78-004-7792

DETERMINATION OF HOT AND COLD START PERCENTAGES FOR NEW JERSEY

Task No. 1

Literature Search: Definitions and General Background

by

Mark Marsella, Principal Engineer

prepared by

Bureau of Instrumentation Services
Division of Research and Development
New Jersey Department of Transportation

HPR Study Number - 7792

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration

April 12, 1977

A-7792-3

NOTICE

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

Disclaimer Statement

The contents of this report reflect the views of the author who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the N.J. Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
78-004-7792		

4. Title and Subtitle	5. Report Date
Determination of Hot and Cold Start Percentages for New Jersey Literature Search: Definitions and General Background	April 12, 1977
	6. Performing Organization Code N.A.
7. Author(s) Mark Marsella	8. Performing Organization Report No. 78-004-7792
9. Performing Organization Name and Address New Jersey Department of Transportation Division of Research and Development 1035 Parkway Avenue, Trenton, N.J.	10. Work Unit No. N.A.
	11. Contract or Grant No. N.J. HPR Study - 7792
	13. Type of Report and Period Covered Task Report
12. Sponsoring Agency Name and Address New Jersey Department of Transportation Division of Research and Development 1035 Parkway Avenue, Trenton, N.J.	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

The present method of predicting air pollution for environmental impact statements is based,in part, on engineering judgement as to the percentage of vehicles expected to run above or below operating temperature. However, this is not accurate enough to meet existing requirements, so that another method of determining these percentages is being sought. As an initial step a literature search was conducted for general background, and to obtain a definition of operating temperature, based on temperature only, from which the definitions of "hot" and "cold" starts would follow. This goal was not realized, although a useful definition based on time was developed from data resulting from extensive field monitoring of automotive systems.

It is recommended that this definition be used as the reference from which to analyze data being collected from field operation of a variety of vehicles. This will lead to definitions based on temperature, which in turn will be the basis for a method of determining "hot" and "cold" starts.

17. Key Words	18. Distribution Statement
Air Pollution Environmental Impact Statement Vehicle Operating Temperature	No Restrictions

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	15	

Form DOT F 1700.7 (8-69)

TABLE OF CONTENTS

1. Introduction

Environmental impact statements require that air pollution levels from the roadway be predicted from traffic data. Such predictions are based, in part, on the percentage of vehicles which will be operating below or above operating temperature. Present estimates of these percentages are based on engineering judgement, and are not accurate enough to meet the standards for environmental impact statements. The objective of the project then is to determine, with known accuracy, the average percentages of vehicles which are operating above and below operating temperature. These conditions are assumed to occur as the result of a vehicle being recently started and will be known respectively as "hot starts" and "cold starts". The average percentages of "hot" and "cold" starts will be determined for the following six functional classifications of roadways:

1) Rural principal arterial system
2) Rural minor arterial and collector road systems
3) Rural local road system
4) Urban principal arterial system
5) Urban minor arterial and collector road systems
6) Urban local street system

This will allow predictions for proposed construction to be based on statistically valid techniques, thereby meeting the requirements for environmental impact statements.

The project will achieve its objective in the following way: First, a method to measure hot/cold start operating characteristics in the field will be developed. Second, a statistically sound field survey plan incorporating the measurement method will be developed to find the percentages of hot/cold start operation for vehicles operating in New Jersey. Third, the plan will be implemented to collect data which will provide the percentages of hot/cold start vehicles on New Jersey roads. The first two steps make up the first phase of the project, development of the field survey methodology, while the second phase, implementation, consists of the third step. The first phase will be accomplished by performing the following tasks: 1) literature search for general background, definitions, and information on infrared physics and technology, 2) vehicle operation experiment, 3) demonstration and comparison of measurement methods, 4) sampling scheme development, and 5) sampling scheme field test.

1.1 Statement of Problem

Initially no information was readily available concerning the meaning of "operating temperature", and the terms, "hot starts" and "cold starts". Although the U.S. Environmental Protection Agency published definitions of the last two terms (see Appendix I), they were based ontime, a factor which, for the most part, cannot be determined under field conditions. Furthermore, "operating temperature" is a concept which is intuitively understood, but neither a theoretical nor practical definition was apparent. The first problem therefore, was to obtain enough information to develop acceptable, useful definitions for all three terms.

