

A Fuel Consumption Function
for Bus Transit Operations and
Energy Contingency Planning

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16. Abstract The purpose of this project was twofold: (1) to develop a transit bus fuel consumption function based upon relationships found in state-of-the-art literature between bus fuel consumption and various bus operating characteristics; and (2) to recommend pertinent measures of effectiveness which could be used to evaluate various bus operating characteristics and fuel consumption alternatives. These tasks were part of a larger effort under the direction of Wayne State University to develop a bus transit reallocation procedure, or model, which could be used by transit authorities and operators to reduce transportation energy consumption during times of energy emergencies or shortages. Eventually, the bus reallocation procedure would be a part of a transportation energy contingency plan for public transit activities. This study focused on identifying comprehensive observed data which through simple statistical means could be converted to be representative of the spectrum of gross vehicle weights associated with contemporary transit coaches and their variable passenger loads.			
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1. Introduction

This report describes work conducted under a subcontract from Wayne State University, sponsored by the Michigan Department of Transportation, Bureau of Urban and Public Transportation. The purpose of the subcontract was twofold: (1) to develop a transit bus energy consumption function based upon relationships found in state-of-the-art literature between bus fuel consumption and various bus operating characteristics; and (2) to recommend pertinent measures of effectiveness which could be used to evaluate various bus operating characteristics and fuel consumption alternatives. These tasks were part of a larger effort under the direction of Wayne State University to develop a bus transit reallocation procedure, or model, which could be used by transit authorities and operators to reduce transportation energy consumption during times of energy emergencies or shortages. Eventually, the bus reallocation procedure would be a part of a transportation energy contingency plan for public transit activities.

Deterministic expressions and simulations have been developed to relate driving cycles (i.e., velocity, acceleration-deceleration, grade climbing, etc.) to instantaneous fuel consumption, so that the total fuel consumption over a complete driving cycle, or trip, can be calculated.¹ These and other approaches are useful in engineering analyses and vehicle/drive-train design, but their efficacy in accurately describing vehicular performance and fuel consumption under real-world conditions, including driver behavior and other dynamic variables, is suspect.

As a result, this study focused on identifying comprehensive observed data which through simple statistical means could be converted to be representative of the spectrum of gross vehicle weights associated with contemporary transit coaches and their variable passenger loads.

1. Examples are:

"Vehicle Mission Simulation," T. Schutz, K. Klokkenga and D. Strattenfield; Commons Engine Company, SAE paper no. 700567, presented at the Earth Moving Industry Conference, Peoria, Illinois, April 14-15, 1970.

"The Energy Use of Public Transit Systems," Timothy J. Healy, proceedings of the Third National Conference on Effects of Energy Constraints on Transportation Systems, Energy Research and Development Administration, August 1967. See section 2, "Fundamental Mechanics of Transportation Energy Use."

"Vehicle Dynamics Simulation Model" General Motors Corporation Truck and Coach Division, Pontiac, Michigan, 1974. (Out of print).

The following sections identify the parameters which influence bus fuel consumption; present the rationale for selecting those parameters which appear most appropriate for incorporation into the bus reallocation procedures; and present the relationships between the selected parameters and fuel consumption. A final section suggests measures of effectiveness which could be used in the bus reallocation procedures.

2. Fuel Consumption Factors

In a study performed by the Congressional Budget Office (CBO)², it is noted that ". . . the energy savings of changes in an urban transportation system depend on behavioral responses such as increases in the number of trips made, shifts from other modes of travel, changes in vehicle occupancy, and the like. Bus, subway, trolley, carpool, and vanpool tend to be energy efficient on a passenger-mile basis, but if improvements in any one of these services draws passengers from other energy-efficient modes instead of from low-occupancy automobiles, then the effect on energy can be small and possibly wasteful."

"Other factors to be considered in evaluating energy requirements are, first getting to and from public transportation services, and second, the directness of such travel on a door-to-door basis. Fixed-route services are not as ubiquitous as automobile service, and much of the travel on fixed-route services depends on private automobiles for access to stations. As a result, the net energy savings of a trip that uses transit as opposed to trip by private automobile is significantly smaller than appears from a glance at just the transit portion of the trip."

"In short, although some quick rules-of-thumb can be obtained from the conventional index of energy intensiveness (computed by dividing the propulsion energy per vehicle mile by the average number of people aboard the vehicle), a full review of energy savings requires examination of the energy used in manufacturing vehicles, constructing right-of-ways, and maintaining the system; adjustments for access and circuitry; and allowance for the previous mode of travel of new users."

2. "Urban Transportation and Energy: The Potential Savings of Different Modes," prepared by the Congressional Budget Office for the Committee on Environment and Public Works, U.S. Senate, Congress of the United States, September 1977. Serial no. 95-8.

The report delineates nine basic energy components, or factors, of urban transportation and combines these to form a hierarchy of four measures of energy use in which each measure has an increasing level of comprehensiveness. (See Table 1). "Program Energy" is the most comprehensive of the four measures. It combines direct and indirect energy use of transit modes and adjusts for the behavioral response of travelers to result in the total change in energy consumption per passenger mile. The report contains data and ranges of estimates for the various basic energy components and describes the steps required to estimate "program energy."

The basic energy components in "energy intensiveness" are based upon data taken from the literature which is aggregate and average. That is, "energy per vehicle-mile" is based upon a summary of experience of transit properties with various transit modes. The data are not sensitive to operational considerations such as the traffic environment, operating speed, road grade, etc.

The energy components concerned with station, maintenance, construction, and vehicle manufacturing energy do not appear to be relevant to short-term transportation energy contingency planning. However, "mode of access," "fraction of trip devoted to access," "circuitry," and "source of new patronage" may be relevant to measuring the effectiveness of a bus reallocation procedure, even if these variables are in aggregate terms. "Mode of access" measures the energy used to gain access to the transit service. "Fraction of trip devoted to access" gives some indication of access distances. "Circuitry" measures the nonproductive miles that are necessary to provide the transit service.

With regard to circuitry the report notes that ". . . the typical transit trip involves additional miles of travel because of the need to gain access to the linehaul vehicle and because transit vehicles mainly follow fixed routes that do not usually conform to the most direct route desired by each traveler. These problems are most severe for a dial-a-ride service and for fixed guideway systems. Dial-a-ride services average about forty percent more miles than would be required by automobile trips. Carpools and vanpools use fifteen percent more miles, while most buses require even fewer extra miles."

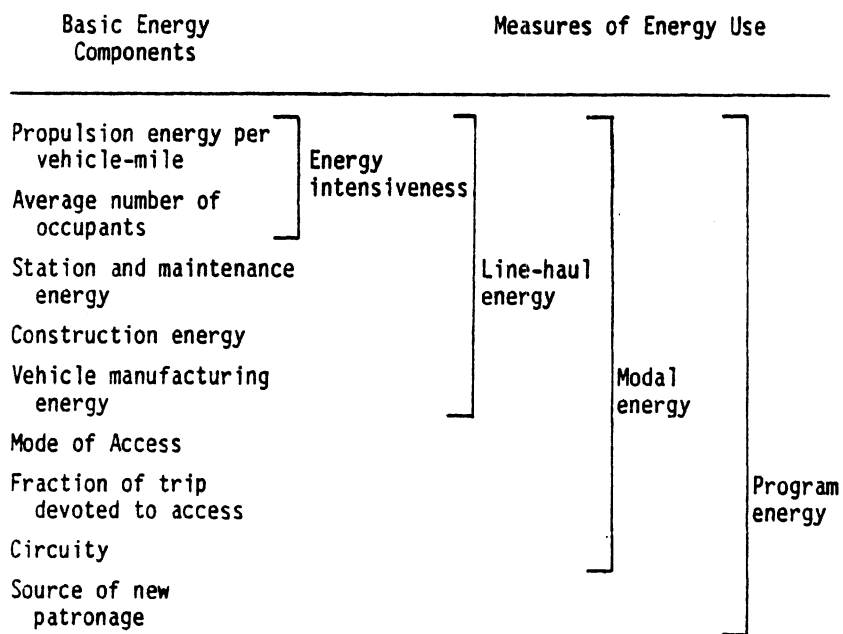
The question of trip circuitry is examined in more detail from a methodological and data point of view in a paper³ presented at the Fifty-Sixth

3. "Dial-a-Ride's Impact On Transportation Energy Consumption in Small Cities, William R. Hershey, the Huron River Group, Inc., Ann Arbor, Michigan, January 1977.

Annual Meeting of the Transportation Research Board in 1977. In the three cities examined by Hershey (Ludington, Holland, and Mt. Pleasant, Michigan), dial-a-ride was shown to be more energy intensive than the mix of alternatives it replaced. The difference between energy required for a dial-a-ride system and the energy required for the alternative modes produces a rough measure of the energy impact of dial-a-ride. This impact is measured in terms of net additional gasoline used, which totaled approximately 3,200 liters (850 gallon) per month for the three cities.

The "source of new patronage" energy component identified by the CBO (Table 1) is comparable to Hershey's analysis of the energy intensiveness of travel mode alternatives to dial-a-ride. The CBO report contains data from several larger cities of the mode split of passengers from former modes to preferred transit modes. The report also contains high, medium, and low estimates of access, circuitry, and source of patronage by urban transportation modes, nationally.

TABLE 1 - CBO STUDY FRAMEWORK



Source: Footnote 1

3. Fuel Consumption Parametric Relationships

A comprehensive presentation of the parameters which influence bus fuel consumption is presented in Figure 1. The parameters take into account the energy efficiency of the bus itself, the influence on fuel consumption of the driving cycle which is based upon the nature of the operation of the bus, the traffic environment in which the bus will operate, and the load factor. Not all of these parameters will need to be used in the bus reallocation procedure. For example, increased altitude increases fuel consumption but this effect should be minimal in Michigan. For a four-thousand-pound passenger car, measurements indicate that below-two-thousand feet altitude has little influence on fuel consumption. Above about twenty-five hundred feet, consumption begins to increase for the same steady-state speed, and dramatically increases when steep grades are encountered (i.e., mountain climbing).⁴ The highest point in Michigan is Mount Curwood, elevation 1,980 feet above sea level, located in Baraga County near L'Ance, Michigan in the Upper Peninsula. There is no indication in the literature that altitude would affect bus and truck fuel economy any differently than auto fuel economy. Therefore, for the bus reallocation procedure it is assumed that the influence of altitude, if any, is the same throughout the state of Michigan.

