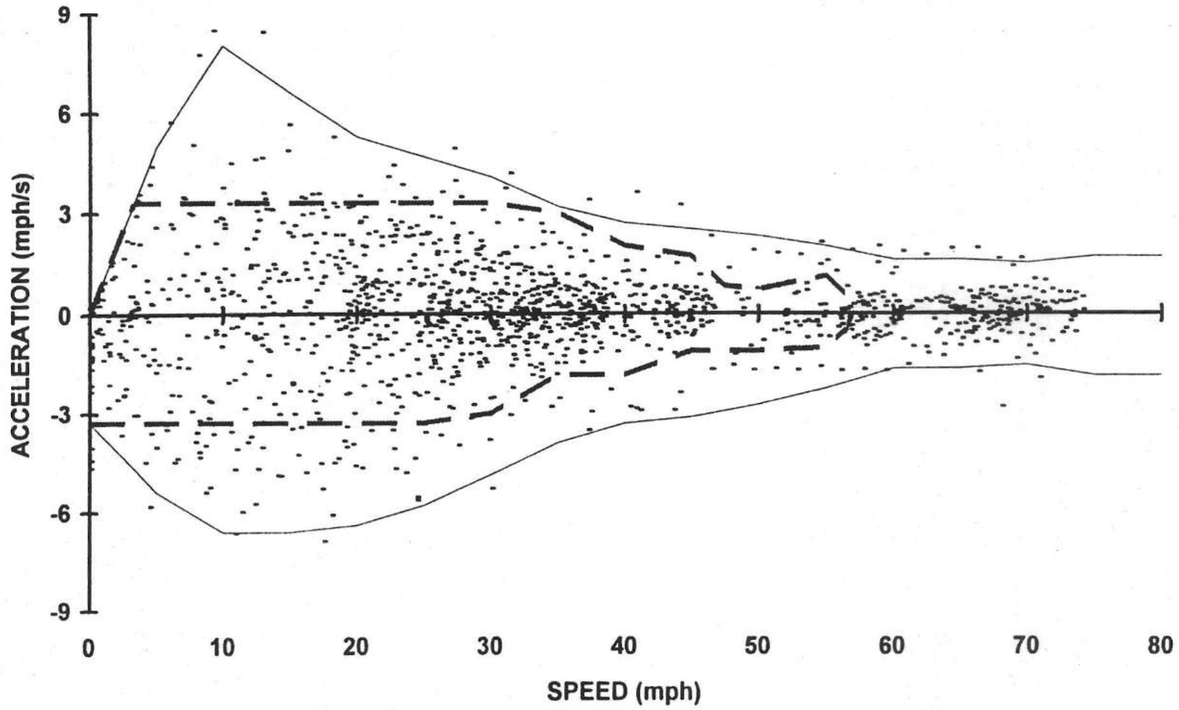
REP05 SPEED/ACCEL DISTRIBUTION
(EPA Non-FTP Inventory Cycle)



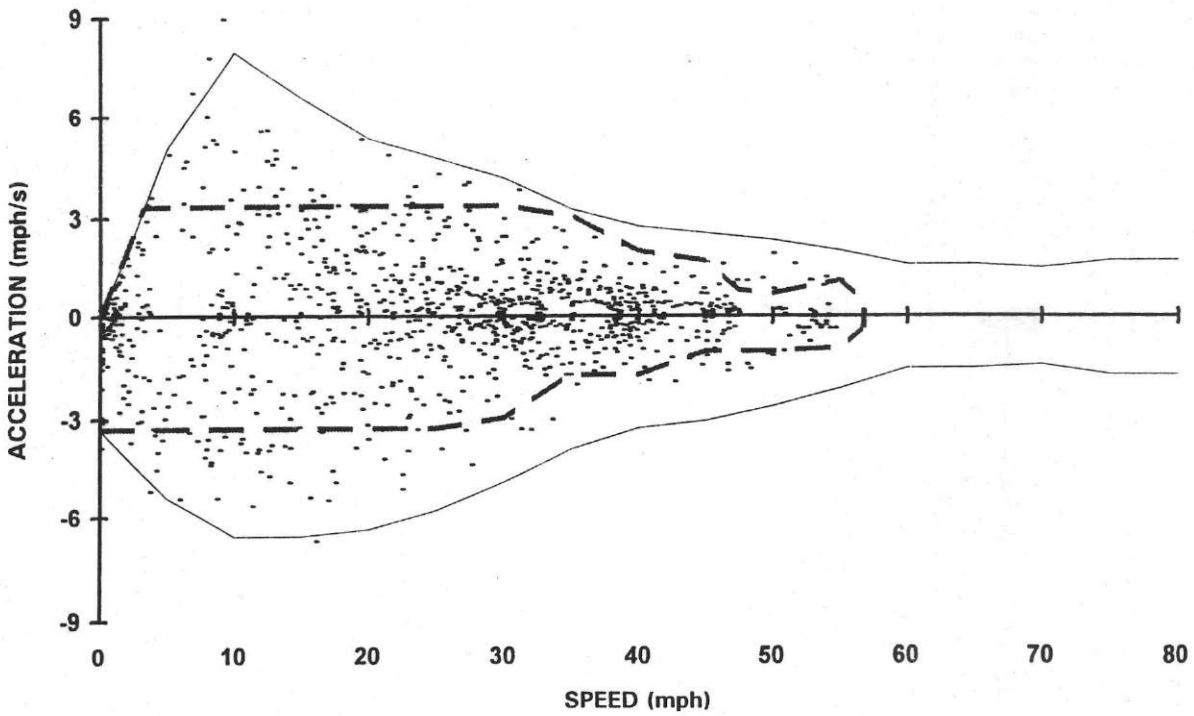
ARB02 SPEED/ACCEL DISTRIBUTION
(CARB Non-FTP Control Cycle)



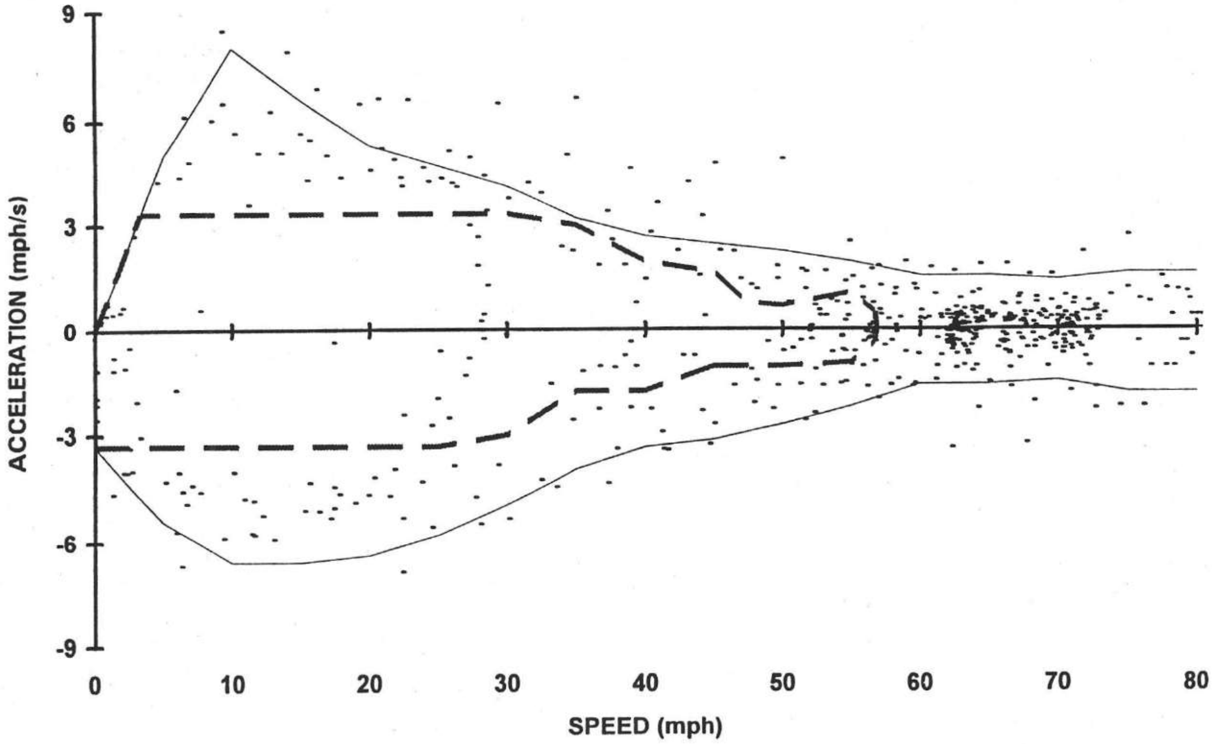
UNIF01 SPEED/ACCEL DISTRIBUTION
(CARB INVENTORY CYCLE)



REM01 SPEED/ACCEL DISTRIBUTION
(EPA REMNANT CYCLE)

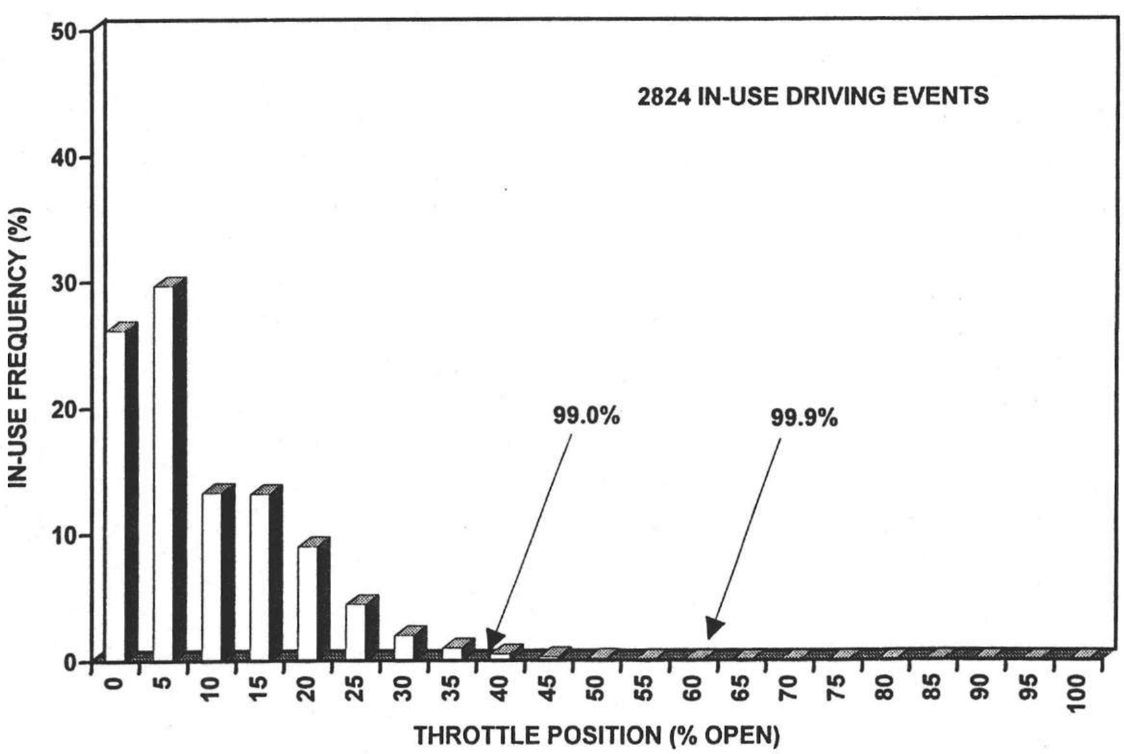


US06 SPEED/ACCELERATION DISTRIBUTION

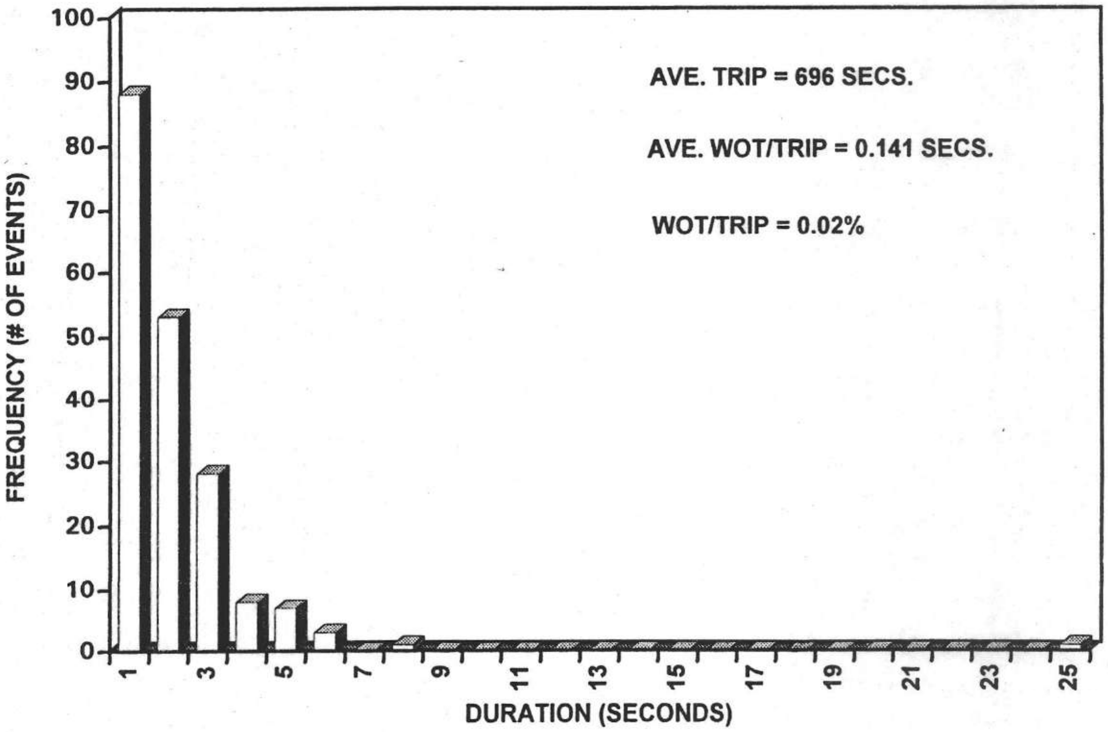


THROTTLE OPENING DISTRIBUTION

BALTIMORE/SPOKANE



WIDE OPEN THROTTLE DURATION DISTRIBUTION
BALTIMORE/SPOKANE



WOT = THROTTLE POSITION > 84.9% OPEN

EPA's Augmented FTP *Cycle*,

Jim Markey
US EPA, Ann Arbor, MI

"EPA's Federal Test Procedure Review Project: Driving Cycle Development Activities"

International Workshop on Vehicle Driving Cycles
Ottawa, CANADA
February 6, 1995

James P. Markey
Certification Division
U. S. Environmental Protection Agency

CAAA Requirements

- **Review and revise as necessary** the regulations .....to ensure that vehicles are tested under circumstances which reflect **the actual current driving conditions** under which motor vehicles are used....
- **Complete within 18 months**
- **Notice of Proposed Rulemaking signed 1/31/95**

Actual Driving Behavior

Origins of Existing FTP Driving Cycle

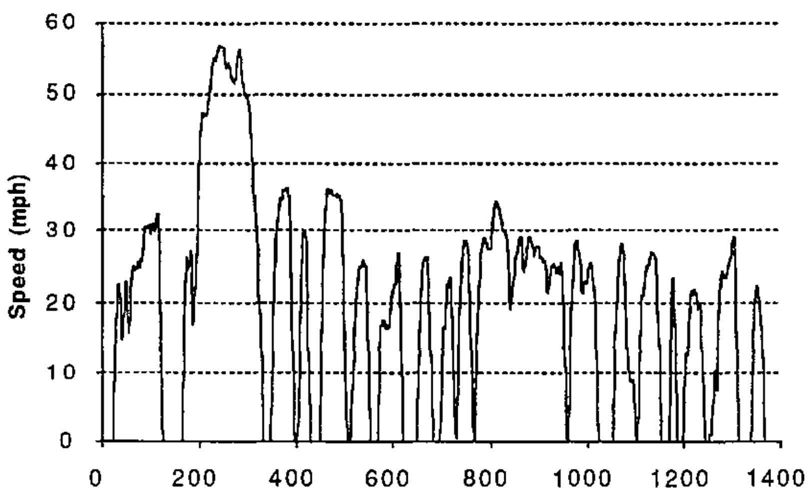
Preliminary work done by ARB in mid-1960s

EPA recorded speed/time trace on 6 drivers in 1970
- Typical driver selected
- Used strip chart (minor speed variations lost)

Urban route in L.A. of 12.0 miles reduced to 7.5 miles to match average trip length

Accelerations > 3.3 mph/sec cut (dyno limitations)

FTP Driving Cycle (LA4)



Actual Driving Behavior

Concerns with FTP Driving cycle

- **Acceleration** — 3.3 mph/sec max
- **Speed** — 57 mph max
- **Start driving behavior** — start segment deleted

Are different vehicle types driven differently?

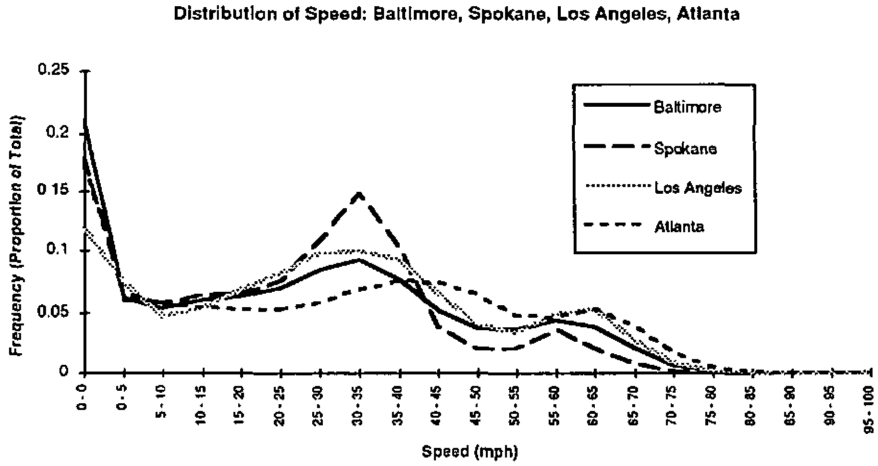
Surveys Conducted

City	Instrumented Vehicles	Chase Car Routes
Spokane	144	249
Baltimore	150	248
Los Angeles (CARB)	----	102
Atlanta (EPA/ORD)	101	----

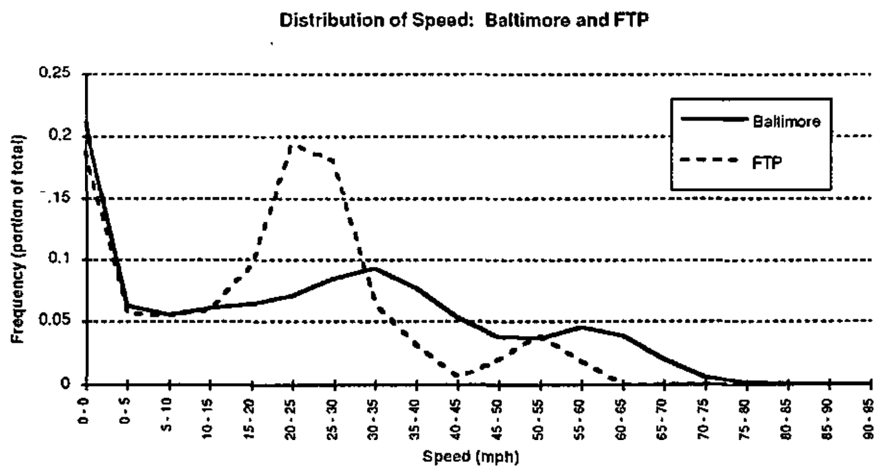
Over 2,300 hrs of second-by-second data

Actual Driving Behavior

Speed Distributions

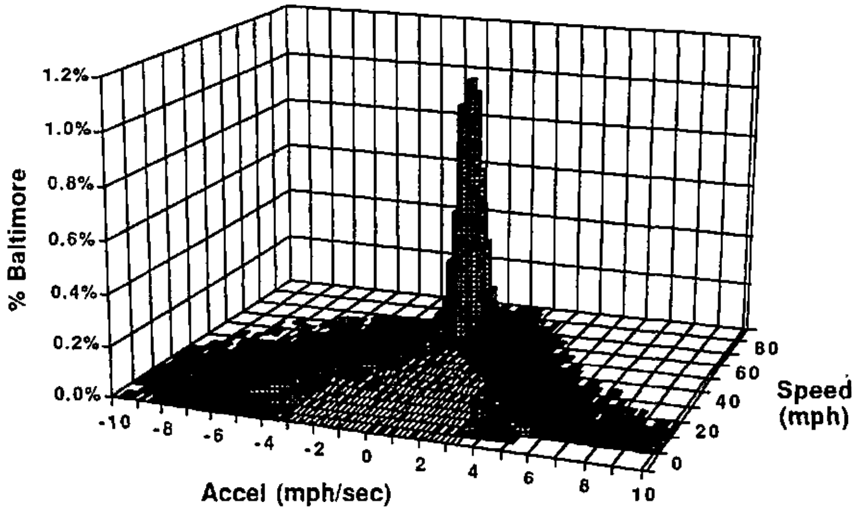


Speed Comparison to FTP



Actual Driving Behavior

In-Use Driving Outside the FTP



Start Driving Behavior

First 80 seconds of driving (after initial idle) very different:

	Avg. Speed (mph)
First 80 secs. in-use	14
Rest of in-use	28
FTP (first hill)	23

Actual Driving Behavior

Development of Representative Cycles

- *Database:* In-use data from Baltimore and Los Angeles
- *Building Blocks:* Segments of in-use driving (micro-trips)
- *Method:* Match in-use distribution of speed and acceleration

Actual Driving Behavior

Cycle Generation Method

Quasi-random Approach

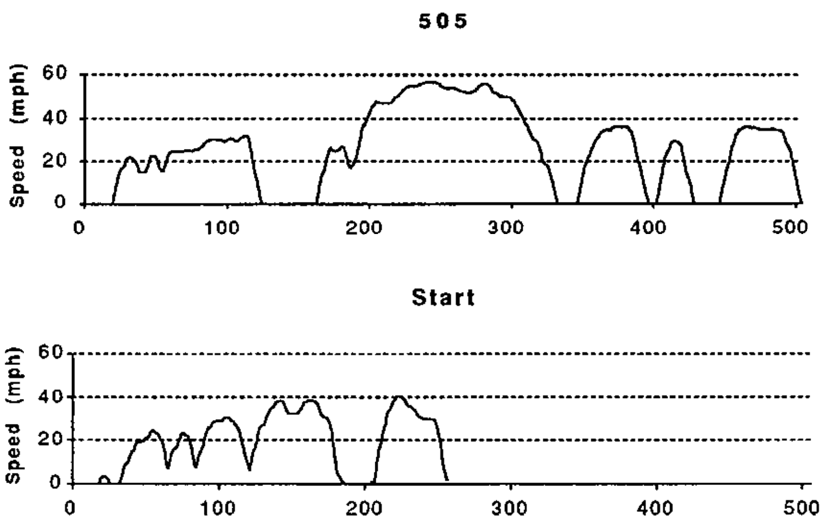
- Randomly select "seed" microtrips
- Select best "incremental fit" microtrip
- Rank candidates cycles according to best overall fit

New Representative Cycles

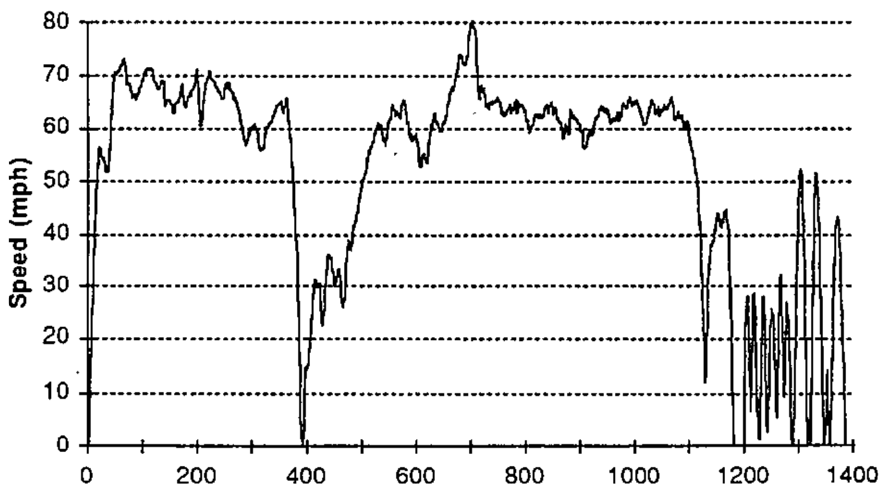
- *Start cycle:* First 240 seconds
- *High speed/accel:* Non-FTP operation(REP05)
- *Remnant cycle:* "FTP-like"; greater speed variation
- *CARB cycle:* Non-FTP operation; focus on driving extremes

Actual Driving Behavior

Comparison of 505 and new Start Cycle

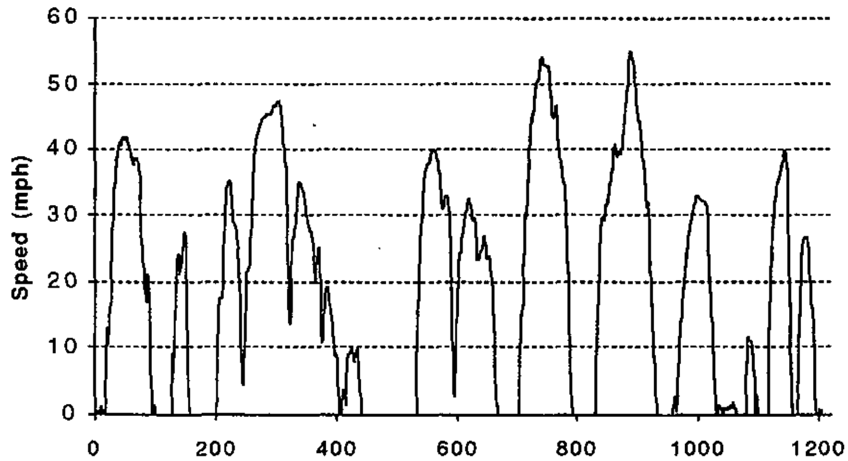


High Speed/Accel Cycle (REP05)

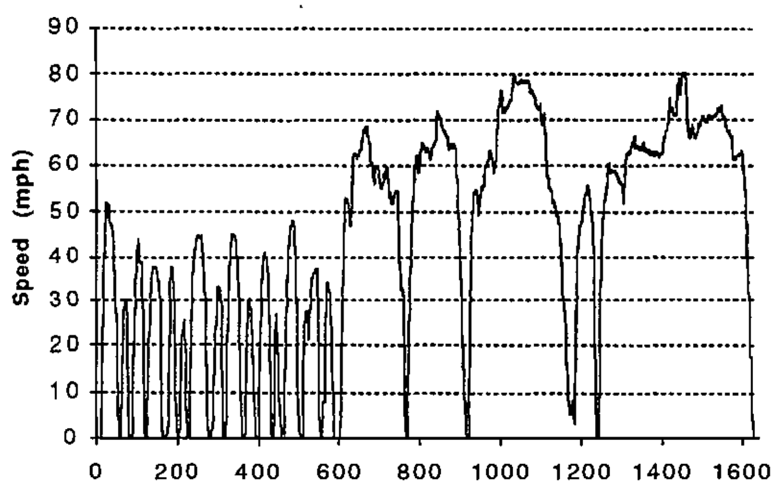


Actual Driving Behavior

Remnant Driving Cycle

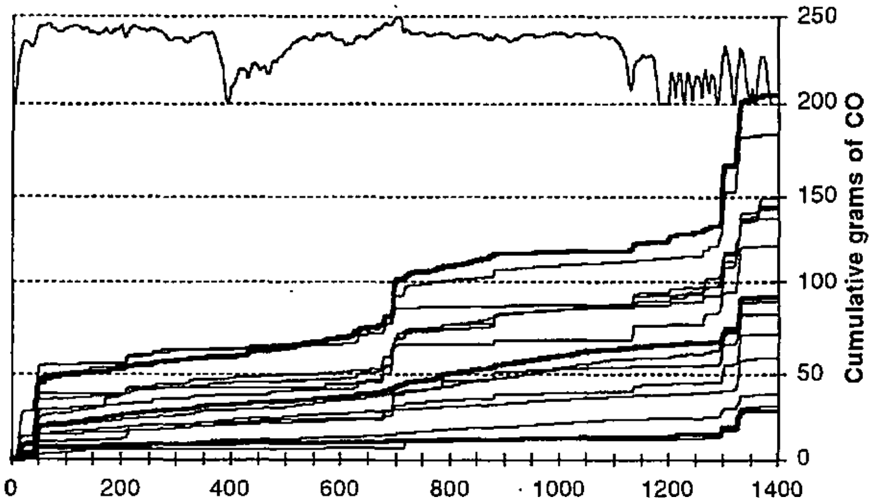


ARB02 Cycle

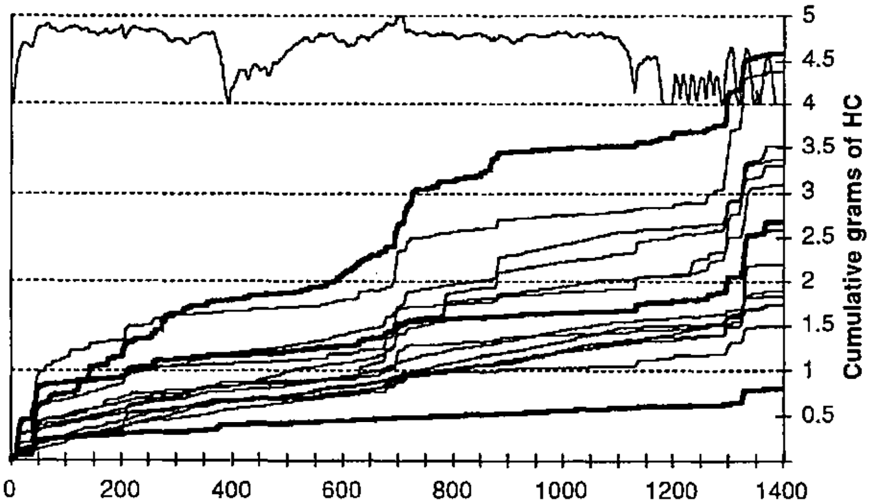


Actual Driving Behavior

LDV CO Emissions- REP05

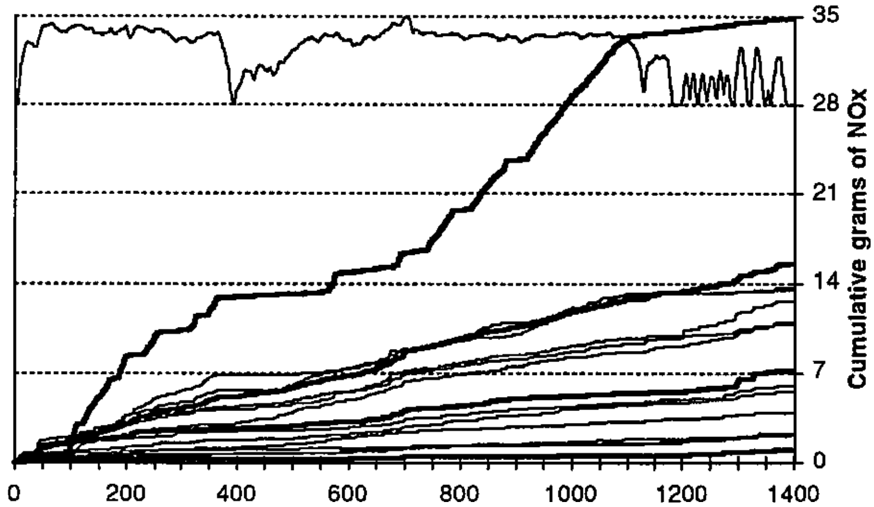


LDV HC Emissions- REP05



Actual Driving Behavior

LDV NOx Emissions- REP05



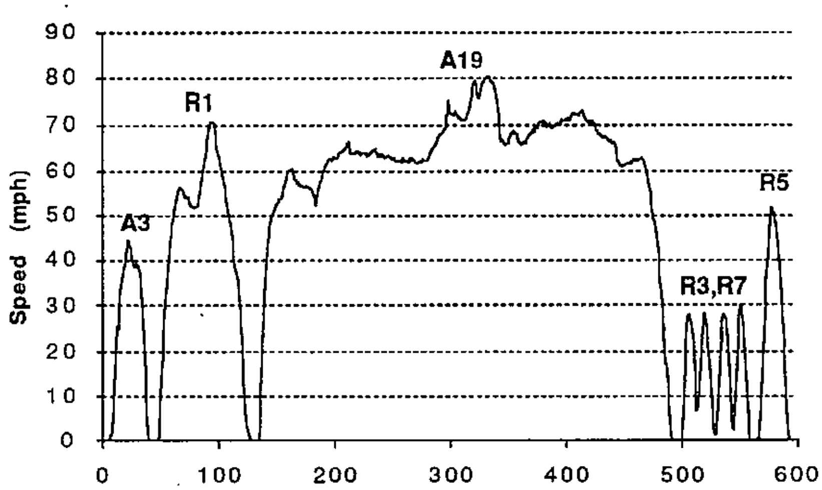
Emission Control Cycle Development

Objective: Emission control over range of non-FTP operation

- **Addresses concern of both agencies**
- **Testing burden (cycle duration)**
- **Appropriateness for full spectrum of light-duty vehicles**

Actual Driving Behavior

US06 Driving Cycle



In Summary...