Concurrent with this problem were the ones of determining which automotive systems could be used in formulating the desired definitions, and which should be instrumented for vehicle operation experiments. These experiments would result in the establishment of a temperature range above or below which a vehicle could be considered to be running "hot" or "cold". It was clear that the most useful systems would be those with the least temperature fluctuation at "operating temperature", but would nonetheless clearly indicate "hot" and "cold" start conditions.

Obviously the three problems were interrelated, and the literature search was directed accordingly.

In addition, the fact that the vehicle population in New Jersey is very large and varied, precluded the possibility of using a vehicle of each different year, make, model, etc. in the vehicle operation experiments. Consequently, it was necessary to find a way to reduce the sample to a workable size.

1.2 Objective

The initial three-fold problem required a literature search which would lead to a thorough working knowledge of the various automotive systems. It was assumed that this knowledge would lead to the desired definitions, directly or indirectly. Since from the outset it seemed clear that a consideration of time alone (i.e. duration of operation) would not yield this result, a prime consideration was the location of publications which would support some other approach.

A further objective was to categorize the vehicle population to some extent by engine, make and year, and to determine what Department vehicles were readily available for experimentation purposes.

2. Discussion

Although a number of books from several libraries were consulted during the literature search, the most immediately useful information was a result of telephone conversations with technical personnel from various organizations, especially those with the Coordinating Research Council and the Ore-Lube Corporation, both in New York, and the Ford Motor Company and the Society of Automotive Engineers in Detroit. These conversations had two benefical results. The first was that references (4) and (9) were obtained directly from industrial sources, with no expense or delay. These two reports have proven to be the primary sources of applicable information to date. The second was that it became obvious that the temperatures at certain locations had an operating range far too wide to be useful in formulating definitions sought.

2.1 Exhaust and Fuel Systems

As a result of the conversations noted above, it was ascertained that the exhaust system (manifold through tail pipe) could be eliminated as a basis for the definition of operating temperature. The skin temperature of a typical catalytic converter was said to range from about 205 degrees C to 705 degrees C (400 degrees F to 1300 degrees F). The low temperature was cited for a properly tuned engine at idle, with no load, while the upper limit is for a badly tuned engine at highway speed. The narrowest range of converter skin temperature for highway driving (after reaching operating temperature) was said to be from approximately 343 degrees C to 482 degrees C (650 degrees F to 900 degrees F). Similar ranges were indicated for a standard muffler, and for other exhaust system components. Since these temperatures are so dependent on tuning, load and especially speed there is no way to determine whether an engine is above the maximum of the equipment presently available for the vehicle monitoring experiments.

At the other extreme is the fuel system. The maximum temperatures reached here are under 49 degrees C (120 degrees F) (9), and some components rise only five or ten degrees C above ambient. While the range is within that of the available recording equipment, the increases in temperatures of the different elements are rather gradual over a prolonged period (up to a half-hour). There are no abrupt changes to signal the approach of "operating temperature" nor is it clear when this condition is reached, even when coolant and oil temperatures indicate that it has. Last, there seems to be no clear indication of a "cold start" condition.

2.2 Cooling and Lubrication Systems

The definition of operating temperature given in Section 3 is a result of the data presented in the reports by N.E. Gallopoulos (4), and Scott Research Laboratories (9). From (9) it can be seen that there is a rather rapid change in temperature of both oil and coolant up to the time the thermostat opens, thus signalling the observer that operating temperature will be reached in about ten minutes. Since oil temperature is a function of coolant temperature (4), both tend to stabilize after the thermostat opens, both cool at about the same rates and both have a maximum operating temperature of about 150 degrees C (300 degrees F). Viewed collectively, these factors indicate that coolant and oil temperatures, taken on a time basis, are logical choices for a definition of operating temperature.

2.3 Limitations of New Definitions

The fact that a definition of operating temperature has been formulated from the analysis of field data is encouraging. A logical outcome of this is to define "hot starts" and "cold starts" as operation above or below operating temperature. While these definitions are more realistic than those given in Appendix I, time is still the basic factor involved. Therefore, the definitions have an immediate practical value (as far as the overall project objective is concerned) only in very specialized cases. One such case would be a freeway location which is at least 15-20 minutes driving time from the nearest interchange, service area, or rest area. Assuming Level of Service D or better, nearly every vehicle would be at operating temperature. Another example would be a manufacturing plant twenty minutes or more from a residential area. Almost all vehicles coming in for a shift change would be at operating temperature, while those leaving would be in a cold start condition.