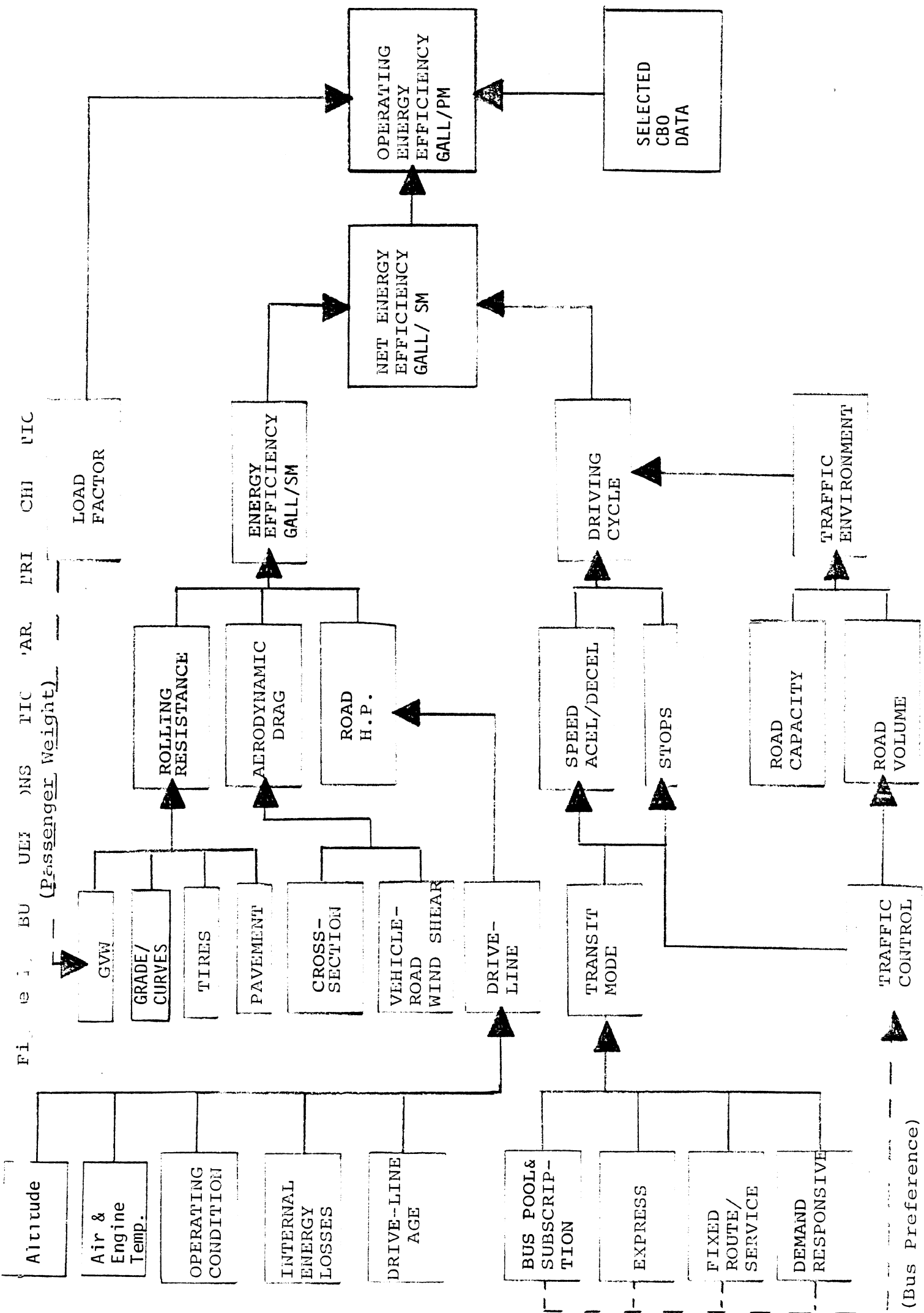
Ambient air temperature and engine operating temperature directly influence fuel consumption. If an evaluation of the bus allocation procedure is desired in which consumption before and after reallocation are compared on a percentage improvement basis, then these temperature factors can be assumed to be equal for both before and after cases. If, however, an estimate of absolute fuel savings is desired, correction factors for ambient air temperature variations will need to be employed (Claffey, 1971).

It has been well documented⁵ that automobiles have excessive fuel consumption when started and run "cold" than when at their designed operating

4. "Running Costs of Motor Vehicles as Effected by Road Design and Traffic" NCHRP Report no. 111, Paul J. Claffey and Associates, Highway Research Board, 1971.

5. "Customer Fuel Economy Estimated from Engineering Tests" Scheffler & Niepoth, SAE paper no. 650861, November 1964.
"A Report on Automotive Fuel Economy" U.S. Environmental Protection Agency, October 1973.
"Soaktime Effects on Car Emissions and Fuel Economy" Srubar, et al. SAE paper no. 780083, March 1978.

Figure 1. BUS UEFI NS TIC 'AR' FRI CHI TIC
 (Passenger Weight)



temperatures. Table 2-A illustrates relative "instantaneous fuel economy" (MPG ÷ fully warm MPG) at operating times after start for various pre-start soak times⁶ in the first part of the EPA city cycle test.

Table 2-B illustrates relative instantaneous EPA city MPG values for both dynamometer and test track operations after soaks of eight hours or more. The data indicate that the fully warmed-up condition and its associated maximum fuel economy is reached by the end of the 7.5 mile EPA city cycle. Similar data for trucks and buses are not available from EPA at this time. If absolute fuel consumption comparisons are desired before and after the bus reallocation procedure is employed, extrapolations from existing auto gasoline and diesel tests will have to be made. However, this may prove to be very difficult. Diesel engines are known to be highly efficient at part load and less so at high RPM. This characteristic and the diesel's higher compression ratio may greatly reduce "run cold" fuel consumption. It is known that for gasoline engines fuel economy increases with average miles driven per day (AMPD), whereas with small diesels fuel consumption is relatively insensitive to AMPD, which suggests that the "warm up" penalty for at least small diesels may be slight.⁷

However, these and other sources⁸ indicate that for normal soak temperatures and cold soak temperatures (below 0°F), larger vehicles and vehicles with diesel engines have better fuel economy characteristics during the warm-up period. This is true over the range of passenger cars tested, and although no data could be found in the literature for buses, trucks or large diesel engines, it would appear that for larger transit vehicles and diesel engines the MPG loss during the warm-up phase would be considerably less than for passenger vehicles. One investigator concludes (Ostruchov, 1979) that "a lowering of soaking temperature results in an increase in fuel

-
6. "Soaktime" is the period of time the vehicle is idle with its engine off before EPA performs tests for emissions and fuel economy. Typically this is overnight at room temperature.
 7. Unpublished EPA Report, Ann Arbor, Michigan 1980.
 8. "Effect of Cold Weather on Motor Vehicles Emissions and Fuel Consumption-II" N. Ostrouchov, Mobil Sources Division, Environment Canada, Ottawa, Canada, SAE no. 790229 presented at the SAE Congress, Detroit, Michigan, February 26 - March 2, 1979.

Table 2-a Relative Instantaneous Fuel Economy

<u>Soak time, hours</u>	Minutes after Start:				
	<u>1.05</u>	<u>2.10</u>	<u>3.15</u>	<u>4.20</u>	<u>8.42</u>
1/2 or less	1.000	1.000	1.000	1.000	1.000
1	0.966	0.961	0.986	0.969	1.024
2	0.862	0.895	0.974	0.952	0.977
4	0.726	0.846	0.894	0.902	0.960
8 or more	0.592	0.739	0.772	0.845	0.929
Miles Traveled:	0.22	0.67	0.82	1.67	3.59

Table 2-b Relative Instantaneous Fuel Economy

<u>Test Site</u>	Minutes after Start:				
	<u>2.33</u>	<u>5.67</u>	<u>8.42</u>	<u>17.33</u>	<u>22.87</u>
Laboratory (Dyno)	0.658	8.884	0.934	0.979	1.022
Test Track	0.657	0.872	0.929	0.972	0.987
Miles Traveled:	0.68	2.65	3.59	6.34	7.50

consumption and there appears to be a relatively greater loss with decreasing vehicle weight..," and "...the temperature sensitivity of fuel consumed by vehicles equipped with diesel engines appears to be significantly lower than the sensitivity of gasoline engines."

The "operating condition" (in Figure 1) which is based upon the state of maintenance and repair is not easily measured in terms of energy consumption. "Internal energy losses" are inherently a part of energy efficiency data for steady-state speed. Detailed information on the fuel consumption effects of "drive-line age" cannot be found in the literature. However, for passenger cars it was indicated that "...for vehicles kept in good running condition through careful adherence to good maintenance procedures ...fuel consumption rates are only five to six percent higher after four years of service and more than 60,000 miles of travel than they were when the vehicle was new." (Claffey, 1971)

"Aerodynamic drag" and the factors which influence it, as well as the efficiency of the drive-line and the delivered road horsepower, are inherently a part of bus and truck steady-state speed energy efficiency data (Claffey). "Rolling resistance," on the other hand, is an important variable with regard to energy consumption. It is influence by the gross vehicle weight, the roadway grade and curvature, tires, and the condition of the pavement. If the influence of tire condition and inflation pressure on energy efficiency could be measured, it is debatable whether it would be useful information, because these factors vary from bus to bus and on the same bus. Underinflation can add to rolling resistance and increase fuel consumption, but for the purpose of the reallocation procedure it is argued that bus fleet maintenance procedures will ensure against chronic underinflation of tires of the vast majority of the vehicles. The influence of gross vehicle weight, grade and curvature, and pavement condition on bus and truck fuel economy is in the literature and can be extrapolated over ranges of values not covered in the data (Claffey).

It has been argued (Healy, 1976) that the effects of passenger weights on fuel consumption is generally not large. It has been noted⁹ that "a BART vehicle with every seat occupied has a total weight of nineteen per-

9. "Total Direct and Indirect Costs of BART," Timothy J. HEaly, proceedings of the Third National Conference on Effects of Energy Constraints on Transportation Systems, Energy Research and Development Administration, August 1976.

cent greater than its zero passenger weight. It is interesting to note that a 4000 pound automobile with five seats has almost exactly the same percentage increase in weight, when fully loaded, as the BART vehicle." Though the similarity may exist between an automobile and a BART car with regard to percentage added by passenger weight, it does not hold true with regard to transit coaches. For a forty foot RTS-2 coach, the curb (empty) weight is 25,463 pounds. With forty-five passengers (at 150 pounds average each) the gross vehicle weight is increased twenty-seven percent to 32,213 pounds. At peak load with maximum standees the GVW is 36,189 pounds, or an increase of forty-two percent.

The "driving cycle" has obvious effects on the net energy efficiency of motor vehicles in general. As indicated in Figure 1, the choice of transit modes will influence the dynamics of transit vehicle operation, in terms of speed, accelerations and decelerations, and stops. Though not depicted in Figure 1, the choice of transit mode (route, area of operations, etc.) will also influence the effect that roadway grade and turning movements will have on bus energy efficiency. Data for these parameters are in the literature (Claffey, 1971) but most bus data will have to be extrapolated from truck operating experience.

The traffic environment will influence the driving cycle in two ways: As road traffic volume approaches road capacity, the level of service declines, and the speed of the traffic stream is reduced as start and stop traffic is encountered; secondly, the driving cycle will be influenced by active and passive traffic controls which may include provision for bus preference operation (e.g., diamond lanes, remote control of traffic lights, etc.). Claffey (1971) and other sources¹⁰ provide data and calculations with regard to roadway capacity and volume and the influence on traffic stream speed with additional variables such as stops per mile.

As indicated in Figure 1, all of the parameters discussed above can be used to calculate "net energy efficiency" as measured in gallons per seat mile. This measure can be converted into "operating energy efficiency in gallons per passenger mile by including load factor information in the calculation.

10. "Characteristics of Urban Transportation Systems" U.S. DOT/UMTA Report no. UMTA-IT-06-0049-79-1, June 1979.
"Highway Capacity Manual" Highway Research Board, Special Report 87 National Academy of Sciences, Washington, D.C. 1965.
"Transportation and Traffic Engineering Handbook, Institute of Traffic Engineers, John E. Baerwald, ed. Prentiss-Hall, Inc. 1976. (see chapter 8 "Highway Capacity" C. Robinson, p. 309).

4. Fuel Consumption Function

Based upon the analysis in the preceding section, the following factors are selected for inclusion in a fuel consumption function for use in analyzing the fuel consumption impacts of various operating characteristics of transit buses.

- (a) vehicle weight
- (b) weight of passengers (load factor)
- (c) speed
- (d) grade
- (e) turning curvature
- (f) frequency of stops and idle time
- (g) fuel consumption (steady state speeds)
- (h) road volume and capacity
- (i) road surface condition
- (j) speed cycle changes.

