LOW TEMPERATURE AUTOMOTIVE EMISSIONS

VOLUME 1
FINAL REPORT

by

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Summary

Fourteen late model vehicles were tested under a variety of conditions in order to determine the effect on carbon monoxide (CO) emissions and fuel economy of three factors:

(1) Extended idling times when vehicles are first started in the morning.

(2) Changes in ambient temperature from 0°F to 70°F.

(3) Tune-ups for vehicles which fail a warm idle emissions test, such as would be administered during an inspection and maintenance program.

The first two factors are believed to play a role in the carbon monoxide air quality problems experienced in Anchorage and Fairbanks, Alaska. The third factor is one potential approach for addressing the CO problem.

The results of the test program support the following main conclusions:

(1) For driving trips longer than about 3½ miles, extended idling during warm-up does not affect trip average CO emission levels. For shorter trips, extended idle times could increase trip average CO emission levels beyond what they would be if the vehicles were started and immediately driven.

(2) Extended idles associated with short trips (less than 3½ miles) can reduce gas mileage by 10-25%. However, with average trips longer than about 7½ miles, no significant fuel economy loss is associated with 2-6 minutes extended idling after a cold start.

(3) Carbon monoxide emissions and fuel consumption increase significantly, as ambient temperature decreases from 70°F to 0°F. The grams per mile increase in emissions appears to be about the same regardless of a vehicle's

warm temperature emission level. Fuel consumption increases by up to 60% at cold temperatures during short trips. Most of the increase in emissions and fuel consumption occurs during the first 3½ miles of driving after a cold start.

(4) Tune-ups for vehicles which fail a warm idle inspection test appear to achieve approximately the same percentage reduction in carbon monoxide emissions at cold temperatures as at warm temperatures. However, the sample of vehicles repaired was limited, and the extent of the repairs appears to have been broader than normally occurs in an inspection and maintenance program.

(5) Tune-ups result in greater increases in fuel economy at cold temperatures than at warm temperatures. Fuel economy improved by 6-16% at cold temperatures after repairs, but only by ½-3½% at 70°F.

LOW TEMPERATURE AUTOMOTIVE EMISSIONS AND INSPECTION AND MAINTENANCE EFFECTIVENESS

H. J. Coutts

1.0 INTRODUCTION

During the winter, Anchorage and Fairbanks often experience high concentrations of carbon monoxide (CO) which are disproportionate to the size of the communities. Carbon monoxide levels in Fairbanks exceeded the 8-hour average national ambient air quality standard of 9 parts per million during 30 days in 1980. In Anchorage, the CO standard was exceeded 45 times during the winter of 1980-81. Peak concentrations recorded in each city are among the highest in the country.

The high CO concentrations are due to a variety of geographic, meteorological, and technical factors. Strong inversions, surrounding mountains, and vehicle emission controls which are relatively ineffective during short trips at cold temperatures all combine to produce a difficult problem.

Many strategies have been proposed for dealing with Alaska's carbon monoxide problem. These include requiring that new vehicles be designed to control CO emissions at low temperatures; requiring that vehicles operated in Fairbanks and Anchorage be "retrofitted" with devices or systems which reduce cold temperature emissions; and the adoption of a motor vehicle inspection and maintenance program. Each of these approaches has been successfully tried in warmer climates; however, none have been evaluated at the cold temperatures experienced in Anchorage and Fairbanks.

This study was part of a cooperative program between the U.S. Environmental Protection Agency, the Alaska Department of Environmental Conservation, and the Alaska Department of Transportation and Public Facilities to evaluate the effectiveness of vehicle inspection and maintenance programs under typical Alaskan conditions.

The Environmental Protection Agency (EPA) provided their Mobile Emissions Testing Facility (METFac) for use in the study. The Department of Environmental Conservation and Department of Transportation and Public Facilities provided funding for obtaining test vehicles and operating METFac during the 1981/82 winter season. By use of this facility, Alaskan researchers were able to run emissions tests according to standard Federal Test Procedures, while allowing the test temperatures to range from typical winter temperatures in Fairbanks to the standard 68-86°F. This latter temperature range is used by EPA to represent the conditions under which air pollution is usually most severe in other states. This study provides the first test results of mass emissions measurements conducted on Alaskan vehicles under Alaskan conditions.

The testing was conducted from January through May 1982 on 14 gasoline-fueled vehicles, 11 of which failed a typical warm climate inspection and maintenance (I/M) test. A total of 187 separate tests were conducted. The vehicles were left standing in the ambient air (cold soaked) for from 4 to 48 hours at temperatures ranging from -40° to 70°F. A modified Federal Test Procedure (FTP) was conducted at 70°, 20°, and 0°F on each vehicle. Emissions of carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NOx), as well as fuel economy, were determined before and after tune-ups. CO concentrations at warm idle were also measured after every driving test.

As part of the I/M evaluation, 2- and 6-minute extended warmup idle times were added to the standard 20-second warmup idle of the FTP during some tests. Studies conducted for the Department of Environmental Conservation have suggested that many drivers allow cold engines to warm up for 2-6 minutes before driving their vehicles. The effect of these extended idles on emissions, as well as on the benefits of I/M, were evaluated.

The following sections of this report describe the test procedures used during the study, the vehicle fleet which was tested, and the results of the testing.

2.0 TEST FACILITIES AND PROCEDURES

2.1. Test Facility

The test building was a large, heated, insulated warehouse in Fairbanks, Alaska. Test and soak temperatures were controlled by a combination of the building's three garage doors and four oil-fired furnaces. The soak temperature was recorded with a Bedford model 5-518 recording thermograph on a 7-day chart graph. Soak and test cell temperatures were also recorded on a Leeds and Northrup type J thermocouple and multi-point chart recorder. The layout of the test garage is shown in Figure 1.