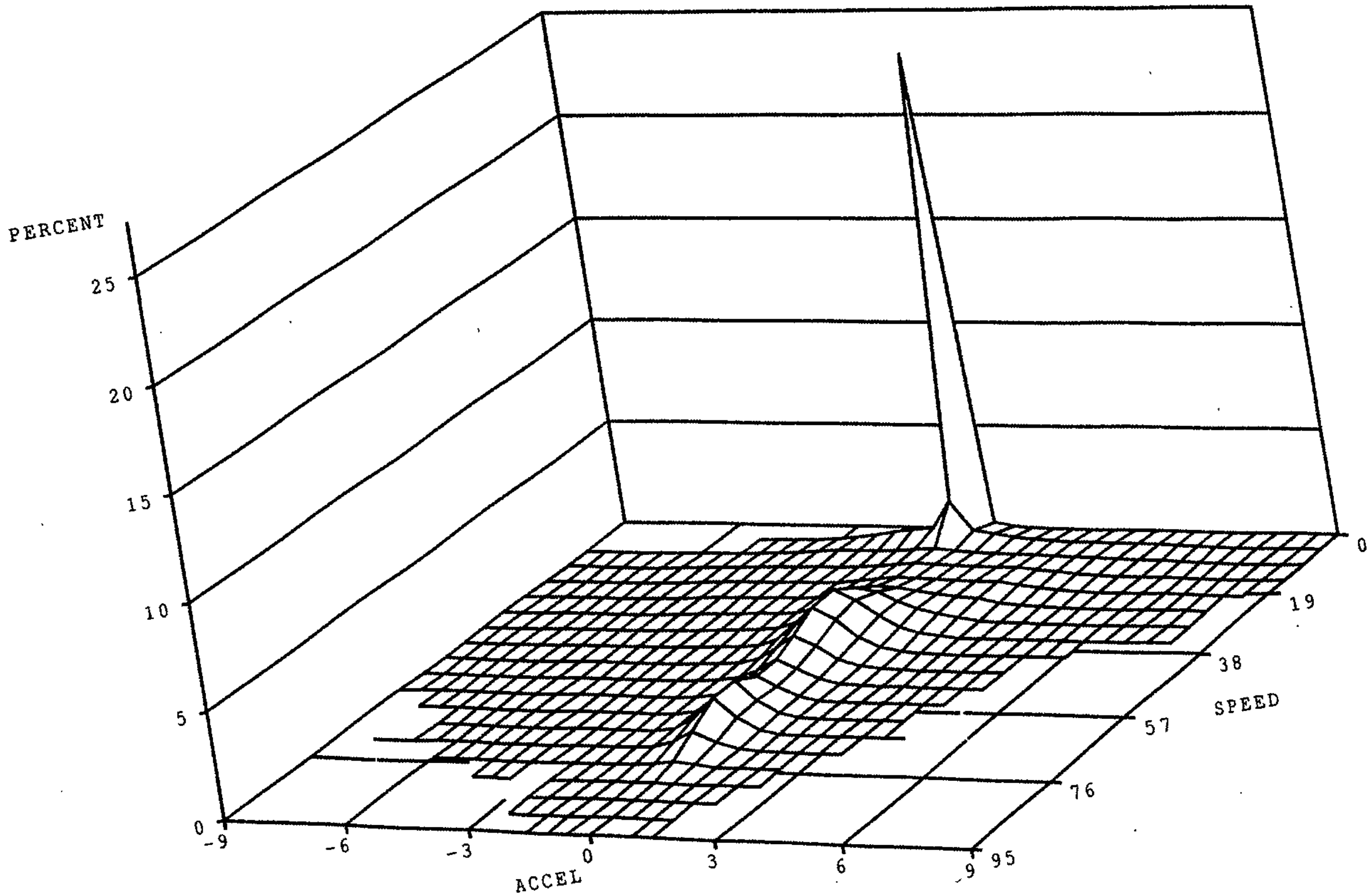
FTP Review Proeject's Contribution:

- **Extensive database of in-use driving behavior**
- **Two cycle generation software programs**
- **Representative cycles and emission database**
- **Emission control cycle to improve air quality**

page 6

BALTIMORE/LA92 COMPOSITE DRIVING

SPEED-ACCELERATION DISTRIBUTION



[redacted] [redacted]

Facility Based Driving Cycles

Larry Larson
California Air Resources Board, Sacramento, CA

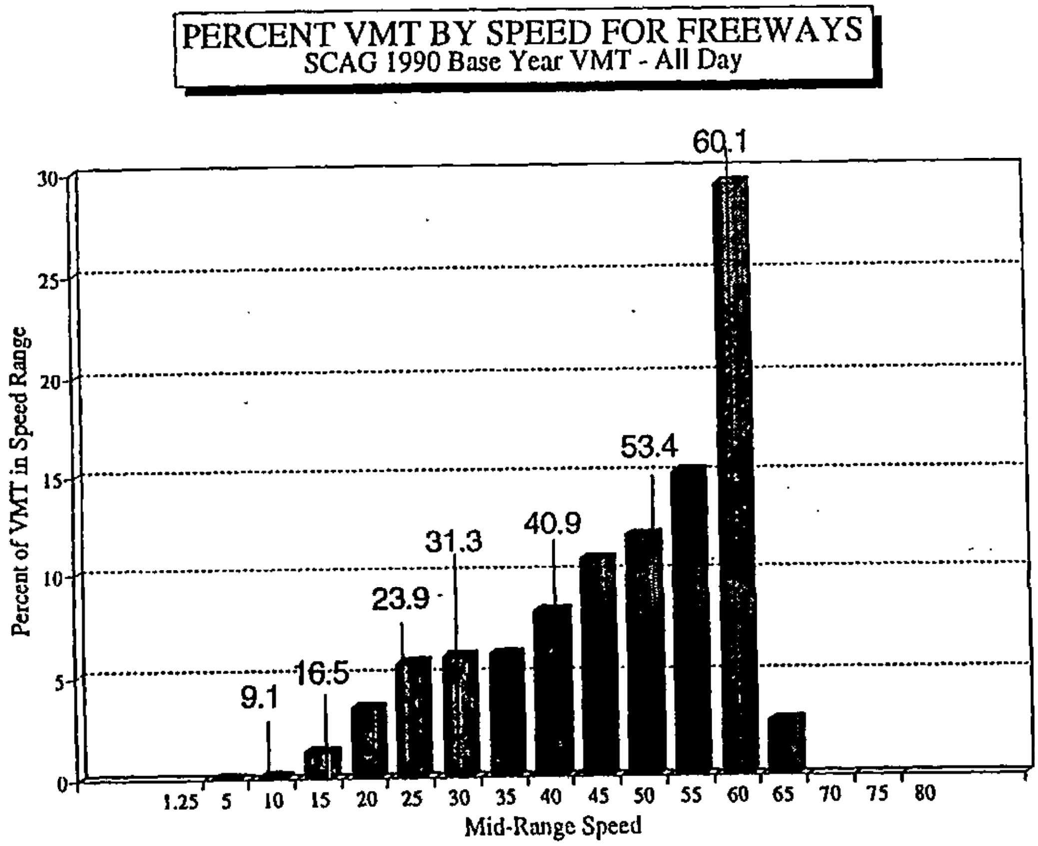
Facility-Based Driving Cycles for California:

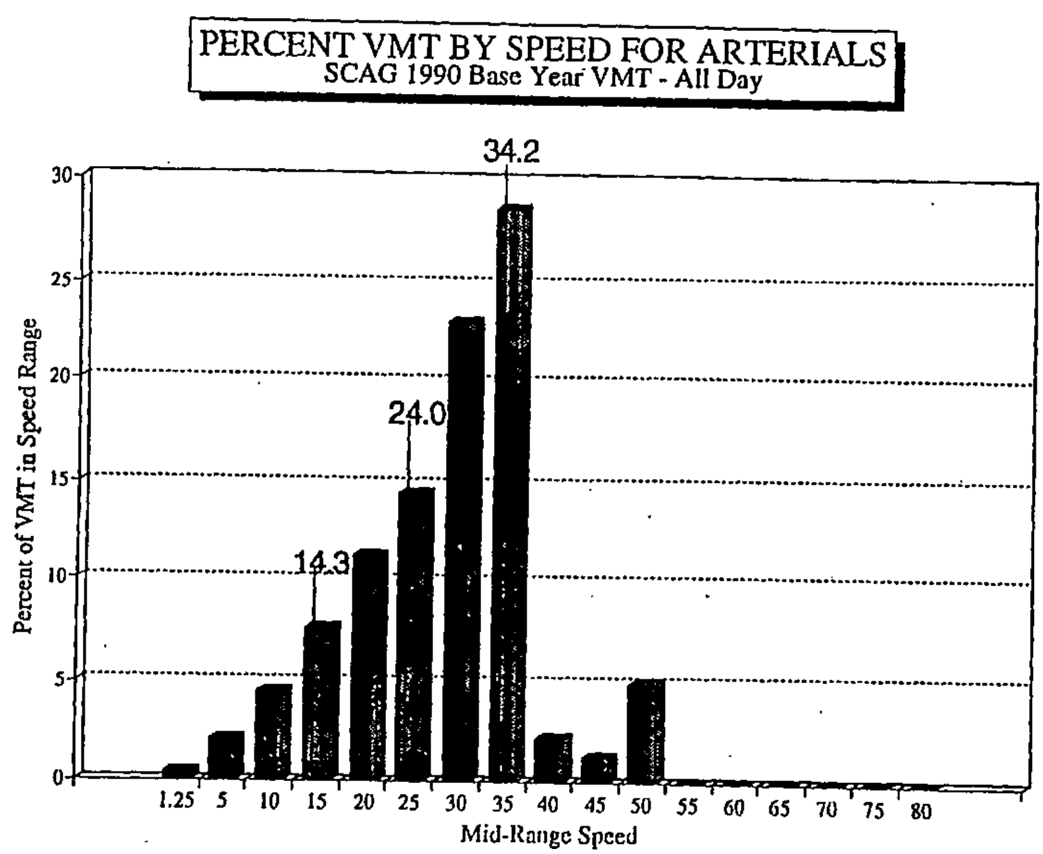
Background, Construction, and Preliminary Evaluation

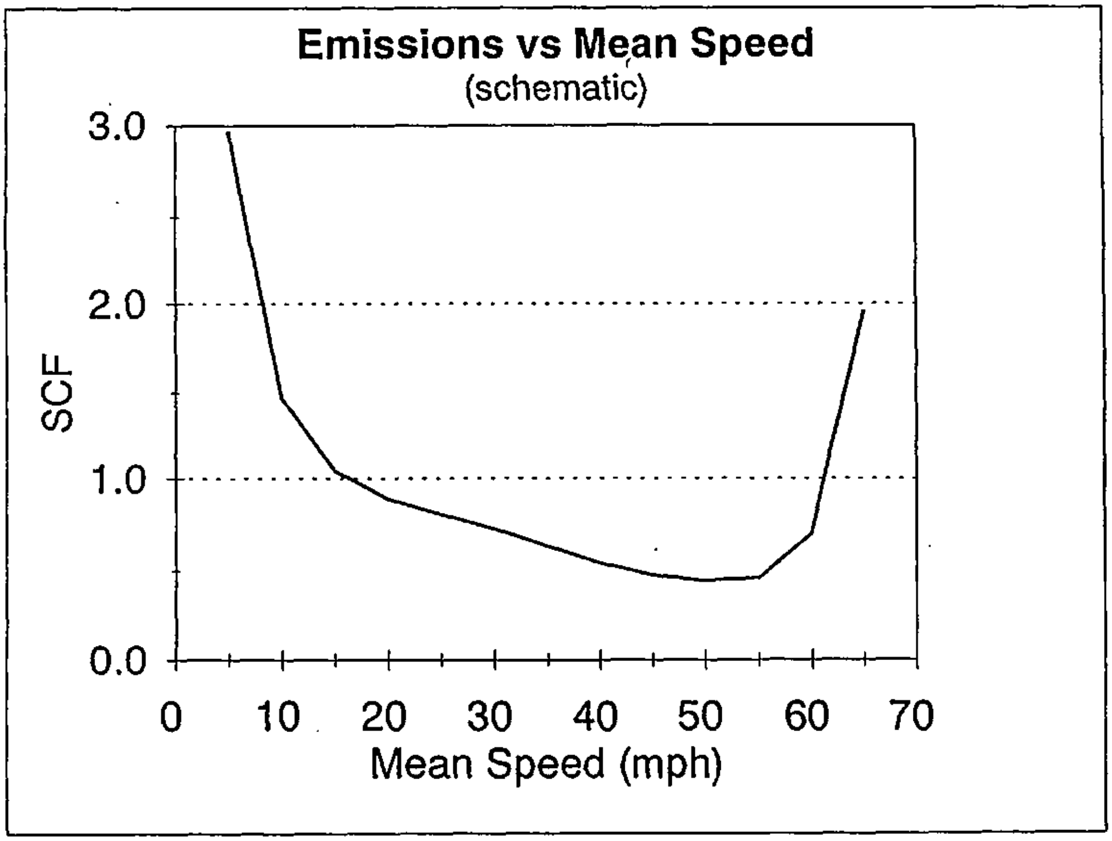
Lawrence C. Larsen
Cal/EPA
Air Resources Board - Technical Support Division

Presentation Outline

- Problem
- Objectives
- Data Base
- Cycle Development
- Cycle Evaluation & Selection
- Cycle Results


PERCENT VMT BY SPEED FOR FREEWAYS
SCAG 1990 Base Year VMT - All Day
60.1
53.4
40.9
31.3
23.9
16.5
9.1
Percent of VMT in Speed Range
0
5
10
15
20
25
30
1.25
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Mid-Range Speed


PERCENT VMT BY SPEED FOR ARTERIALS
SCAG 1990 Base Year VMT - All Day
34.2
24.0
14.3
Percent of VMT in Speed Range
0
5
10
15
20
25
30
1.25
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
Mid-Range Speed



J.E D:\MSD\ELLIS\86PLOTS.WB1 02/03/95 15:09

Problem Statement

- Current cycles not representative of today's driving
- Limited testing
- No distinction between driving on freeways vs. surface streets

Presentation Outline

- Problem
- Objectives
- Data Base
- Cycle Development
- Cycle Evaluation & Selection
- Cycle Results

Study Objectives

- Develop new cycles
- Test a large representative fleet on all cycles
- Produce new inventory estimates

Study Objectives

- Develop cycles based on observed contemporary driving behavior
- Develop separate sets of cycles for freeways and for arterials
- Develop cycles covering a range of congestion/speed conditions

---

Study Objectives

- Develop cycles based on readily available data
- Develop cycles compatible with output from transportation models

Presentation Outline

- Problem
- Objectives
- Data Base
- Cycle Development
- Cycle Evaluation & Selection
- Cycle Results

Chase Car Data

- Original contract (LA92 data)
- Laser-equipped chase car
- Data on "target" and "chase" cars
- Key data collected and used in study :
  - Speed-time traces
  - Type of facility
  - Route I.D.
  - Estimate of observed congestion
  - Videos of each drive

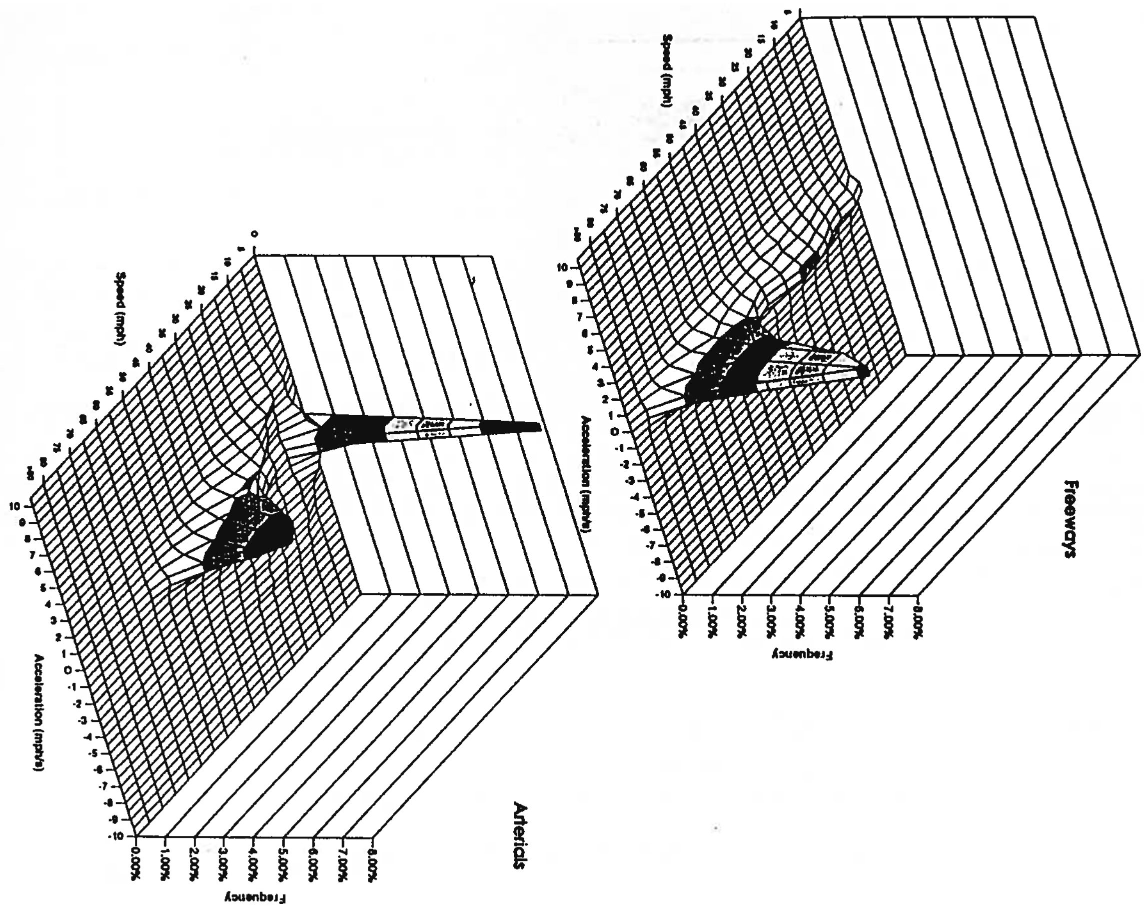


Figure 1. Frequency Distribution of Speed and Accelerations for typical driving on Los Angeles freeways and arterials (LA92 chase car data).

Table 1. Percent of time spent in various driving modes for the LA92 chase car data.

	Facility Type	
Mode	Freeways	Arterials
Idle*	<1	16
Cruise **	53	28
Acceleration	26	31
Deceleration	21	25

* Idle is defined as speed=0.0 mph and acceleration=0.0 mph/s

** Cruise is defined as absolute value of accel or decel < 0.5 mph/s

Chase Car Data

- Augment low-speed freeway driving (LA93 data)
- Contractor review of LA92 videos
  - Accurately locate facility's begin/end points
  - I.D. facility types in greater detail
- Task force review of LA92 videos
  - Locate SCAG link nodes
  - Locate controlled intersections

Chase Car Data

(Combined LA92 and LA93 Data)

Facility Type	Miles Driven	Minutes Driven
Freeways	777	1239
Arterials	390	1091
Ramps	60	167
Other	7	26
Total	1234	2523

Chase Car Data

Key data not available for study
- Real-time measured data on congestion/density
- Physical locations of SCAG nodes for all routes driven

Presentation Outline

- Problem
- Objectives
- Data Base
- Cycle Development
- Cycle Evaluation & Selection
- Cycle Results

Cycle Development

- Stratify by facility (Freeway/Arterial)
- Break traces into 'Snippets'
- Stratify 'Snippets' by density/speed
- Break 'Snippets' into 'Events'
- Determine required cycle lengths
- Construct 1000's of cycles
- Evaluate and select "best' cycles

Cycle Development

Stratify by facility (Freeway/Arterial)

- Data included codes for facility type which made this step simple

Cycle Development

Break Traces into 'Snippets'

- Freeways
  - Snippets start and stop when difference in density observed
- Arterials
  - Snippets start and stop at SCAG nodes (controlled intersections)

Cycle Development

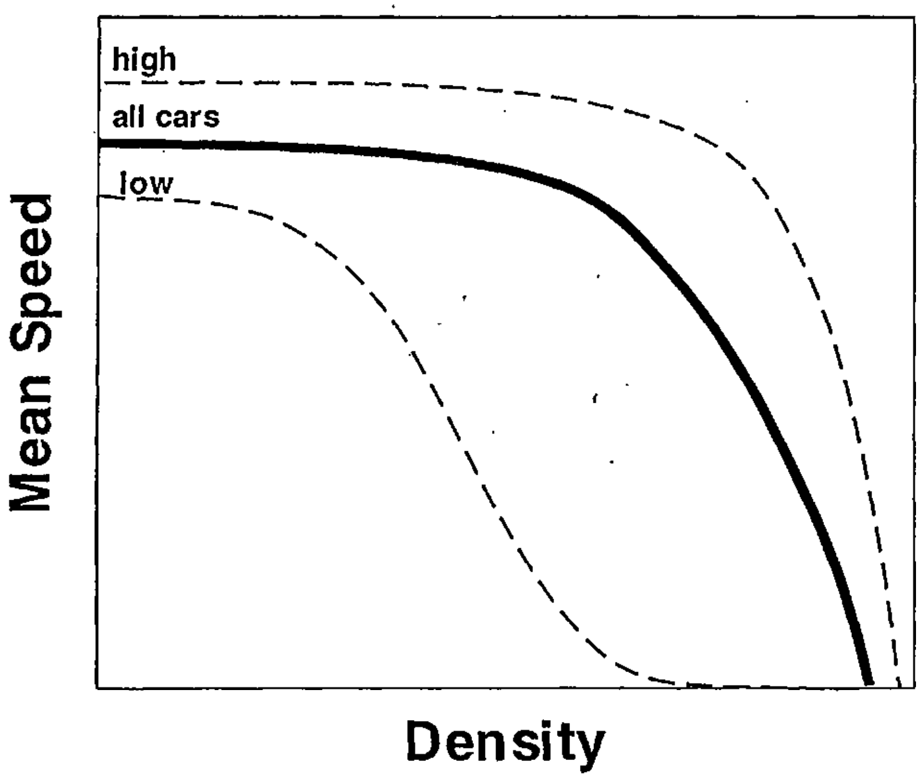
Stratify 'Snippets' by density/speed

- Freeways
  - Real-time density unavailable
  - Identified density-sensitive variables
  - Clusters (7) based on variables
- Arterials
  - Real-time density unavailable
  - Accurate initial speeds unavailable
  - Lacked crucial density-sensitive variables
  - Grouped snippets into 3 sets based on mean speed and equal milage

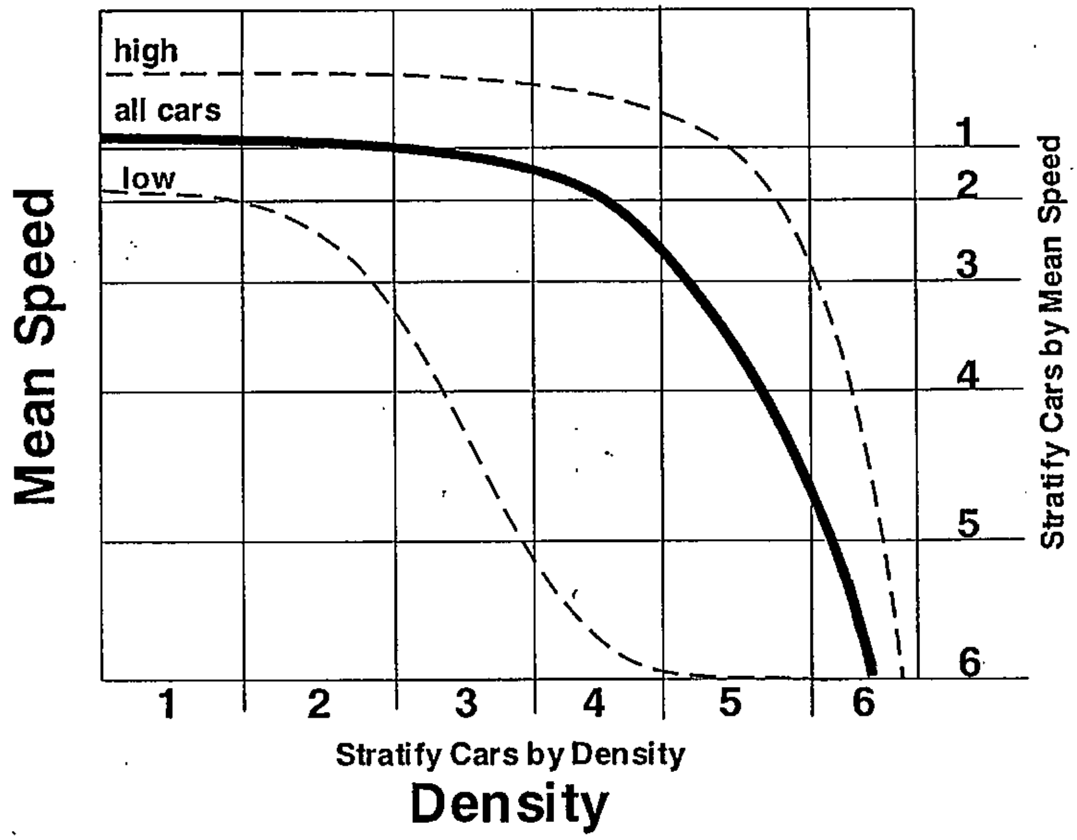
Cycle Development
Stratify Freeway Snippets by Density

- Variables for clustering freeway snippets
  - Standard deviation (sigma)
  - Coefficient of variation (CV)
  - Total Absolute Differences (TAD)
  - Percent Idle
- Clustering Method
  - Ward's Minimum Variance
  - Similar 'size' clusters
  - Distribute mean speeds