Operating fuel consumption for modern buses cannot be found in the literature except for Claffey (1971) and the CUTS manual (1979). Data from the latter source are at significant variance with Claffey, and are not substantiated or qualified. The EPA Labs in Ann Arbor do not test vehicles at steady-state speeds. General Motors Corporation does not have such data available, but during the Summer of 1980 will perform tests in conjunction with DOT and SAE at the Ohio Transportation Center and is currently conducting parametric studies.¹¹ It is not known if the GM activities will include testing of buses other than those currently in production (i.e., RTS-2).

Prior to the availability of GM data, or data from other sources, on the contemporary bus fleet, the existing data and relationships developed by Claffey can be used to estimate the operating fuel consumption characteristics of existing buses. Though the Claffey data are nine years old, and the vehicles tested older still, the operating characteristics of truck and bus drive train have not changed significantly during that time period. A second consideration is that the vehicle-weight-to-fuel-consumption relationship is striking (Figure 2), leading one investigator (Ostrouchov 1979) to conclude that "under certain circumstances auto design parameters such as vehicle weight may be better for ranking in-use fuel economy than the EPA values." Thirdly, the

11. See Attachment 1. pp 11-12.

estimated values based on Claffey's data will be used in a bus reallocation procedure on a comparative basis. Such comparisons will seek relative measures of changes in fuel economy performance for different driving cycles, roadway environment, etc.

Vehicle weight is directly related to fuel consumption. Figure 2 illustrates this relationship for automobiles in miles per gallon and is based upon combined city and highway driving cycles used by EPA.

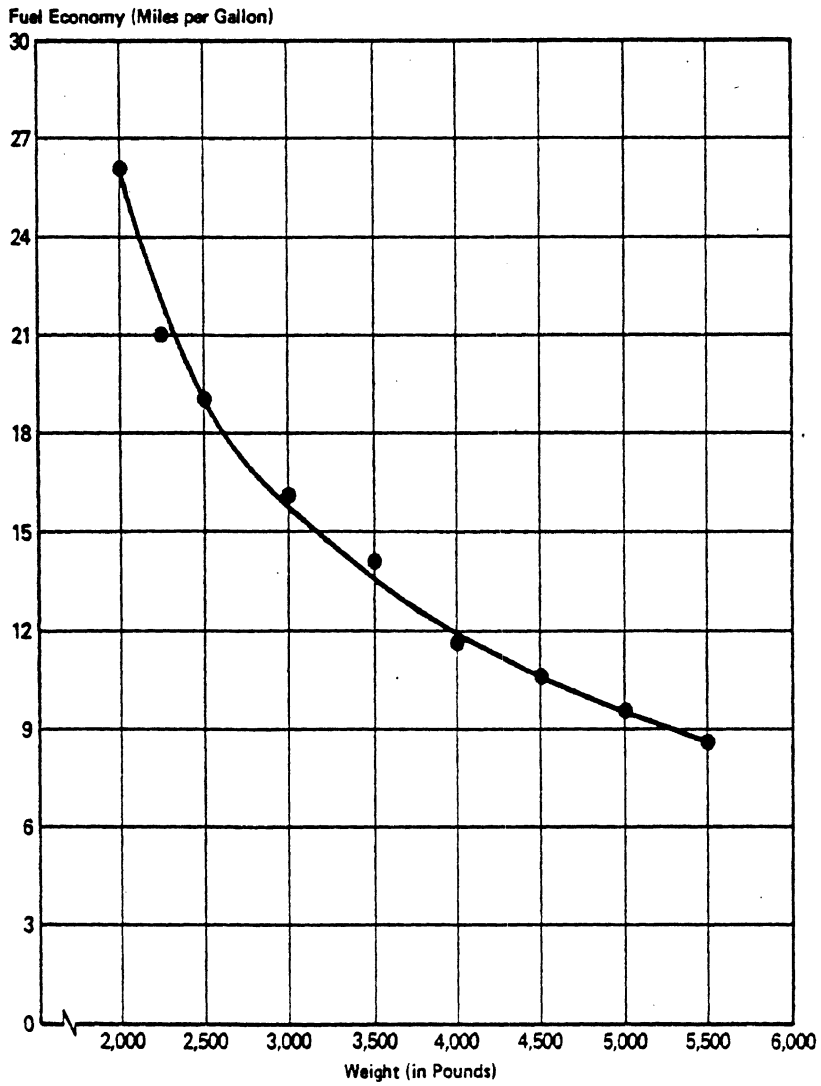
For the bus reallocation procedure a range of vehicle weights from 5000 to 40,000 pounds is required, and to be consistent with the literature and for convenience, fuel consumption should be in gallons per mile for steady-state speeds. Figure 3 presents a regression equation of vehicle weight versus gallons per mile for gasoline-powered trucks and a bus based on Claffey (1971). This plot is for a steady-state speed of 30 mph. Table 3 identifies the points in the plot and includes data for 20 and 50 mph.

Table 4 lists the relevant fuel consumption factors and refers to where values for the factors may be found in Claffey (1971). Table 5 presents two equations which, taken together, form a fuel consumption function. Equation (1) solves for gallons (gasoline) per mile with values taken from Claffey. Equation (2) contains a factor which corrects the Claffey data to correspond to the actual vehicle and passenger weights for buses being analyzed, and a factor to convert gasoline fuel consumption to diesel fuel consumption. Equation (2) then solves for gallons (diesel) per passenger mile.

An example of the broad range of bus vehicle weights which will be encountered when employing the bus reallocation procedure is shown in Table 6. This is a listing of medium and large-size GM transit coaches currently in use, along with their curb weights and gross weights as a function of the number of passengers. In equation (2) G_{MC} is used to correct the Claffey fuel consumption data to allow for the weight of passengers and the particular bus weight under study. An example of the development of this correction factor is shown in Table 7. A bus currently in use, but no longer in production in the United States, has been selected from the GM "new look" series, a Type T6H 5307. The curb weight of the eight-cylinder version of this bus can be found in Table 6. The estimated fuel consumption for this bus at 30 mph steady-state speed can be found using the regression equation in Figure 3. Data point 6 (24,000 pounds) is the closest to the selected bus (22,050 pounds). Table 7 indicates the correction factors which can be used to con-

Figure 2

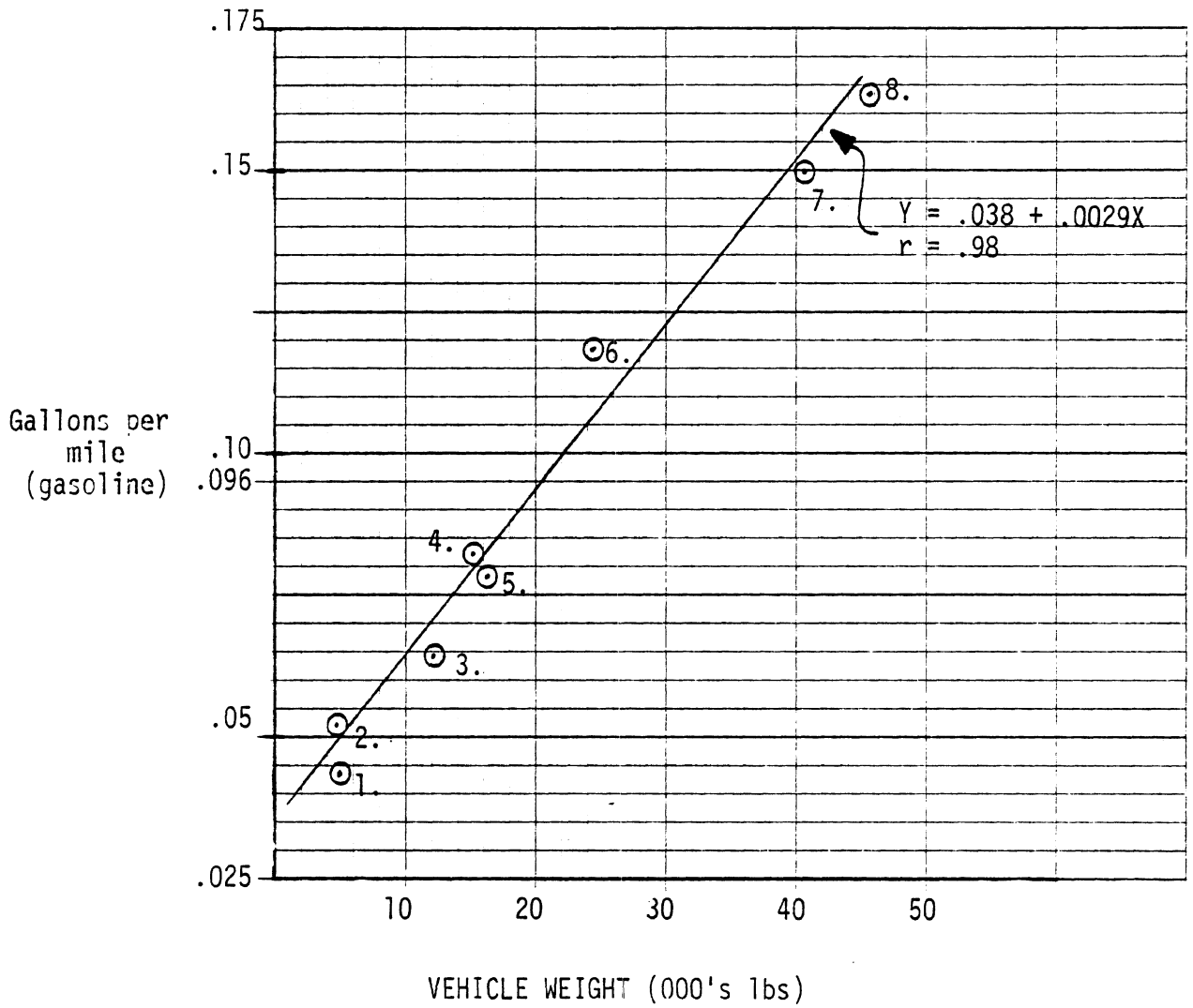
AUTOMOBILE FUEL ECONOMY AS A FUNCTION OF WEIGHT



SOURCE: Based on U.S. Environmental Protection Agency, Office of Air and Water Programs, "Fuel Economy and Emission Control," November 1972.

Figure 3

Bus and Trucks Fuel Consumption
Regression Equation
(30 mph)



- (1) 30 mph steady speed
- (2) No grade
- (3) No turns
- (4) Good pavement
- (5) No traffic

TABLE 3
 Vehicle Weight and Steady State
 Fuel Consumption

<u>Type</u>	<u>Reference</u>	<u>Weight(lbs)</u>	<u>(20mph) Gallons per mile</u>	<u>(30mph) Gallons per mile</u>	<u>(50mph) Gallons per mile</u>
1. Pickup Truck	Table 10	5,000	.047	.047	.065
2. 1964 Chevrolet Sedan	Figure A-18	4,000	.05	.055	.051
3. Truck, 2 axle 6 tires	Table 13	12,000	.059	.067	.101
4. Transit Bus	Figure A-46	14,500	.080	.084	.138
5. Truck, 2 axle 6 tires	Figure A-38	16,000	.077	.081	.125
6. Truck, 2 axle 6 tires	Figure A-39	24,000	.148	.120	.170
7. Tractor-trailer	Figure A-52	40,000	.200	.150	.198
8. Tractor-trailer	Table 16	45,000	.208	.164	.195
9. Tractor-trailer	Table A-52	50,000	.230	--	.240

Source: From Claffey (1971)

TABLE 4.
Fuel Consumption Factors

	<u>Reference</u> (1)
F_{SG} : Fuel consumption at selected speed and grade.	Table 13, A-44 Table 16, A-39, A-38 16C, 16D, 16E
C_{SV} : No. of stops and traffic volume. Correction factor.	Table 13E, 17, A-47, A-4 A-44, A-45, A-53, A-54, A-43, A-39
C_c : Curvature, Correction	Table 13-A, 16A, A-40, A-51
S : Speed cycle change.	Table 15, A-42, Table 18, A-52
C_{if} : Idle fuel (while stopped)	Table 14, 17, 9
C_{rs} : Road Surface. Correction factor.	Table 13B, A-41, Table 16
G_{MC} : Fuel consumption correction factor to allow for weight of passengers and vehicle.	Table 7 (this report)
C_D : Convert gasoline consumption to diesel.	Appendix D Table D-2
G_{MD} : Gallons (diesel) per mile	
G_{PMD} : Gallons (diesel) per passenger mile	
GM : Gallons (gasoline) per mile	
P_M : Passengers, Average per mile	

(1) Claffey, 1971.