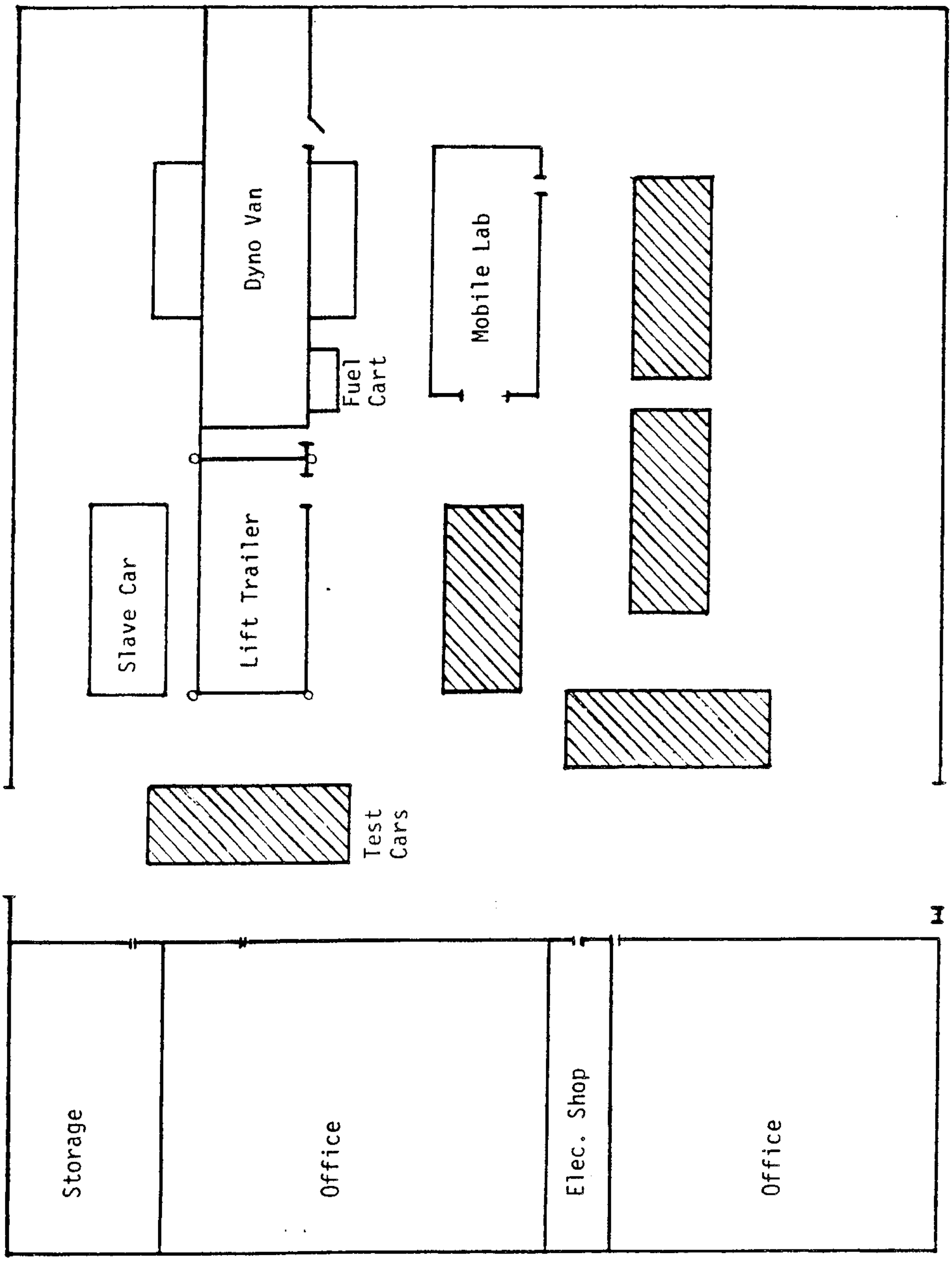
2.2. METFac Unit

The Mobile Emissions Test Facility (METFac) consists of two major units: an 8 by 38 ft. Mobile Laboratory, and an 8 by 40 ft. Dynamometer Van. The Dynamometer Van and Mobile Laboratory contain all the equipment necessary to conduct the FTP.

METFac was built for EPA in 1978 by Automotive Environmental Systems, Inc. to assist in the agency's surveillance and enforcement work.

Figure 1

Layout of Test Facility



The Dynamometer Van contains a chassis dynamometer, a Constant Volume Sampler (CVS) and heating and air conditioning units. The dynamometer is a Clayton model ECE50, capable of simulating the inertia of a vehicle and typical driving loads. The "slave car" shown in Figure 1 was used to bring the dynamometer up to its regular operating temperature at the start of each day's testing.

The Mobile Laboratory houses the gas analyzers, the computer, and calibration gases and blenders for the analyzers. The sample drawn from the diluted exhaust stream or from exhaust slipstream collection bags is pumped to the gas analyzers. The analyzers are connected to a computer and a chart recorder for automatic recording and analysis.

2.3. Test Procedures

The METFac units were designed to test vehicles using standard EPA test procedures. These procedures are described in detail in federal regulations (40 CFR 86 Subpart B), and will not be repeated here. However, in order to accomplish the specific objectives of the study, some variations from the standard test procedures were made. These variations are described below.

2.3.1. Test Fuel

The test fuel used for the study was a typical winter grade of unleaded regular available on Fort Wainwright. An analysis of the test fuel is shown in Table 1. The fuel meets the EPA's boiling range criteria for test fuels, but its octane rating is lower. In addition, the test fuel was not drained and renewed before each test because, at the low temperatures in the test garage, evaporation loss was expected to be small. (Evaporative losses from "aged" fuels can cause a test fuel to vary from EPA specifications after several test cycles.)

Table 1

Test Fuel Analysis
(winter-grade of lead-free gasoline)

54.9° API
Reid vapor pressure 11.25
ASTM D86 distillation

Boil off	°F
IBP	87
10%	102
50%	223
90%	310
EP	390

Motor octane number	83.3
Lead	0.0 g/gal.
Water and sediment	0.0
GUM	2.0 mg/100 mL

2.3.2. Soak Time and Temperature

In the FTP, vehicles are left to stand for from 12 to 36 hours within a specified temperature range, so that the engine will cool down and stabilize. This "soak" time is intended to make test results more repeatable. In this study, however, some test vehicles were soaked for only 4 hours because they were either rapidly warmed to the test temperatures above 60°F or rapidly cooled to the test temperatures of 20° and 0°F. Engine oil temperature, rather than soak time, was used as the criterion for determining when the engine temperature had stabilized.