In these cases (and perhaps others) the observer would be safe in assuming a very small percentage of vehicles running anomalous to the particular logically assumed conditions. Probably in such cases it would hardly be worth the effort to undertake sampling except perhaps to check scanning equipment operation. In general, however, no time-based definitions will be suitable for field conditions. A temperature-based set of definitions must be developed.

2.4 Difficulties in Developing Temperature-Based Definitions

Aside from the two references already cited, the literature search has yielded information useful as background material only. At best, operating temperature is treated as a theoretical concept, rather than a reality. There is ample reference to a minimum normal temperature, which is the temperature at which the thermostat opens. This varies from 71 degrees C to 93 degrees C (160 degrees F to 200 degrees F), depending upon the vehicle. However, there are pressure caps presently being used which allow the coolant to approach 149 degrees C (300 degrees F) before boiling, the purpose being to allow the engine to run near 93 degrees C (200 degrees F) without any chance of boiling away the coolant, according to H. E. Ellinger (3). Unfortunately, it is not clear what portion of the engine will be maintained at this temperature. On the other hand J. F. Gulau (6) implies that temperatures in the engine compartment range from about 110 degrees C to 172 degrees C (230 degrees F to 340 degrees F) normally. Lastly, while it might be inferred that the exterior operating temperature of the engine block may range from 71 degrees C to 172 degrees C (160 degrees F to 340 degrees F), there are obvious pitfalls in choosing this range as "operating temperature".

Certainly none of the publications reviewed indicates a method of finding the temperature range ("hot", "cold", or "operating") of an engine under so-called normal driving conditions, nor did a search through the Engineering Index from 1960 through 1976 produce any technical papers of immediate value. It appears, in fact, that there is no overall engine operating temperature, but rather a different operating temperature for each component or system, which when taken collectively form the basis for the intuitive, undefined term of "operating temperature" found in the literature.

While the literature search did not produce the desired set of definitions, it did show that there is a wealth of publications dealing with automotive engine operation and resultant air pollution. These range from rather esoteric engineering texts to tune-up manuals, and provide a thorough grounding, as well as occasional specific bits of useful information. Taken as a whole, these publications can provide a sound basis for the vehicle operation experiments, which in turn should result in the set of practical definitions originally sought.

3. Conclusions

As stated above, there are many operating temperatures, each system having its own, but there seems to be no overall "operating temperature" which would satisfy the project needs. It is, therefore, necessary to choose a system (or systems) which will best serve these needs. References (4) and (9) indicate the engine cooling system and engine lubrication system are the most likely choices. Furthermore, there is no evidence to the contrary, or to support other choices. From (9) then, the following definition may be made:

Operating Temperature:

The temperature occuring in the engine cooling and lubricating systems ten minutes after the thermostat opens, assuming driving conditions remain substantially the same throughout. This temperature varies over a rather narrow range (± 8 degrees C, 15 degrees F) during normal highway and city driving.

This definition is based on time, and is not generally applicable to formulating a prediction method, as discussed in Section 2.3. However, it has been developed from extensive field data, and is, therefore, a considerable step forward.

4. Recommendations

The literature search has not resulted in the required temperature-based definitions of "operating temperature", or "hot" and "cold" starts. It is logical to assume, therefore, that they must be arrived at by some other means. One such means is to use the information gleaned from the literature search as a basis for instrumenting a number of vehicles, applying the definition of operating temperature, and recording and analyzing the data thus obtained. This data would in fact, be the basis for further tests using a scanning device of the type eventually to be used once a sampling plan is devised. The final result would be practical definitions of the terms in question, based on temperature rather than time, and incorporating such devices as are appropriate for sampling under actual field conditions.

APPENDIX I

DEFINITIONS

1) Cold Start Operation (See page 6, Preliminary Edition of Supplement 5 to Compilation of Air Pollution Factors (AP-42):

   a) Catalyst Vehicles (1975 and subsequent model years) - This condition exists in the first 505 seconds of vehicle operation following a one hour or longer engine off period.

   b) Non-Catalyst Vehicles (1974 and prior model years) - This condition exists in the first 505 seconds of vehicle operation following a four hour or longer engine off period.