TABLE 5

Fuel Consumption Function

$$(1) \quad G_M = F_{SG} + (C_{SV} F_{SG}) + (C_C F_{SG}) + S + C_{if} + (C_{rs} F_{SG})$$

Speed & Grade
Traffic Volume & Stops
Curvature
Speed Change
Idle
Road Surface

$$(2) \quad G_{pMD} = [G_{MC} (G_M)] \quad C_D \quad / \quad P_M$$

Vehicle & Passenger Weight
Diesel Fuel
Passengers

TABLE 6

GM Transit Coach Weights
(Diesel powered except as noted)

<u>Type</u>	<u>Demin.</u>	<u>Engine</u>	<u>Seated Passengers</u>	<u>Average Curb Weight</u>	<u>Average Seated Weight</u>	<u>Crunch Load (w/standees)</u>
RTS-II	102"x40'	6 cyl. (large)	48 max	25984	33184	36709
	"	6 cyl. (small)	"	25463	32663	36189
	96"x40'	6 cyl. (large)	"	25740	32941	36466
	"	6 cyl. (small)	"	25220	32420	35945
	102"x35'	6 cyl. (large)	39 max	24685	30685	33610
	"	6 cyl. (small)	"	24164	30164	33090
	96"x35'	6 cyl. (large)	"	24447	30447	33372
	"	6 cyl. (small)	"	23926	29926	32852

(Models prior to the RTS:)

TGH-4523	n.a.	6 cyl.	45 max	20235	26985	30435
T6H 5307	n.a.	6 cyl. 8 cyl	53 max 53 max	21425 22050	29375 30000	33425 34050
TDH-3302N	n.a.	n.a.	33 max	14360	19310	21860
TDH-3302A	n.a.	n.a.	"	15100	20050	22600
TGH-3301 ⁽¹⁾	n.a.	n.a.	"	14130	19080	21630

Source: Developed from GMC Truck and Coach Division, May 1980. Telephone communication.

(1) Gasoline powered.

TABLE 7

Example Calculation of G_{MC}

Selected bus:

Type T6H 5307 (GM)

53 Pass., Diesel, 8 cyl.

(30mph, 0⁰grade)

Curb Weight 22050# : .102 gpm ⁽¹⁾

(Claffey) 24000# : .120 gpm ⁽²⁾

To correct Claffey fuel consumption for selected bus:

$$.120c = .102$$

$$c = .85 \text{ correction factor}$$

26 pass wt. 25950# ⁽³⁾ = .114 gpm

(GVW)

24000# : .120

$$.120c = .114$$

$$c = .95 \text{ correction factor}$$

53 pass wt. 30,000 ⁽³⁾ # : .125 gpm

(GVW)

$$.120c = .125$$

$$c = 1.04 \text{ correction factor}$$

Crunch Load ⁽⁴⁾ 33900 ⁽³⁾ # " 1.35 gpm

(79 pass)

(GVW)

$$.120 = .135$$

$$c = 1.13 \text{ correction factor}$$

(1) From Figure 3 : $Y = .038 + 0029x$

(2) " " " : Point 6. (Claffey)

(3) Avg. 150#/pass.

(4) [Total seats x 50%] + Total seats = "crunch"

vert the Claffey data to estimated fuel consumption data for the selected bus with different passenger loads at a steady-state speed of 30 mph. In order to calculate correction factors for different speeds, regression equations are presented in Figures 4 and 5 for 20 mph and 50 mph, respectively, based upon the data in Table 3. Figure 6 illustrates the equations and lines for all three steady state speeds.

A typical transit coach driving cycle is summarized in Table 8. The fuel consumption factors that relate to equations (1) and (2) in Table 5 are listed in the left column. In this example the driving cycle is broken into one-mile segments, the total bus route being four miles long. Table 9 illustrates the application of the fuel consumption function equations to the typical driving cycle. Equation (1) solves for "gallons per mile" (gasoline) using Claffey data exclusively. Equation (2) solves for gallons per passenger mile (diesel) using correction factors and load factor information. Table 10 summarizes results which can be obtained from the solution of equations (1) and (2) for the example driving cycle, both in gallons per mile and miles per gallon. Table 11 presents correction factors for steady-state speeds of 20, 30, and 50 mph for a range of vehicle weights of 14,000 to 36,000 lbs.

5. Measures of Effectiveness

Two general effectiveness measures suggest themselves for the evaluation of bus reallocations and operations to conserve energy: impacts on fuel consumption, and impacts on level of service. Each measure is composed of several components, and in some cases they are competitive, if not mutually exclusive.

If the energy scenario used for the bus reallocation analysis does not place a limit on the amount of fuel supplies allocated to the public transit sector during an energy emergency, then fuel consumption per se (gallons per seat mile) is not, by itself, a relevant measure. If the objective of the bus reallocation is to reduce in absolute terms the amount of fuel consumed by a particular property, then gallons per mile or gallons per seat mile is a crucial measure of effectiveness (shown as "net energy efficiency" in Figure 1). If, on the other hand, the reallocation procedure is employed to reduce the fuel consumption of all transportation modes in the region of