In addition, nominal soak and test cell temperatures of 0°F and 20°F were used for the cold temperature tests in place of the standard 68-86°F range.

2.3.3. Humidity

EPA procedures require that test cell humidity be controlled to specific limits. However, humidity was not controlled in this program because the humidity control equipment included with METFac would not function when the inlet air temperature was below freezing.

2.3.4. Driving Schedule and Sample Collection

The federal Urban Dynamometer Driving Cycle is designed to simulate a typical 7.5 mile trip. The typical trip is weighted to represent 43% of the actual trips starting with a cold engine (such as during a morning rush-hour commute), and 57% of the trips beginning with a warmed engine (such as after a brief stop for shopping).

In order to reduce testing costs, and to avoid the need to drive two complete 7.5 mile cycles (one cold, one warm), the standard 7.5 mile cycle is divided in two parts: the transient mode, which covers the first 505 seconds and 3.59 miles of driving; and the stabilized mode, which covers the remaining 867 seconds and 3.91 miles. The transient mode is intended to include the period when the engine is approaching its normal operating temperature, while the stabilized mode includes the period after the engine has reached operating temperature. Thus, the composite 7.5 mile trip can be represented by three modes: a transient mode beginning with a cold start; a stabilized mode, equally applicable to a cold or hot start; and a transient mode beginning with a hot start. By mathematically combining the results from the three modes, the emissions from a "standard" 7.5 mile trip can be calculated:

$$FTP = \frac{(0.43)(CT) + HS + (0.57)(HT)}{7.5}$$

where:

FTP = emissions for the federal test procedure, in grams per mile
CT = emissions during the cold transient mode, in grams
HS = emissions during the stabilized mode, in grams
HT = emissions during the hot transient mode, in grams

Emissions samples are collected and analyzed separately for each of the three modes. During the test, the samples are stored in specially treated bags until they are analyzed. Thus, the cold transient sample is called "Bag 1", the stabilized sample "Bag 2", and the hot transient sample "Bag 3".

Three changes were made to the standard driving cycle and sampling procedures. First, during some cold temperature tests, an extra 2 or 6 minutes of idling time was added immediately after the cold start. The emissions during this additional mode were collected and analyzed separately ("Bag 0").

The second change was the collection of a small, continuous sample during the extended idle mode so that the change in carbon monoxide emissions could be followed during the 2- or 6-minute idle.

Finally, for all tests conducted below 60°F, the vehicle's interior heater was turned on to its highest setting. Although this tended to lengthen somewhat the time required for the vehicles to reach their operating temperatures, it was believed to be more representative of typical Alaskan winter driving conditions.

2.3.5. Choke Sensor

On some vehicles, a long leaf-spring microswitch was taped to the air filter housing such that when the choke plate was fully open the switch contacts were closed. The contacts triggered an indicating light in the passenger compartment, so that the test driver could note the actual time when the choke was fully open.

2.4 Data Analysis

For each test, the following parameters were recorded: test number and date; soak (building), test cell (Dynamometer Van) and vehicle oil temperatures; soak time and end of test time; and Bag 0 (extended idle) times. In addition, the CVS mass pump, inlet and differential pressures and temperatures were recorded, as were the concentrations of CO, HC, CO_2 and NOx for each of the three or four bags. After each test, the vehicle's warm idle speed and idle concentrations of CO and HC were measured and recorded both at normal idle and at a fast idle of 2500 rpm.

Emissions were calculated in grams per mode (or bag) for each pollutant. Composite FTP emissions, in grams per mile, were also computed. The emissions from Bags 0 and 1 were combined when calculating composite emissions for tests with extended idle times.

In some tests, the Bag 0 solenoid allowed leakage into Bag 1. When this happened Bag 0 and Bag 1 emissions were added together and recorded as Bag (0+1).

Fuel economy in miles per gallon (mpg) was calculated based on the standard EPA carbon balance technique. No changes were made to the formula, and it was assumed that the METFac test fuel had the same carbon content as EPA's standard indolene test fuel.

2.5 Test Sequence

Scheduling and equipment difficulties prevented the use of an identical test sequence for each vehicle. However, an attempt was made to test each vehicle at least once at each of the following conditions:

Nominal Temperature (°F)	Extended Idle Time (Minutes)
0°	0
0°	2
0°	6
20°	0
20°	2
20°	6
68-86°	0

In addition, the eleven vehicles which failed the warm idle inspection were tuned up after the above tests were performed, and the tests were then rerun. Thus, each vehicle was tested up to seven times before repairs, and up to seven additional times if repairs were performed.

2.6 Test Vehicles

The test vehicles were owned by private individuals and borrowed by ADEC for this test program. The need for test vehicles was advertised in the local press. The incentives to owners of selected vehicles were a $100 savings bond, a free car to use during the tests, and a free tank of gasoline. Since the principal objective of the test program was to evaluate the effects of I/M repairs on cold temperature emissions, vehicles which exceeded an I/M type warm idle CO concentration standard were preferentially selected for the program. The I/M standards used were 1.2% CO for model years 1980-81 and 2.1% CO for model years 1975-79.

No duplicate makes and model years were accepted. In addition, if the emission control system had been tampered with or if parts of it had deteriorated to the point that they were no longer operable, the vehicle was not accepted into the program.

A description of the 14 vehicle test fleet is shown in Table 2. The LeBaron, Corolla and Malibu were accepted into the program even though they did not fail the warm idle CO test.

The 11 vehicles which failed the warm idle test were repaired at a local repair facility. Each vehicle was given a standard tune-up, which included replacing all spark plugs, the fuel filter, and air filter and the positive crankcase ventilation (PCV) valve. In addition, the mechanic would check, and adjust as needed, the ignition timing, ignition dwell and carburetor idle mixture. The mechanic was specifically told to adjust the carburetor if necessary to meet the 1.2 or 2.1% CO idle standard. Cylinder compression and the electrical charging system were also tested.