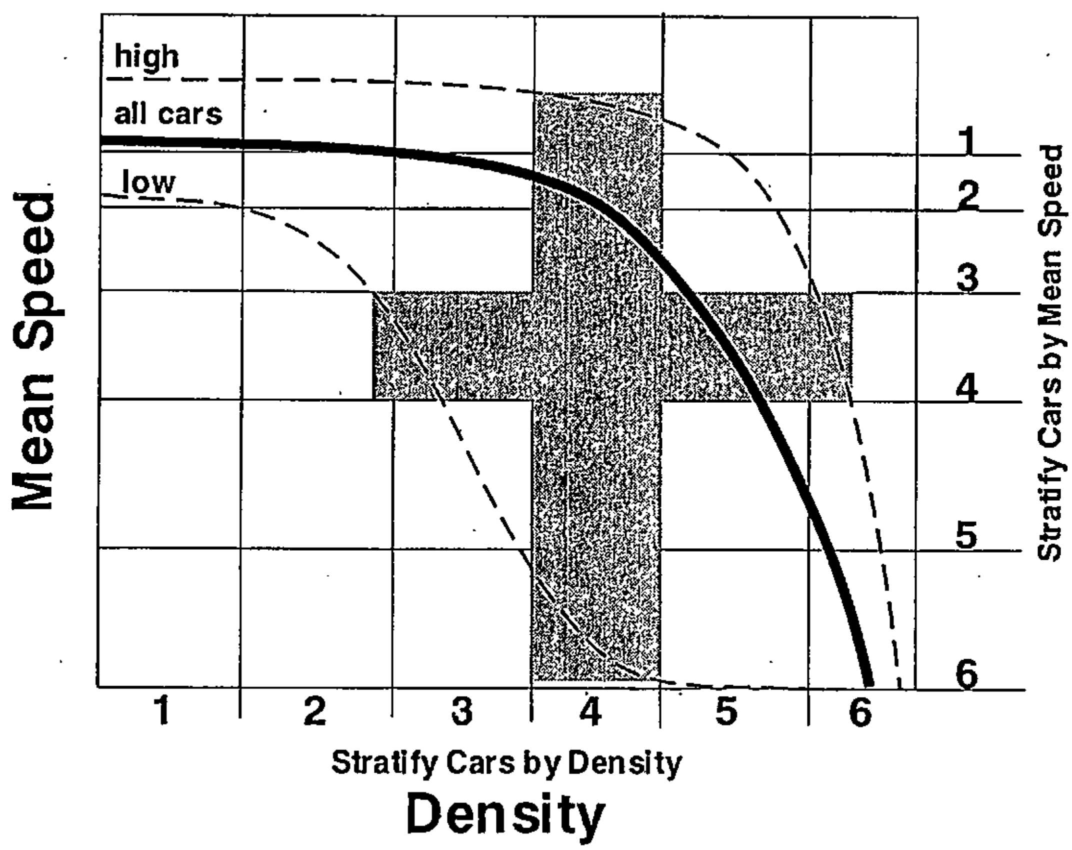
Speed*Density Relationship for Freeways



Speed*Density Relationship for Freeways



Speed*Density Relationship for Freeways



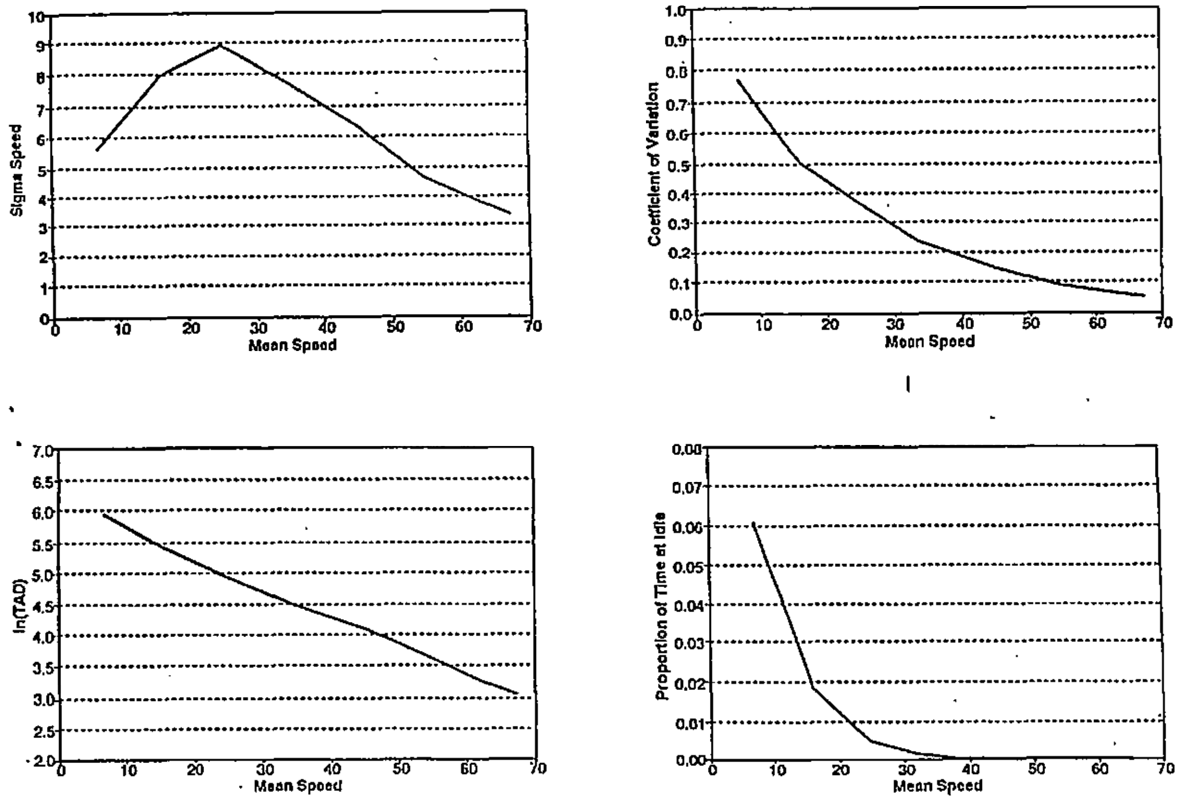
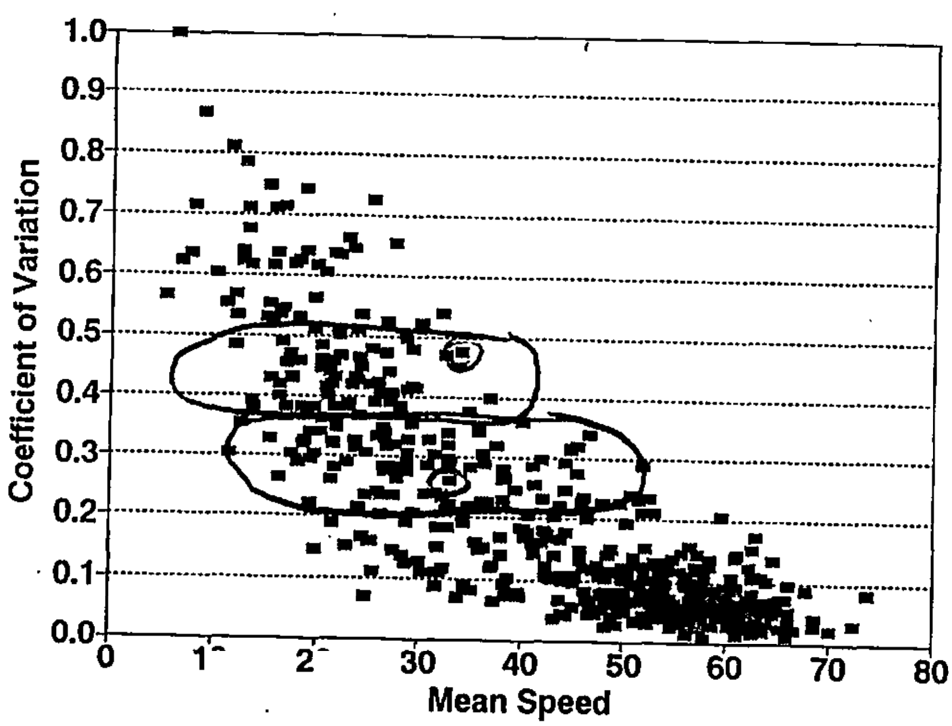
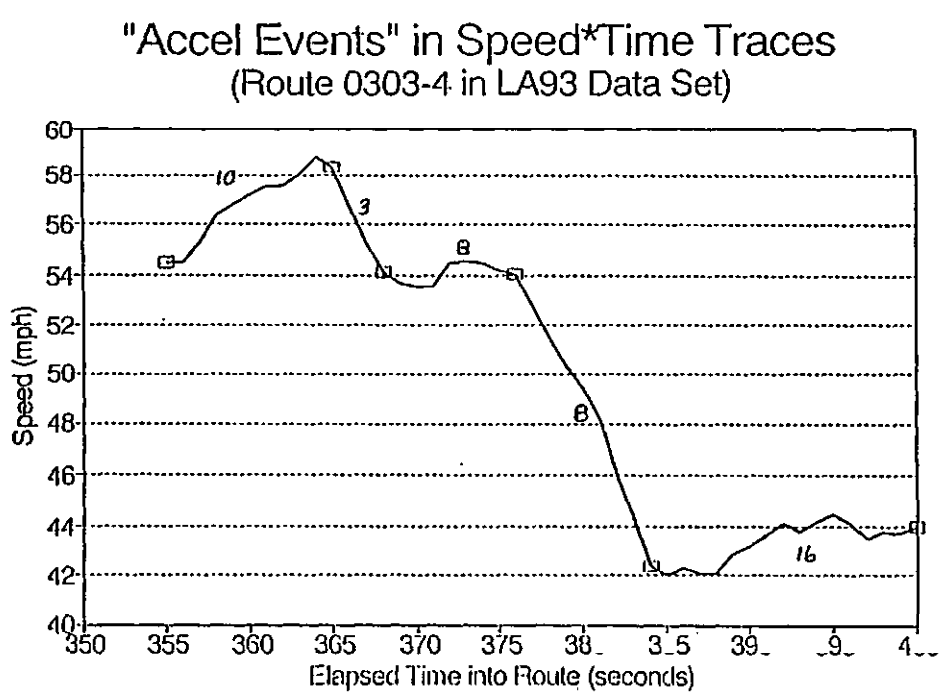


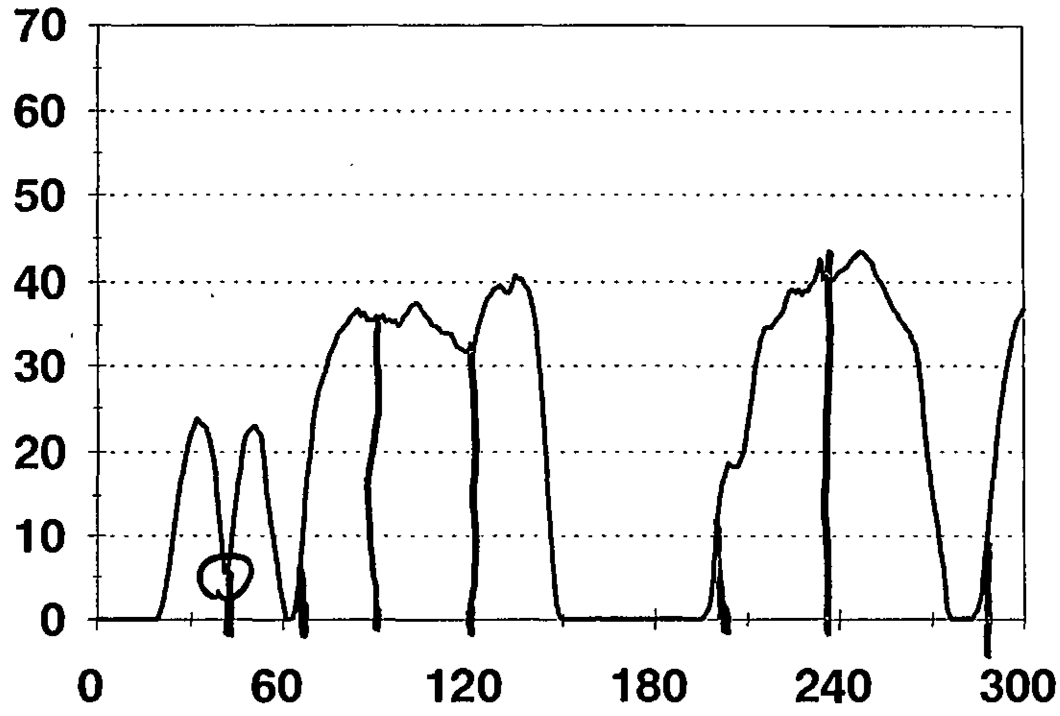
Figure 2. Relationship between the mean speeds of freeway snippets and the statistics used for assigning snippets to bins.



Cycle Development
Break 'Snippets' into 'Events'

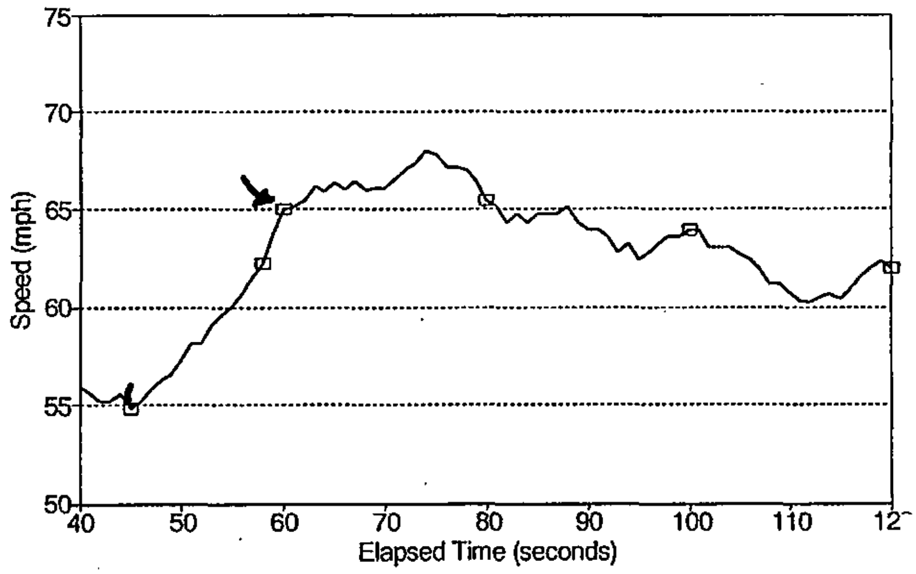
- Events are building blocks for cycles
- Events are segments of observed driving
- Freeways
  - Segments of similar driving
  - Accel, decel, and cruise types
- Arterials
  - Between controlled intersections



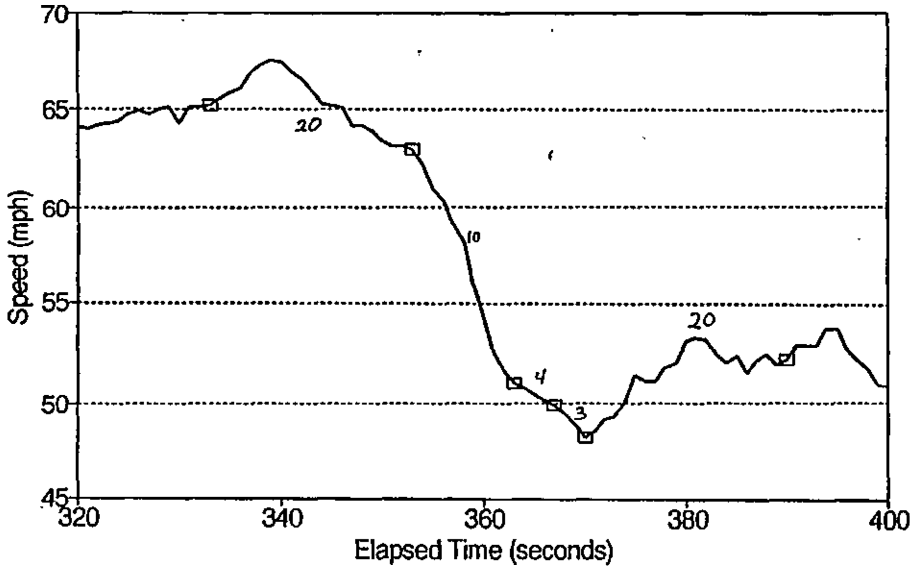


"Accel Events" in Generated Cycles

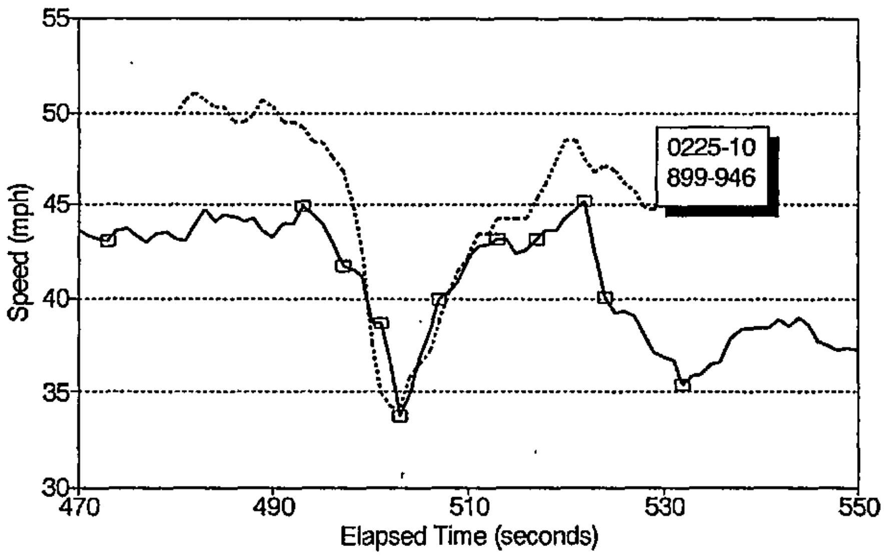
(Cycle 2_144)



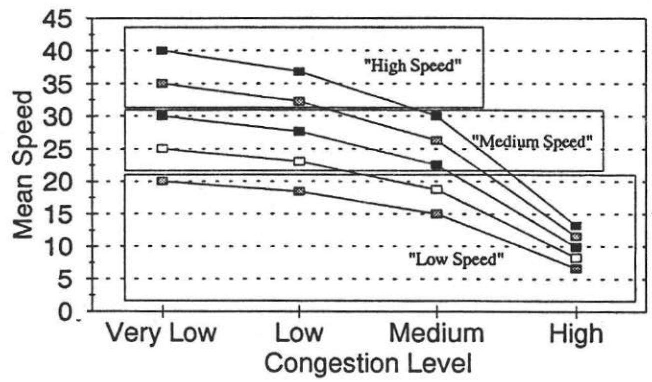
"Accel Events" in Generated Cycles
(Cycle 2_144)



"Accel Events" in Generated Cycles
(Cycle 2_144)

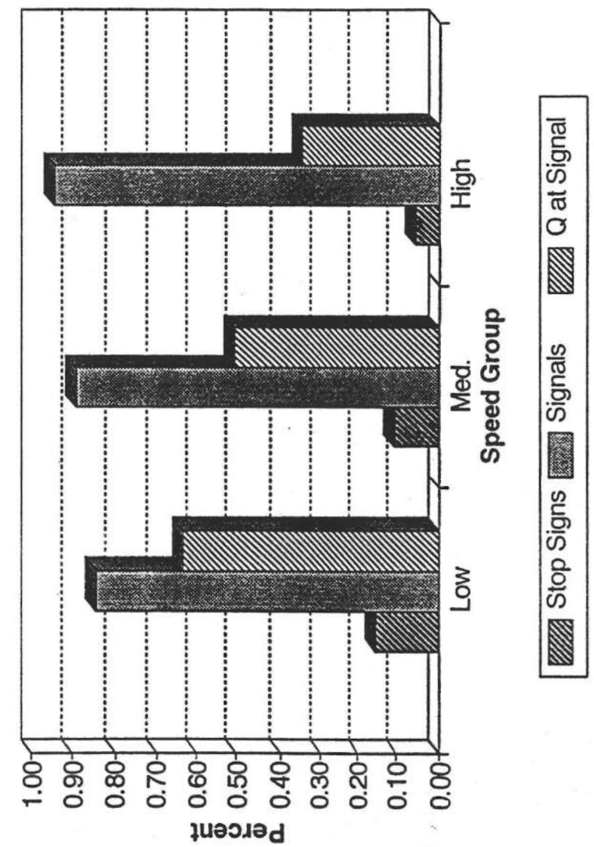


Theoretical Speed vs Congestion for Arterial Facilities

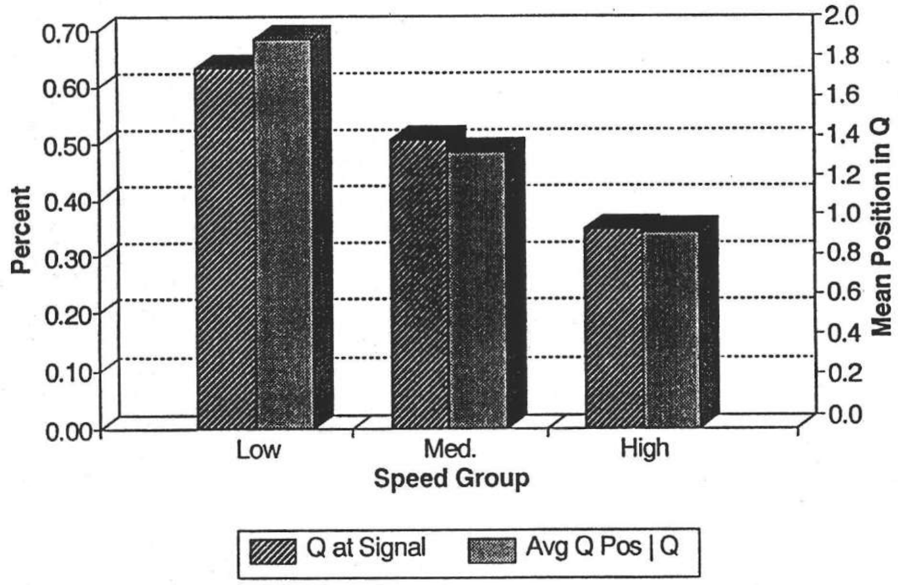


- Explored a Factor Analysis Categorization
- Generally Engouraging, but ...
- Too Little Data
- Too Little Time
- Finally Used Three Speed Groups

Features of Three Arterial Speed Groups (Low=14, Med=24, High=34 mph)



Features of Three Arterial Speed Groups
(Low=14, Med=24, High=34 mph)



Cycle Development

Determine required cycle lengths

- Sensitivity analyses for each 'bin' length vs. 'coverage'
- Coverage = proportion of speed*accel freq. matrix represented by a cycle
- Coverage goal = 80 percent for resol. of 5.0 mph by 0.5 mph/s
- Evaluate several cycle lengths

Potential Coverage of Bins by Stochastically Generated Cycles

Bin Mean Speed	Length of Cycles (minutes)					
	4.0	7.5	10.0	15.0	20.0	30.0
60	0.83	0.84	0.91	0.9	0.93	0.92
54	0.71	0.78	0.79	0.85	0.87	0.88
40	0.66	0.76	0.76	0.77	0.82	0.84
32	0.64	0.75	0.76	0.79	0.83	0.85
25	0.64	0.74	0.77	0.79	0.83	0.85
18	0.72	0.78	0.8	0.83	0.85	0.87
10	0.79	0.85	0.86	0.86	0.88	0.88

Values in each cell of the table are the maximum coverage among 50 generated cycles.

Cycle Development

Construct 1000's of cycles

- Construct by sequencing 'events'
- Establish boundary conditions
  - Begin and end speeds
  - Criteria for compatible 'events'
  - Reality checks
- Randomly select from the set of compatible events (with replacement)

Difference Between Successive Accelerations (mph/s)

Speed (mph)	***	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10
0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0
5	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
10	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
15	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
20	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
25	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
30	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
35	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
40	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Presentation Outline

- **Problem**
- **Objectives**
- **Data Base**
- **Cycle Development**
- **Cycle Evaluation & Selection**
- **Cycle Results**

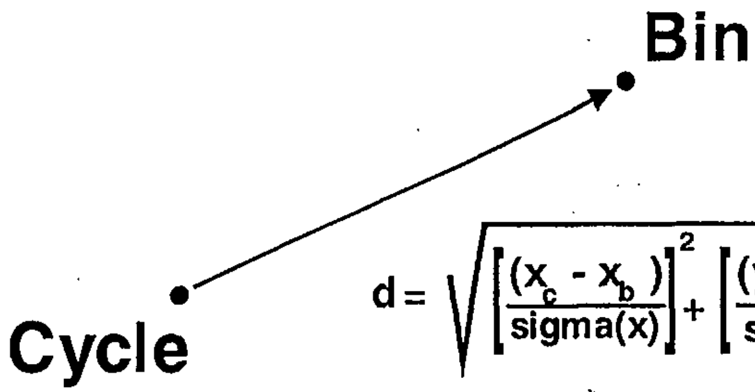
Cycle Development
Evaluate and select 'best' cycles

- Evaluate 500 cycles per bin
- Evaluate cycles on 2 criteria
  - Percent 'coverage' of bin
  - Closeness to bin 'center'
- Select best cycle for each bin

"Center-of-the-Bin" Variables

Freeways	Arterials
Mean	Mean
Sigma	Sigma
TAD	TAD
PKE	PKE
	%Idle
	Queues Per Mile

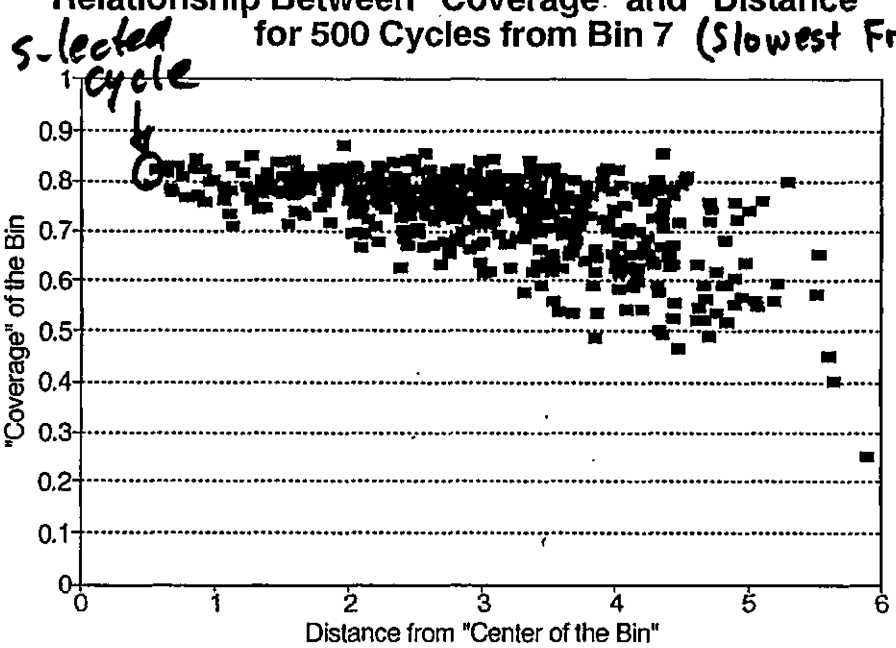
Distance from "Center" of the Bin



$$d = \sqrt{\left[\frac{(x_c - x_b)}{\text{sigma}(x)}\right]^2 + \left[\frac{(y_c + y_b)}{\text{sigma}(y)}\right]^2 + \cdots}$$

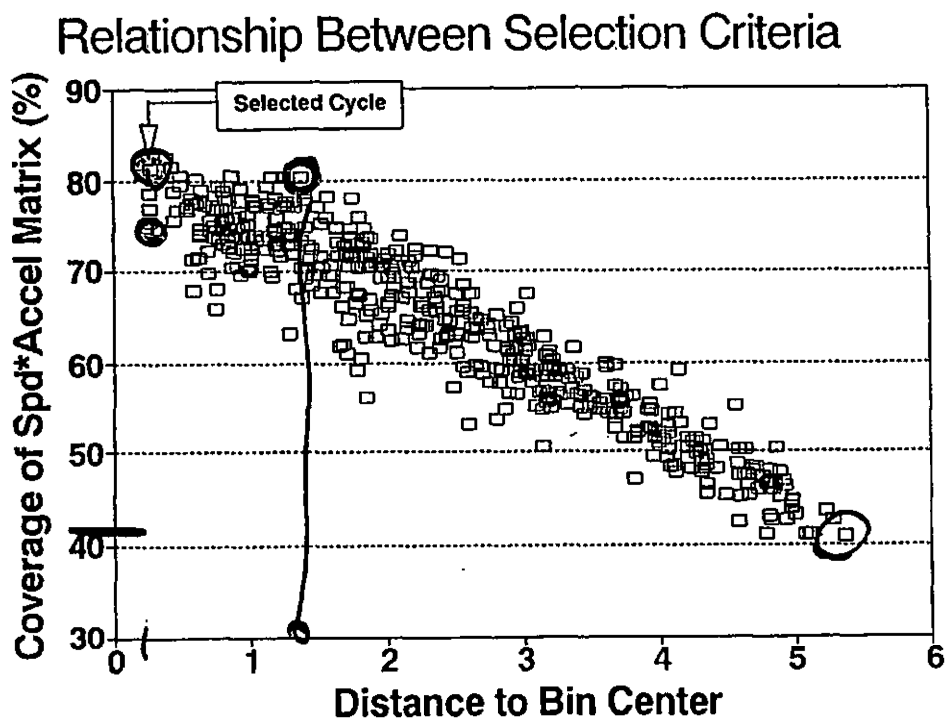
x = mean speed
y = total absolute deviations/mile
z = power demand/mile
.
.
.

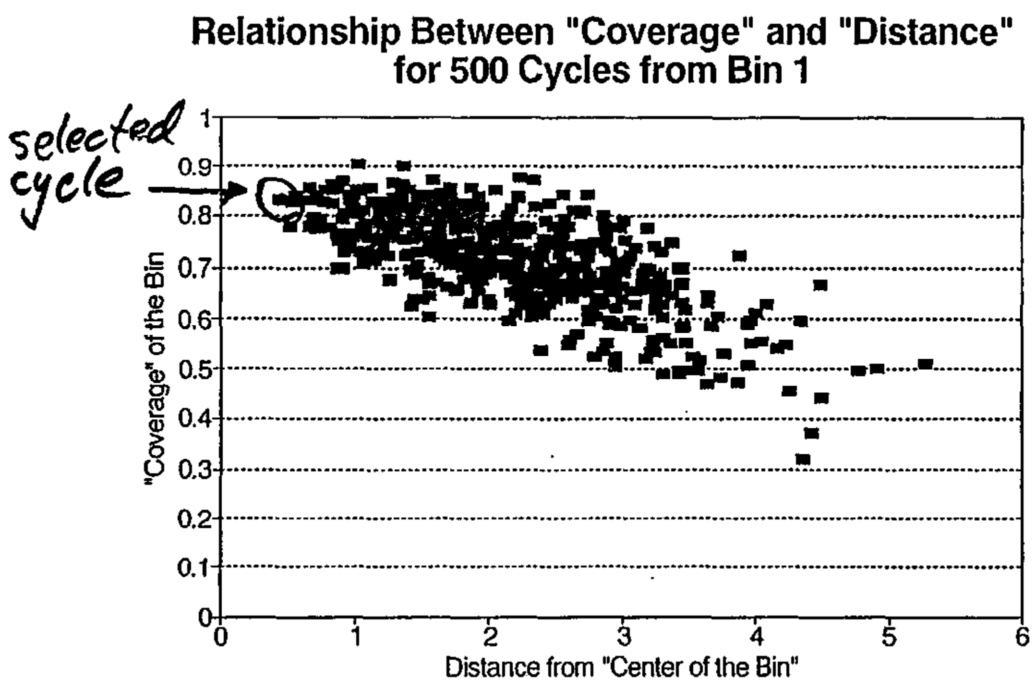
Relationship Between "Coverage" and "Distance" for 500 Cycles from Bin 7 (Slowest Freeway Bin)



Based on similarity of speed * accel matrix of Bin versus cycle.

based on mean, sigma, TAD & PKE


Relationship Between Selection Criteria
Selected Cycle
Coverage of Spd*Accel Matrix (%)
90
80
70
60
50
40
30
0
1
2
3
4
5
6
Distance to Bin Center


Relationship Between "Coverage" and "Distance"
for 500 Cycles from Bin 1
selected
cycle
"Coverage" of the Bin
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
Distance from "Center of the Bin"

Presentation Outline

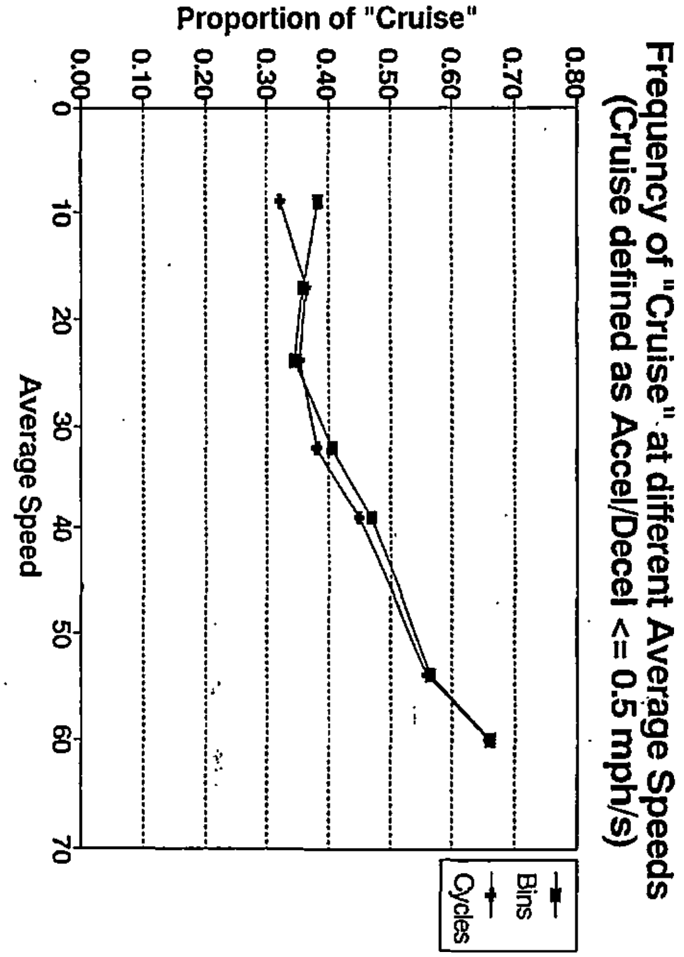
- Problem
- Objectives
- Data Base
- Cycle Development
- Cycle Evaluation & Selection
- Cycle Results

Cycle Results

- Freeways

  - 7 Cycles
  - Mean speeds from 9 to 60 mph
  - Durations from 7.5 to 15 min.
  - Distances from 1.5 to 10.3 miles

  - Top speed = 71.3 mph
  - Maximum Accel = 5.1 mph/s
  - Maximum decel = -6.4 mph/s