2) Hot Start Operation:

   a) Catalyst Vehicles (1975 and subsequent model years), (See page 34, AP-42, Supplement 5) - This condition exists during the first 505 seconds of vehicle operation following engine restart after a less than one hour engine off period, which in turn follows a 505 second or longer period of vehicle operation.

   b) Non-Catalyst Vehicles (1974 and prior model years), See pages 23, AP-42, Supplement 5) - This condition does not apply.

APPENDIX II

ANNOTATED BIBLIOGRAPHY

(1) American Society for Testing and Materials, 1972 Annual Book of ASTM Standards, Part 17; ASTM, Philadelphia, Penna.:
Part 17 contains information on fuels and lubricants. The tests described add some background information to that obtained from other sources.

(2) Theodore Baumeister and Lionel S. Marks, Standard Handbook for Mechanical Engineers, Seventh Edition; McGraw-Hill, New York, 1967:
Section 9 contains a condensed, non-mathematical presentation of internal-combustion engine theory and operation. A general reference book.

(3) Herbert E. Ellinger, Automotive Systems- Fuel, Lubrication and Cooling; Prentice-Hall, Inc., Englewood Cliffs, N.J. 1976:
An explanation of the operation of the indicated systems, especially in relation to anti-pollution devices, and a description of methods used in the tune-up and repair of engines using such equipment. Excellent background for understanding present-day automotive engines.

(4) N. E. Gallopoulos, GMC Research Laboratories, Temperatures of Fluids in Passenger Car Power Trains; SAE publication #740337, 1974:
The temperatures of engine oil, transmission fluid and differential lube were measured under steady state conditions. Vehicles used were 1969-1973 model year GM cars, tested on an outdoor circular track. Of primary interest was the range of engine oil temperatures resulting from high speed driving, and the fact that oil temperature is directly related to coolant temperature.

(5) P. W. Gill, J. H. Smith, Jr., E. J. Ziurys Fundamentals of Internal Combustion Engines; U.S. Naval Institute, Annapolis, Md. 1959, 4th ed.:
A textbook on reciprocating internal-combustion engines beginning with a basic, idealized engine, and covering the pertinent areas of thermodynamics, fuels, operations, systems, etc. A good general reference. The chapter on cooling is of special use.

(6) J. F. Gulau, Temperature Environment of Engine Compartment Wiring SAE Paper 710083, 1971, Abstract:
Data developed from this study shows that some engine compartment wiring must withstand temperatures of 231 degrees F to 337 degrees F.

(7) Edward F. Obert, Internal Combination Engines and Air Pollution; Intext Educational Publishers, New York 1973:
An engineering text beginning with basic engine types and their operation, and encompassing all aspects of engine operation pertinent to air pollution. Appropriate theory on thermo-dynamics, combustion, lubrication, and other areas is presented. Useful as general background and as a reference.

(8) Donald J. Patterson, N.A. Henein, Emissions from Combustion Engines and Their Control; Ann Arbor Science Publishers, Inc., Ann Arbor, Mich. 1972:
An introductory text on engine emissions and their control. A good reference book with an extensive bibliography for each chapter.

(9) Scott Research Laborotories, Inc., Time-Temperature Histories of Specified Fuel Systems, Volume I: Scott Project #2602, 1969:
This is a report on the results of monitoring the temperatures at eleven different locations on eighty vehicles of various makes. Monitoring included oil, coolant, and ambient, as well as various points in the fuel and carburetion systems. Driving patterns included both city and highway courses. Of particular value are the time-temperature graphs which are the basis for the theoretical definition of operating temperature in Section 2 of this report.

(10) Society of Automotive Engineers, SAE Handbook, 1973, SAE, New York:
This book contains the industry standards for all automotive materials, parts, systems, tests, etc. The various tests described give some indication of the temperatures encountered in various systems under actual driving conditions.

(11) George S. Springer, Donald J. Paterson, Engine Emissions - Pollutant Formation and Measurement; Plenum Press, New York, 1973:
An engineering textbook presentation, in which each chapter is written by a different author, each treating the subject matter in the light of his own expertise. Certain information on temperature ranges in the exhaust system is of value.

(12) U.S. Environmental Protection Agency, Office of Air Quality Standards Research, Preliminary Edition of Supplement 5 to Compilation of Air Pollutant Emission Factors, (AP-42); Triangle Park, N.C. 1975:
This document is the source of the definitions given in Appendix I of this report.