Table 3 is a listing of the items checked, adjusted or replaced for each vehicle.

Table 2

Description of Test Vehicles

Vehicle Number	Model Year	Make	Model	Engine Size (CID)	No. of Cylinders	Fuel System	Odometer
1	76	AMC	Hornet	232	I-6	1-1V	85,300
2	76	Dodge	Aspen	225	I-6	1-1V	60,900
3	76	Mazda	808	78	I-4	1-2V	84,200
4	77	Chevrolet	Monza	140	I-4	1-2V	44,800
5	78	Subaru		98	H-4	1-2V	26,400
6	80	Audi	4000	97	I-4	FI	22,500
7	80	Chrysler	LeBaron	318	V-8	1-2V	13,600
8	80	Datsun	210	85	I-4	1-2V	30,700
9	81	Plymouth	Horizon	135	I-4	1-2V	7,500
10	81	Ford	Escort	98	I-4	1-2V	32,000
11	81	Chevrolet	Malibu	229	V-6	1-2V	7,500
12	81	Mercury	Zephyr	200	I-6	1-1V	3,300
13	81	Toyota	Corolla	108	I-4	1-2V	3,600
14	81	Toyota	Pick-up	144	I-4	1-2V	16,800

Table 3

Tune-up Parts and Adjustments

Vehicle	Spark-plugs	Air filter	Fuel filter	PCV valve	Distributor parts				Adj. carbur-etor	Modify carbur-etor	Major problem	Adj. fuel inject.
					Rotor	Cap	Points	Condensor				
1. 1976 Mazda	X	X		X					X		X	
2. 1976 Aspen	X	X	X	X					X		X	
3. 1976 Hornet	X	X	X	X					X			
4. 1977 Monza	X	X	X	X					X			
5. 1978 Subaru	X	X	X				X		X			
6. 1981 Escort	X	X	X									
7. 1980 Audi	X	X					X	X				X
8. 1981 Toyota PU	X	X	X	X						X		
9. 1980 Datsun	X	X	X	X					X			
10.1981 Mercury	X	X	X	X	X	X			X			
11.1981 Horizon										X	X	

3.0 RESULTS AND DISCUSSION

3.1. METFac and Vehicle Performance

This was the first time that the METFac unit had been used with Dynamometer Van temperatures as low as 0°F. Modifications for these temperatures were made, but there were still some equipment problems. The low temperatures accelerated wear and tear on the equipment to the extent that many test days were lost to repairing, remodifying and recalibrating the equipment.

Many of the vehicles stalled on the first acceleration after only 20 seconds of warmup at 20°F and 0°F. The Aspen stalled 54 times during one 0°F test and wouldn't reach 40 mph on another 0°F test; it was removed from further testing.

Of 187 completed tests, 163 provided sufficient data for calculating CO emissions: 86 before repairs at cold temperatures, 25 before repairs at warm temperatures, 37 after repairs at cold temperatures, and 15 after repairs at warm temperatures.

3.2. Warm Idle CO Concentration

The warm idle CO concentrations were unstable for the older vehicles, particularly when the CO value was less than 1%. For new vehicles, readings at 0.10% or less were quite stable. The average idle CO concentrations for the 11 repaired vehicles before and after tune-up are listed in Table 4. The tuneups were found to yield an overall warm idle CO reduction of about 90%. The reduction in 2500 rpm CO concentrations was 72%.

One indication of the instability of warm idle CO was that the last four test vehicles were screened, found to have idle CO concentrations greater than 1.2%, and were scheduled for testing one week later. However, when they arrived at the test facility, two were found to have a warm idle CO value of less than 0.2% without an adjustment. The

Table 4

Mean Idle CO Concentration
Before and After Tune-up
0-70°F*

Vehicle	Normal Idle		Percent reduction	At 2500 rpm		Percent reduction
	Before	After		Before	After	
Datsun	4.75	0.24	95	0.04	0.04	0
Toyota Pickup	2.26	0.27	88	0.35	0.26	26
Aspen	3.00	0.10	97	0.16	0.16	0
Hornet	9.00	0.17	98	0.46	0.14	70
Monza	3.07	0.02	99	0.28	0.01	96
Mazda	2.52	2.40	5	0.28	0.88	-252**
Zephyr	1.68	0.0	100	0.33	0.0	100
Escort	0.0	0.0	0	0.24	0.30	-25
Subaru	4.42	0.69	84	0.10	0.16	-60
Horizon	4.15	0.01	100	1.53	0.01	100
Audi	8.13	0.49	95	4.11	0.26	94
Mean			78			14
Mean	3.91	0.40		0.71	0.20	
	Mean reduction = 90%			Mean reduction = 72%		

*Measurements taken with Hamilton Standard Emissions Analyzer.
**Negative values indicate increase in emissions.

vehicle owners stated that the carburetors had not been adjusted since the screening inspection. One of the two vehicles had a fairly rough warm idle, with a tendency to stall; it was rejected from the program. The other vehicle was a Ford Escort that was accepted into the program to see the effect of a tune-up on a vehicle that already had an acceptable warm idle. On another vehicle, the Mercury, the idle CO levels dropped after the third test (before a tune-up), and did not increase again.

In order to minimize the idle CO variability problem at cold temperatures, an I/M program in Alaska may need to include a brief preconditioning (such as a short, high-speed idle) prior to the actual idle inspection.

3.3. Effect of Extended Idle Times on Carbon Monoxide Emissions and Fuel Economy

Thirteen of the fourteen test vehicles had enough tests run to allow a comparison of carbon monoxide emissions with the standard 20-second idle and 2- and 6-minute extended idles. The result of this comparison, shown in Table 5, suggest that extended idle times resulted in only a slight increase in Bag (0+1) emissions (3-5%) and FTP emissions (0-5%).

An analysis of fuel economy data for the same series of tests (Table 6) indicates that the 2- and 6-minute extended idles decrease gas mileage by 10% and 25%, respectively, for Bag (0+1). The results for the full FTP suggest that there is no significant change in gas mileage over the longer, 7.5 mile distance.