Figure 4
Regression Equation-20 mph

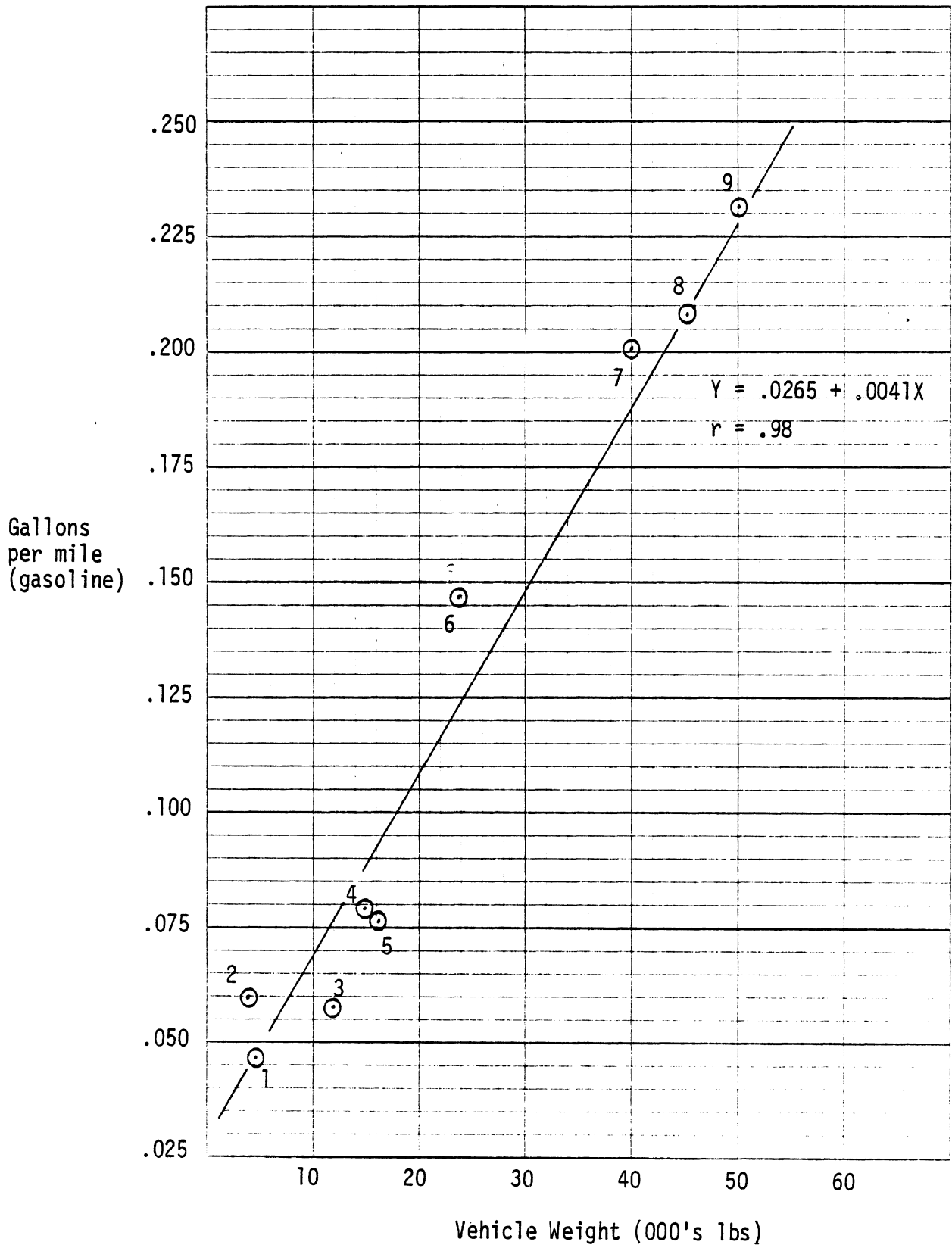


Figure 5

Regression Equation-50 mph

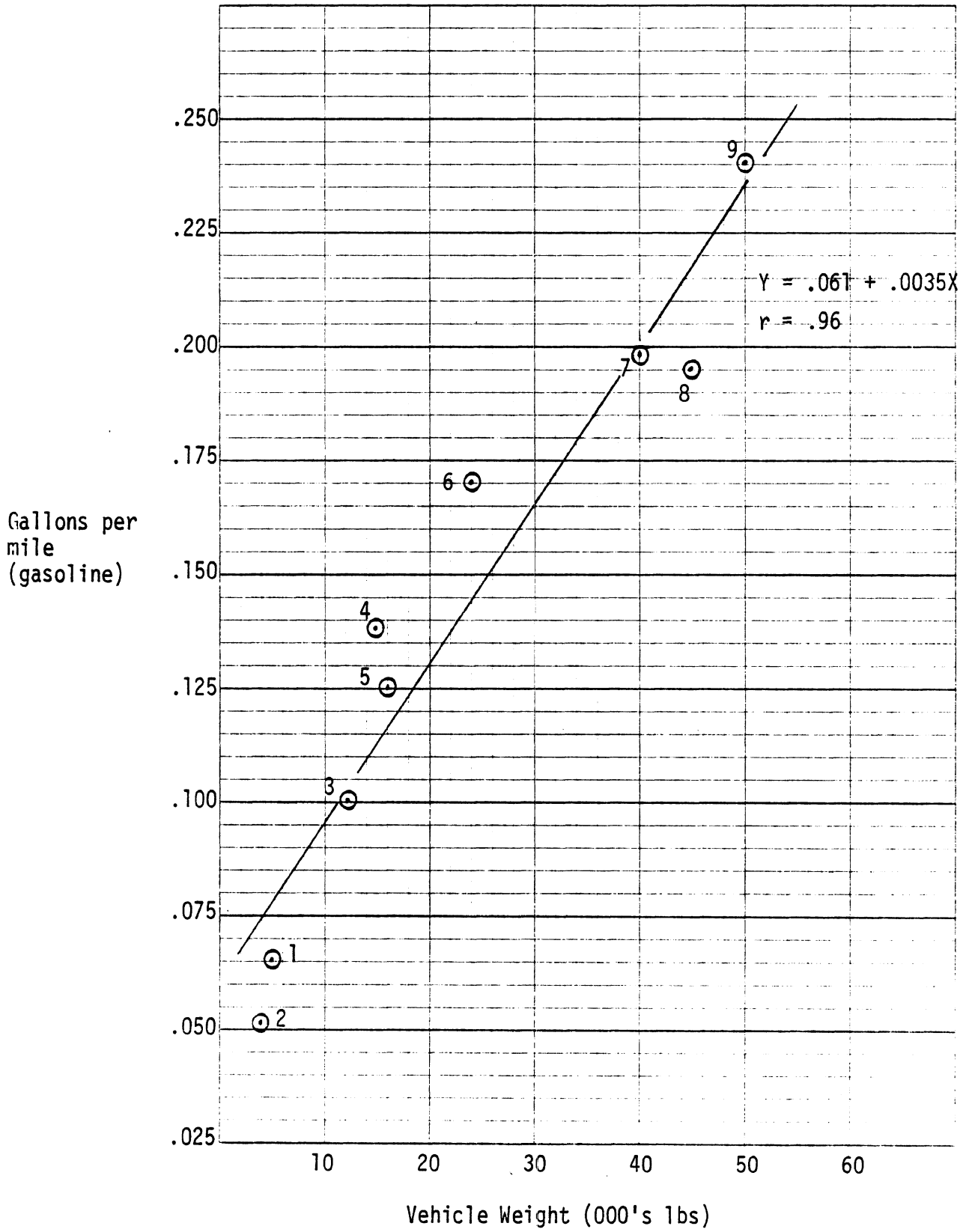
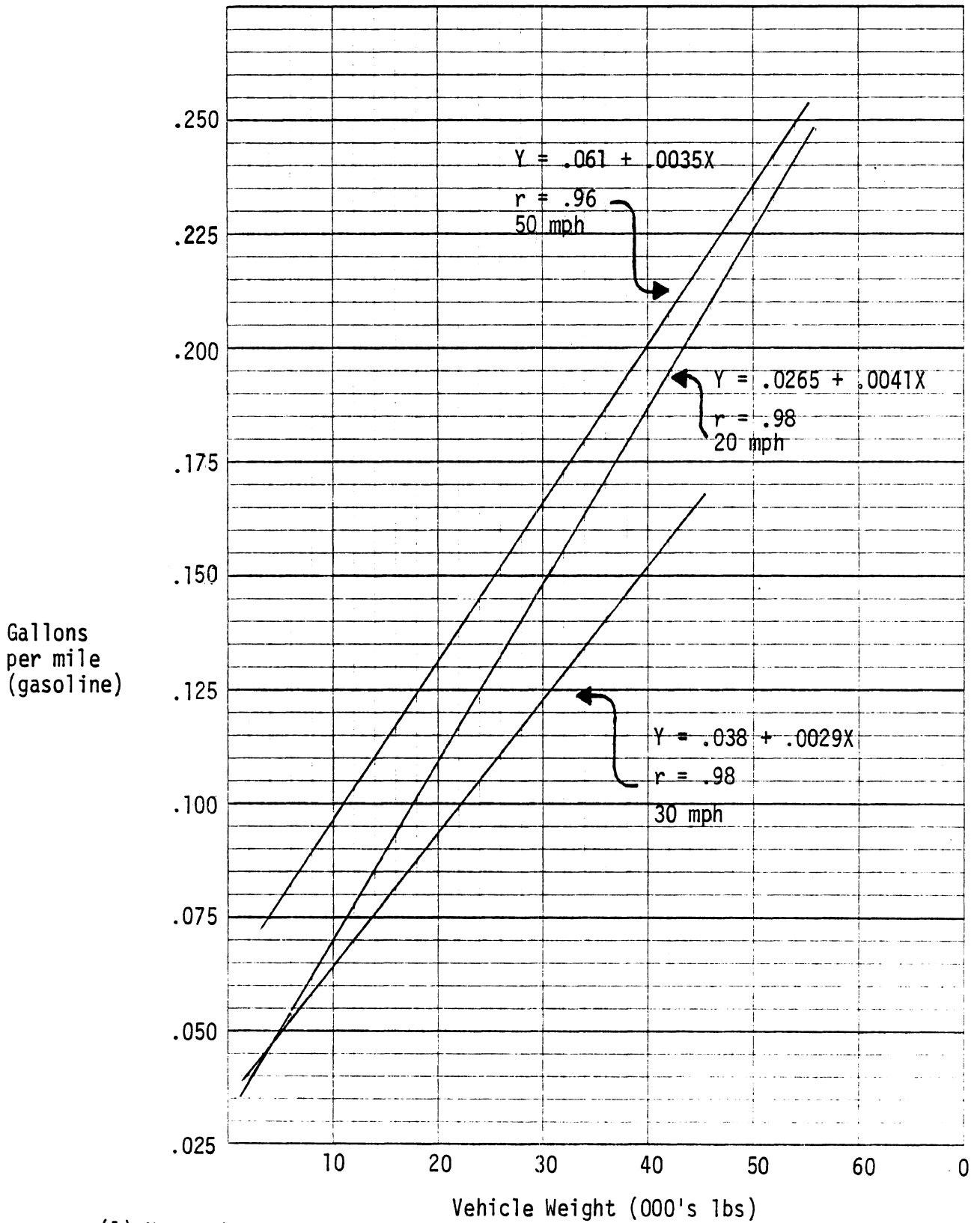


Figure 6
 Bus and Trucks Fuel Consumption
 Regression Equations
 (20,30 and 50 mph)



- (1) No grade
- (2) No turns
- (3) Good pavement
- (4) No traffic

TABLE 8
Driving Cycle-Example

Fuel Consumption Factors	MILES			
	0	1	2	3
Street	4 Lane Arterial	4 Lane Arterial	6 Lane CBD	4 Lane Arterial
Level-of- Service (1)	A	A	C	A
Attempted Speed	30 mph	30 mph	30 mph	30 mph
Stops (30 sec. duration)	2	4	4	2
Grade	0°	+1°	0°	0°
Passengers (Avg.)	26	53	79	53
Curvature	0°	0°	0°	10° (1/10 mile)
Road Surface	High Type	High Type	High Type	Broken Asphalt (1 mile)
Slowdown Speed Cycle Changes	0	0	10mph x.10 cycles	10mph x 2 cycles

- (1) Traffic conditions categorized "A" through "F". "A" is unobstructed driving, free flowing traffic with sustained steady state speeds. "F" is stop and go driving, heavy congestion and inconsistent speeds. See Baerwald (1976).

TABLE 9

Driving Cycle Fuel Consumption Calculation-Example

$$\text{Mile 0-1} \quad (1) \underbrace{F_{SG} + (C_{SV}F_{SG})}_{.195^{(1)}} + (C_C F_{SG}) + S + C_{IF} + (C_{RS} F_{SG}) = G_M$$

$$+ 0 + 0 + .01^{(2)} +) = .205$$

$$(2) [G_{MC}(G_M)] \quad C_D / P_M = G_{PMD}$$

$$(.95)^{(3)} (.205) (.63)^{(4)} / 26 = .0047$$

$$\text{Mile 1-2} \quad (1) \underbrace{F_{SG} + (C_{SV}F_{SG})}_{.338^{(1)(5)}} + (C_C F_{SG}) + S + C_{IF} + (C_{RS} F_{SG}) = G_M$$

$$+ 0 + 0 + .02^{(2)} + 0 = .250$$

$$(2) [G_{MC}(G_M)] \quad C_D / P_M = G_{PMD}$$

$$(1.04) (.250) (.63) / 53 = .0031$$

$$\text{Mile 2-3} \quad (1) \underbrace{F_{SG} + C_{SV}F_{SG}}_{.200^{(1)}} + (C_C F_{SG}) + S + C_{IF} + (C_{RS} F_{SG}) = G_M$$

$$+ 0 + .226^{(6)} + .02^{(2)} + 0 = .446$$

$$(2) [G_{MC}G_M] \quad C_D / P_M = G_{PMD}$$

$$(1.13) (.446) (.63) / 79 = .0040$$

$$\text{Mile 3-4} \quad (1) \underbrace{F_{SG} + (C_{SV}F_{SG})}_{.195^{(1)}} + (C_C F_{SG}) + S + C_{IF} + (C_{RS} F_{SG}) = G_M$$

$$+ (1.28)^{(7)} (.195) + .045^{(6)} + .01 + (1.1)^{(8)} (.195) = .714$$

$$(2) [G_{MC}(G_M)] \quad C_D / P_M = G_{PMD}$$

$$(1.04) (.714) (.63) / 53 = .0074$$

(1) Fig. A-44, Claffey.

(2) Table 9, Claffey.

(3) Table 7.

(4) Table D-2, Claffey

(5) Fig. A-39, Claffey

(6) Extrapolated from Table 15, Claffey,

(7) Extrapolated from Tables 13A & 15A, Claffey

(8) Extrapolated from Tables 13B & 16B, Claffey

TABLE 10

Summary Data
 Driving Cycle Calculation-Example
 (from Table 9)

	<u>Gasoline</u>	<u>Diesel Fuel</u>
Total gallons consumed (4 miles) :	1.615	1.018
Average gallons consumed per mile :	0.404	0.254
Average gallons per seat mile :	0.0076	0.0048
Average gallons per passenger mile :	0.0077	0.0048
Average miles per gallon :	2.48	3.93
Average seat miles per gallon :	131.44	208.29
Average passenger miles per gallon :	130.82	207.31

TABLE 11
Correction Factors (G_{MC}) Based on
24,000# Truck (Claffey) at Various Constant Speeds

Mph	Selected Vehicle Weight (000's lbs)											
	14	16	18	20	22	24	26	28	30	32	34	36
20	.60	.66	.72	.76	.834	.89	.95	1.02	1.07	1.13	1.19	1.24
30	.66	.70	.75	.80	.85	.90	.95	1.00	1.04	1.09	1.14	1.19
50	.65	.69	.73	.77	.81	.85	.89	.94	.98	1.02	1.06	1.10

Regression Equations:

(20 mph) $Y = .0265 + .0041 x$ $J = .140$

(30 mph) $Y = .038 + .0029 x$ $J = .120$

(50 mph) $Y = .061 + .0035 x$ $J = .170$

$$c = \frac{(a + bx)^*}{j}$$

where c : Correction factor

j : Gallons per mile, selected data point : #6, 24,000#
(from Table 3 and Claffey Table A-39)

* : Selected speed regression equation, above.

a transit property, then gallons per passenger mile ("operating energy efficiency" in Figure 1) includes energy "debits" and "credits" for transportation functions associated with the overall person-trip. These functions or variables include the mode of access to the transit service, the percentage of the overall person-trip devoted to access, the circuitry of the transit operations, and the distribution of transportation modes used by new patrons before being diverted to the transit service. Estimates for these variables are contained in CBO (1977), and are discussed in Section 2, above.