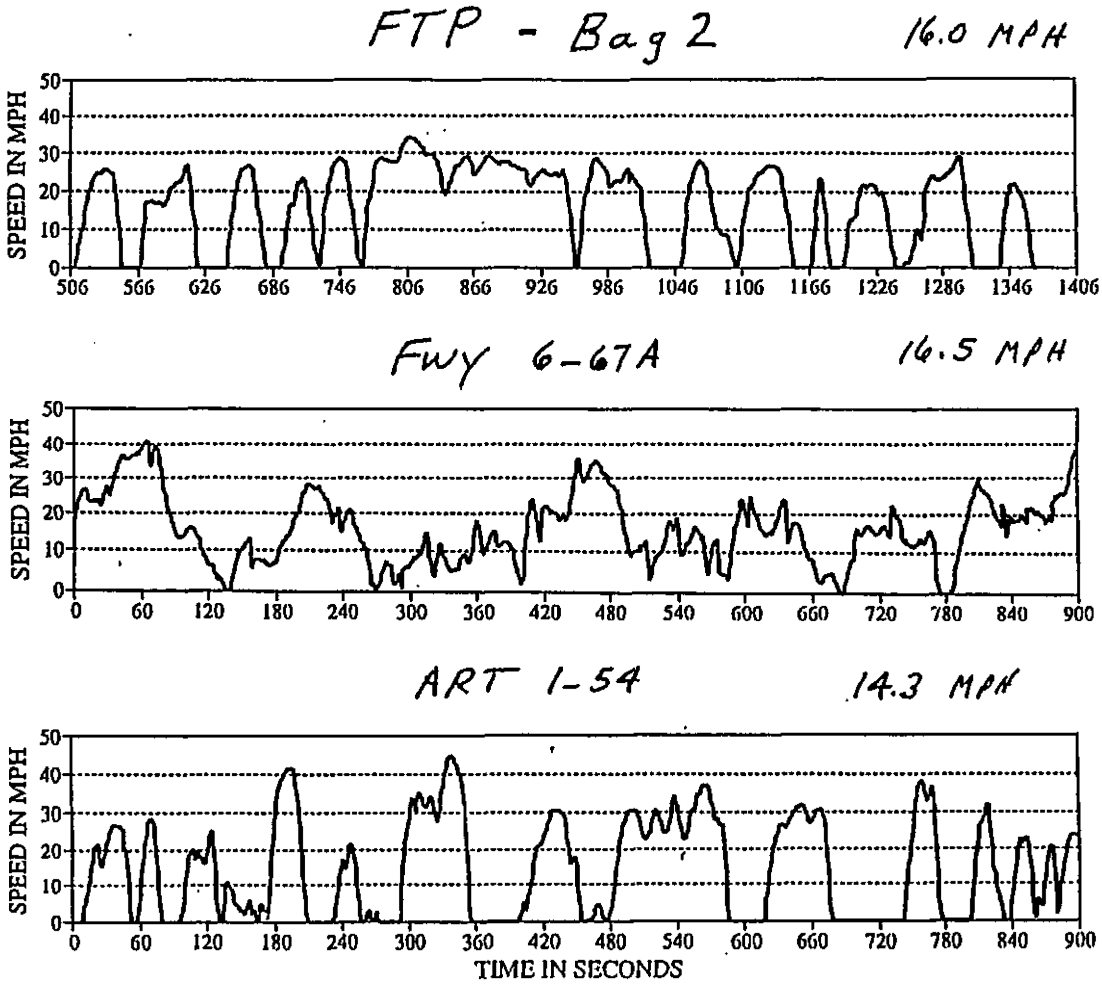


Cycle Results

- **Arterials**

  - 3 Cycles
  - Mean speeds from 14 to 34 mph
  - All Durations 15 min.
  - Distances from 3.6 to 9.0 miles

  - Top speed = 54.9 mph
  - Maximum Accel = 6.9 mph/s
  - Maximum decel = -12.3 mph/s



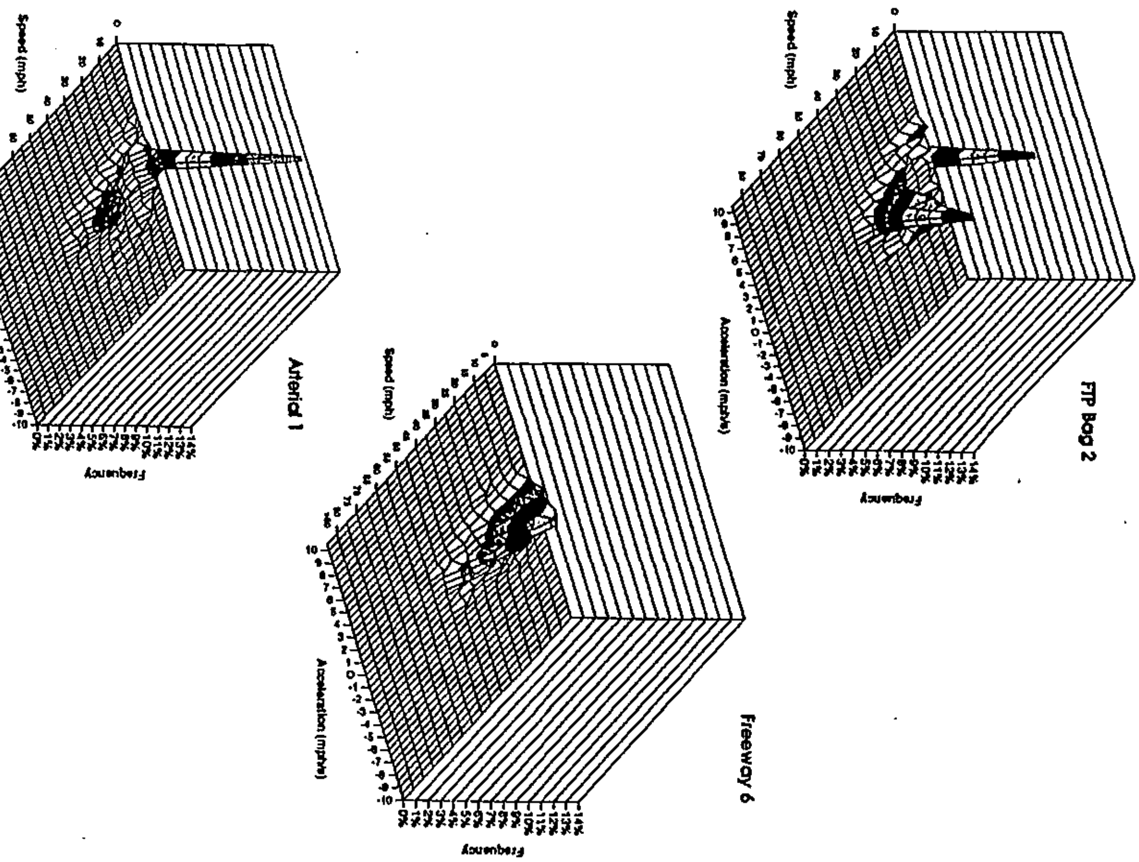
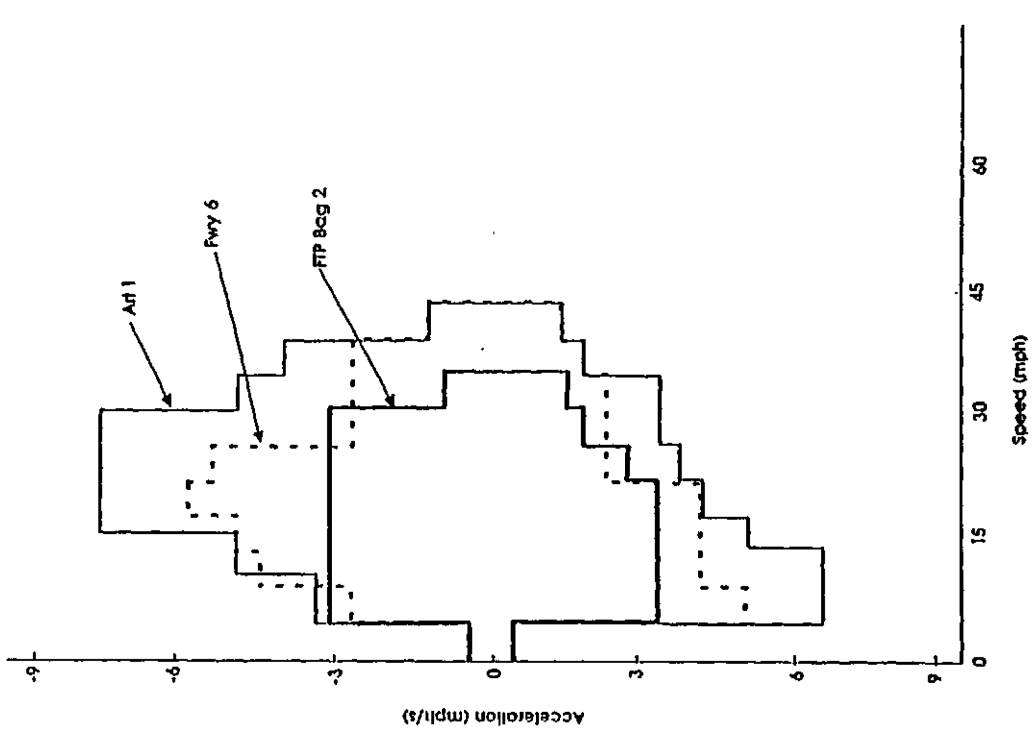


Figure 7. Frequency Distribution of Speed and Accelerations for three cycles with similar mean speeds.

Comparison of Cycles

Cycle	Mean Speed (mph)	Max Speed (mph)	Max Accel (mph/s)	% Idle	Stops per mile	Avg. length of Stops (sec)	PKE	TAD
FTP Bag 2	16	34	3.3	19	2.8	15	2905	200
Fwy 6-67A	16.5	45	5.1	2	1.2	4	3403	193
Art 1-54	14.3	45	6.9	29	3.6	21	4885	294



Envelope of speeds and accelerations for three cycles with similar mean speeds.

Potential Improvements in Future Studies

- Identify physical nodes in network
- Collect real-time density data
- Obtain accurate initial (free-flow) speeds for each link
- Collect info needed to select best cycles (e.g., queues)

Vehicle Activity Monitoring

Augustus Pela
California Air Resources Board, Sacramento, CA

VEHICLE ACTIVITY MONITORING

AUGUSTUS PELA
CALIFORNIA AIR RESOURCES BOARD

PRESENTED AT THE
INTERNATIONAL WORKSHOP ON VEHICLE DRIVING CYCLES:
MEASUREMENT, ANALYSIS AND SYNTHESIS
OTTAWA, CANADA 1995

VEHICLE INSTRUMENTATION STUDY - DRIVING PATTERN STUDY IN THE USA

EPA
* Baltimore
* Spokane
* Atlanta

CARB
* South Coast

1992/93
Driving Pattern

1994
Surrogate - Activity

VEHICLE INSTRUMENTATION - ACTIVITY MONITORING

CARB

- * Phase 1: Methodology & Protocol
  AUGUST 1994 TO JANUARY 1995
- * Phase 2: Statistically Robust data collection in Northern California
  FISCAL 1995 START DATE

ELEMENTS OF PHASE 1

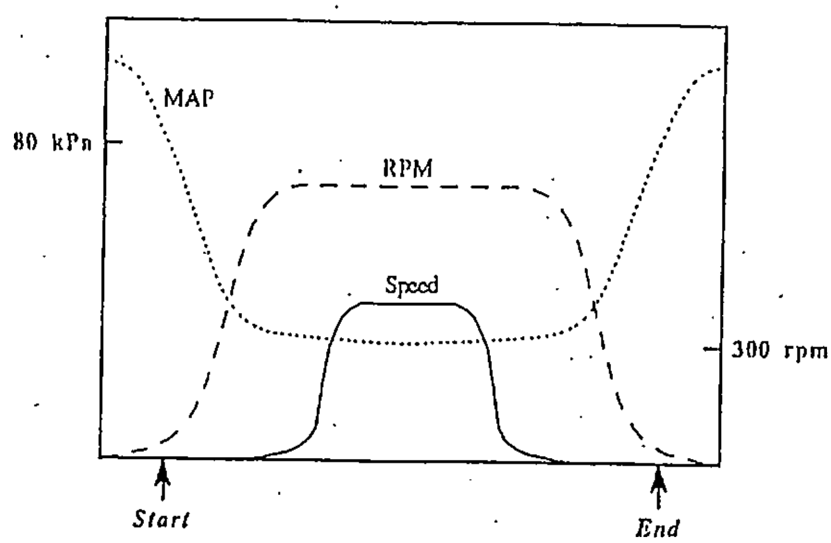
- * 3-PARAMETER DATALOGGER DOCUMENTATION
- * REPRESENTATIVE OF VEHICLE/POPULATION MIX
- * TIME RESOLVED TREATMENT OF DATA
- * REGIONAL DIFFERENCES ADJUSTMENTS
- * DURATION OF DATALOGGER INSTALLATION
- * DOWNLOADING OF DATA

ACTIVITY CHARACTERIZATION

* START RATE
* SOAKS DISTRIBUTION
* MODEL YEAR DISTRIBUTION
* VMT BY PERIOD
* TIME OF DAY
* DAY OF WEEK
* TRIP PROFILE
* FACILITY (*GIS)

TIME-RESOLVED TREATMENT OF DATA

* TIME DEPENDENT
* FUNCTION DEPENDENT



a) A normal trip

DATALOGGER MONITORING RELEVANT TO START OR END CONDITIONS

SUBSET OF DATA
WHERE,
SPEED IS BETWEEN 0 AND 0.2m/s

DETERMINE A STEP CHANGE
IN MAP?

DETERMINE STEP CHANGE
RPM AND SPEED ?

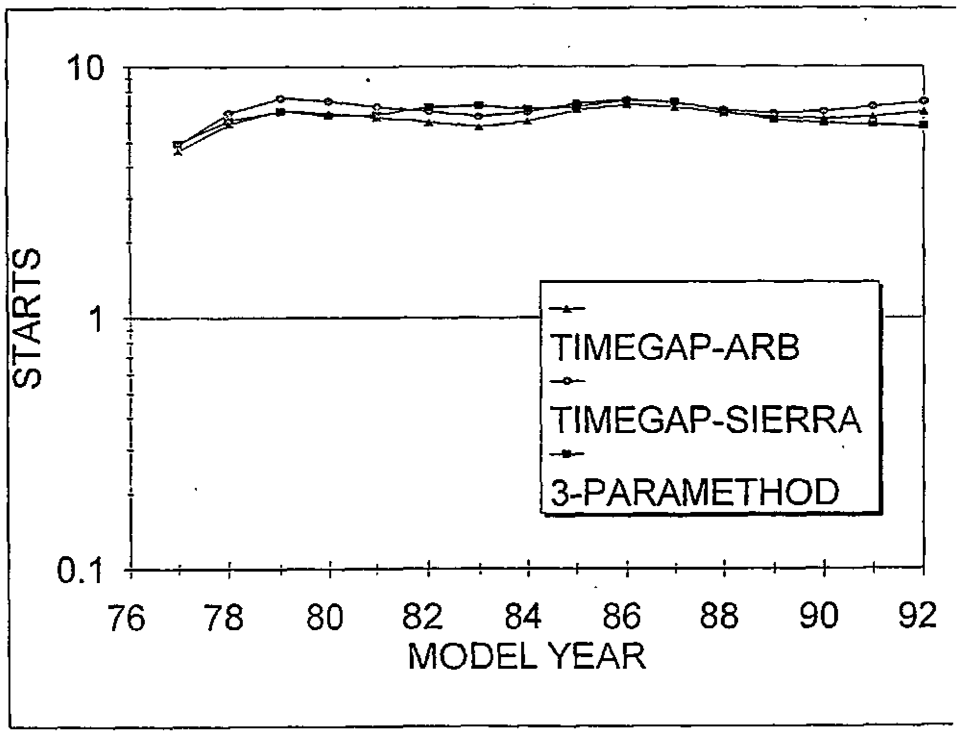
IF MAP IS LESS THAN
80kPA

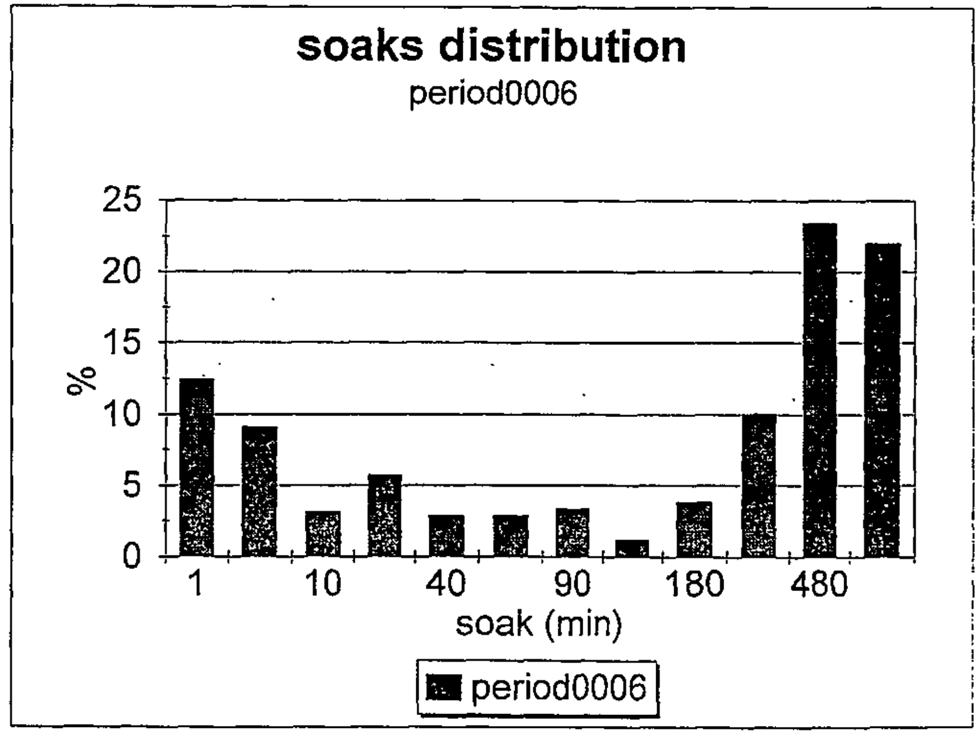
OR

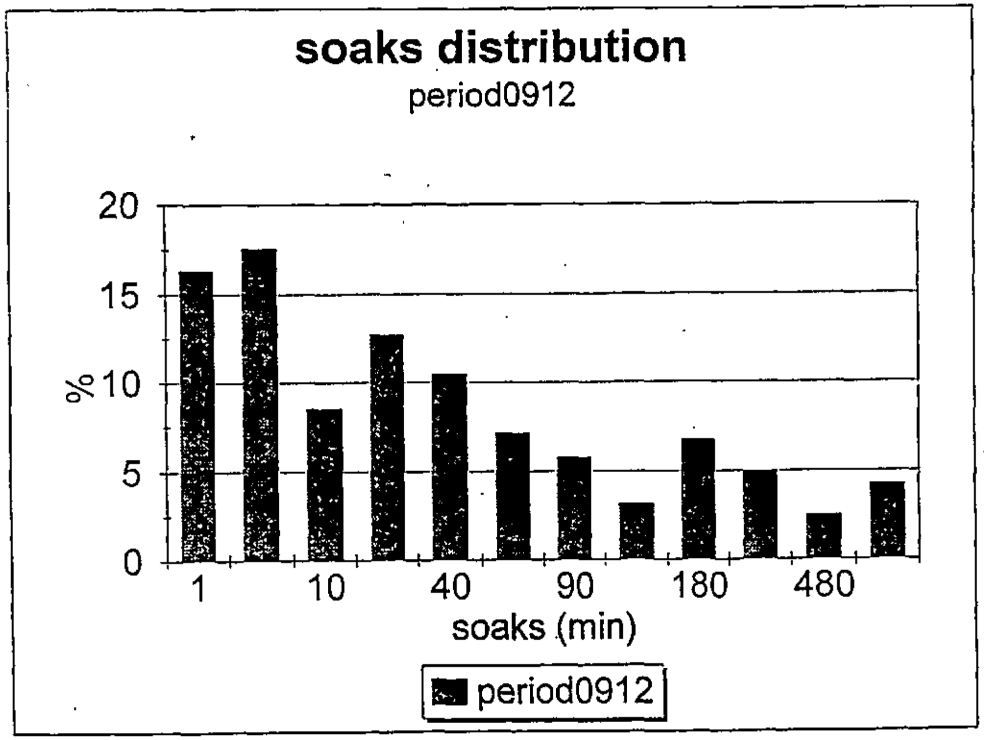
IF MAP IS GREATER THAN
80kPA

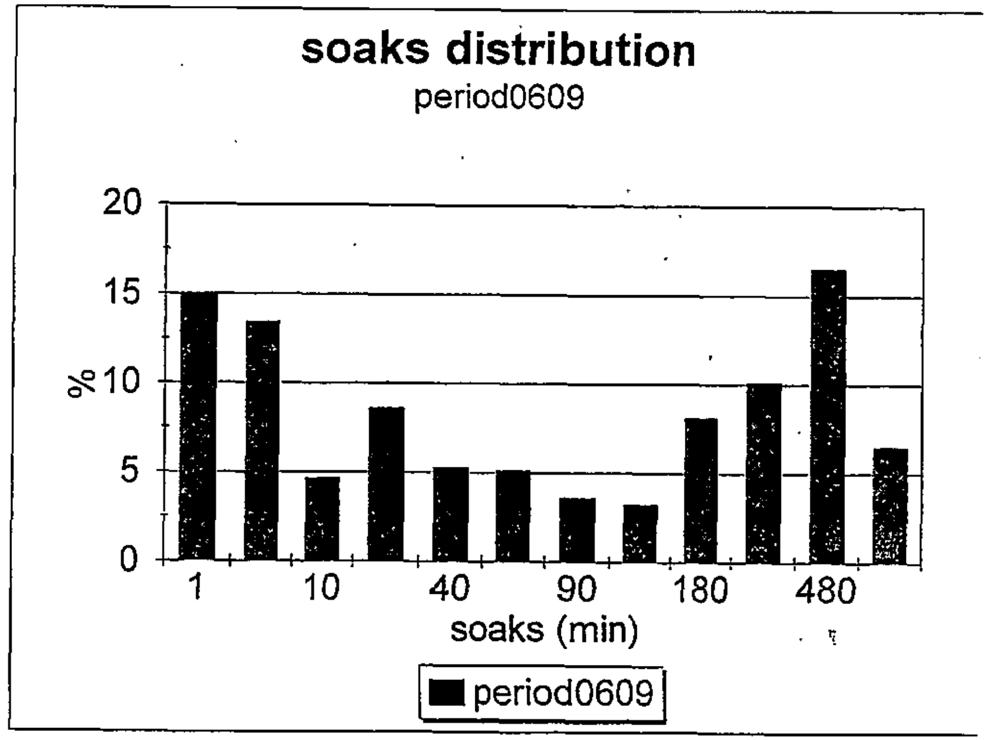
IF RPM IS LESS THAN
300

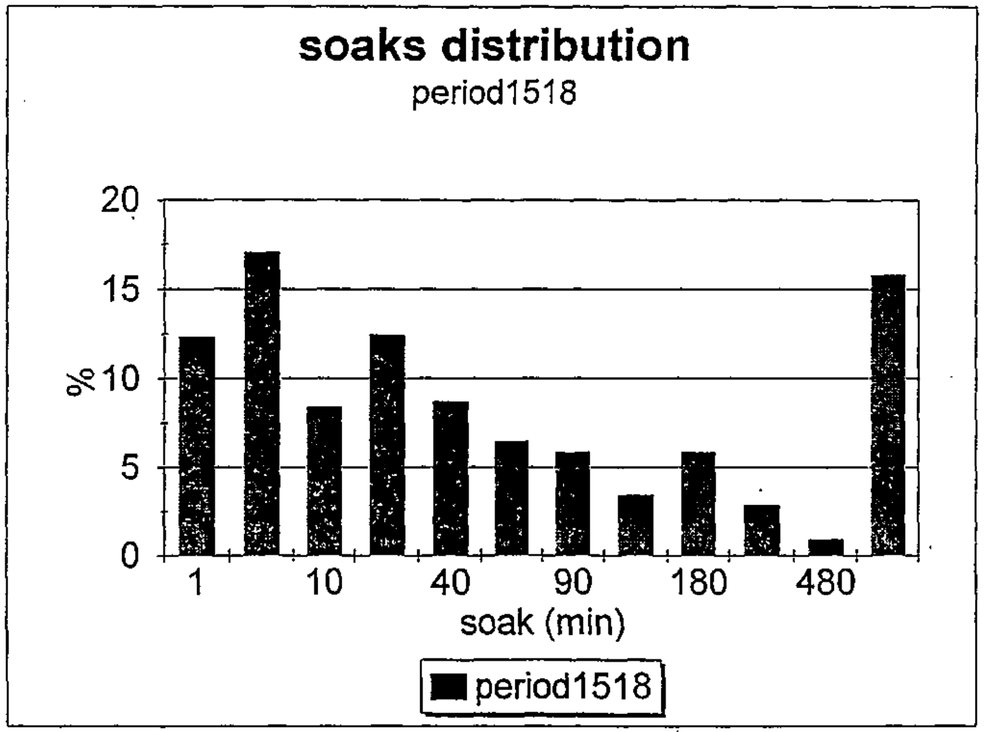
jsome show + tell

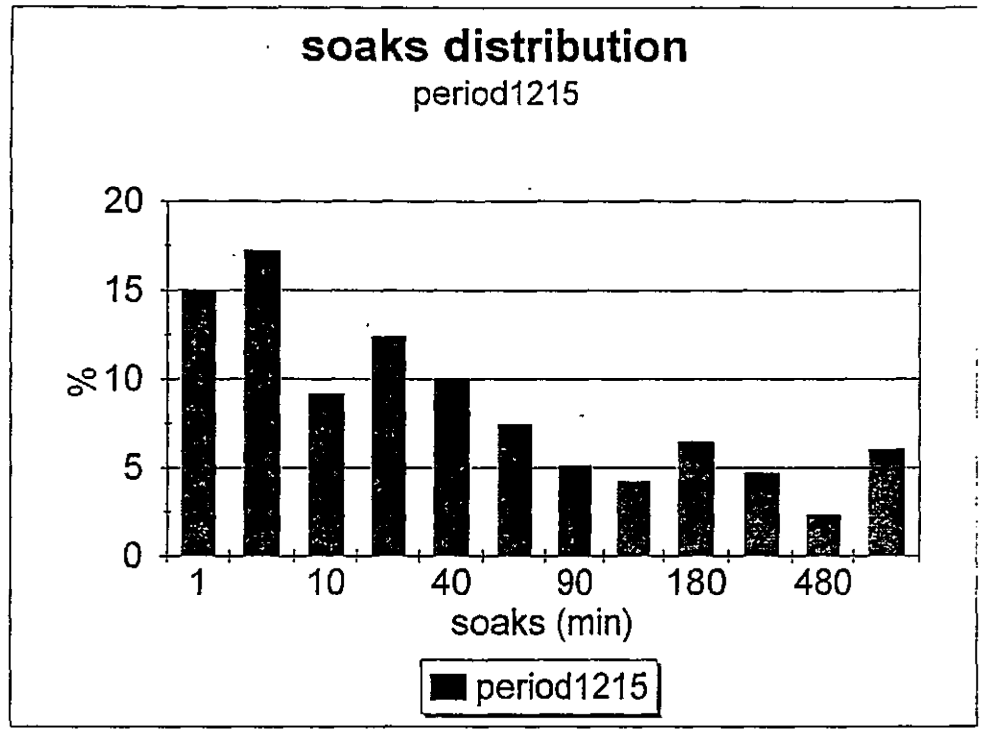


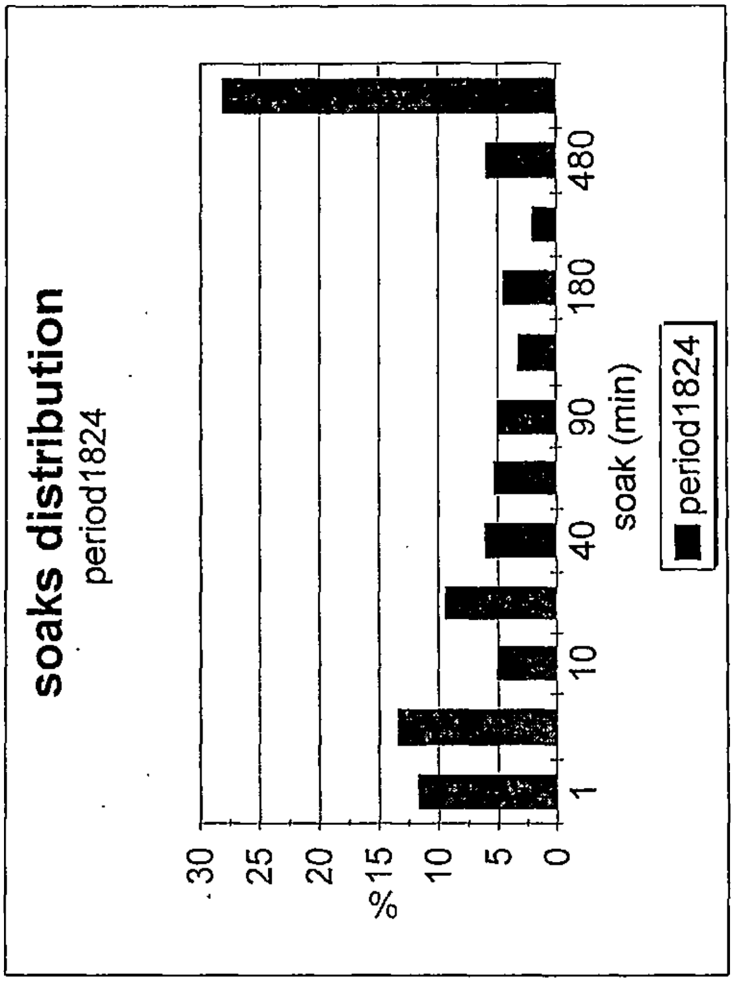



soaks distribution
period0912
20
15
% 10
5
0
1
10
40
90
180
480
soaks (min)
period0912


soaks distribution
period0609
20
15
% 10
5
0
1
10
40
90
180
480
soaks (min)
period0609

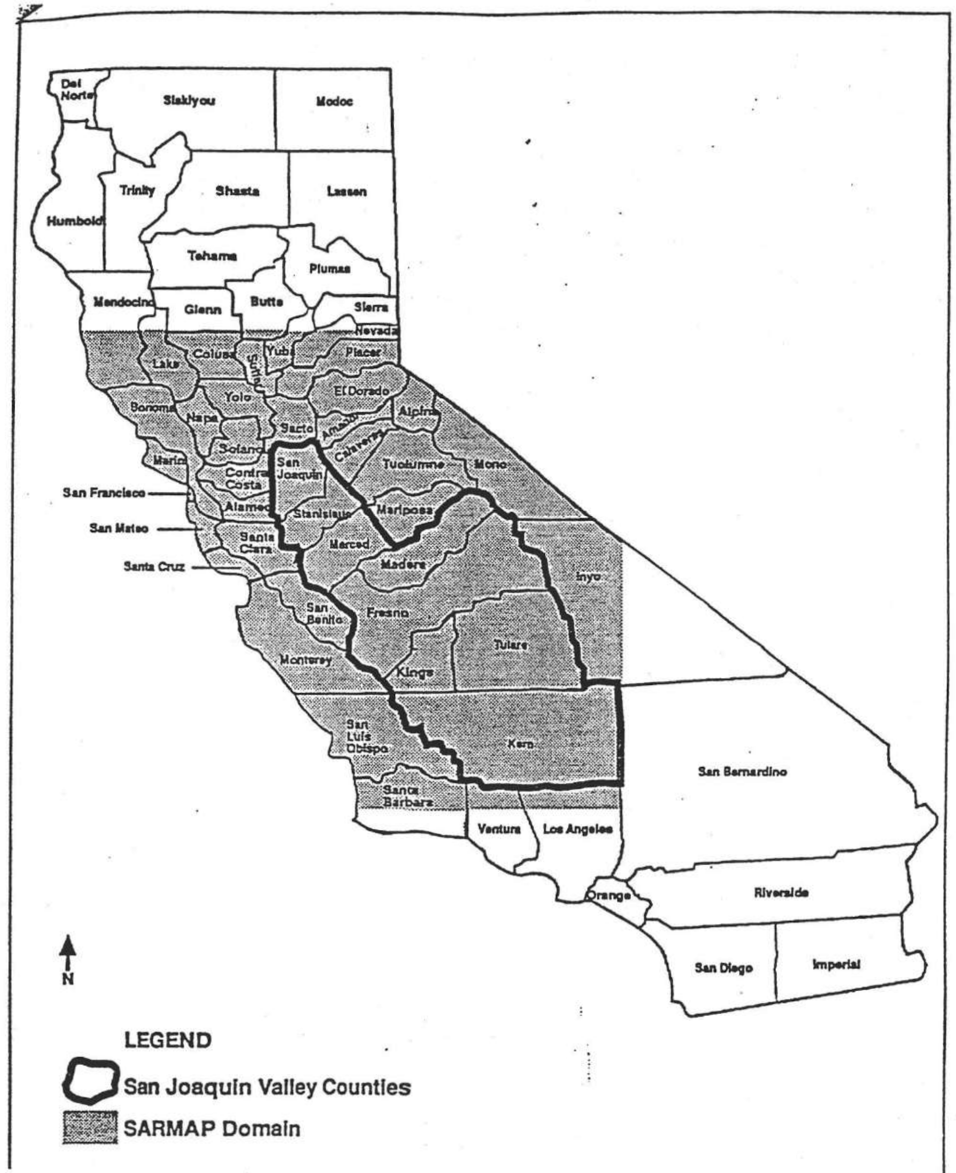

soaks distribution
period1518
20
15
% 10
5
0
1
10
40
90
180
480
soak (min)
period1518


soaks distribution
period1215
20
15
% 10
5
0
1
10
40
90
180
480
soaks (min)
period1215