A paired t-test of the data (Table 7) indicated that none of the emissions increases were significant at the 80% confidence level. Only the increase in Bag (0+1) fuel consumption was significant at this level.

The reason for the fuel economy effect appears to be that a fixed amount of heat energy is required to warm-up

Table 5

Effect of Extended Idle Time
on Carbon Monoxide Emissions
(Before Tune-Up)

Vehicle	Bag (0+1) 0 minutes	Bag (0+1) 2 minutes	Bag (0+1) 6 minutes	FTP 0 minutes	FTP 2 minutes	FTP 6 minutes
1. 76 Hornet	98.52	101.38	160.09	87.79	90.02	103.54
2. 76 Aspen	75.18	78.52	100.28	35.37	36.38	37.29
3. 76 Mazda	110.59	85.38	139.19	33.77	37.74	35.65
4. 77 Monza	79.95	92.55	121.47	32.60	38.63	49.58
5. 78 Subaru	74.46	35.65	ND	27.58	15.53	ND
6. 80 Audi	36.41	54.08	ND	29.14	41.59	ND
7. 80 LeBaron	92.94	74.65	30.12	23.91	16.32	6.92
8. 80 Datsun	43.18	26.80	35.00	12.35	10.68	12.84
9. 81 Horizon	104.40	ND	ND	34.44	ND	ND
10. 81 Escort	49.14	37.72	ND	16.95	17.40	ND
11. 81 Malibu	127.58	52.67	50.89	27.57	11.70	11.52
12. 81 Zephyr	110.87	229.74	94.16	64.72	77.02	39.17
13. 81 Corolla	47.91	78.65	68.03	10.24	16.74	14.28
14. 81 Toyota PU	71.40	101.40	101.84	29.05	41.42	41.41
Sample size	13	13		13	13	
Avg. Temp.	20°F	18°F		20°F	18°F	
Avg.	78.32	80.71		33.16	34.71	
Std. deviation	28.86	51.28		21.19	24.84	
Sample size	10		10	10		10
Avg. Temp.	15°F		14°F	15°F		14°F
Avg.	85.81		90.11	35.74		35.22
Std. deviation	27.50		43.73	23.60		28.35

Table 6

Effect of Extended Idle Time
on Fuel Economy
(Before Tune-Up)

Vehicle	Bag (0+1) 0 minutes	Bag (0+1) 2 minutes	Bag (0+1) 6 minutes	FTP 0 minutes	FTP 2 minutes	FTP 6 minutes
1. 76 Hornet	10.9	11.7	8.9	13.0	13.0	12.6
2. 76 Aspen	10.3	10.1	7.9	14.1	14.1	13.4
3. 76 Mazda	16.4	17.2	12.4	19.1	21.9	22.3
4. 77 Monza	15.7	13.9	12.0	18.8	17.9	16.8
5. 78 Subaru	22.8	29.2	ND	25.4	38.0	ND
6. 80 Audi	24.4	25.6	ND	24.8	30.8	ND
7. 80 LeBaron	10.1	8.5	7.0	12.4	11.7	11.1
8. 80 Datsun	17.5	15.7	17.4	25.8	24.8	26.1
9. 81 Horizon	24.1	ND	ND	31.5	ND	ND
10. 81 Escort	24.0	27.1	ND	26.3	33.9	ND
11. 81 Malibu	11.2	10.9	9.8	14.9	15.3	14.4
12. 81 Zephyr	12.6	8.5	10.8	14.0	13.9	15.0
13. 81 Corolla	18.8	14.5	14.5	21.3	20.1	21.0
14. 81 Toyota PU	17.5	13.3	12.8	20.8	18.2	19.9
Sample size	13	13		13	13	
Avg. Temp.	20°F	18°F		20°F	18°F	
Avg. Fuel Consumption (gal/mi)	0.067	0.074		0.056	0.054	
Std. deviation	0.021	0.028		0.016	0.019	
Avg. MPG	14.86	13.55		17.95	18.43	
Sample size	10		10	10		10
Avg. Temp.	15°F		14°F	15°F		14°F
Avg. Fuel Consumption (gal/mi)	0.075		0.094	0.061		0.062
Std. deviation	0.018		0.027	0.014		0.017
Avg. MPG	13.36		10.58	16.49		16.11

Table 7

Paired t-test for Extended Idle Times

Carbon Monoxide Emissions

0 minutes vs. 2 minutes:

Bag (0+1): t = -0.19, d.f. = 12, not significant*

FTP: t = -0.62, d.f. = 12, not significant*

0 minutes vs. 6 minutes:

Bag (0+1): t = -0.30, d.f. = 9, not significant*

FTP: t = 0.11, d.f. = 9, not significant*

Fuel Consumption

0 minutes vs. 2 minutes:

Bag (0+1): t = -1.69, d.f. = 12, significant*

FTP: t = -0.85, d.f. = 12, not significant*

0 minutes vs. 6 minutes:

Bag (0+1): t = -5.18, d.f. = 9, significant*

FTP: t = -0.88, d.f. = 9, not significant*

*at 80% confidence level.

the engine and the length of time required for warm-up falls somewhere between the 505 seconds of the Bag 1 portion of the test and the end of the 7.5 mile cycle. With extended idle times, more of the energy required to warm-up the engine is expended during the first 3.6 miles of vehicle operation. The vehicle is more thoroughly warmed up after 3.6 miles of driving after an extended idle and more fuel per mile of travel has therefore been burned. However, an extended idle does not cause a greater amount of fuel to be burned to warm-up the engine during a 7.5 mile long drive. Warm-up is essentially complete before 7.5 miles have been driven whether an extended idle has been used or not.

However, total CO emissions do not appear to increase over a 3.6 mile driving distance when extended idles are used. This apparently indicates that choke pull-off occurs before the end of Bag 1 even though the engine is not thoroughly warmed up. The high emissions associated with choked engine operation may have already been reduced to the much lower unchoked levels by the end of Bag 1, whether or not an extended idle is used. This hypothesis is consistent with choke pull-off times recorded during the testing.