"Level-of-service" attempts to measure the quality of transportation supply, which is often measured in terms of overall trip time from origin to destination. The components of this measure are access time, waiting time (frequency of service), ride time (line haul) and time from the end of the transit service to the final destination. Some of these variables can be estimated from CBO (1977) and can be developed from the spatial characteristics of reallocation design alternatives.

Many other variables have been proposed to measure "level-of-service" and it has been recommended that research be conducted to develop an operational definition of level-of-service which is both internally consistent across transit modes and externally comparable to the highway level-of-service definitions.¹² Other variables are bus schedule integrity, seat availability, fare rate and structure, bus stop shelter availability, interior and exterior design of the vehicle, accessibility of the vehicle and the overall transit system, comfort, aesthetics, and other system attributes, real or perceived. However, it is suggested that during times of energy emergency or during times of enforced energy conservation for all modes most of these additional level-of-service variables will be relegated to third and fourth levels of importance as a matter of public policy.

Depending on the energy emergency scenario used in the evaluation of alternative reallocation designs, significant increases in demand for bus

12. "Level of Service Concepts in Urban Public Transportation," W. Taylor and J. Brogan, Michigan State University for the Michigan Transportation Research Program, Highway Safety Research Institute, The University of Michigan, Ann Arbor, Michigan, September 1978. Sponsored by the Michigan Department of Transportation. (This report contains an excellent list of references on contemporary transportation level-of-service studies.)

transit can occur such that in many cases, if not most, some deterioration in level-of-service can be expected. In the case of a well run door-to-door dial-a-ride system a high level of service and convenience can be offered but as has been seen, the energy efficiency of such operations is relatively low (CBO and Hershey, 1977). Therefore, it seems appropriate that "gallons per passenger mile" should be the first-order measure of effectiveness, the second order being the ability of a reallocation design alternative to sustain existing travel times and schedule frequency and reliability--or to minimize the reduction in these level-of-service measures.



Environmental Activities Staff
General Motors Corporation
General Motors Technical Center
Warren, Michigan 48090

Date: April 3, 1980
Subject: Summary of GM F.E. Improvements for Medium and Heavy Duty Vehicles
From: E. J. Niederbuehl *E.J. Niederbuehl*
To: Distribution

The attached report on the GM progress in improving heavy duty truck and bus fuel economy has been transmitted to DOT.

I would like to thank you for your support in its development, and include a reminder that this and similar reports by the various members of the Voluntary Truck and Bus Fuel Economy program have thus far discouraged HD vehicle fuel economy legislation.

EJN/wmh

Attach.

cc: Messrs. M. H. Bauer
R. L. Beckmann
W. C. Chapman
M. E. Fisher
D. D. Forester
D. D. Fortune
G. P. Hanley
J. F. Hittle
J. D. Johnson
F. J. Kalvelage
W. S. Kenyon
J. E. Pasek
A. H. Rasegan
J. D. Rosen
L. L. Saathoff
G. W. Schmidt
C. R. Sharp
F. W. Sinks
G. F. Stofflet
H. B. Tyson
C. J. Weatherred
W. L. Weber
S. R. Will

FE 1998



Environmental Activities Staff
General Motors Corporation
General Motors Technical Center
Warren, Michigan 48090

April 2, 1980

Mr. Harry Close, Manager
Voluntary Truck and Bus Fuel Economy Program
Office of Heavy Duty Vehicle Research
U.S. Department of Transportation
National Highway Traffic Safety Administration
Washington, DC 20590

Dear Mr. Close:

This letter transmits updated information which General Motors annually shares with members of the Voluntary Truck and Bus Fuel Economy Program. It reports GM progress during 1979 in assisting our truck and bus customers to conserve fuel in the operation of their commercial vehicles.

In reporting our efforts for the previous three years (1976-1978), we furnished detailed information on such items as improved automatic transmissions, plans for medium-duty diesel engines, release of information on fuel-efficient products, and the market penetration of these devices that had been achieved through January of 1979. The attached summary updates this information and, in addition, covers new products and increased efforts at General Motors directed toward conservation of fuel in commercial vehicle operation.

This reporting period saw the start of production of the 8.2 liter "Detroit Diesel" engine. In over six years of development, this engine was designed specifically for medium duty truck application and is produced in a new manufacturing facility with more than 473,000 square feet under one roof. Customer acceptance of this engine is greater than our initial sales projections.

We are pleased to provide you with information on our programs to improve further the fuel economy of our products, and you may feel free to share this with the other members of the program. We believe that this exchange of ideas on the progress of the Voluntary Truck and Bus Fuel Economy Improvement Program has contributed greatly to its success.

If you have any questions on the material, please feel free to contact George Hanley of my staff.

Sincerely,

T. M. Fisher
for T. M. Fisher, Director
Automotive Emission Control

3EJN/326/5

Attachment

12-1550

Summary of General Motors Fuel Economy Improvements

For Medium and Heavy Duty Vehicles

This summary updates General Motors efforts during 1979 to further improve the fuel use efficiency of commercial vehicles. It is our fourth annual report as a member of the Voluntary Truck and Bus Fuel Economy Program. We believe that this exchange of information has greatly contributed to the success of the program, and has helped to establish a credible base for commercial vehicle fuel economy improvement claims. It also has provided evidence that fuel economy legislation for these vehicles is not needed.

Six major phases of General Motors participation in the program are identified as follows:

Fuel Efficient Option Availability - General Motors has expanded availability of fuel efficient products.

Customer Education - General Motors has increased the dissemination of new product information and the publication of economy tests, fleet experiences, etc., in the communications media.

Market Penetration Achieved - General Motors has provided statistical data which are used to measure the degree of the fuel efficient option popularity.

Development of New Fuel Efficient Products - General Motors has developed new products to improve the fuel efficiency of new trucks, engines and transmissions and has supported the application of fuel efficient engines in busses and improvements in transit system operations.

Support of the DOT/SAE Truck and Bus Fuel Economy Program - General Motors has contributed to the success of the program by its active participation.

Fuel Economy and Emission Control Interaction - General Motors continues to express its concern over the often conflicting requirements of energy conservation and emission reduction.

Fuel Efficient Option Availability

General Motors has and will continue to concentrate on greater usage and further development of fuel saving components which have been introduced in recent years. We will increase the fuel efficiency of our vehicles by broad applications of technological developments such as:

High Torque Rise (Constant Horsepower) Diesel Engines
Aerodynamic Vehicle Design and Add-On Devices
Light Weight Components

Carryover of Dragfoiler® Application - The Dragfoiler® which was specifically optimized for unique application on our Chevrolet and GMC lines of Class 7 and 8 line-haul tractors and van-type trucks is carryover for 1980 model year (MY) line of heavy duty trucks.

Increase of Fuel Efficient Engine Application - Four additional diesel engines have been added to the General Motors (GM) 1980 MY line of medium and heavy duty trucks. These new offerings include the new Detroit Diesel Allison Division (DDAD) 8.2N (naturally aspirated) and 8.2T (turbocharged) engines, the Caterpillar 3208 and the Cummins VT225 engines. The Cummins VT225 is also available on the 1980 MY heavy-duty (HD) "Brigadier" and "Bruin" trucks. Other new fuel economy engines for 1980 MY include the DDAD 6V-92TTA, (307 HP @ 1900 RPM) and the Cummins NTC 300 Formula, (300 HP in the 1800 or 1900 RPM version). These engines have excellent specific fuel economy. The release of the Cummins Big Cam II engine provides an additional fuel economy improvement.

Introduction of New Truck Models - During MY 1980, the GMC Truck and Coach Division (GMC) will introduce the "Top Kick," a 92 inch BBC (bumper-to-back-of-cab) model medium-duty short conventional tractor. It is especially suited for pulling trailers in congested metropolitan areas and features a new five-piece molded fiberglass front end for reduction in weight and improved fuel use efficiency.

Increased Use of Lightweight Components - For 1980 MY, the "General/Bison" and "Astro/Titan" will be equipped with lightweight components as standard equipment, which were previously optional. These include tapered-leaf rear springs on the Astro/Titan model and tapered-leaf front springs on the General/Bison model with weight savings of approximately 94 and 90 lbs respectively per vehicle. Sheet molded fiberglass doors providing a weight reduction of 20 lbs were released on these models for the 1980 MY. On the Astro/Titan model, the lightweight chassis options were made standard decreasing vehicle weight by approximately 475 lbs and a new lightweight bumper, a 30 lb weight reduction, with flexible end caps was released. A weight reduction program is also in progress on the Astro/Titan model for the 1981 model year.

Improvements in Aerodynamics - GMC is actively pursuing a development program to improve the aerodynamics of all of its truck models. An actual vehicle has been assembled with aerodynamic equipment and scale model wind tunnel tests are being conducted on other models to evaluate the effectiveness of the proposed improvements.

Fuel Efficient Option Availability - The table below summarizes the major fuel efficient (FE) components offered by GMC either as optional or standard equipment.

	<u>Medium Conv.</u>	<u>Bruin/ Brigadier</u>	<u>Bison/ General</u>	<u>Titan/ Astro</u>
Radial Tires	Optional	Optional	Optional	Optional
Diesel Engines	Optional	Standard	Standard	Standard
FE Diesel Engines	Optional	Optional	Optional	Optional
Demand Fans	Standard	Standard	Standard	Standard
Low Axle Ratios* (i.e., 3.55, 3.70, 3.90)	Optional (5.83)	Optional	Optional	Optional
FE Transmissions (i.e., 6, 7 and 9 Speed)	Optional (4 & 5 Speed)	Optional	Optional	Optional
Dragfoiler	None Offered	Optional	Optional	Optional
Weight Savings	Standard	Standard	Opt/Std	Opt/Std

*Axle ratios are matched to FE engines for optimum economy.

In addition to these major fuel efficient components, there are many more design improvements and options that are offered which increase the fuel economy (FE) of the vehicles sold by GM. Our current model year truck sales data books contain this information and special dealer bulletins advise of new available fuel efficient options. For example: the "Astro" Class 8 line-haul tractor, in addition to its standard lightweight components is also available with many more lightweight, extra-cost options which will reduce its weight by an additional 1,500 lbs.

Other optional FE equipment includes the availability of the Low Tire Pressure Sensing System produced by the AC Spark Plug Division. This system is designed to detect low-tire-pressure conditions and to automatically relay them to the driver. Since improperly inflated (underinflated) tires adversely affect fuel economy, proper tire pressures are not only an important safety consideration but also contribute to improved fuel economy.

GMC is actively pursuing a development program involving cruise control and road speed governor systems. These systems are being road tested now and evaluated for possible future availability.

Customer Education

The sales promotion materials which are provided to our dealerships and the advertisements which are placed with various public media (newspaper, trade magazines, weekly's, radio, TV, etc.) promote more than ever before the fuel economy aspects of our vehicles and the improvements that can be achieved by a careful selection of components (standard or optional).

Dealer and Driver Training Programs by DDAD

DDAD--Transmission Operations--has continued in its efforts to improve the fuel economy of the in-service vehicle fleet through an active program of dealer and driver education which has greatly contributed to the overall voluntary national program to conserve energy.

Major Fleet Driver Training Programs - In excess of 1,000 man hours were expended during calendar year 1979 to supervise driver training for approximately 50 major fleets across the country for the purpose of improving their effective use of vehicles with automatic transmissions and maximizing the fuel economy and productivity of those vehicles.