INTERGRATION OF DATABASE

* TEMPORAL & SPATIAL REGIONAL RESOLUTION - SOUTH/NORTH CALIFORNIA
* DEVELOP METHODOLOGY
* GLOBAL GENERALIZATION


Del Norte
Siskiyou
Modoc
Trinity
Shasta
Lassen
Humboldt
Tehama
Plumas
Mendocino
Glenn
Butte
Sierra
Nevada
Lake
Colusa
Yuba
Placer
Yolo
El Dorado
Sonoma
Napa
Alpine
Sacto
Amador
Calaveras
Marin
Solano
San Joaquin
Tuolumne
Mono
San Francisco
Contra Costa
Alameda
Stanislaus
Mariposa
San Mateo
Santa Clara
Merced
Madera
Santa Cruz
Inyo
San Benito
Fresno
Tulare
Monterey
Kings
San Luis Obispo
Kern
San Bernardino
Santa Barbara
Ventura
Los Angeles
Orange
Riverside
San Diego
Imperial
N
LEGEND
San Joaquin Valley Counties
SARMAP Domain

Development of an On-board Emission Measurement System

Costa Kaskavaltzis
Ontario Ministry of Transportation, Toronto, ON

Development of an On-Board Emission Measurement System

Presented to

International Workshop on Vehicle Driving Cycles

Ottawa, Ontario

C. Kaskavaltzis, P.Eng.

Ontario Ministry of Transportation

Strategic Transportation Research Branch

February 7, 1995

Project Overview

- Air Quality Study
  - Ambient Monitoring
  - Remote Sensing
  - Traffic Density
  - Emissions Factors

↓ ↓

Computer Model

Available Resources

In House

- Chassis Dyno Facility
- Electronics Lab
- Data Acquisition Hardware & Software
- Vehicle

Outside

- Rugged O.E.M. Vehicle Sensors
- Portable Exhaust Gas Analyzers

System Components

- 1991 Chev Lumina (FFV)
- Nova Portable Exhaust Gas Analyzer
  - (CO, HC, NO, NO_2, CO_2, O_2)
- A/D Board w/ approx. 30 channels
- Labtech Notebook Data Col'n. Software
- Portable Computer
- Power Inverter & 2 Lead Acid Batteries

Input Signals

Primary

- Mass Airflow Sensor (MAF)
- Total Injector Pulse Width (TPW)
- Exhaust Gas Concentrations
- Vehicle Speed Sensor (VSS)

F(MAF + TPW) = Mass Exhaust

Analyzer Concentrations

Volume Exhaust

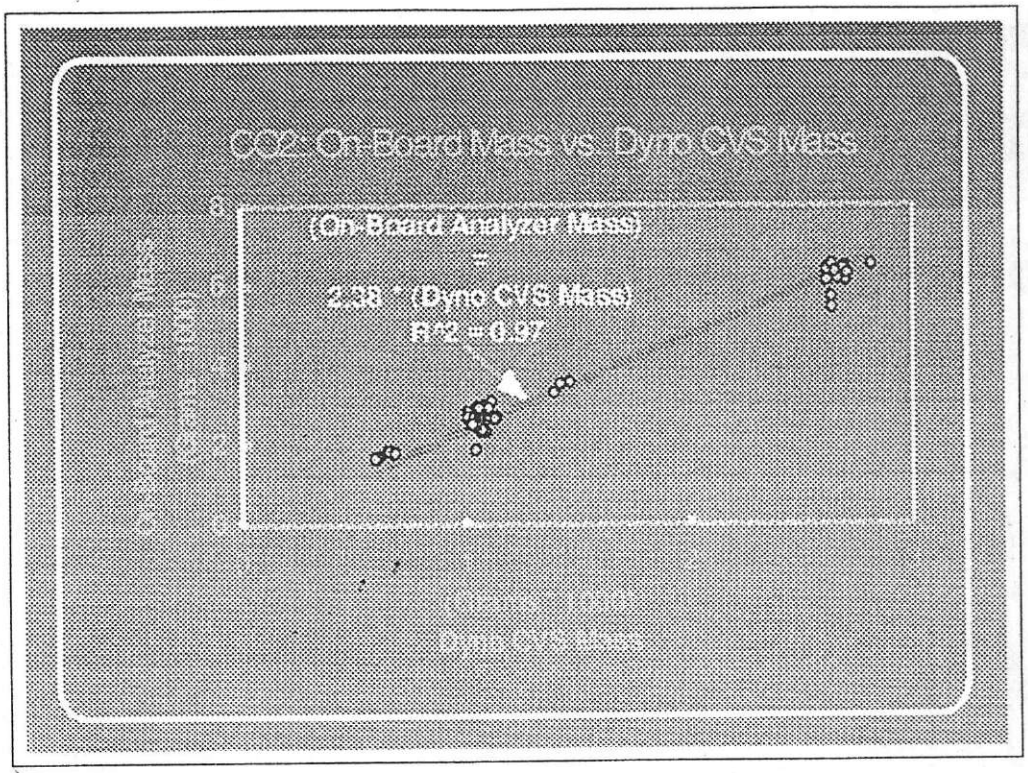
Ind. Gas Volumes

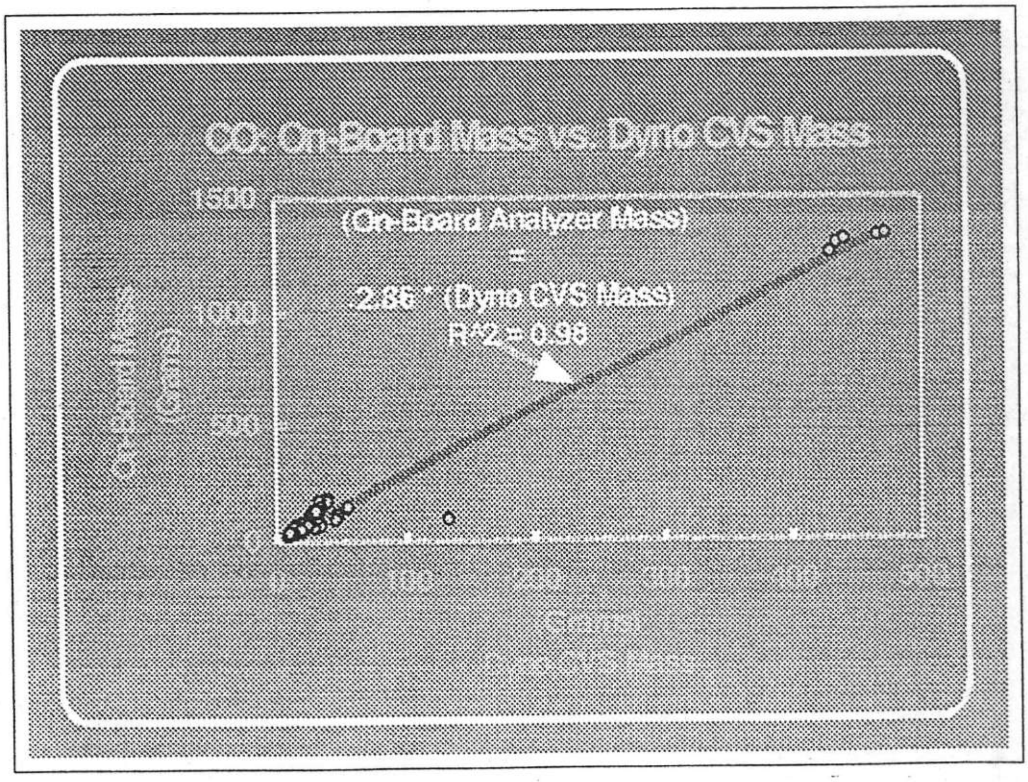
Ind. Gas Masses

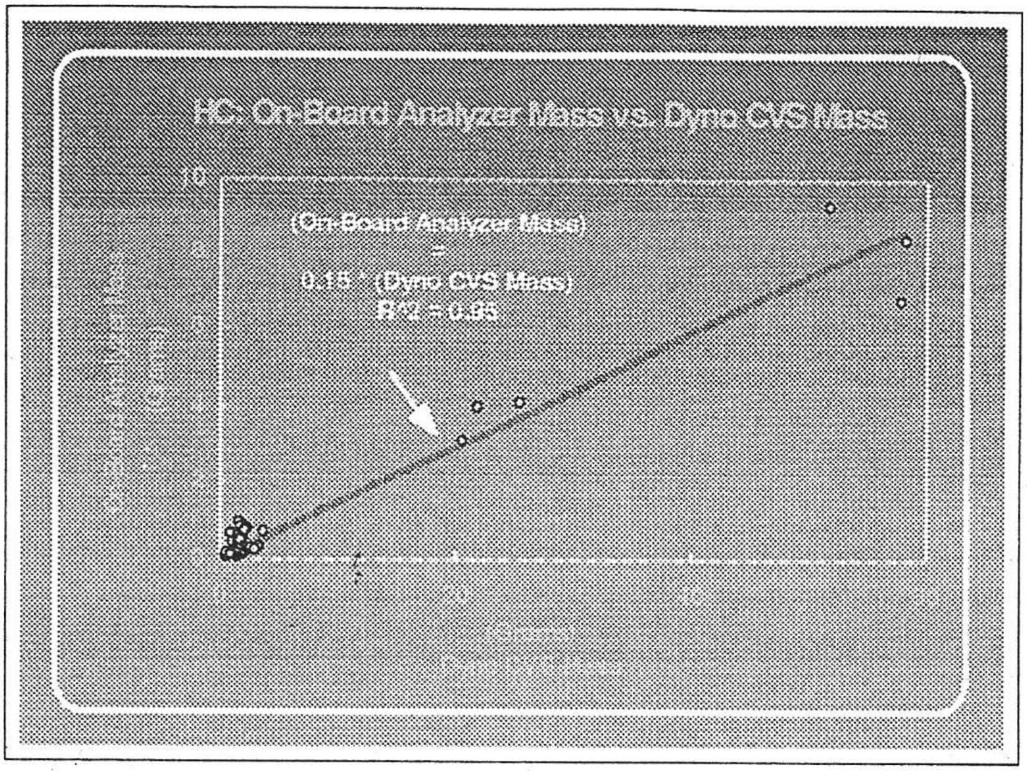
Input Signals

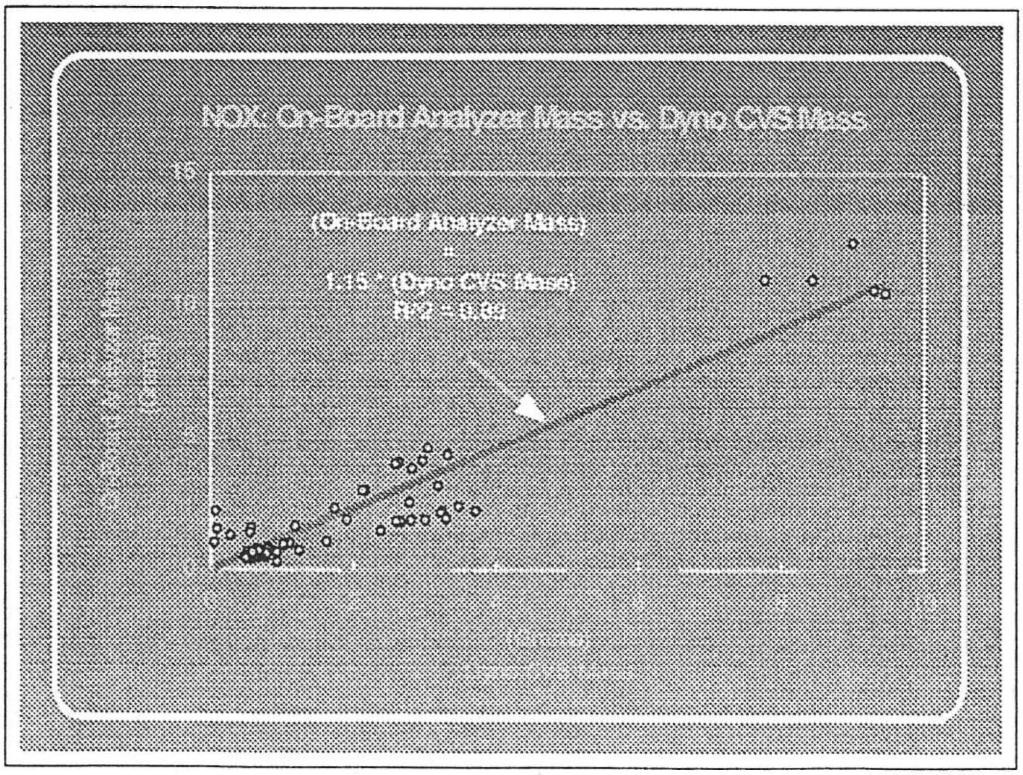
Secondary

- O_2 Sensor
- Catalyst Temp.
- Coolant Temp.
- Engine RPM
- Throttle Position
- EGR Position
- MAP Sensor
- Transmission Gear
- Alcohol Sensor


CO2: On-Board Mass vs. Dyno CVS Mass
(On-Board Analyzer Mass)
=
2.38 * (Dyno CVS Mass)
R^2 = 0.97
8
6
0
Dyno CVS Mass


CO: On-Board Mass vs. Dyno CVS Mass
(On-Board Analyzer Mass)
=
2.86 * (Dyno CVS Mass)
R^2 = 0.98
On-Board Mass
(Grams)
1500
1000
500
0
0
100
200
300
400
500
(Grams)


HC: On-Board Analyzer Mass vs. Dyno CVS Mass
10
(On-Board Analyzer Mass)
=
0.15 * (Dyno CVS Mass)
R^2 = 0.95
0
20


NOX: On-Board Analyzer Mass vs. Dyno CVS Mass
15
(On-Board Analyzer Mass)
=
1.15 * (Dyno CVS Mass)
R^2 = 0.89
10

Current Use

- Daily Operation in Toronto
- Fixed Route & Driver
- Determine Emission Rates

Other Uses

- I/M Emissions Verifications
- Commuting Emissions
- Development of Typical Operating Cycles

Further Developments

- Adding grade sensor
- Improving Response of NO/NO_2 sensors
- Studies with Methanol Fuel Blends

Special Thanks

Howard Shasuvar / Mahabir Singh / Stefan Mastu / Nick Woo /

MTO Research Lab

Development of Vehicle Driving Cycles for Bangkok

Sandeep Kishan
Radian Corporation, Austin, TX

Driving in Bangkok

S. Kishan
C.G. Weyn
T.H. DeFries
Radian Corporation

The Bangkok Situation

High ambient Particulate Matter: 80 - 200 $\mu g/m^3$

Rapid vehicle population growth: 12% per year

Road construction lagging

Most automobiles uncontrolled

Motorcycles mostly 2-stroke

Uncontrolled diesels

Comparison of Cities

	Los Angeles	Bangkok
Population Density	9000 mi^{-2}	58,000 mi^{-2}
Area	1110 mi^2	102 mi^2
Motor Vehicles	10.3 million	2.3 million
Autos + Gas Trucks	96%	43%
2-Stroke motorcycles	0%	40%
4-Stroke motorcycles	3%	4%
Diesels	1%	13%
Dominant Concern	Ozone	PM

Mitigation Approach

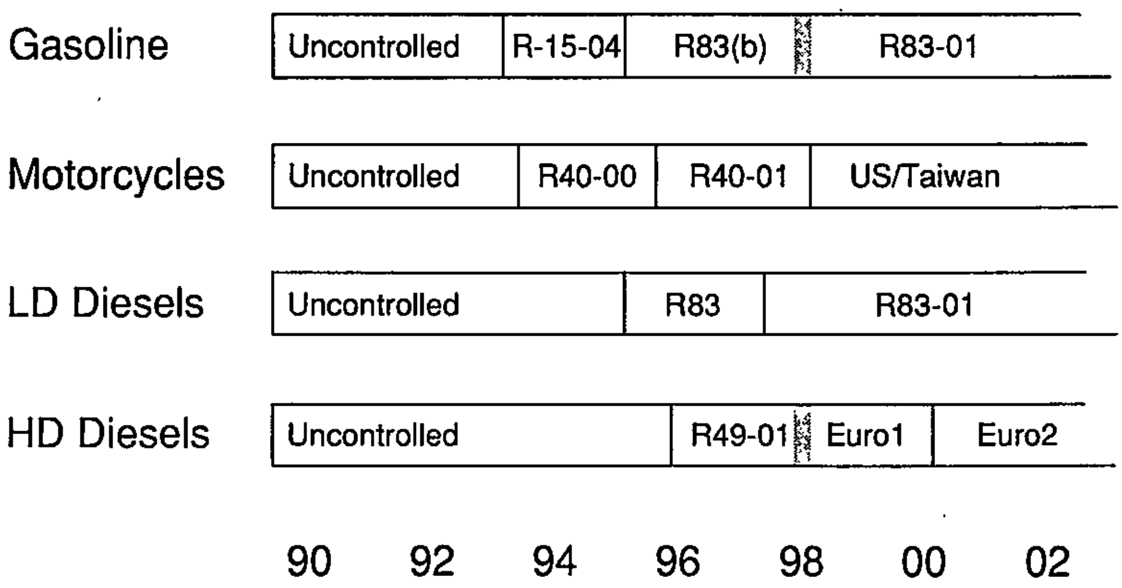
Traffic Management

Fuel and Lubes trends
- Unleaded gasoline
- Low S diesel
- Low smoke 2-cycle oil

New Vehicle Standards
- Currently using European standards
- Future Thai standards?

Vehicle Inspection/Maintenance
- Decentralized
- Develop test cycles

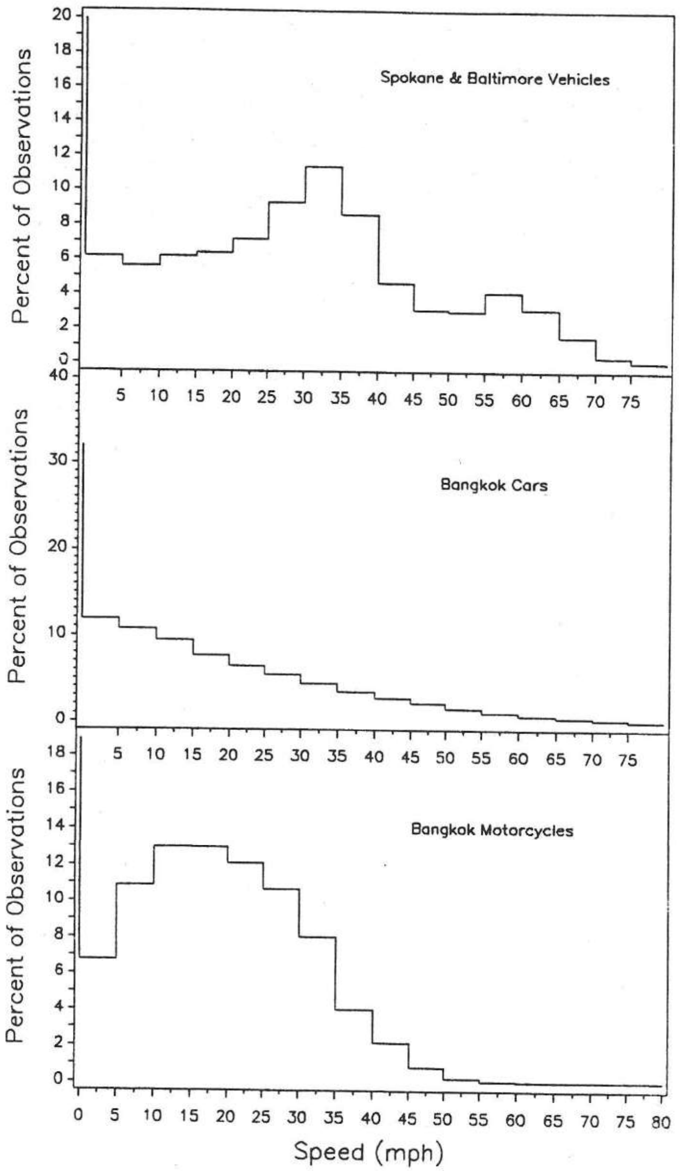
Evolution of Regulations



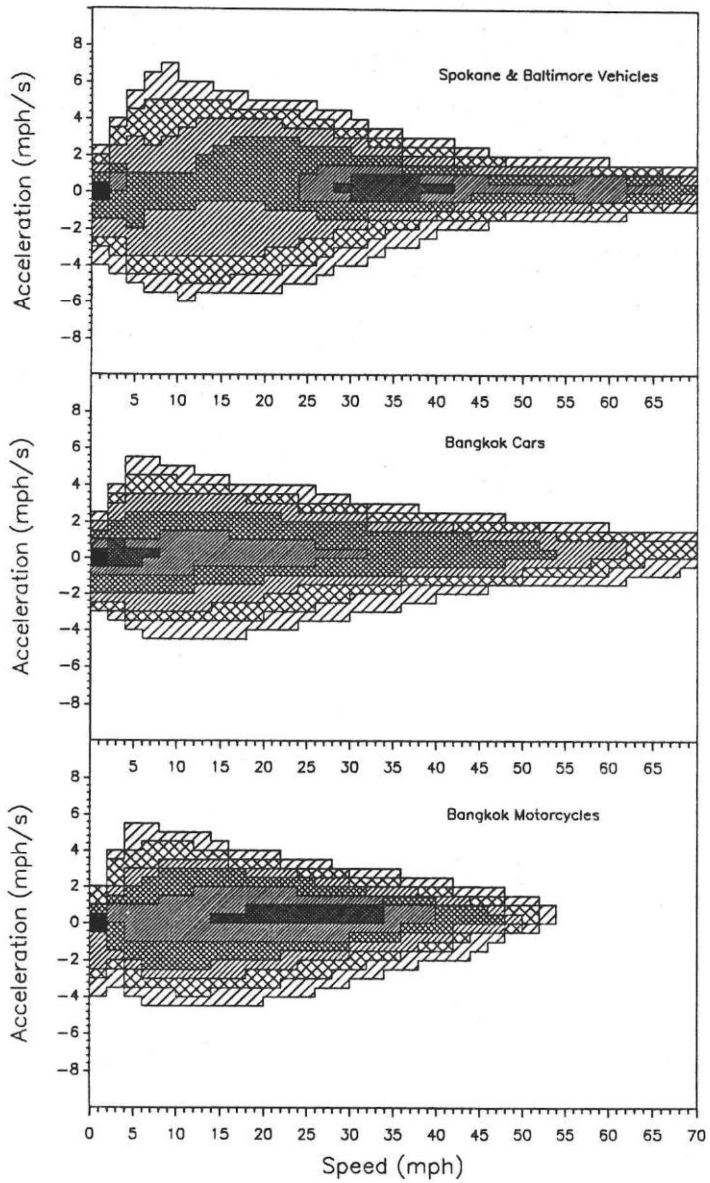
Vehicles Selected

Year	Make	Model	Disp	Trans
Automobiles				
1980	Daihatsu	Charade	1000	M5
1980	Nissan	Sunny	1200	M5
1977	Mitsubishi	Galant	1600	M4
1992	Toyota	Corolla	1600	M5
1987	Honda	Accord	2000	A
1987	BMW	316i	1600	M5
1984	Nissan	Sunny	1500	M5
1984	Mercedes	230e	2300	M5
1973	Ford	Falcon	3600	M3
1972	Mitsubishi	Colt	1600	A
1992	Nissan	Sentra	1600	M5
1993	Toyota	Corolla	1600	A
1993	Toyota	Corolla	1300	M5
1986	Honda	Accord	2000	M5
1982	Volvo	265	2700	A
Motorcycles				
1992	Honda	Nova	150	M5
1992	Yamaha	VR150	150	M6
1990	Suzuki	RC100	100	A
1991	Yamaha	TZR150	150	M6
1989	Yamaha	RXZ	135	M6
1994	Yamaha	VR150 Sp	150	M6
1989	Yamaha	VR150	150	M6
1994	Suzuki	RC100	100	A
1990	Yamaha	Belle R100	100	M4
1990	Yamaha	RXZ135	135	M6

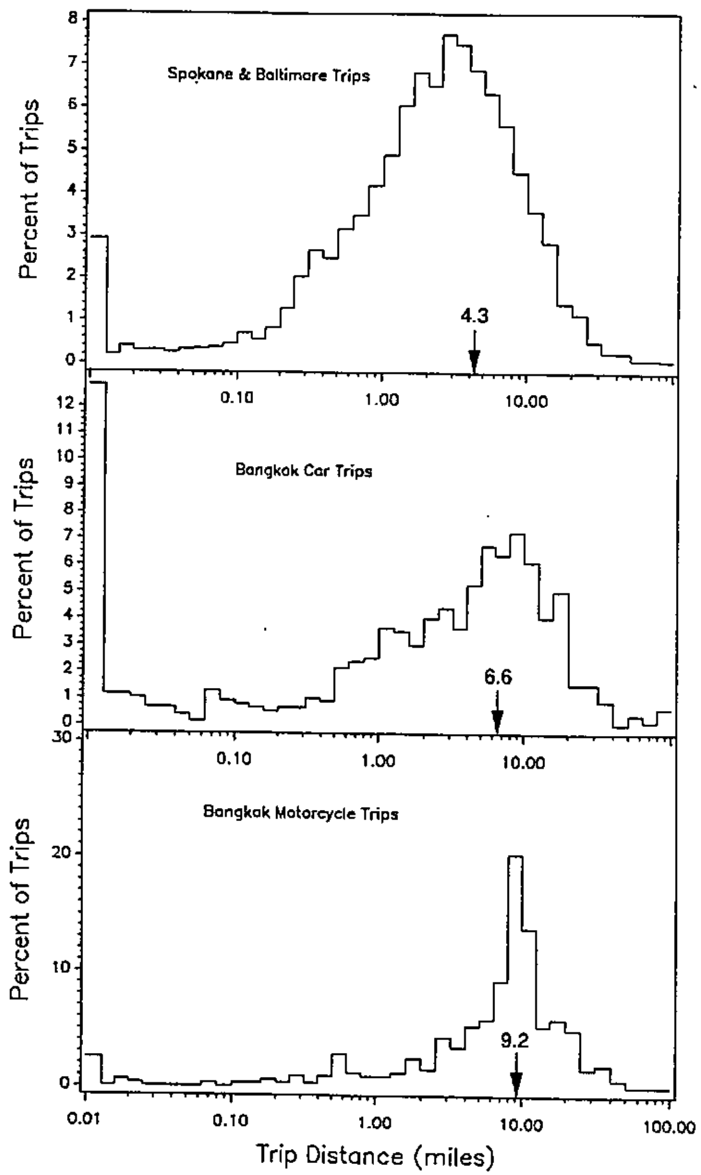
Speed Distribution



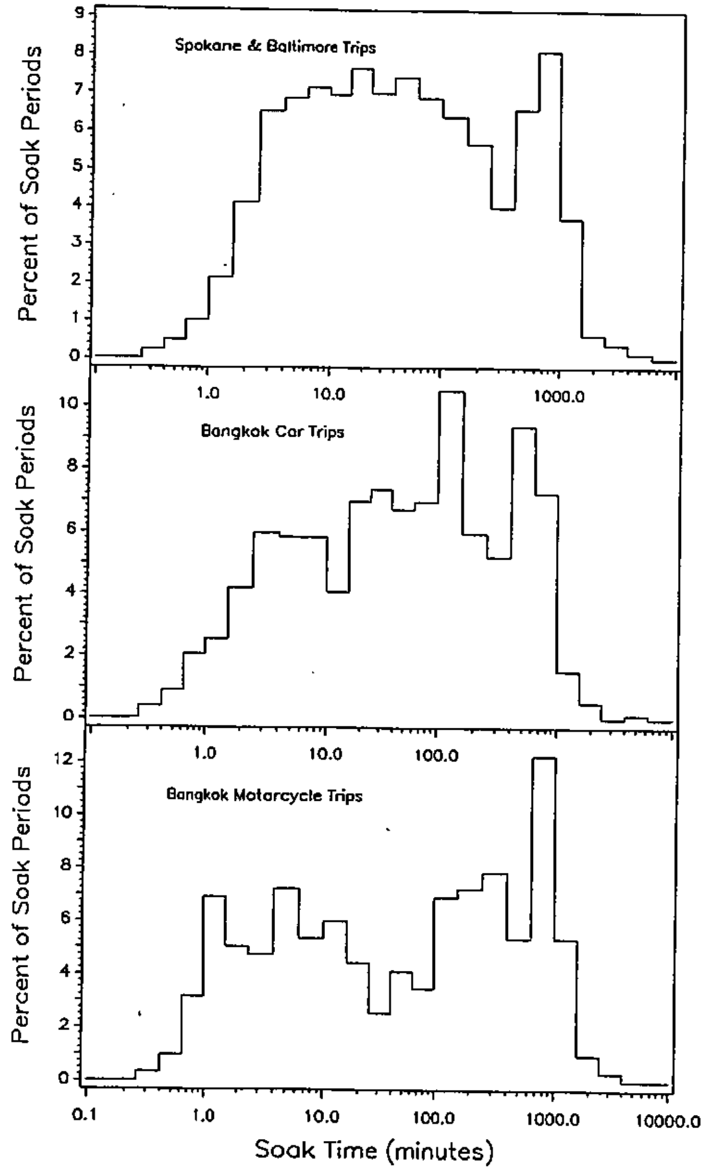
Speed – Acceleration Distribution



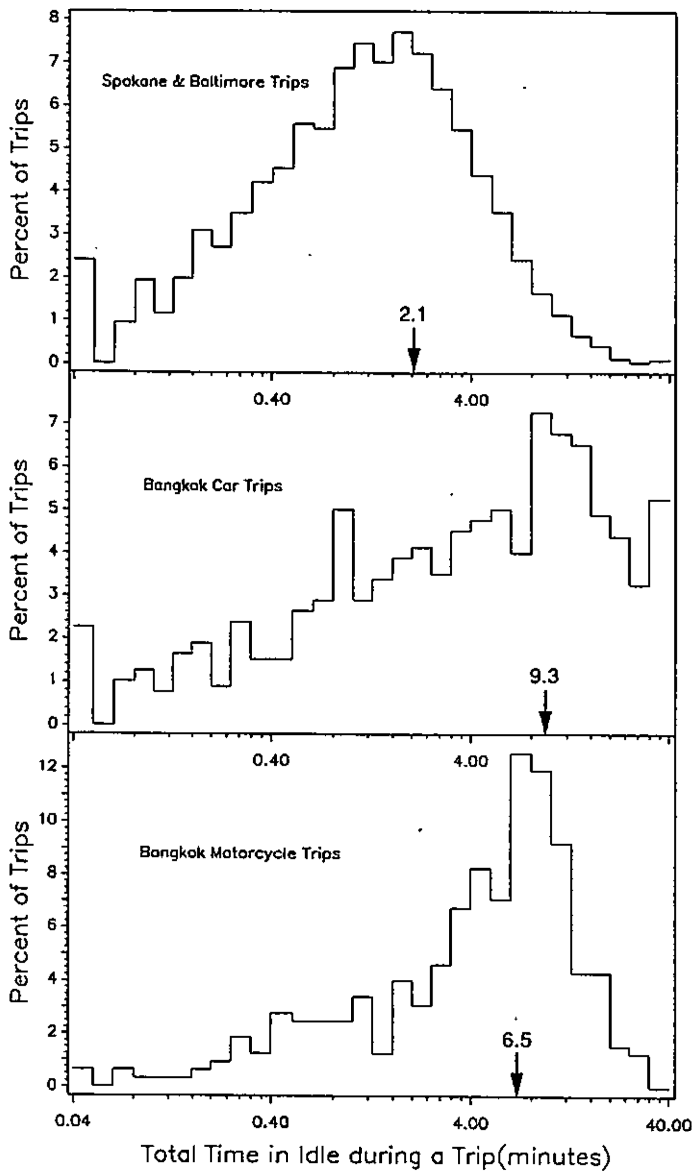
Trip Distance Distribution



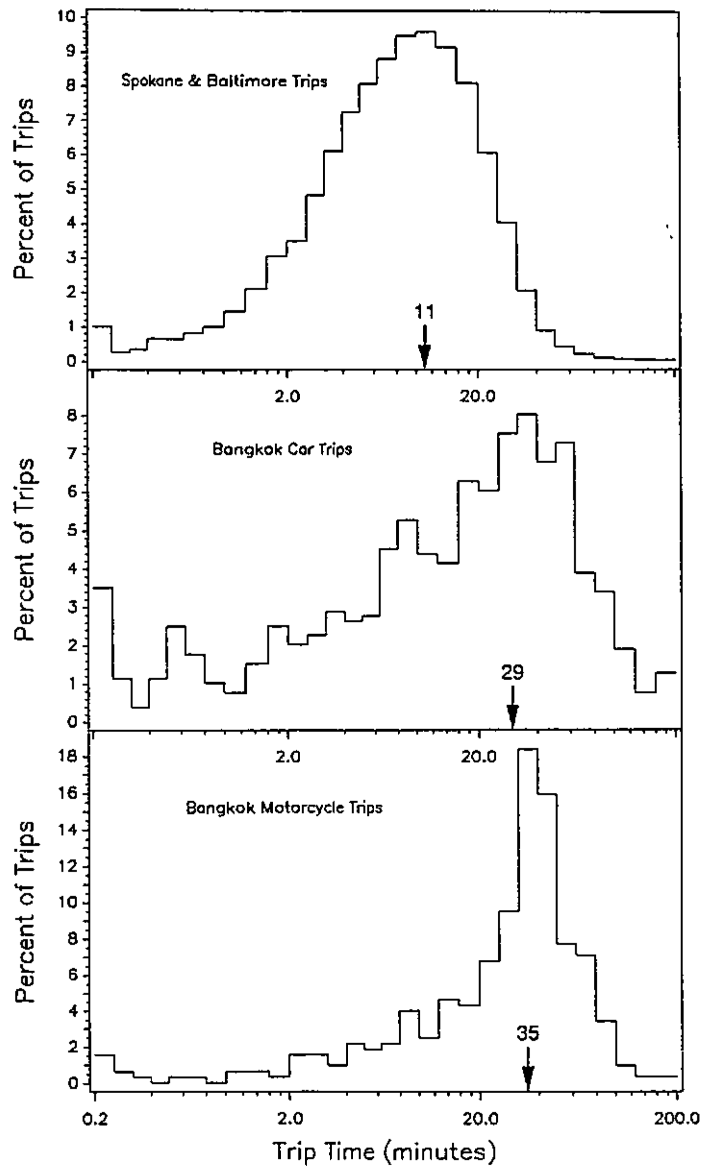
Soak Time Distribution



Trip Idle Time Distribution



Trip Time Distribution



Summary

Light-Duty Vehicles
- Much idling
- Long trip duration

Motorcycles are transportation of choice
- Speed peaks at idle and 25 mph
- Long trip duration
- Noisy and often heavily loaded