On four of the METFac test runs, a microswitch was installed to indicate when the choke fully opened. In each case the choke was fully opened well before the end of Bag 1. Thus, for driving trips which are at least 3½ miles or longer from a cold start, an extended idle would not be expected to increase average emissions for the trip.

It should be noted, however, that emission rates during the idle period were found to be quite high. Thus, in areas with little air flow and large numbers of vehicles undergoing cold starts, CO concentrations could build up due to the use of extended idle periods. However, to the extent that cold start emissions are mixed with emissions from vehicles which are already driving, such as from a nearby roadway, one would expect no net effect of extended idling.

This is because the emissions from cars driving right after an extended idle would be lower than if the cars were driven immediately after start-up.

3.4. Effect of Temperature on Carbon Monoxide Emissions and Fuel Economy

Ten of the fourteen vehicles were tested at 0°F, 20°F and 70°F; all fourteen vehicles were tested at 20°F and 70°F. The average CO emissions for each vehicle at each temperature range was calculated; the results are presented in Table 8 for Bag (0+1) emissions and Table 9 for FTP emissions.

The data show, quite clearly, that carbon monoxide emissions at cold temperatures are significantly higher than at warm temperatures. Cold start (Bag 0+1) emissions at 0°F are more than four times the levels at 70°F, while FTP emissions are more than doubled. At 20°F, Bag (0+1) emissions are more than triple the 70°F levels, while FTP emissions are nearly doubled.

An additional analysis, shown in Tables 10 and 11, provides some further insight into the problem. This analysis separates the test fleet into two smaller groups: 1976-79 model year vehicles, and 1980-81 model year vehicles. The breakpoint (1980) is the year that more stringent hydrocarbon and carbon monoxide standards took effect.

As the data in Table 10 indicate, vehicles designed to meet the newer standards had 42% lower emissions in Bag (0+1) and 55% lower FTP emissions at the 70°F temperature range where compliance with the standard is judged. This roughly corresponds to the 53% reduction in the standard itself, from 15 to 7 gm/mi.*

*Some 1981 models were required to meet a 3.4 gm/mi standard.

Table 8

Effect of Test Temperature
on Carbon Monoxide Emissions
(grams per mile)
Bag (0+1)
Before Repairs

	Nominal 0°F		Nominal 20°F		Nominal 70°F	
Vehicle	Temp.	Emissions	Temp.	Emissions	Temp.	Emissions
1. 76 Hornet	2	126.12	20	115.10	74	48.00
2. 76 Aspen	2	65.13	20	84.94	71	32.06
3. 76 Mazda	4	145.55	21	75.77	71	18.30
4. 77 Monza	2	116.90	19	86.29	71	38.16
5. 78 Subaru	-	ND	34	55.06	75	15.63
6. 80 Audi	-	ND	35	48.19	70	19.30
7. 80 LeBaron	4	95.54	20	72.54	68	48.12
8. 80 Datsun	4	32.03	20	34.24	68	7.91
9. 81 Horizon	-	ND	34	104.40	73	34.60
10. 81 Escort	-	ND	37	43.43	74	9.78
11. 81 Malibu	3	95.82	17	82.64	71	5.03
12. 81 Zephyr	0	125.63	20	190.42	72	1.34
13. 81 Corolla	5	109.19	20	59.77	69	9.08
14. 81 Toyota PU	1	97.22	23	79.87	71	23.82
Model Years 76-79						
Sample size	4	4			4	4
Avg.	2.5	113.43			71.8	34.13
std. dev.		34.34				12.43
Sample size			5	5	5	5
Avg.			22.8	83.43	72.4	30.43
std. dev.				21.61		13.58
Model Years 80-81						
Sample size	6	6			6	6
Avg.	2.8	92.57			69.8	15.88
std. dev.		13.81				17.56
Sample size			9	9	9	9
Avg.			25.1	79.50	70.7	17.66
std. dev.				47.04		15.46
All Model Years						
Sample size	10	10			10	10
Avg.	2.7	100.91			70.6	23.18
std. dev.		32.76				17.65
Sample size			14	14	14	14
Avg.			24.3	80.90		22.22
std. dev.				38.86		15.62

Table 9

Effect of Test Temperature
on Carbon Monoxide Emissions
(grams per mile)
FTP
Before Repairs

Vehicle	Nominal 0°F Temp.	Nominal 0°F Emissions	Nominal 20°F Temp.	Nominal 20°F Emissions	Nominal 70°F Temp.	Nominal 70°F Emissions
1. 76 Hornet	2	90.78	20	96.18	74	58.39
2. 76 Aspen	2	37.58	20	35.63	71	20.61
3. 76 Mazda	4	37.70	21	33.06	71	14.85
4. 77 Monza	2	48.27	19	35.34	71	23.73
5. 78 Subaru	-	ND	34	21.56	75	12.50
6. 80 Audi	-	ND	35	37.44	70	27.43
7. 80 LeBaron	4	20.86	20	18.09	68	11.90
8. 80 Datsun	4	11.91	20	11.91	68	8.83
9. 81 Horizon	-	ND	34	34.44	73	28.80
10. 81 Escort	-	ND	37	17.18	74	6.79
11. 81 Malibu	3	20.61	17	18.12	71	1.54
12. 81 Zephyr	0	82.98	20	53.38	72	3.22
13. 81 Corolla	5	22.83	20	12.74	69	2.19
14. 81 Toyota PU	1	39.30	23	31.54	71	16.37
Model Years 76-79						
Sample size	4	4			4	4
Avg.	2.5	53.58			71.8	29.40
std. dev.		25.30				19.68
Sample size			5	5	5	5
Avg.			22.8	44.35	72.4	26.25
std. dev.				29.54		16.68
Model Years 80-81						
Sample size	6	6			6	6
Avg.	2.8	33.08			69.8	7.34
std. dev.		26.03				6.03
Sample size			9	9	9	9
Avg.			25.1	26.09	70.7	11.90
std. dev.				13.96		10.36
All Model Years						
Sample size	10	10			10	10
Avg.	2.7	41.28			70.6	16.16
std. dev.		26.49				16.70
Sample size			14	14	14	14
Avg.			24.3	32.62	71.3	16.94
std. dev.				21.70		14.91