Dealer Handbook Publication and Dissemination - Approximately 6,000 original equipment manufacturers (OEM) customized dealer handbooks were mailed directly to the highest producing dealer sales personnel for the nine major OEM's in the United States. These handbooks contain availability, specification and product definition information which insures proper installation and truck specification for maximum fuel efficient use of Allison automatic transmissions.

Major Fleet Fuel Consumption Study Program - We have continued and expanded programs with almost two dozen major fleets around the country to establish and utilize record keeping systems to develop data for effective control and monitoring of vehicle fuel usage.

Product Fuel Economy Demonstrations - Approximately a dozen in-vehicle installed transmission demonstrations were conducted around the country for OEM management, to 100 top producing dealers, and for a national cross-sampling of about 200 dealers and 200 major fleets to demonstrate Allison automatic fuel economy performance under actual on-site conditions.

Production of One Millionth Transmission - Recognizing the established fact in the truck and bus industry that the vehicle driver is the one most significant variable affecting overall vehicle fuel economy, the Allison Automatic Transmission is designed to minimize the adverse effects of this driver variable. To this end, achieving the millionth unit production milestone must be commensurate with maximizing overall national fuel energy savings.

Chevrolet Promotes Increased Fuel Economy

Our Chevrolet Division has increased its efforts to promote fuel efficiency of vehicles and components to its dealers and customers. It has launched an aggressive educational program emphasizing the fuel economy features of its products including the availability and proper application of the newly introduced mid-range diesel engines.

Medium Duty Diesel Conference - In-depth training on the three new diesel engine offerings was conducted. The major topics included (1) a discussion on proper diesel engine application; (2) 16 mm films on DDAD 8.2 and CAT 3208 engines; (3) return on investment (ROI) charts comparing initial purchase price vs. fuel and dollar savings; and (4) familiarization with available Diesel Decision worksheets (should you buy diesel or gas?).

Medium Duty Videodisc - An in-dealership training and consumer visual program which consists of 27 minutes of motion picture (on TV) featuring Chevrolet medium duty value with emphasis on diesel engine offerings, use of heavy duty automatic transmissions to conserve fuel, and proper application of mid-range diesels has been made available.

Medium Duty Truck Sales Brochures - These brochures are available at our dealerships and feature the conventional cab and school bus chassis to promote diesel engines for fuel economy and other customer benefits.

Heavy Duty Truck Sales Brochures - Large quantities of these brochures are made available at our dealerships and to new truck buyers and feature the use of several different diesel engine designs and driveline combinations that help provide maximum fuel economy on our Bruin, Bison and Titan models.

Direct Mail Piece - This Chevrolet release which features the DDAD 8.2 and CAT 3208 engines is being sent to some 270,000 selected owners of current Chevrolet and competitive make medium duty trucks.

Chevrolet Medium and Heavy Duty Data Book - This data book is furnished to Chevrolet Dealers, as well as to several hundred fleet owner/operators across the country. This is significant because, while the book is not a direct advertising medium, it stresses throughout the use of fuel efficient options and components, diesel engine fuel economy, automatic transmission application, etc. and makes that information available at the point of sales finalization.

Increased Emphasis on Fuel Economy by GMC

Materials originating from the GMC Sales Promotion Department to our dealerships have stressed increasingly the fuel efficient aspects of the complete line of GMC vehicles. They outline and draw to the attention of the dealer and his customers the positive achievements in engineering, and component offerings (standard or optional) for improved fuel economy. National and local advertising placed with various public media (newspaper, trade magazines, weekly's, radio, TV, etc.) have stressed the fuel efficient efforts of GMC to provide a line of vehicles that are best suited for fuel economy while providing required performance.

E-Z Specification Truck Orders - GMC has expanded its "E-Z Spec" truck order system. Included are various heavy duty models (Brigadier, General, and Astro) pre-specified and engineered to save fuel and money and still maintain good highway performance. These fuel-efficiency tailored "E-Z Specs" combine high-torque rise diesel engines, transmissions with fewer gears, temperature controlled fans that require engine power only when needed, GMC Dragfoilers®, and radial tires. GMC has also embarked in a program of nationwide vocational "E-Z Spec" seminars with its dealers and sales personnel to provide field input and feedback on component selections and offerings. Mr. Grayson, consultant to the U.S. Department of Transportation, has been retained as a keynote speaker at these seminars. He presents and discusses the results of the "Double Nickel Challenge" which he helped to conduct in cooperation with the Department of Transportation.

Mid-Range Diesel Seminars - GMC invited its entire retail and wholesale organization to participate in a Medium Duty Diesel seminar in Pontiac, on the DDAD 8.2 liter, Caterpillar 3208, and the Cummins VT225 engines. The program stressed the fuel and ROI aspects of these mid-range engines. Mr. Grayson again was the keynote speaker and stressed the fuel consumption advantages of diesel engines in medium duty trucks.

Fuel Efficient Option Market Penetration

At the present time, the 1979 totals for the market penetration achieved by fuel efficient options sold on new vehicles have not yet been reported by the Motor Vehicle Manufacturers Association (MVMA) (through an independent accounting firm). We will, therefore, submit a comparison of the industry composite with the GM only sales figures at a later date to provide an assessment of the GM performance.

Popularity of Fuel Efficient Options on "9500 Series" Tractors

The table below indicates the trend of increased market penetration of fuel economy related components on the GM "9500 Series" tractors.

Percent of "9500 Series" by Model Year
(Astro/Titan Only)

	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980 YTD</u>
Dragfoiler@	4.5	33	32	12	30	34
"Fuel Squeezer"	---	11	26	31	44	30
Cummins "Formula"	1	19	26	44	35	54
Temperature-Controlled Fans	4	38	57	69	99.8	99.9
Radial Tires	4	25	21	36	44	57

Development of New Fuel Efficient Products

General Motors will continue to develop improved and new fuel efficient components (engines, transmissions, etc.) which will, when integrated into a complete vehicle, maximize its fuel economy and performance for the required operating conditions be it a bus or a truck.

New Engine Development - DDAD announced a 307 horsepower version of its popular 6V-92 turbocharged and aftercooled truck engine for on-highway applications. Called the "Fuel Squeezer Plus 307," this new diesel engine model is designed for trucks in the 60,000 to 90,000 lb. gross combined weight (GCW) class.

The new engine was unveiled by the division at the International Trucking Show held at the Anaheim Convention Center. The 307 horsepower rating will provide the trucking industry with a high output engine for good performance while still retaining the fuel economy advantages and other improvements which characterize the Fuel Squeezer Plus line. The new model produces 307 horsepower at either 1,800 or 1,900 governed rpm. The buyer gains the advantages of extremely good fuel economy and excellent over-the-road performance.

With a properly geared vehicle, this engine is more fuel efficient than previous non-aftercooled, lower horsepower models and has added performance.

The Fuel Squeezer Plus 307 buyer will also gain the benefits of the added durability, reliability and performance built into the entire Fuel Squeezer Plus line. Redesigned cylinder liners, matched turbocharger, revised GM unit fuel injectors and an aftercooler are used to produce high thermal efficiency of the engine.

These improvements have led to lower exhaust emission levels and fuel economy increases of up to six percent over the original Detroit Diesel Fuel Squeezer engines.

The Fuel Squeezer engines were introduced by DDA in 1975 with an anticipated 10 to 20 percent improvement in fuel economy when compared to the turbocharged engines operating at 2,100 rpm. The Fuel Squeezer Plus engines were announced in 1978 and offered additional fuel economy as well as a number of mechanical refinements. It is worth noting that the Fuel

Squeezer Plus engines comprised 64% of the total 1979 calendar year truck engine sales.

Introduction of the 8.2 Liter Engine Series - DDAD has started production of the 8.2 liter medium duty truck engine. This new Detroit Diesel "Fuel Pincher" engine, was designed as a fuel-saving substitute for gasoline engines in medium duty trucks, and will be initially available in GMC, Chevrolet and Ford trucks in 1980. Priced considerably lower than traditional heavy duty truck diesels, there is a possibility that under certain conditions, the 8.2 liter (500-cubic-inch) V-8 will provide fuel economy savings of up to 100 percent over comparable gasoline engines.

It is estimated that owners of the "Fuel Pincher" engine, engaged in average city delivery service, will realize sufficient fuel savings to allow full payback of the additional cost of the engine within two years. The buyer will also benefit from the traditional diesel engine advantage of low service cost, long life and dependable service.

Over six years in development by DDAD, the Fuel Pincher also features advanced state-of-the-art technology in the control of noise and exhaust emissions.

Available in two versions, naturally-aspirated and turbo-charged, the engine is rated at 165 and 205 brake horsepower at 3,000 rpm, and is especially suited to medium duty vehicles in the 10,000 to 50,000 lb. GVW range.

Fuel economy is not the only thing that should improve for purchasers of Detroit Diesel Allison's new "Fuel Pincher" diesel engine for medium duty trucks and buses. This new engine will have a 50,000 mile or 24 month warranty. This is more than twice the standard 12 month, 12,000 mile warranty offered on most gasoline truck engines in similar service.

The engine will be produced in a new manufacturing facility specifically built for its production. The plant has more than 473,000 square feet of floor space under one roof. Using the most modern tools and machinery, DDAD has applied advanced manufacturing techniques to help contain production costs.

Transit Bus Development

In last year's report, we discussed in detail the development and evaluation of the 6V-92TA engine as a powerplant for transit and inter-city coaches. We also discussed the conflict between the national goal of fuel conservation and the DOT/UMTA Advanced Design Bus (ADB) specifications including exhaust emission control requirements.

More Efficient Diesel Fuel - During the 1980 model year, No. 2-D diesel fuel was added to the previous recommendation of No. 1-D only for coach engines. Coach engines have been certified for No. 2-D diesel fuel. This change should increase the fuel economy approximately by 15% for the 6V-92TA and 8V-71N engines and 8% for the 6V-71N engine when operating on the ADB Transit Coach Duty Cycle.

The additional advantage of using No. 2-D diesel fuel is lower cost and more readily available fuel.

GMC Powerplant Study Program - A performance trade-off study is being conducted by GMC to help Transit Authorities to order coaches tailored to their individual needs while improving fuel economy and vehicle life.

The following vehicle parameters and their effects on performance and fuel economy will be evaluated:

1. Vehicle Length/Width/Weight (Curb, Empty, Fully Seated, Standees)
2. Tire Size and Type
3. Axle Ratio
4. Engine/Injector Size
5. Type of Diesel Fuel (#1 or #2)
6. Transmission Shift Points
7. Air Conditioning (With or Without)
8. Variation in Maximum Road Speed/Frequency of Stops
9. Variation in Maximum Road Grade

Bus Transmission Improvements - The engine speed at which the first two Detroit Diesel Allison V-730D Transmission Shift Points (Alternate Shift) occur in the 6V-71N equipped coaches have been reduced approximately 150 RPM. This increases the fuel economy by about 8% on the Central Business District (CBD) portion of the ADB Transit Coach Duty Cycle.

Another version of the V-730D transmission (Optional Shift) will be installed with the 6V-92TA engine which has all three shift points at reduced engine speed of 100 RPM when compared to the 8V-71N engine. This not only allows the vehicle to reach a more fuel efficient transmission gear range sooner, but also will allow the use of a lower engine governed maximum speed. Customers who do not require a 60 mph vehicle will be able to reduce the full load engine governed speed from 2100 RPM to 2000 RPM. Improved fuel economy, reduced noise, and increased engine durability should result from this change.

Reduction of Parasitic Power Losses - A new engine cooling fan and fan drive will be introduced in the 1981 MY coach models. The engine power loss has been reduced by 22 horsepower with the air conditioning (AC) system in operation and should result in a fuel economy improvement of approximately 10%.