Cycle Development for Cars and Motorcycles

Additional Instrumentations Planned
- More cars
- Diesels with on-vehicle PM

Using GPS for Speed and Grade Measurement,

Ted Younglove
CE-CERT, Riverside, CA

CE-CERT

COLLEGE OF ENGINEERING - CENTER FOR ENVIRONMENTAL RESEARCH AND TECHNOLOGY

Using GPS Technology to Obtain Accurate Speed, Acceleration and Grade Information for On-Road Emission Measurements

Eric Johnston

14 December 1994

UNIVERSITY OF CALIFORNIA - RIVERSIDE
Riverside, California 92521-0434

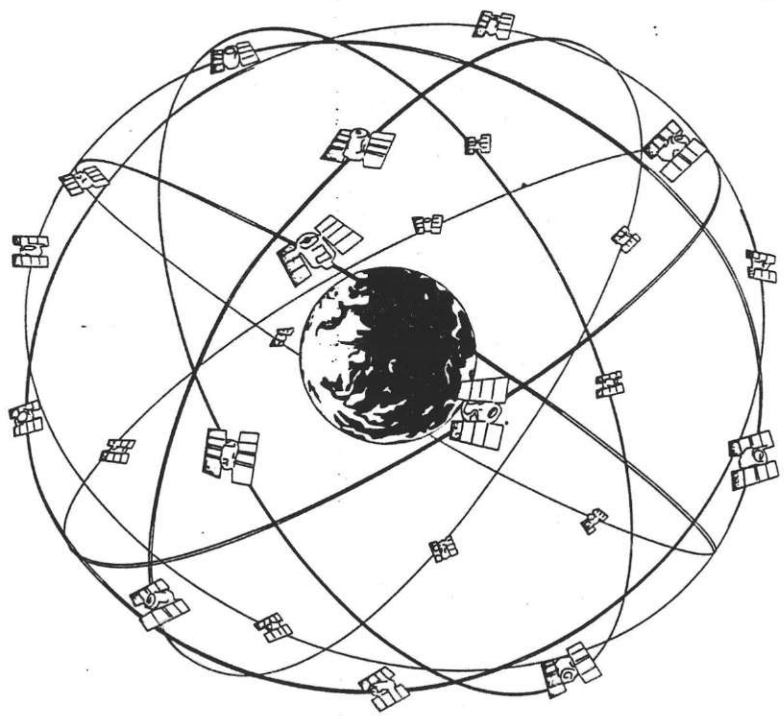
Background

- The NAVSTAR Global Positioning System (GPS) is a satellite-based navigation system operated by the United States military.

- The satellites orbit at an altitude of about 10,898 miles with a period of approximately 12 hours.

- Through the use of 24 satellites, the system can provide geodetic positions and velocity for a receiver in three dimensions, as well as highly accurate time, nearly worldwide.

- Position and time are determined by measuring the signals from four or more satellites in view simultaneously. If altitude is known, only three satellites are required.



GPS Systems

There are two main codes broadcast by the satellites:

- P-Code (Precision) is what the military uses to get cm accuracy.
- C/A Code (Coarse Aquisition) is locked into the P-Code but can be used by civilians.

- P code GPS units are accurate down to .5cm.
- CA code GPS units are accurate down to 5cm.

- Small hand held civilian units accurate to 100 meters can be purchased for as little as $300
- Large accurate units such as the two station Differential GPS (DGPS) used at CE-CERT can cost as much as $40,000.

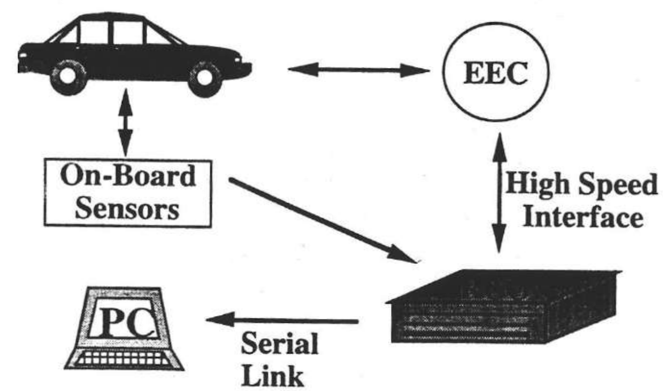
CE-CERT Ford Taurus With GPS Installed

- The vehicle was instrumented with a Ashtech GPS receiver and antenna.
- Two GPS receivers are used to achieve high positioning resolution, using the differential technique (DGPS).
- The receivers allow the user to view and/or change orbit information, navigation information, tracking information, satellite selection control, and site and session control, among other options.
- The receivers begin collecting data as soon as they are turned on and lock-on to three or more satellites.

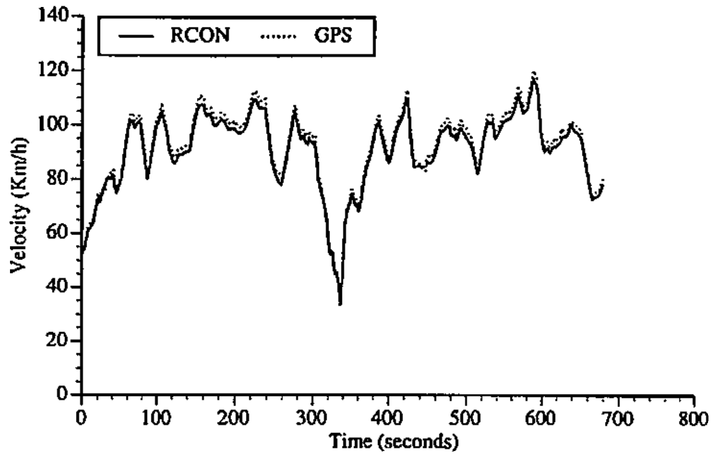
Vehicle Data Acquisition System

- The Vehicle Data Acquisition System (VDAS) used in this experiment is called a Research Console (RCON).
- The RCON was developed by Ford Motor Company.
- The RCON is a portable computer used for gathering dynamic vehicle data using a high speed interface to the vehicle's EEC and using external sensors.

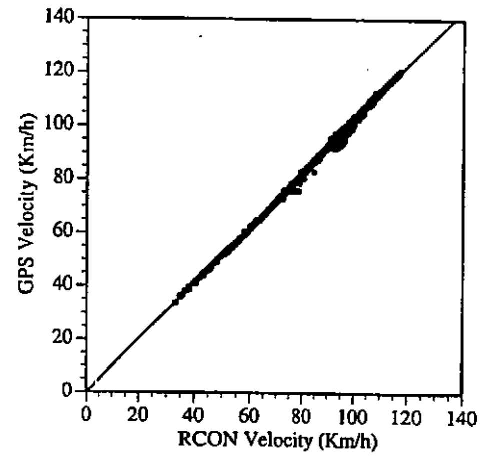
RCON Parameter	Description
n	Engine rpm
vs	Vehicle speed, in mph
accflg	Air conditioning flag
boo_lvl	Brake operation flag
olflg	Open loop flag
load	Engine load
ect	Engine coolant temperature
act	Air charge temperature
tp_rel	Relative throttle position
lambse1	A/F ratio (calculated)
fuelpw1	Fuel injector pulse width
pm	Percent methanol
lambda	A/F Ratio (measured)
gr_cm	Gear
ambient_t	Ambient temperature
pre_cat_t	Pre-catalyst temperature
cat_temp	Catalyst temperature
accel	Acceleration, in G's
maf	Mass air flow (intake)



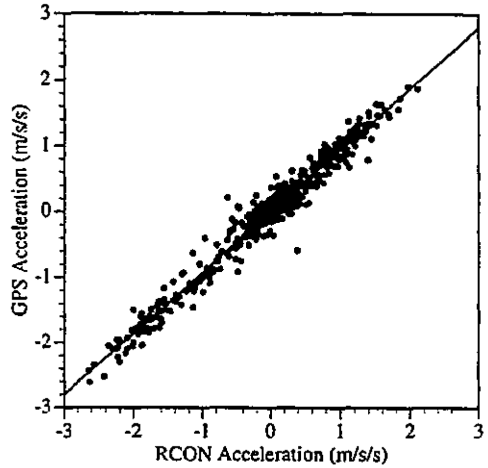
RCON - GPS Comparison



The average difference between the two velocity curves is 2.47%.



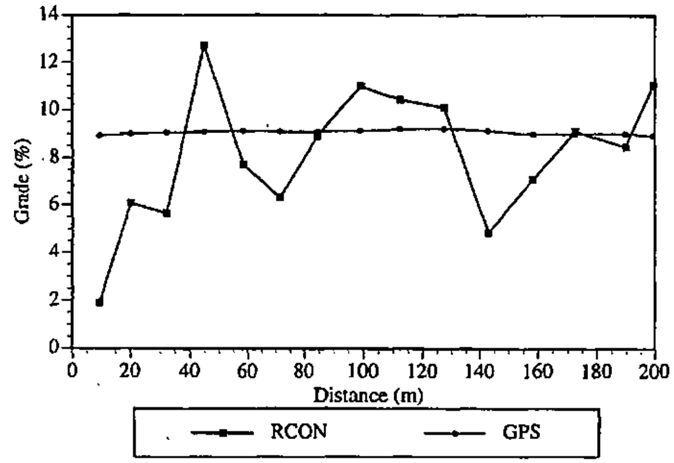
When the GPS velocity was plotted against the RCON velocity (see Figure 4) for this same data, the slope was very close to unity at 1.029 and had an R^2 value of 0.9981.



When the GPS acceleration was plotted against the RCON acceleration the R^2 value was 0.9668.

Grade Test

- The average grade measured by the RCON is 8.08%, with a standard deviation of 2.84.
- The average GPS grade for this section of road is 9.06%, with a standard deviation of only 0.09.



CONCLUSIONS

- This study has shown that GPS technology offers a method for obtaining vehicle velocity and acceleration measurements comparable to data collected by using on-board instrumentation.
- The GPS system is simple and versatile, and readily overcomes the limitations of on-board instrumentation and dynamometers.
- Correlation between the GPS velocity data and the RCON velocity data was very high, having an R^2 value of 0.9981.
- For acceleration, the GPS and RCON measurements were also very close, with an R^2 value of 0.9668 .
- Using the GPS to collect vehicle driving behavior data will enable the identification of road type and route.

The Atlanta Project

Michael Rogers
Georgia Institute of Technology, Atlanta, GA

Modal Driving Patterns for Emissions Modeling

Workshop on Vehicle Driving Cycles
Ottawa, Ontario
February 7, 1995

THE AIR QUALITY LABORATORY

Driving Pattern Research Program

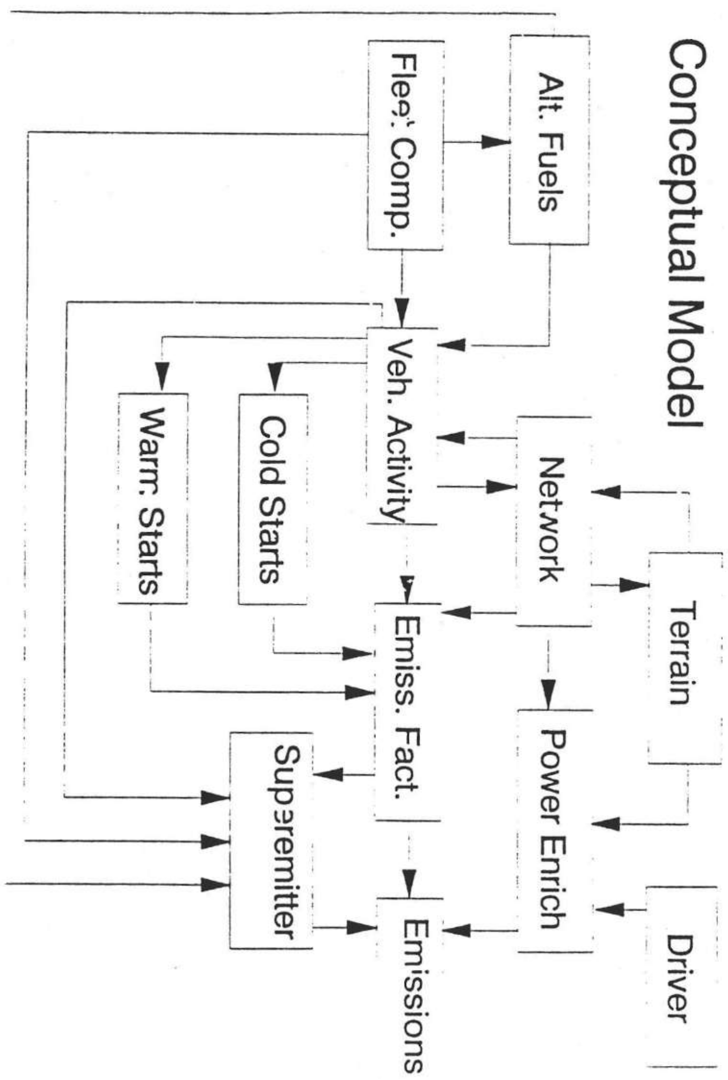
- Fleet Observations
  - Velocity/Accel Remote Sensing
  - Continuous Counters
  - Aerial Photography
  - Trip End Monitoring
- Analysis of Data Sources
  - Fuel Sales
  - I/M Records
  - Vehicle Registrations
  - Demographic Information

Driving Pattern Research Program

- Emissions Remote Sensing
  - Continuous Atlanta Fleet Evaluation (CAFE)
  - "Road Show"
- Instrumented Vehicles
  - Driver Behavior
    - In use vehicles
    - Driver behavior predictions
  - Vehicle Emissions Behavior

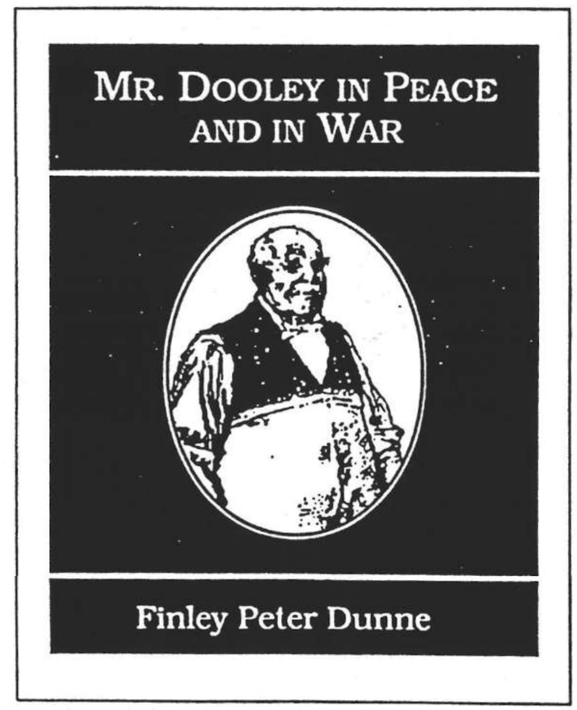
"Model of the Future"

- Modal
  - Vehicle
  - Driver
- Modular
  - Open
  - Extensible
- Measurement Based
  - Driven by Observables
  - Individual Modules can be Verified



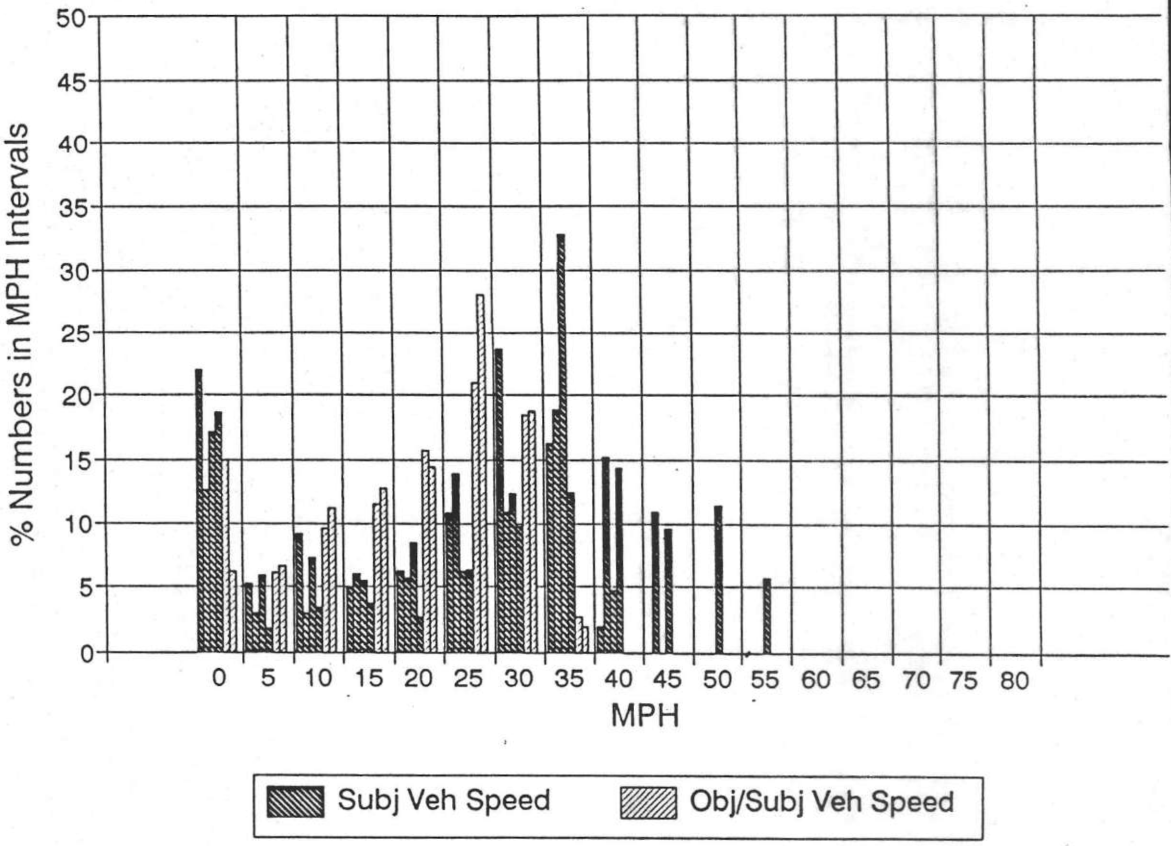
Dooley's Aphorism

It was not the things we didn't know that hurt us. It was all the things we knew for sure that turned out to be wrong.

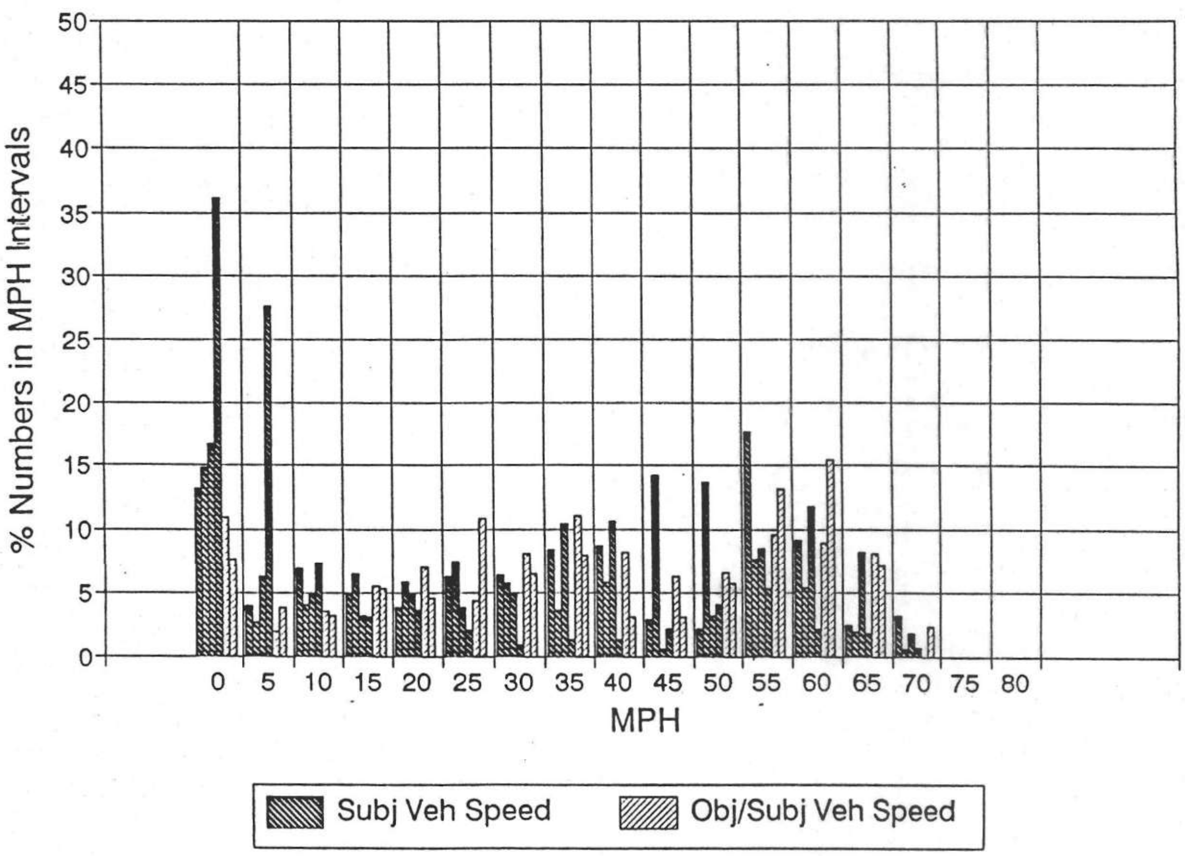


DR-106

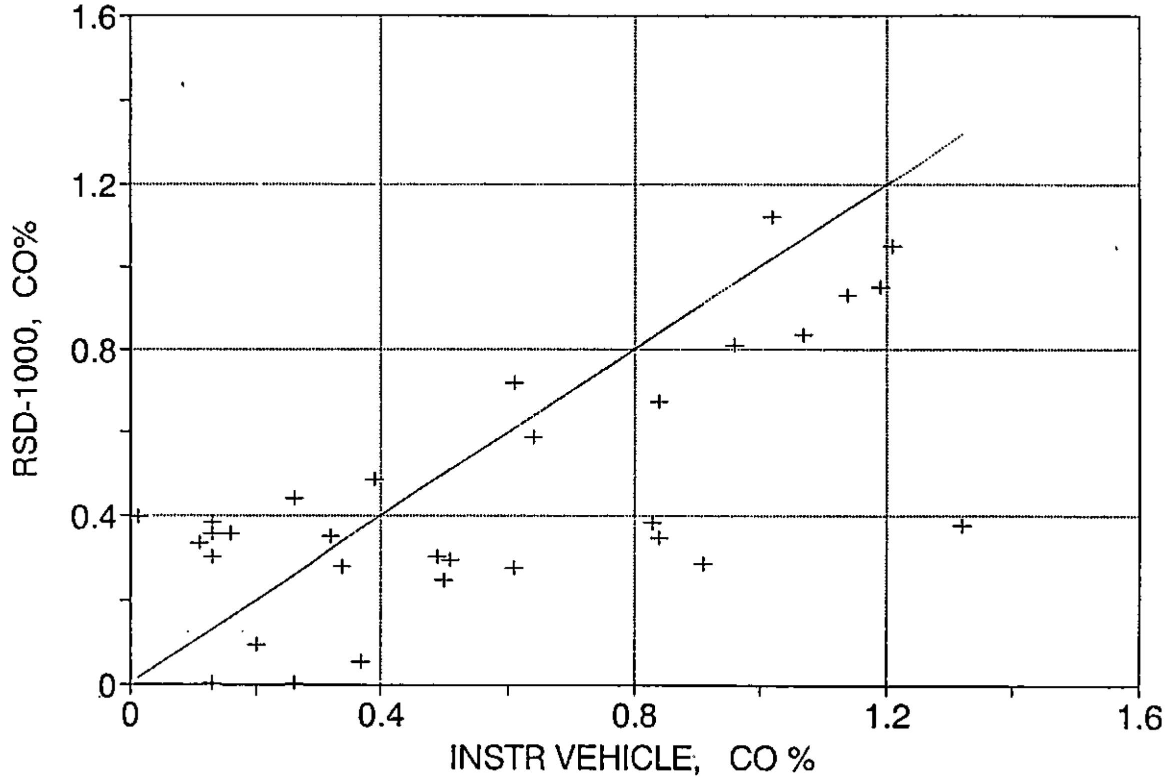
NOVA Home-to-Afternoon Errand
Objec vs Subjec Typical Routes



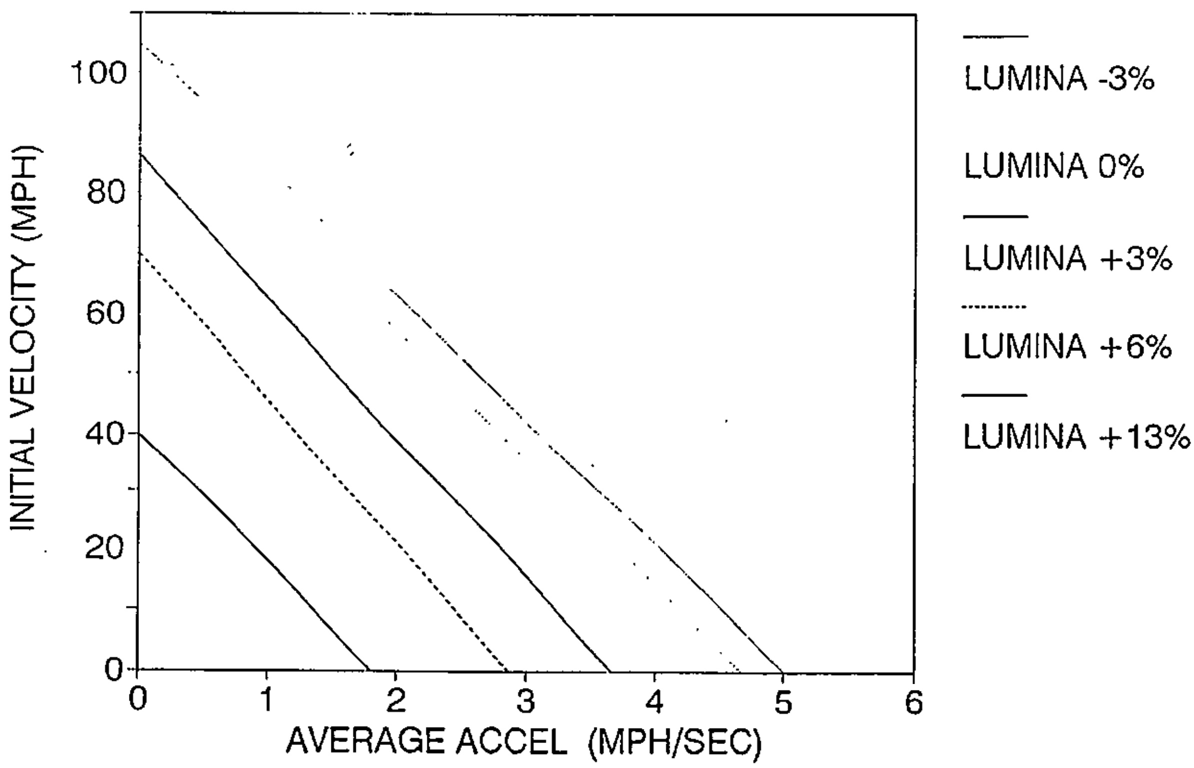
NOVA Home-to-Work
Objec vs Subjec Typical Routes