Table 10

Reduction in
Carbon Monoxide Emissions
Between 1976-79 and 1980-81
Model Years

	Bag (0+1)		
	0°F	20°F	70°F
Grams per mile	20.86	3.93	12.77
% Reduction	18%	5%	42%

	FTP		
	0°F	20°F	70°F
Grams per mile	20.50	18.26	14.35
% Reduction	38%	41%	55%

Table 11

Increase in Carbon Monoxide Emissions
at Cold Temperatures
Compared with 68-86°F Emissions

Bag (0+1)

	0°F	20°F
1976-79 models	79.30 gm/mi (232%)	53.00 gm/mi (174%)
1980-81 models	76.69 gm/mi (483%)	61.84 gm/mi (350%)
All models	77.73 gm/mi (335%)	58.68 gm/mi (264%)

FTP

	0°F	20°F
1976-79 models	24.18 gm/mi (82%)	18.10 gm/mi (69%)
1980-81 models	25.74 gm/mi (351%)	14.19 gm/mi (119%)
All models	25.12 gm/mi (155%)	15.68 gm/mi (93%)

However, the reduction at 0-20°F was much less: 5-18% in Bag (0+1), and 38-41% for the composite FTP. Although the absolute emissions drop (in grams per mile) at cold temperatures was, on average, larger than at 70°F, the <u>percent reduction</u> plays a larger role in judging progress towards attainment of the federal ambient air quality standards.

Table 11 looks at the same issue in another way. Despite the fact that the newer vehicles were generally cleaner, at all temperatures, than the older vehicles, the grams per mile increases due to cold temperatures were virtually identical for both groups. What this suggests is that the effect of cold temperatures on carbon monoxide emissions is to increase emissions, particularly in Bag 1, by a fixed amount.

Furthermore, the data suggest that the reductions in carbon monoxide emissions which resulted from the 1980/81 standards had no effect on this "cold temperature factor."

This is not surprising, since compliance with the new standard is judged only at warm temperatures. It would appear that any effort to reduce the cold temperature factor, which dominates the emissions from late-model cars, will have to entail specific cold temperature requirements for vehicle manufacturers, or will coincidentally result from controls used by manufacturers to meet other warm temperature requirements.

The effect of test temperature on fuel consumption is shown in Table 12. The data show that Bag (0+1) fuel consumption is from 43-59% higher at 20°F and 0°F, respectively, than at 70°F. Over the complete FTP, cold temperature fuel consumption is from 13-28% higher than at 70°F, suggesting that most of the increased fuel use occurs during the first 3½ miles after the cold start.

Table 12

Effect of Test Temperature
on Fuel Economy
(miles per gallon)
Before Repairs

Vehicle	Bag (0+1)			FTP		
	0°F	20°F	70°F	0°F	20°F	70°F
1. 76 Hornet	9.4	11.3	15.9	12.4	13.3	16.9
2. 76 Aspen	9.4	10.0	14.3	12.7	14.5	16.3
3. 76 Mazda	13.1	17.2	25.2	21.7	20.6	28.9
4. 77 Monza	12.3	14.6	18.2	16.7	18.6	19.6
5. 78 Subaru	ND	25.6	33.1	ND	30.4	30.8
6. 80 Audi	ND	25.2	41.9	ND	28.5	23.6
7. 80 LeBaron	7.9	9.1	12.0	11.4	12.1	13.4
8. 80 Datsun	17.2	16.7	28.7	27.0	25.3	29.7
9. 81 Horizon	ND	24.1	27.8	ND	31.5	27.2
10. 81 Escort	ND	25.5	33.0	ND	29.6	28.4
11. 81 Malibu	11.0	10.8	17.4	14.5	15.1	18.7
12. 81 Zephyr	10.7	9.4	16.8	13.8	14.4	19.6
13. 81 Corolla	12.6	15.8	19.2	19.0	21.0	22.5
14. 81 Toyota PU	14.8	15.0	21.0	19.3	20.1	24.2
Sample size	10		10	10		10
Avg. Fuel Consumption (gal/mi)	0.089		0.056	0.064		0.050
Std. Deviation	0.020		0.014	0.017		0.013
Avg. MPG	11.28		17.78	15.72		19.81
Sample size		14	14		14	14
Avg. Fuel Consumption (gal/mi)		0.070	0.049		0.053	0.047
Std. Deviation		0.026	0.017		0.017	0.013
Avg. MPG		14.38	20.51		19.04	21.49

3.5. Effect of Repairs on Carbon Monoxide Emissions and Fuel Economy

As mentioned previously, 11 of the 14 vehicles were repaired and retested to determine the effect of repairs on emissions. One of the 11 vehicles was not tested after repairs at temperatures below 50°F due to scheduling problems. The 10 remaining vehicles were used to compare the emissions reductions due to repairs at 20°F and 70°F. The results of this comparison are shown in Table 13 (Bag 0+1) and Table 14 (FTP).

The data indicate that the percentage reduction in emissions due to repairs are approximately the same at 20°F and 70°F for both Bag (0+1) and composite FTP emissions. However, the Bag (0+1) reductions (33-38%) are generally smaller than the FTP reductions (51-56%), again on a percentage basis. These reductions are the result of back-to-back tests on vehicles which failed the I/M screening test. They do not represent air quality improvements, which must take into account the fact that not all vehicles are repaired under an I/M program, and that the benefits of repairs are greatest immediately after the repair.

Extrapolation of these results is generally beyond the scope of this study; however, the reductions in FTP emissions are generally comparable, or slightly lower, than reductions for late model vehicles published elsewhere. Thus, the data would suggest that an I/M program can be as effective at reducing cold temperature FTP emissions as it is in reducing warm temperature FTP emissions. The data would also suggest that during the first few minutes after a cold start (Bag 0+1), repairs are only about two-thirds as effective as over a longer average trip.