In conjunction with the new engine fan drive, a more efficient AC system will be introduced in the 1981 MY coaches. This system reduces the AC

compressor power requirement by 10 horsepower by reducing the compressor head pressure. A 5% improvement in fuel economy is expected from this innovation.

New and Improved Automatic Transmissions - Trucks and Buses

DDAD--Transmission Operations--is coordinating automatic transmission development work with Engine Manufacturers to optimize transmission shift points to achieve best fuel economy while maintaining the required vehicle performance.

HT-700 and V-730 Series Transmission Calibrations - Close coordination has been achieved with engine vehicle manufacturer engineering departments and work has been completed permitting revised scheduled shift points to maximize duty cycle engine performance at the bottom of the brake specific fuel consumption (BSFC) curve thereby maximizing fuel economy.

Universal Electronic Controls - Development of universal electronic controls for on highway automatic transmissions has continued. This new innovation in transmission shifting will provide the establishment of more precise shift points and result in improved fuel management.

Introduction of New AT-545 Transmission - A new AT-545 transmission has been designed and developed for the medium-duty marketplace. This transmission incorporates improved internal sealing to reduce hydraulic losses resulting in more efficient clutch application and shifting. Also a deeper oil pan was introduced to reduce horsepower inefficiencies due to oil churning losses.

MT 600 Series 360 Torque Converter - A new Torque Converter to compliment the fuel efficient mid-range diesel engines has been introduced.

MT 654CR Transmission - A transmission for an 1800 RPM engine operation to maximize the efficiency of slower-speed fuel-efficient engines such as the 6V-92 engine has been introduced.

Automotive Turbine Development

DDAD--Turbine Operations--is under contract to NASA Lewis Research Center, funded by the Department of Energy (DOE), Office of Transportation Programs, Division of Automotive Technology Development for a program to demonstrate improved specific fuel consumption and the durability of ceramic components in an existing vehicular truck and bus gas turbine engine. In its efforts to reduce consumption of petroleum in automotive applications, DOE is looking at alternative engines (including the gas turbine engine) for future automotive power trains. The key to utilization of gas turbine engines lies in successful application of ceramic gas path components which permit operation at temperatures well above that of the state-of-the-art for metal alloys.

This program is aimed at application of selective ceramic components to an existing vehicular gas turbine engine to gain experience in ceramic component design and fabrication, material data, engine performance, and component durability. In so doing, it promotes involvement of the ceramics industry in advancing the near term state-of-the-art of the materials for the automotive application.

Specific fuel consumption improvement is a substantial fuel savings over the typical operating cycle. To put this into a more practical perspective, one 300 horsepower engine, operating on diesel fuel No. 2 at 2,265°F turbine inlet temperature over a composite Los Angeles to Salt Lake City and Chicago to Boston truck route while loaded at 70,000 lbs gross weight, should save 28,000 gallons of fuel over 500,000 miles of operation when compared to the baseline all metal turbine engine.

The program will culminate in the first half of 1984 with the fuel consumption improvement potential of higher operating temperatures, made possible by the application of ceramics, to be demonstrated in a truck powered by the third and final ceramic engine configuration, operating at 2,265^oF turbine inlet temperature.

Transit System Operation Improvement

The GM Transportation Systems Center is actively involved in a nationwide program to research, develop and demonstrate innovative transit services, planning and analysis techniques, and transit products with the potential for improving bus service and bus transit operations.

Transit System Efficiencies - In a transportation system--particularly a public transit system in the city--efficient use of equipment and personnel is particularly important to reduce operating expense (and related subsidies) and conserve energy. General Motors has addressed this issue in a program in the Cincinnati area. Working with the Queen City Metro in that city, engineers at the GM Transportation Systems Center developed what is called a Transit Information System. This system consists of instrumented buses which automatically feed operating information (bus location, passenger load and time) to a central control center. Using computers, operations of the system can be analyzed to optimize the use of existing bus equipment and personnel.

An evaluation of this system by the Urban Mass Transit Administration of the DOT confirmed its effectiveness. Studies in Cincinnati showed that information produced by the system could improve productivity by 8 to 10% or more, with related savings, of course, in the total use of fuel. GM is now promoting the introduction of Transit Information Systems in several other cities.

General Motors remains strongly committed to transportation in all forms and recognizes the special need to improve public transit. This

commitment extends not only to improved products and increased efficiencies in those products, but also to research and planning to make public transit a more viable and sufficient choice for those who desire to make a choice.

General Motors is involved in the planning for efficient transportation systems in a number of cities. In Midland, Texas, the GM Transportation Systems Center worked with city officials, employers, and state and federal agencies to develop and implement a public transit system specifically suited to the needs of this city of 75,000.

At the outset of the program, the only public transportation available in Midland was that provided by several social service agencies, mostly to their own clients. Working first with the Chamber of Commerce, the transportation needs were established and prioritized. Existing transportation services were inventoried and major employment centers were surveyed.

In the second phase of the project, alternative transportation concepts were developed, including a conventional fixed route-fixed schedule bus system and a small bus system with flexible operating modes. A demand-responsive and subscription service using small buses was selected.

The new public transportation services for Midland began on February 4, 1980. An agency of the City provides subscription bus service to employees during the morning and evening peak periods and demand-responsive service with advanced notice reservation during the off-peak periods. General Motors is proud of its role in assisting Midland in developing the kind of efficient transit needed at a cost they can afford.

The GM Transportation Systems Center is working with the Central Ohio Transit Authority in Columbus on a Transit Productivity Demonstration Project. The objectives of this project are to try out and compare several methods of gathering information on the use of existing services, the needs for expansion, and the means of providing service.

The information gathering process will use a variety of surveys. On-board ridership counts and interviews will be conducted. In-home and activity center surveys will be taken. Additionally, bus occupancies at peak load points will be determined and automatic data collection will be demonstrated. The costs and effectiveness of these methods to improve bus system productivity and related efficiency will be analyzed. These results will be reported to operators of bus systems of a similar size.

Urban Energy Programs - Cities in several metropolitan areas in the United States have joined with the GM Transportation Systems Center in conducting an assessment of their energy supply and demand, local approaches to possible energy shortages and technologies that might be applied locally to enhance their positions with respect to energy.

The GM Transportation Systems Center is working with groups in five states. These groups include the municipalities of Anaheim, Costa Mesa, Fullerton, Garden Grove, LaHabra, Orange and Orange County in the Southern California group, and the municipalities of Evanston, Glenview, Highland Park, Northfield, Skokie, Wilmette and Winnetka in the Northern Illinois group. In the South Florida group, the municipalities of Fort Lauderdale, Coral Springs, Hollywood, Oakland Park, Pompano Beach and Broward County are included in the program. A New York group includes the city of Rochester, Monroe County and Rochester Gas and Electric Company and a Texas group includes Arlington, Dallas and Fort Worth.

The energy forms to be studied will include those used in the urban environment such as fuels for vehicles, for power generation and energy for homes, industrial plants and commercial and local governmental uses. This assessment will address two objectives.

The first objective is the development of possible contingency plans for local governments in the event of major short-term energy problems. These plans will emphasize the need for continuation of key government services such as police and fire protection and medical services in the event that local energy supplies are severely reduced.

The second objective will be the identification of the needs and capabilities of the cities involved in the program to develop longer-term energy strategies in the event of protracted energy reductions.

Endorsement of MVMA Fuel-Efficient-Option Sales Data Reporting

Recognizing the responsibility under the Voluntary Program for manufacturer associations to publicize and encourage fuel conservation, MVMA publishes quarterly and yearly reports (retroactive to model year 1973), through an independent accounting firm, on the market penetration of fuel-efficient options on new vehicles sold. General Motors fully supports this program and GM divisions furnish their data directly for consolidation.

General Motors also supports the DOT recommendation to include road speed governors and tag axles into the fuel efficient option report. We have also recommended that "after-market" fuel efficient option sales be included, since substantial additional savings come from the in-use vehicle fleet by (1) purchase of fuel-saving components to retrofit these vehicles such as radial tires and aerodynamic devices, (2) driver training and improved driving practices, (3) more efficient routing and scheduling, and (4) heavier truck loads and lower truck speeds.

General Motors has asked the DOT program office to reevaluate the fuel saving potentials of the reported fuel-efficient options using the now verified Type I and Type II In-Service Test Procedures and to publish the appropriate fuel savings on a retroactive basis.

We also support the suggestion by DOT to include fuel savings which are achieved by vehicle weight reductions (standard and optional) into the reportable fuel efficiency items.

Support of DOT/SAE Truck and Bus Fuel Economy Program

The DOT contracted with SAE for the development of a fuel economy measurement program and initiated the program with the Fuel Economy Measurement Conference in Ann Arbor, Michigan in April of 1975. General Motors employees are active members of the SAE Advisory Committee and in all but one of the subcommittees responsible for the development of SAE Recommended Practices for the Measurement of Truck and Bus Fuel Economy.

Vehicles Made Available for In-Service Testing - GMC has been actively supporting the SAE/DOT Fuel Economy Program for the past three years. Two "Astros" were made available and have been used for "real world" in-service testing by numerous fleets throughout the United States. During 1979, the two GMC vehicles accumulated over 200,000 miles in these fleets.

The data collected, using the widely publicized Rockwell instrumentation, is being computer stored and analyzed at the DOT Transportation Research Center for (1) identification and quantification of the major operational and environmental factors affecting fuel economy of trucks during testing and in actual service; (2) refinement and validation of the simulation program; and (3) refinement and validation of the driving cycles.

Support of SAE Recommended Practice Development - General Motors employees, as members of the SAE committees and task forces for the development of SAE Recommended Practices for the measurement of truck and bus fuel consumption, have actively participated in the public demonstrations of the Type I and Type II In-Service test procedure verification as applicable to trucks.

Fuel Economy and Emission Control Interaction

More stringent California exhaust emission standards for 1980 resulted in some increase in heavy-duty gasoline engine BSFC as measured on the Federal Heavy-Duty Engine dynamometer test procedure (FTP). Three unique

engines were developed for California only usage to meet the lower 1980 California emission standards. These engines exhibit a 7-11% increase in BSFC when compared with their Federal counterparts. In 1979, all heavy-duty engines were developed for nationwide usage due to the similarity of Federal and California emission standards. The relatively low California volume and revised volume mix from 1979 to 1980, tend to minimize the impact of these California engines on the 1980 nationwide sales weighted BSFC.

On a nationwide sales weighted basis, average BSFC is projected to increase from 0.723 lbs/BHP-hr in 1979 to 0.726 lbs/BHP-hr in 1980. This represents an increase in BSFC of 0.4% as measured on the FTP.

Diesel engines produced by our Detroit Diesel Allison Division for highway application have also suffered a fuel economy penalty as a result of the more stringent California exhaust emission standards. The average BSFC, based on full load throughout the operating speed range, has increased for the 1980 California certified truck engines from 3 to 10% when compared to 1979.

The DDAD transit bus engine offered in California for 1980 is the 6V-92TA and must meet the more stringent California emission standards. This engine suffered a 20% power penalty and a 15% fuel penalty at full power BSFC in addition to a significantly extended time interval to achieve full fuel delivery following driver command. A special fuel injector and revised turbocharger match are presently being certified with EPA for the California transit bus application. Preliminary development data indicate that the power penalty will be reduced to approximately 7% and the fuel penalty to approximately 6%.

The Western Division of the American Public Transit Association is reported to be promoting a CARB or California Legislative exemption for transit buses from CARB, but not from EPA, emission regulation in the interest of better bus fuel economy and flow of traffic.