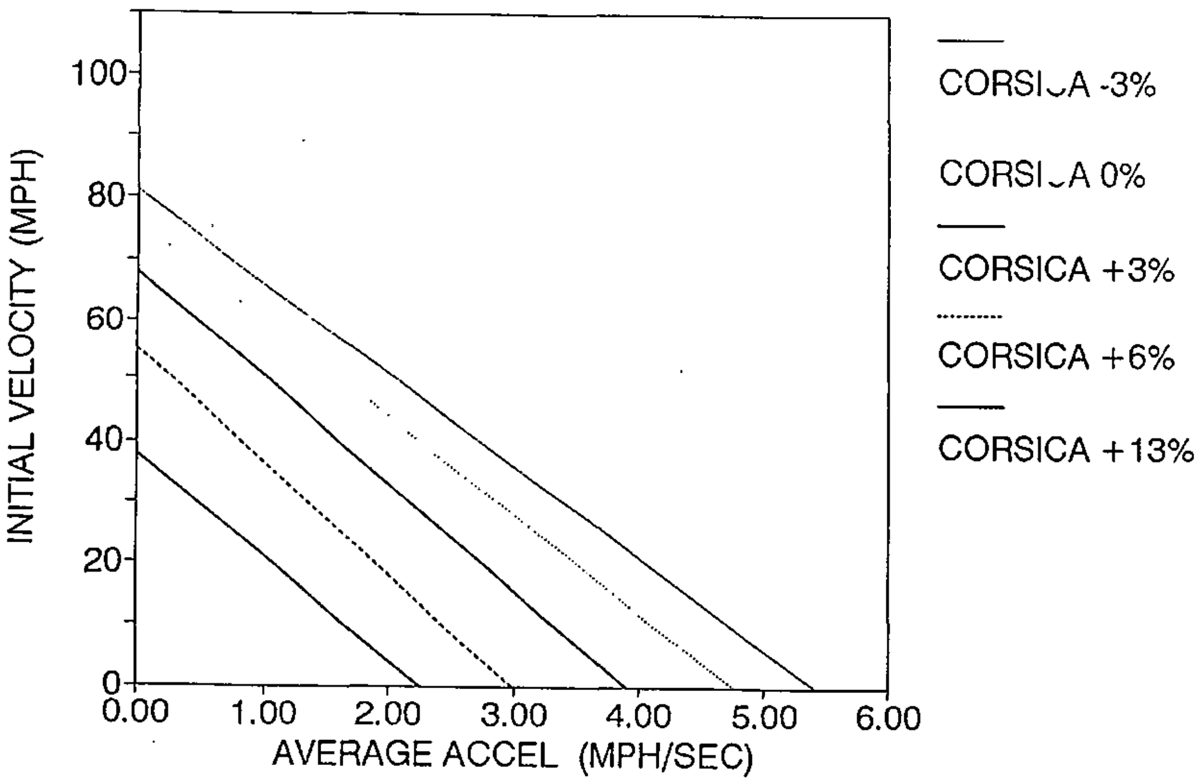
COMPAR OF RSD-1000 AND INSTR VEH DATA FOR CO

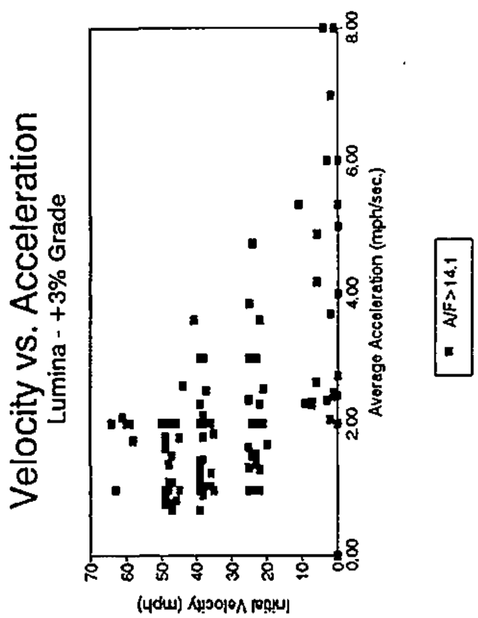


VELOCITY VS. ACCELERATION LUMINA



VELOCITY VS. ACCELERATION
CORSICA





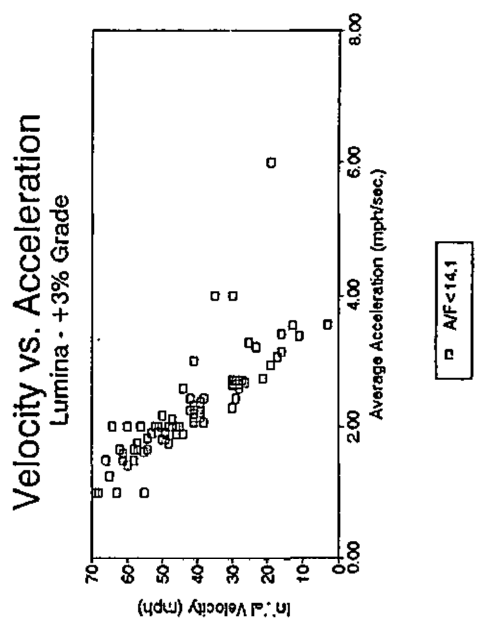
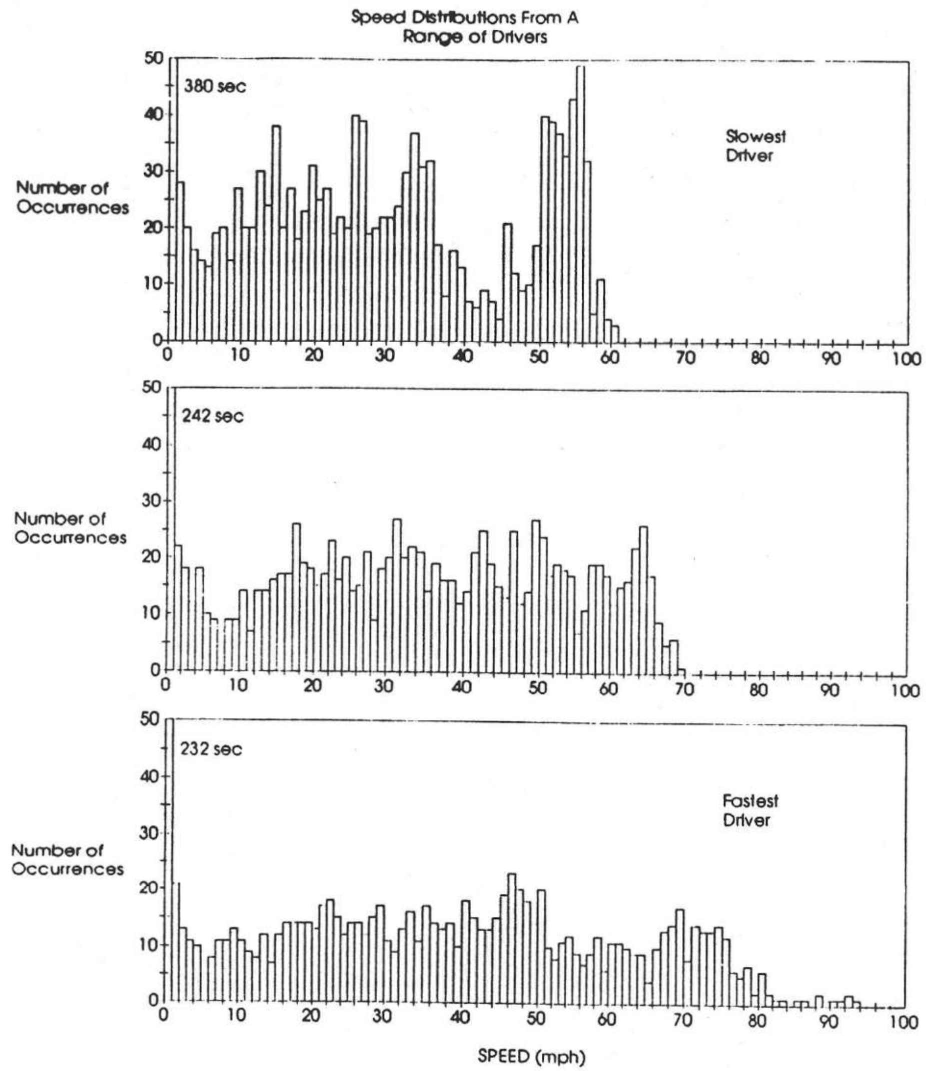
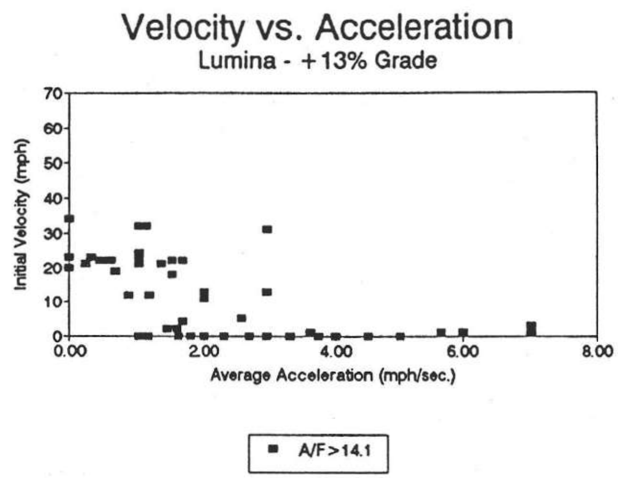


Fig 2

M_SPEED 26-OCT-93 15:43 Page 1





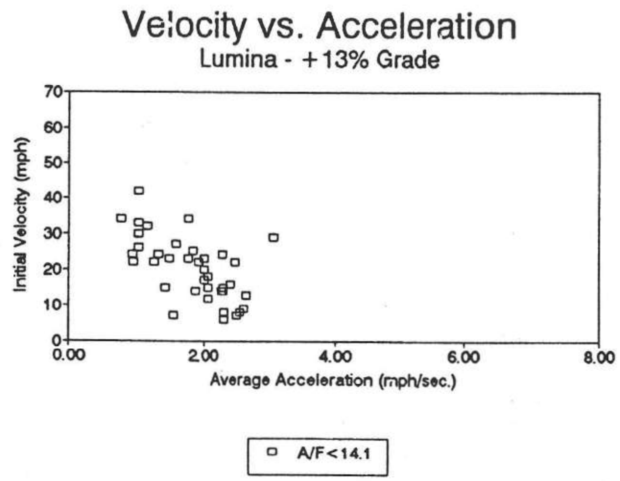
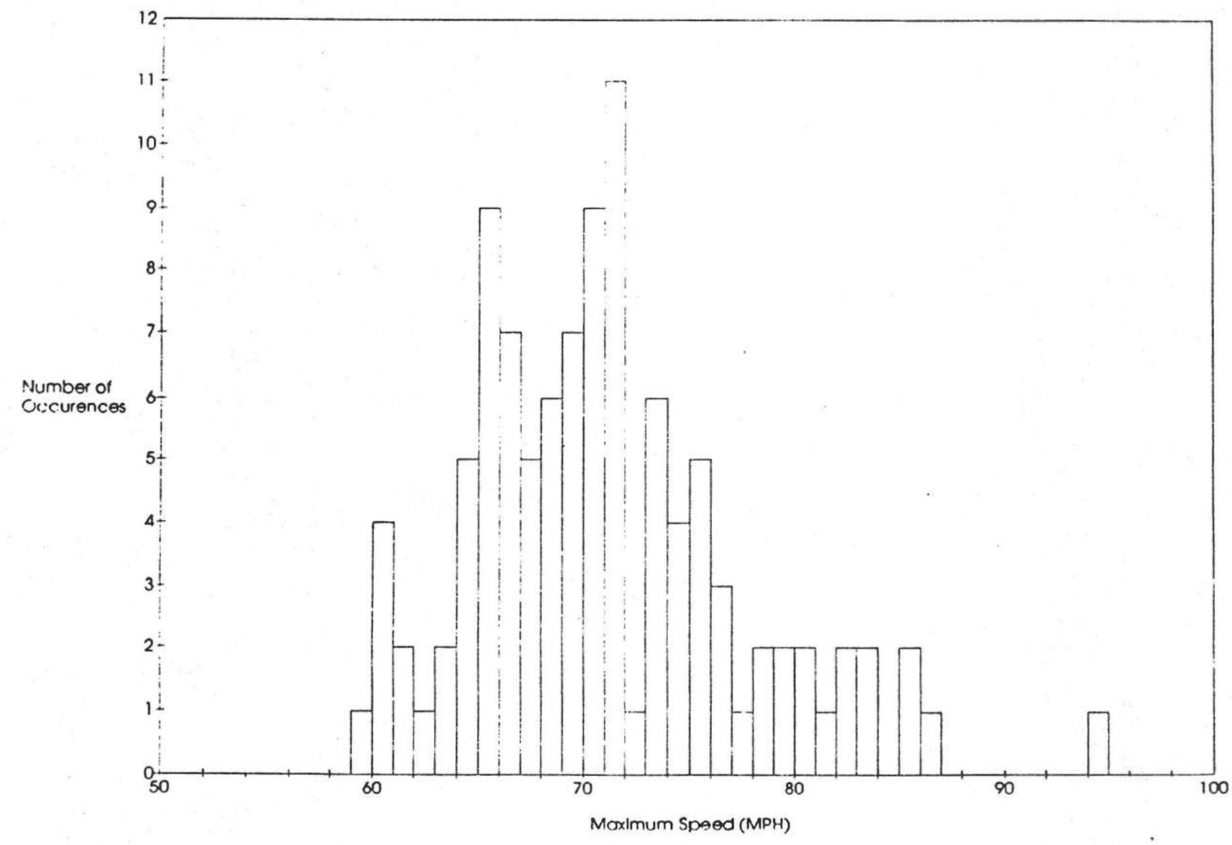
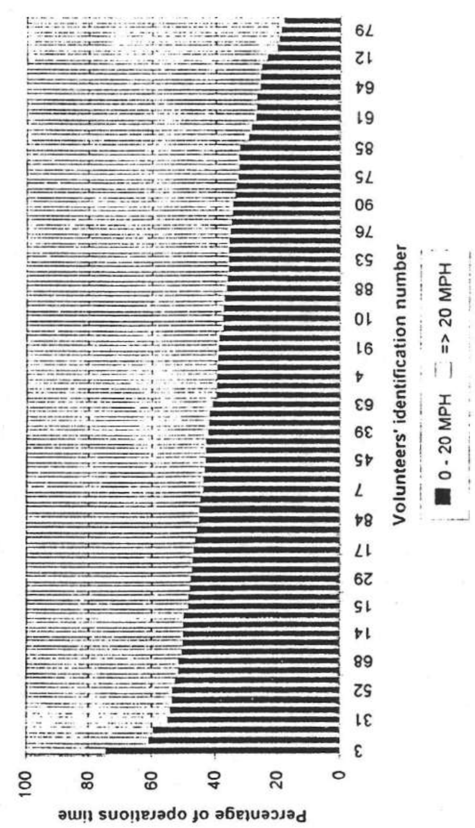


Fig 5

ATLANTA DRIVER SELECTION - 3.1 L CORSICA
MAXIMUM SPEED OF EACH DRIVER'S TRIP



PERSPEED.XLC



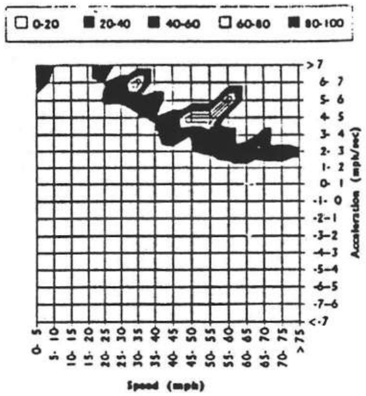


Figure 3-5 Probability of Severe Enrichment

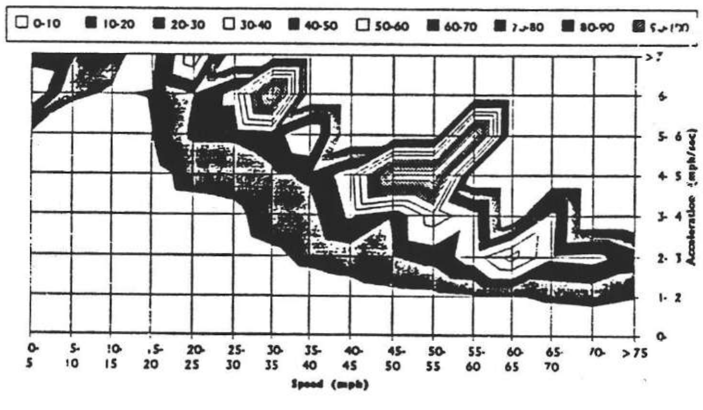
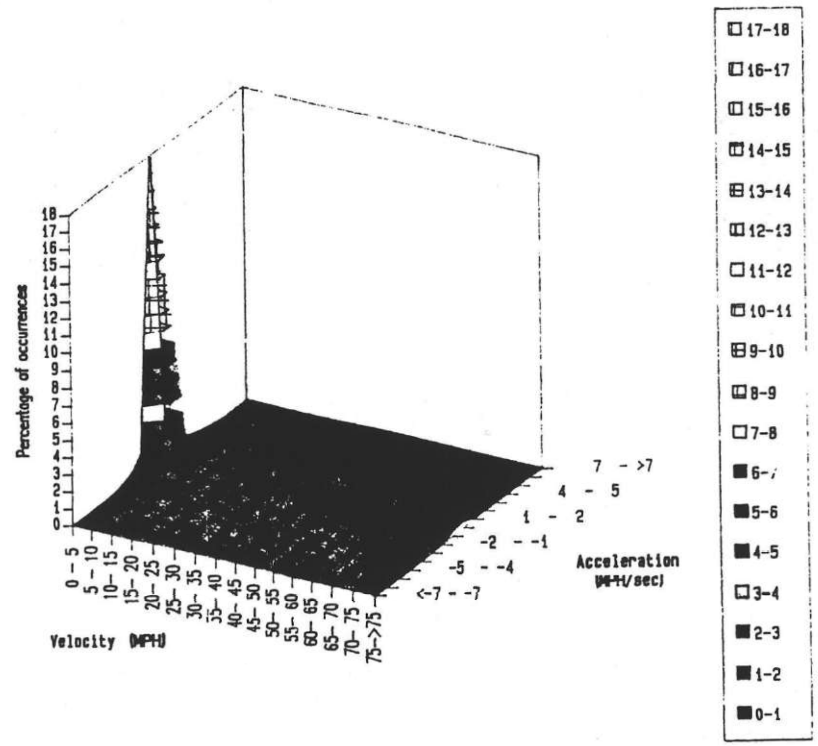


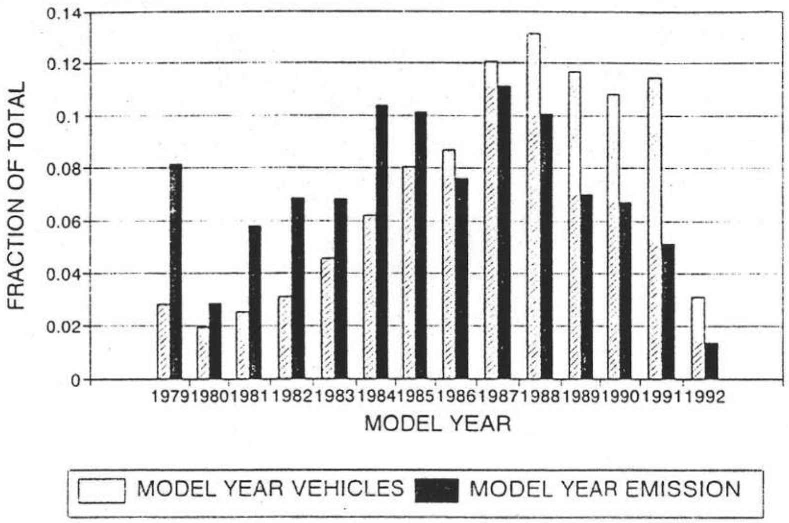
Figure 3-6 Enlarged View of Top Portion of Figure 3-5

Atlanta 3-parameter study: Capitol, Cobb, and Sandy Springs



MODEL YEAR AND CO CONTRIBUTION

ATLANTA, N=4124

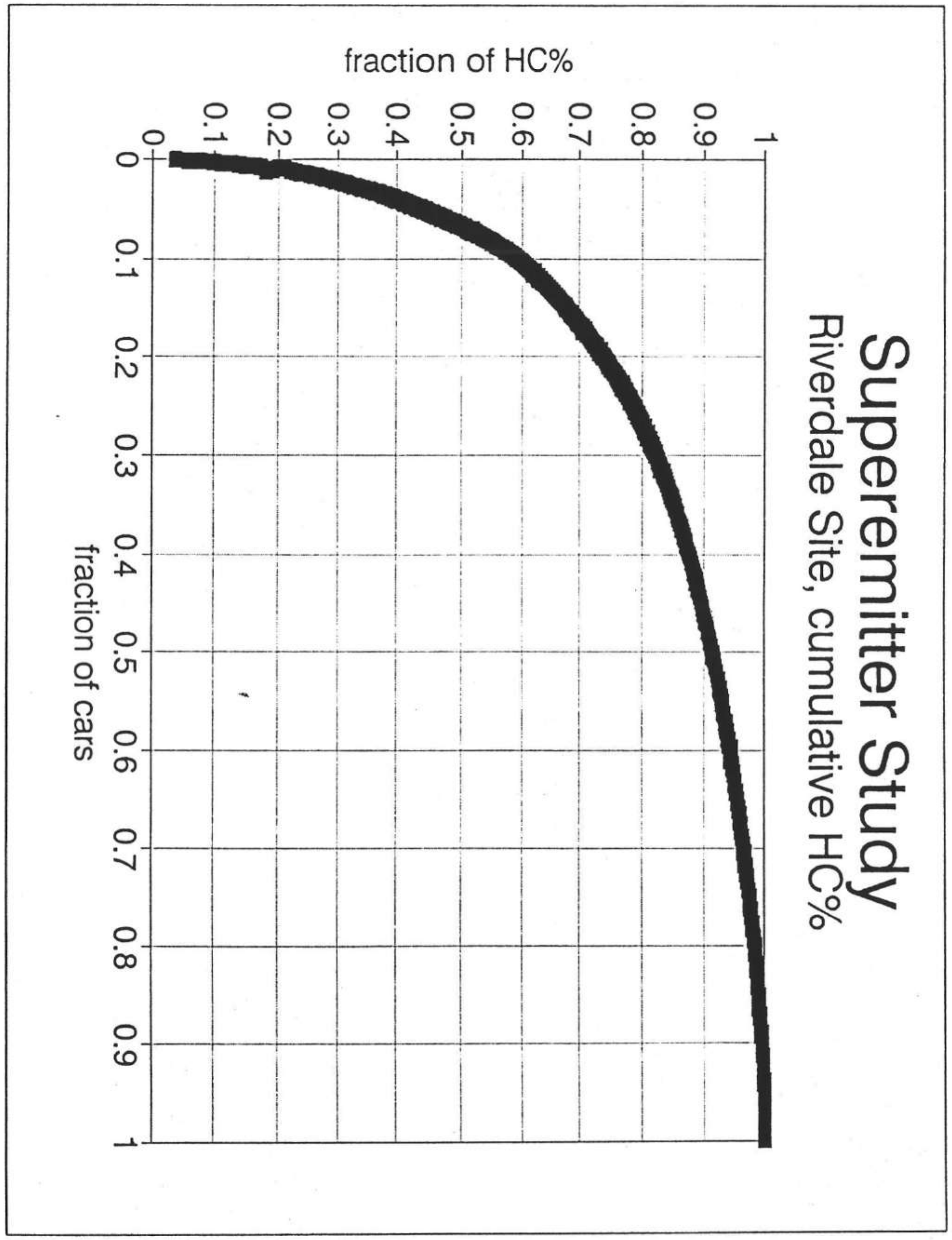


Daily VMT Estimates for Atlanta (Millions)

Dept. of Transportation	68.8
HMPS	53.0
Fuel Consumption (H)	74.7
Fuel Consumption (L)	51.7
Fuel Tax Data (H)	65.2
Fuel Tax Data (L)	45.1
I/M (H)	67.8
I/M (L)	54.9

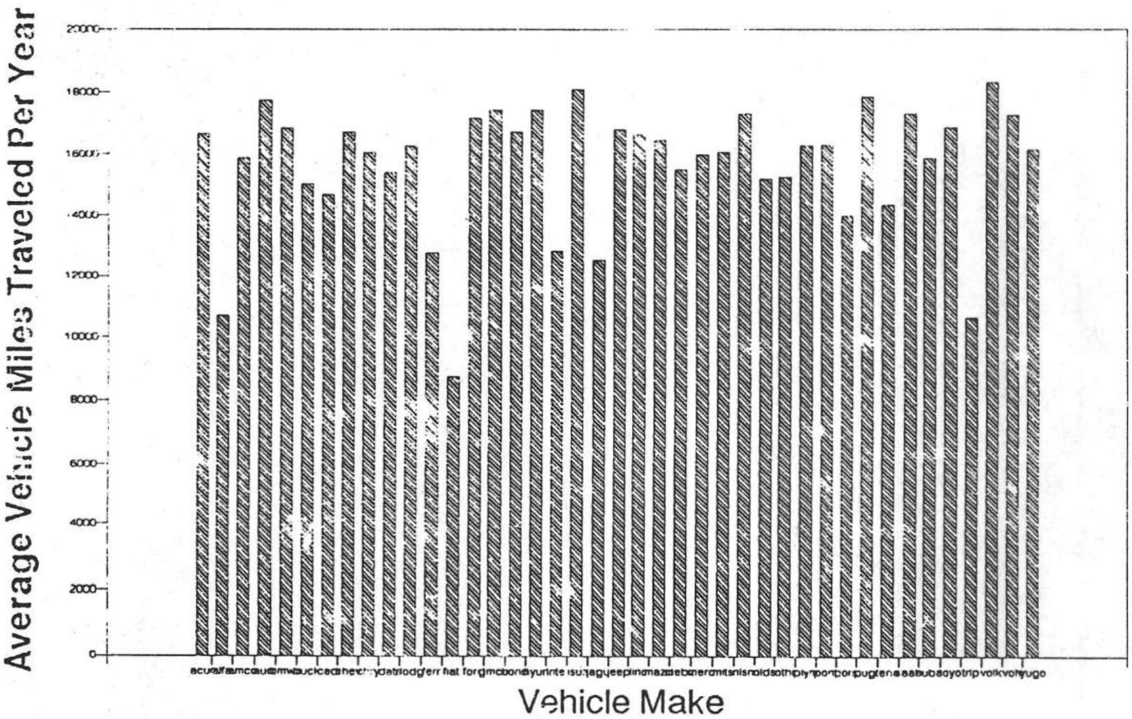
Summary of CO Superemitter Results

Site	Avg. CO	80% cut	<81
Pleasantdale	1.04%	30%	15.1%
Riverdale	1.18%	29%	22.9%
Abernathy	0.87%	33%	15.7%
Howell Mill	0.89%	22%	17.2%
Average	1.0%	28%	