There are several factors which make this analysis unique relative to other I/M analyses. First, vehicles which had evidence of gross tampering were eliminated from

Table 13

Effect of Repairs on
Carbon Monoxide Emissions

Bag (0+1)
(grams per mile)

		20°F		70°F	
		Before	After	Before	After
1.	76 Hornet	115.10	41.58	48.00	19.05
2.	76 Aspen	84.94	41.25	32.06	19.57
3.	76 Mazda	75.77	49.76	18.30	21.75
4.	77 Monza	86.29	77.23	38.16	41.78
5.	78 Subaru	55.06	66.52	15.63	15.18
6.	80 Audi	48.19	12.66	19.30	6.45
8.	80 Datsun	34.24	30.04	7.91	6.71
10.	81 Escort	.43.43	39.17	9.78	9.69
12.	81 Zephyr	190.42	88.61	1.34	0.55
14.	81 Toyota Pu	79.87	60.29	23.82	20.42
	Average	81.33	50.71	21.43	16.12
	Standard deviation	45.40	22.76	14.43	11.53
	Average difference (gm/mi)	30.62		7.00	
	Average difference (%)	-38%		-33%	

Table 14

Effect of Repairs on
Carbon Monoxide Emissions

FTP
(grams per mile)

		20°F		70°F	
		Before	After	Before	After
1.	76 Hornet	96.18	17.45	58.39	7.08
2.	76 Aspen	35.63	20.38	20.61	6.52
3.	76 Mazda	33.06	19.82	14.85	13.52
4.	77 Monza	35.34	24.56	23.73	13.01
5.	78 Subaru	21.56	18.55	12.50	8.19
6.	80 Audi	37.44	3.34	27.43	1.75
8.	80 Datsun	11.91	8.28	8.83	3.77
10.	81 Escort	17.18	17.40	6.79	11.05
12.	81 Zephyr	53.38	31.97	3.22	0.36
14.	81 Toyota Pu	31.54	22.12	16.37	19.24
	Average	37.32	18.39	19.27	8.45
	Standard deviation	23.76	7.98	15.69	5.85
	Average difference (gm/mi)	18.93		10.82	
	Average difference (%)	-51%		-56%	

the test program; this suggests that the benefits of I/M would be higher than shown above. On the other hand, each vehicle which failed the inspection received new spark plugs, filters, etc., in addition to having the cause of the failure identified and repaired. This goes beyond the repairs required in most I/M programs, and suggests that the actual benefits of an I/M program would be smaller. Finally, the fact that only three vehicles were tested which passed the idle inspection makes it difficult to estimate the fleetwide average benefits of I/M. Consequently, the data from this study would have to be combined with data from subsequent test programs to develop estimates of I/M benefits for air quality.

In addition to the CO emissions benefits, the repairs generally resulted in greater increases in fuel economy at cold temperatures than were found at warm temperatures. At 20°F, repairs increased Bag (0+1) fuel economy by 15.7% (Table 15), and FTP fuel economy by 6.4% (Table 16). These improvements were found to be statistically significant at the 80% confidence level using a paired t-test. By contrast, the fuel economy increases at 70°F (0.5%-3.5%) were not significant.

4.0 IMPLEMENTATION

This section was prepared by the Alaska Department of Transportation and Public Facilities.

The Department of Transportation and Public Facilities is implementing the results of this and later research by taking a position in favor of instituting vehicle inspection/maintenance programs in both Anchorage and Fairbanks. Representatives of the Department have spoken publicly on several occasions recommending inspection/ maintenance as the most feasible means of meeting air quality goals established by the U.S. EPA.

Table 15

Effect of Repairs on
Fuel Economy
Bag (0+1)
(miles per gallon)

		20°F		70°F	
		Before	After	Before	After
1.	76 Hornet	11.3	14.0	15.9	13.8
2.	76 Aspen	10.0	12.8	14.3	14.8
3.	76 Mazda	17.2	18.0	25.2	28.1
4.	77 Monza	14.6	14.6	18.2	19.3
5.	78 Subaru	25.6	21.7	33.1	29.4
6.	80 Audi	25.2	28.3	41.9	34.4
8.	80 Datsun	16.7	23.0	28.7	29.3
10.	81 Escort	25.5	25.0	33.0	30.3
12.	81 Zephyr	9.4	12.4	16.8	17.5
14.	81 Toyota Pu	15.0	17.7	21.0	27.4
	Average Consumption (gal/mi)	0.067	0.058	0.045	0.045
	Std. deviation	0.025	0.016	0.016	0.016
	Average MPG	15.01	17.37	22.04	22.16
	Average difference in MPG	+15.7%		+0.5%*	
	Significant at 80% level?	Yes		No (20.93 mpg before, 21.32 mpg after)	

*Without Audi, increase is 1.8%

Table 16

Effect of Repairs on
Fuel Economy
FTP
(miles per gallon)

		20°F		70°F	
		Before	After	Before	After
1.	76 Hornet	13.3	16.3	16.9	17.2
2.	76 Aspen	14.5	14.8	16.3	16.9
3.	76 Mazda	20.6	23.3	28.9	30.2
4.	77 Monza	18.6	18.8	19.6	20.6
5.	78 Subaru	30.4	28.3	30.8	30.8
6.	80 Audi	28.5	30.2	23.6	32.4
8.	80 Datsun	25.3	29.1	29.7	26.5
10.	81 Escort	29.6	28.6	28.4	30.2
12.	81 Zephyr	14.4	14.8	19.6	18.0
14.	81 Toyota Pu	20.1	21.8	24.2	25.9
	Average Consumption (gal/mi)	0.051	0.048	0.044	0.043
	Std. deviation	0.016	0.014	0.011	0.011
	Average MPG	19.73	21.00	22.61	23.40
	Average difference in MPG	+6.4%		+3.5%	
	Significant at 80% level?	Yes		No	

Results of the work contained herein have already been used to plan and conduct additional research during the winter of 1982-83. This later work is a continuation of research on I/M effectiveness using less extensive maintenance procedures on a similar sample of automobiles. It also includes an evaluation of selected retrofit devices for improving cold weather emissions and fuel economy. It was funded entirely by the Alaska Department of Environmental Conservation, which will publish a research report.