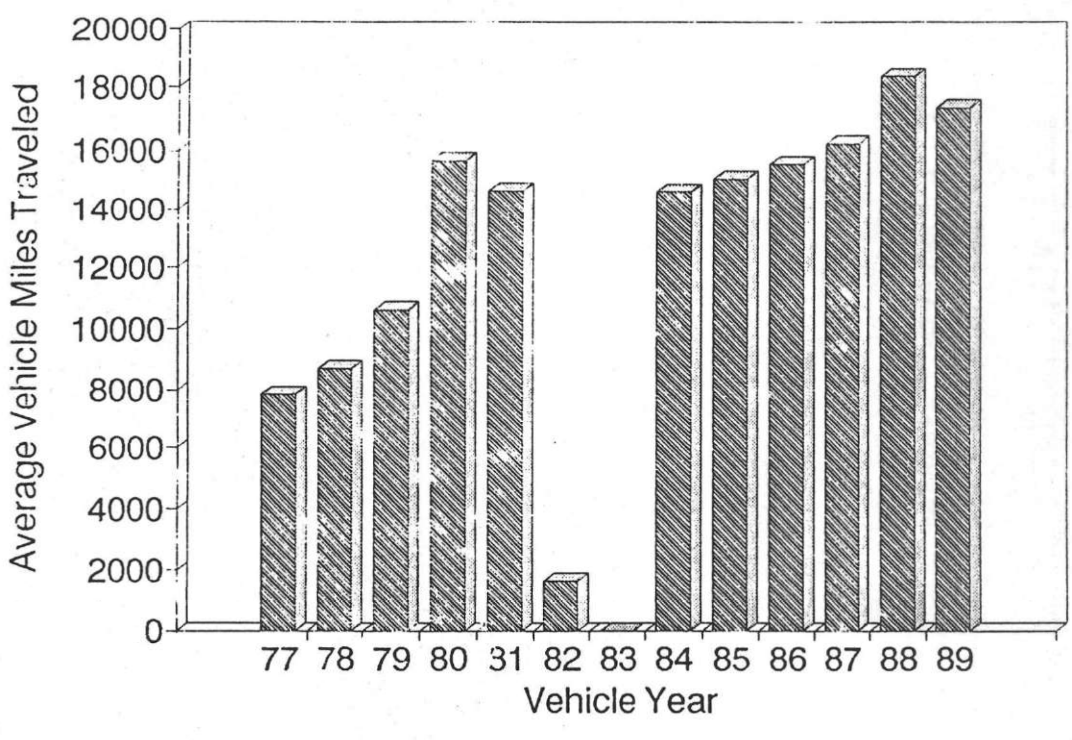
Mobile Source Inspection

All Cylinder Types

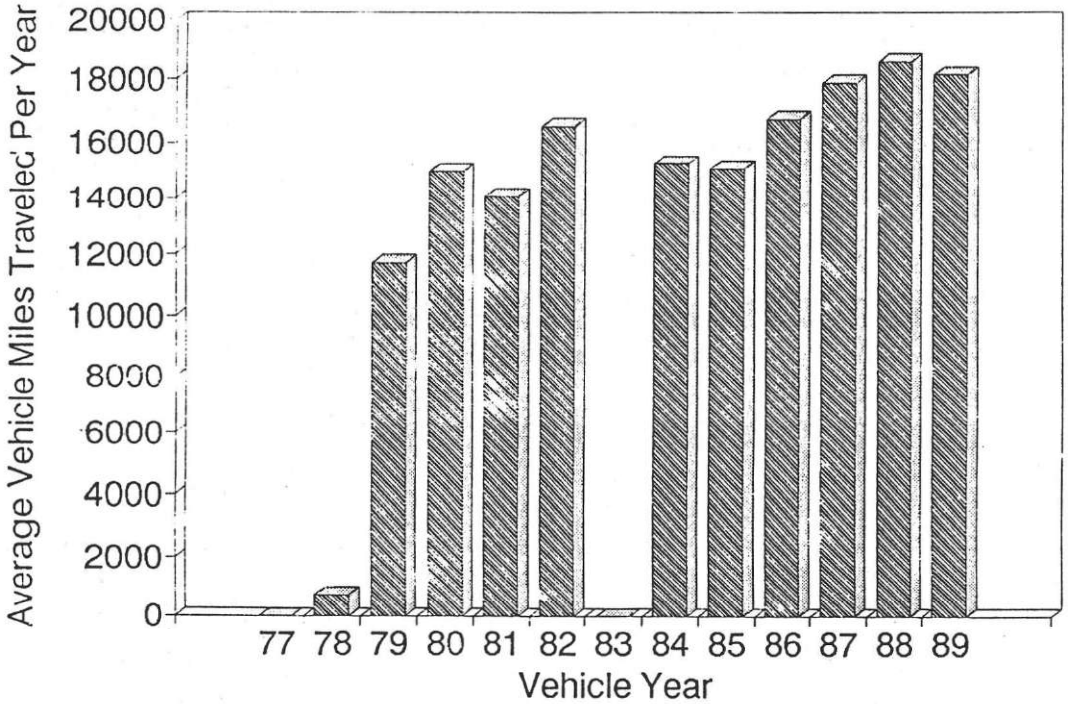


Mobile Source Inspection

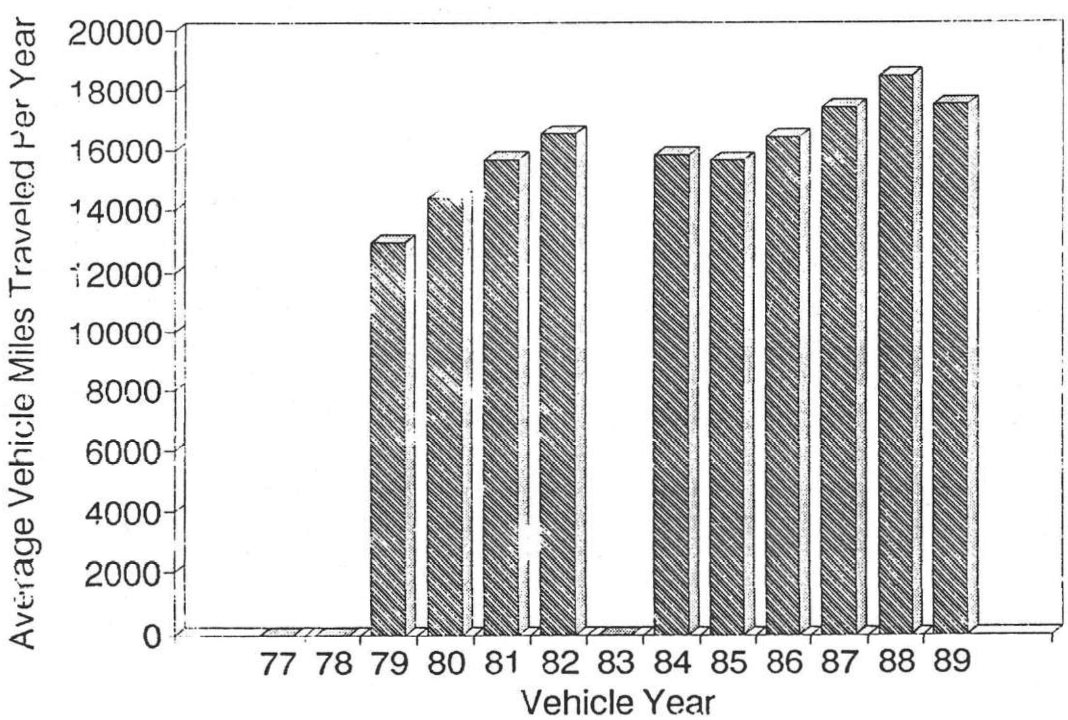
8 Cylinder



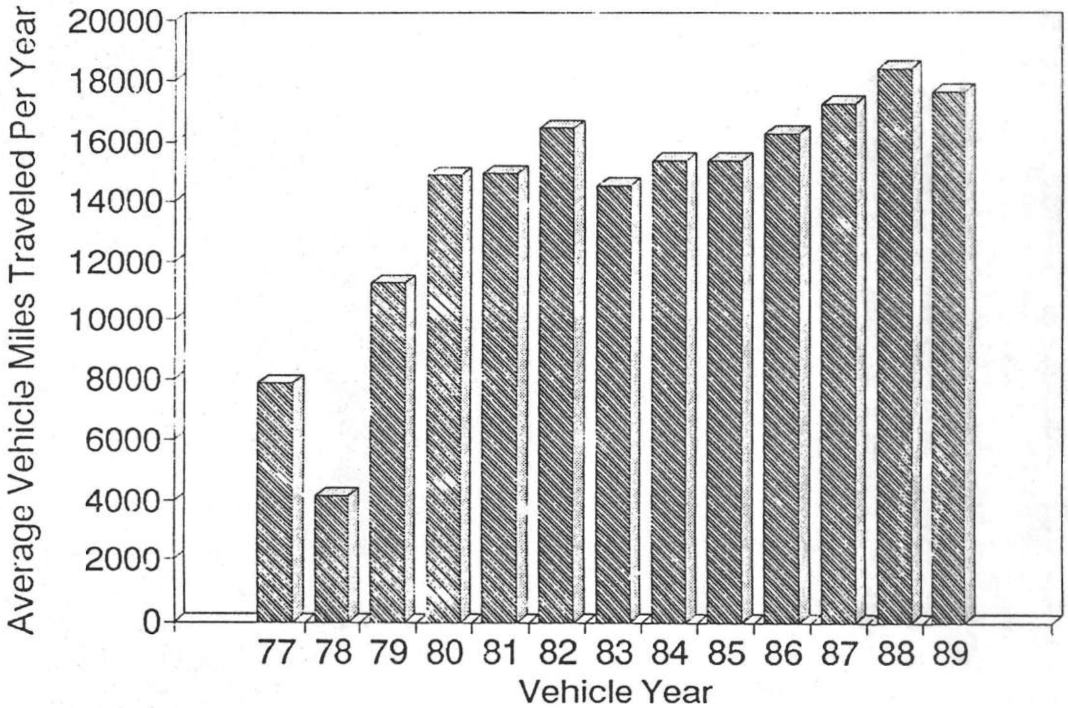
Mobile Source Inspection
6 Cylinder



Mobile Source Inspection
4 Cylinder



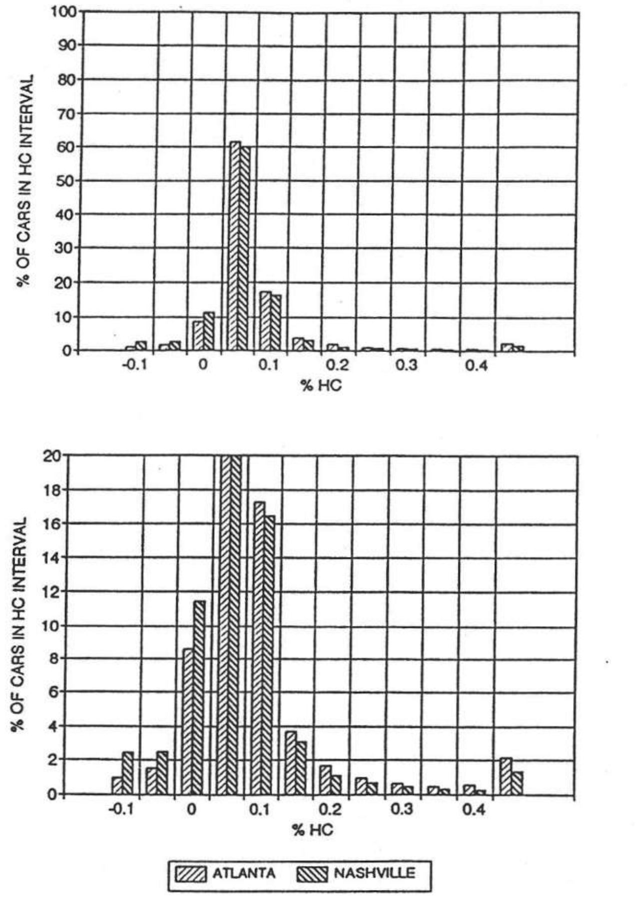
Mobile Source Inspection
All Cylinder



Air Quality Laboratory
Remote Sensing Road Tour

Spring 1994 - Chicago (CATFA)
Summer 1994 - Nashville (NOVA)
Fall 1994 - Baltimore (MOVE-East), New York (ROSETTE) and Maine
Winter 1995 - Phoenix and Houston
Spring 1995 - Kansas City, Spokane (MOVE-West) and Vancouver BC
Summer 1995 - Nashville (NOVA)
Fall 1995 - Salt Lake City
Winter 1996 - Tampa

Original City	Alternative City
Kansas City	St. Louis
Kansas City	Des Moines
Houston	Dallas
Phoenix	San Diego



ATLANTA (62201 cars) MEAN =0.065% MEDIAN=0.032%

68.4 % OF CARS HAVE HC<0.044% (26.6 % OF EMISSION)

6.3 % OF CARS HAVE HC>0.15 % (36.6 % OF EMISSION)

NASHVILLE (32882 cars) MEAN =0.048% MEDIAN =0.028%

71.9 % OF CARS HAVE HC<0.044% (28.5 % OF EMISSION)

4.1 % OF CARS HAVE HC>0.15 % (35.7 % OF EMISSION)

Site Evaluation Criteria:

- **Physical Site Characteristics**

    Single Lane Operation

    Space for Equipment Setup

    Operator Safety

    Site Type (ramp, street, connector, etc.)

    Grade/Vehicle Maneuvers

- **Site Location Characteristics**

    Geographic Location

    Fleet Composition
        Demographics
        Vehicle Mix (passenger cars, trucks, etc.)
        Registrations

    Diurnal Pattern of Traffic

- **Traffic Volume**

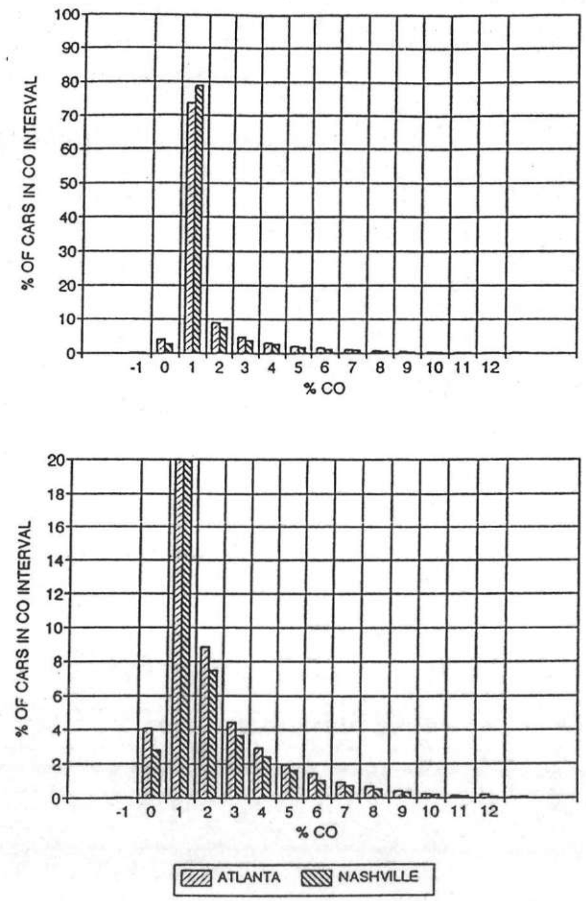
- **Speed**

MOVE - EAST SUMMARY

REMOTE SENSING
9/27/94 - 10/15/94

TOTAL SAMPLING
133,700 CARS

BALTIMORE CITY	32.7 K
BALTIMORE CO.	50.5 K
HOWARD CO.	20.2 K
CARROLL CO.	4.6 K
HARFORD CO.	11.5 K
ANNE ARUNDEL CO.	12.7 K



ATLANTA (64962 cars) MEAN =0.93% MEDIAN = 0.3%

80.4% OF CARS HAVE CO<1.2% (27.1% EMISSION)

7.0% OF CARS HAVE CO>3.6% (44.1 % OF EMISSION)

NASHVILLE (35003 cars) MEAN=0.81% MEDIAN=0.28%

84.1% OF CARS HAVE CO<1.2% (33.4% OF EMISSION)

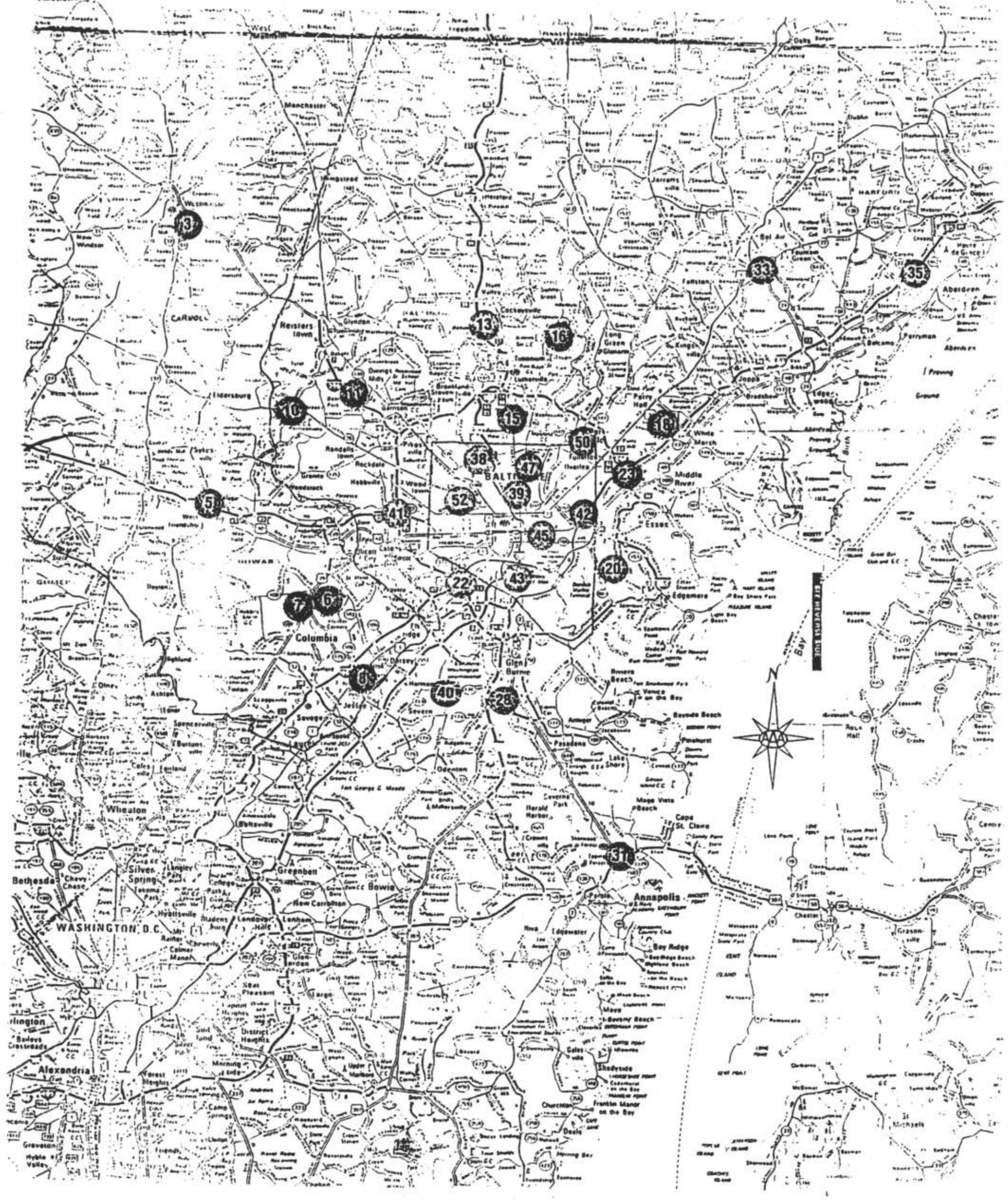
5.5% OF CARS HAVE CO>3.6% (39.0% OF EMISSION)

Obstacle Route Variables

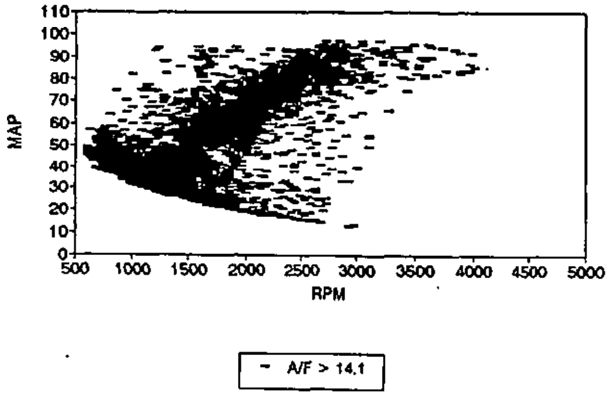
The four variables around which the obstacle route driving centered include:

- *Approach Speed (0, 25, 40, and 50 mph)*
- *Throttle Position (1/3, 2/3, and full)*
- *Slope of Grade (0%, 3%, -3%, 6%, and 13%)*
- *Weight Configuration Inside Vehicle (instruments, instruments plus 150 pounds of sand, or laptop computer only)*

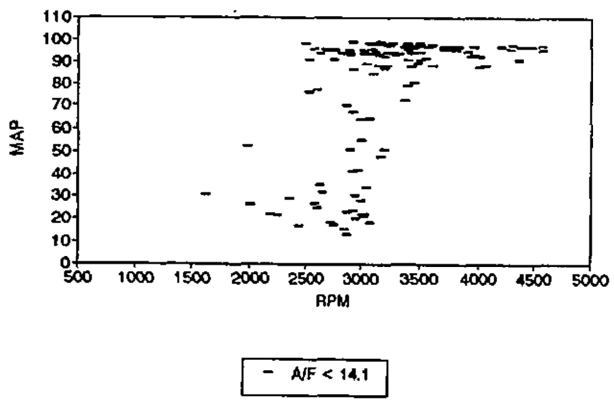
MAP 1: MAP DISPLAYING SITES CHOSEN TO MEASURE EMISSIONS IN THE BALTIMORE SEVERE NONATTAINMENT AREA FOR OZONE



Driver: Tom Nissalke
L117017-L117029; April 27, 1993

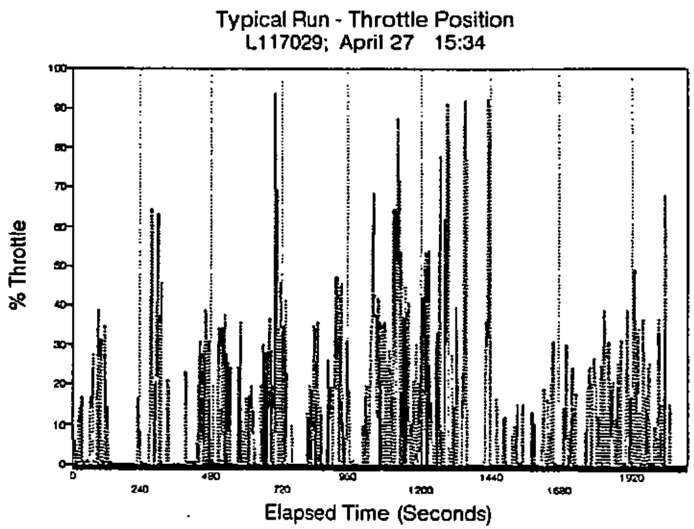


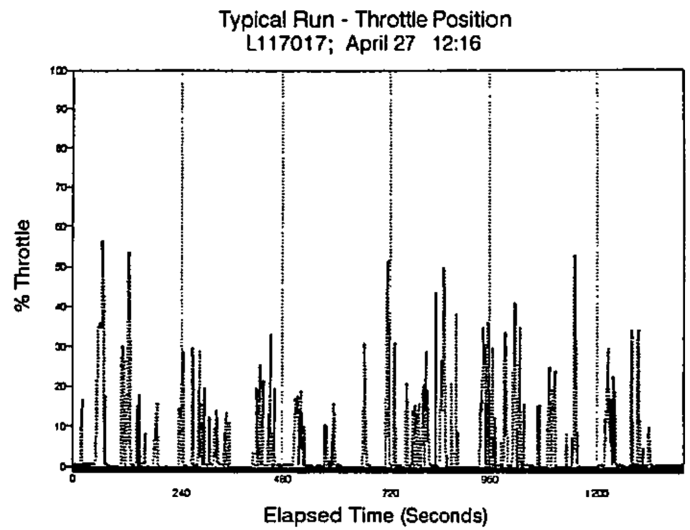
Driver: Tom Nissalke
L117017-L117029; April 27, 1993

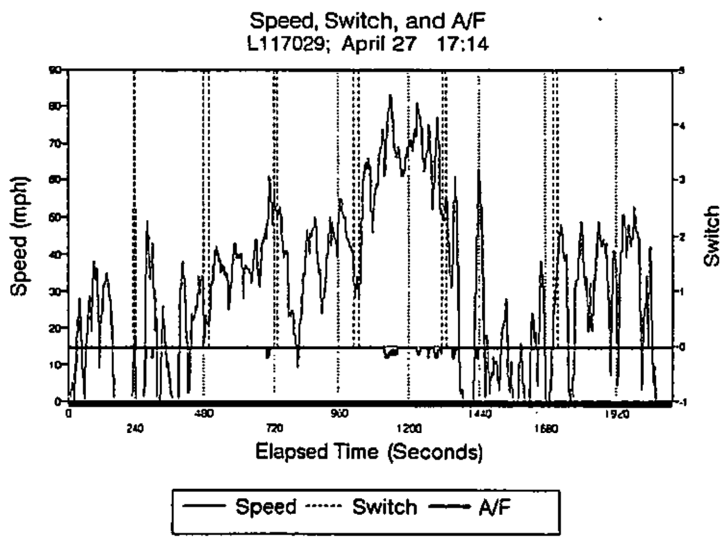


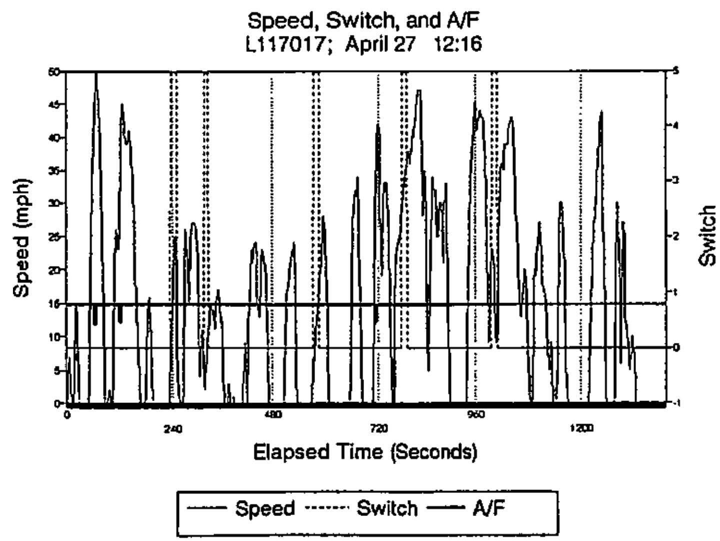
ENRICHMENT FREQUENCIES

6 PARAMETER	1 % OF OPERATING TIME
VEL - ACCEL + 6 PARA	13 % INTERSTATE RAMPS 0.9 [illegible] 0.5 % INTERSTATE SEGMENTS
3 PARAMETER	1.5 % OF OPERATING TIME
3 PARA + MONTE CARLO	2.0 % OF OPERATING TIME
VEL - ACCEL + POWER DEMAND	1.3 % OF OPERATING TIME


Typical Run - Throttle Position
L117029; April 27 15:34
% Throttle
Elapsed Time (Seconds)

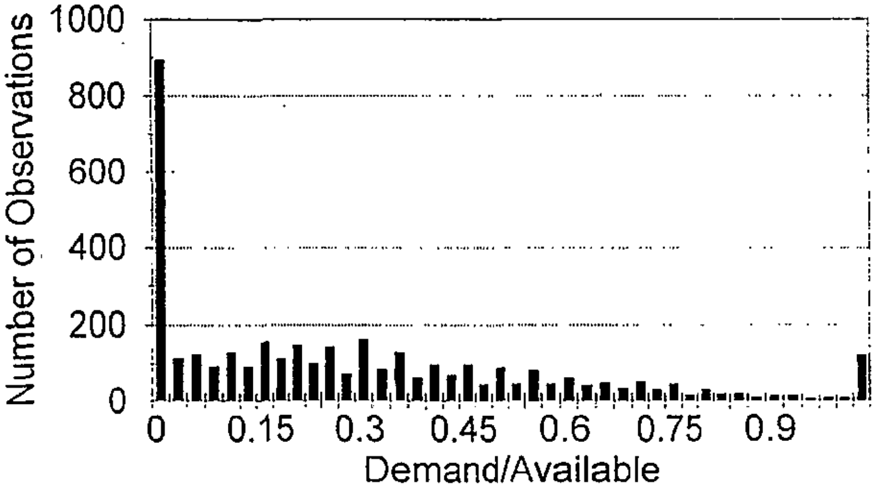

Typical Run - Throttle Position
L117017; April 27 12:16
% Throttle
Elapsed Time (Seconds)


Speed, Switch, and A/F
L117029; April 27 17:14
Speed (mph)
Switch
Elapsed Time (Seconds)
Speed
Switch
A/F


Speed, Switch, and A/F
L117017; April 27 12:16
Speed (mph)
Switch
Elapsed Time (Seconds)
Speed
Switch
A/F

Power Demand

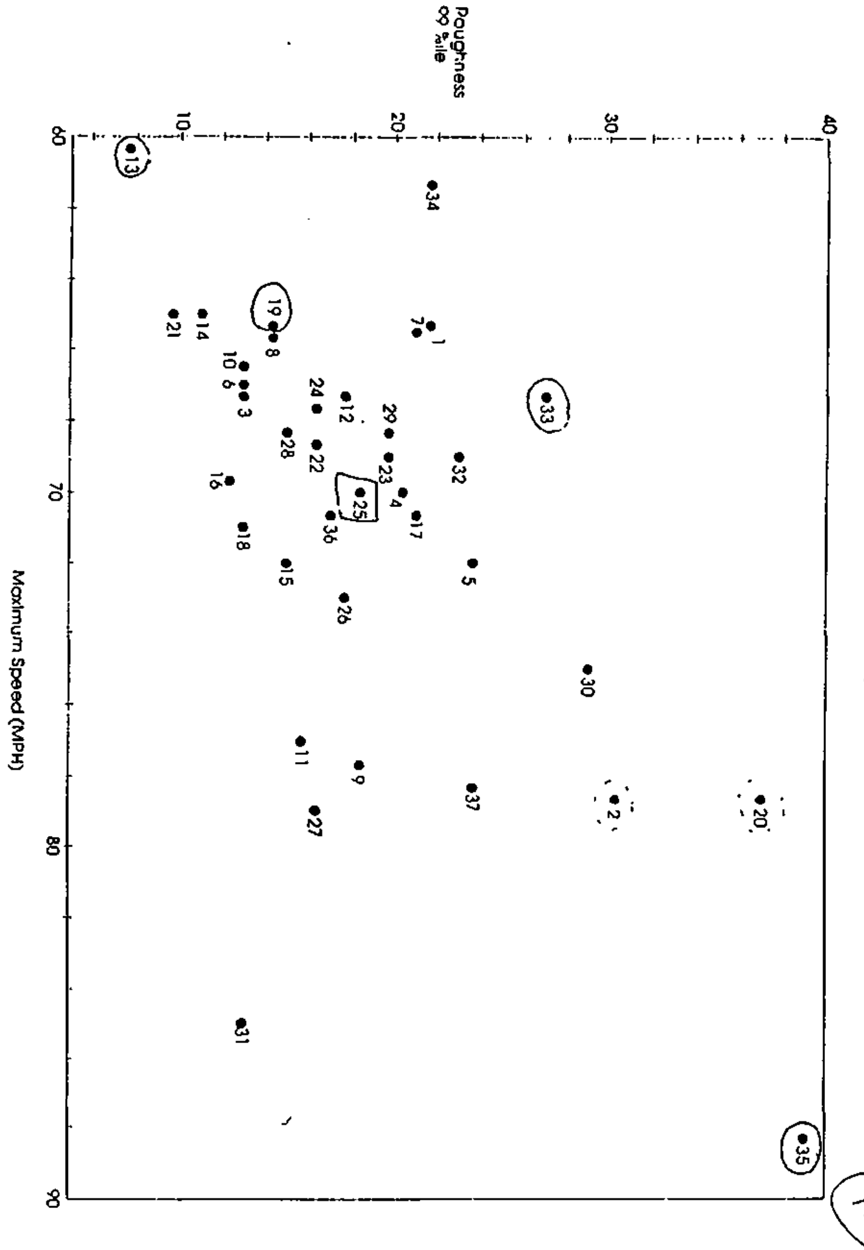
Freeway Ramps



#ATLDATA_SUM_AVG_HISPEED_DTP

Comparison of Drivers Based on High Speed and Roughness Behavior

26-OCT-93 9:38 Page 1



Power Demand Model

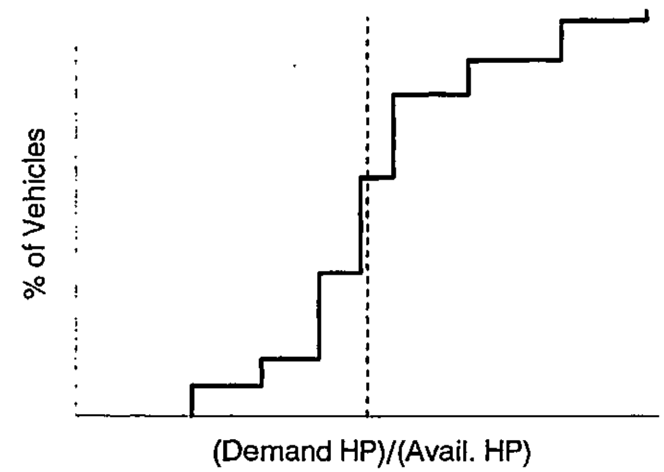
Demand Power = A + G + I + R + F

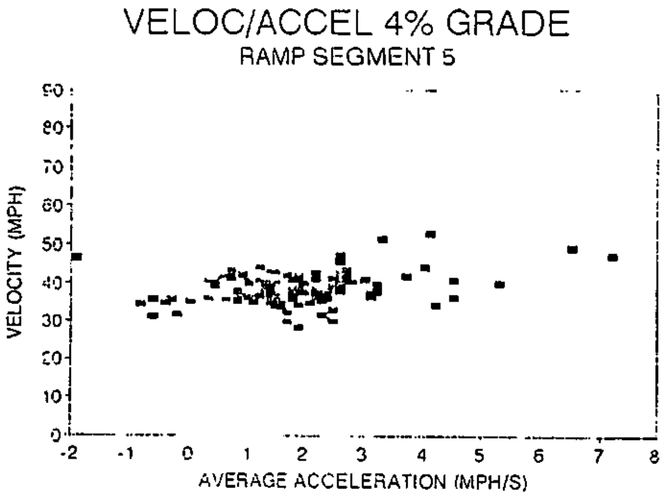
A = Aerodynamic Load
G = Grade Load
I = Inertial load (acceleration)
R = Rolling Resistance
F = Friction

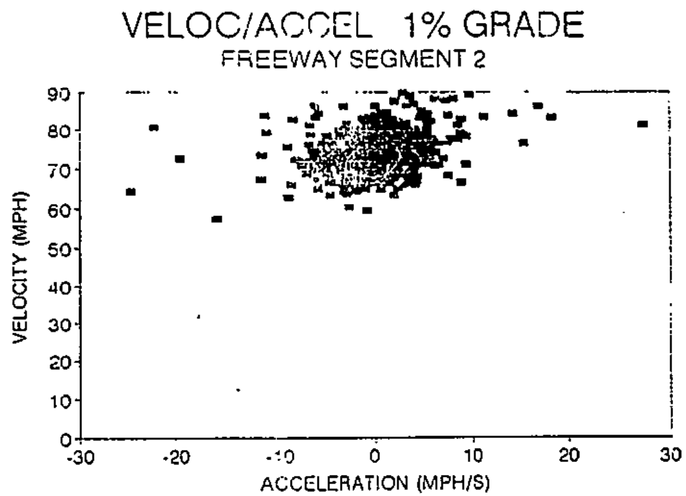
Enrichment Occurs When:

(Demand)/(Available Power) > Threshold

Model Performance




VELOC/ACCEL 4% GRADE
RAMP SEGMENT 5
VELOCITY (MPH)
90
80
70
60
50
40
30
20
10
0
-2
-1
0
1
2
3
4
5
6
7
8
AVERAGE ACCELERATION (MPH/S)


VELOC/ACCEL 1% GRADE
FREEWAY SEGMENT 2
VELOCITY (MPH)
90
80
70
60
50
40
30
20
10
0
-30
-20
-10
0
10
20
30
ACCELERATION (MPH/S)

VELOC/ACCEL 6% GRADE

RAMP SEGMENT 3