CAL3QHCR MODELING ANALYSIS FOR MISSOULA, MONTANA, REDESIGNATION TO CARBON MONOXIDE NAAQS ATTAINMENT

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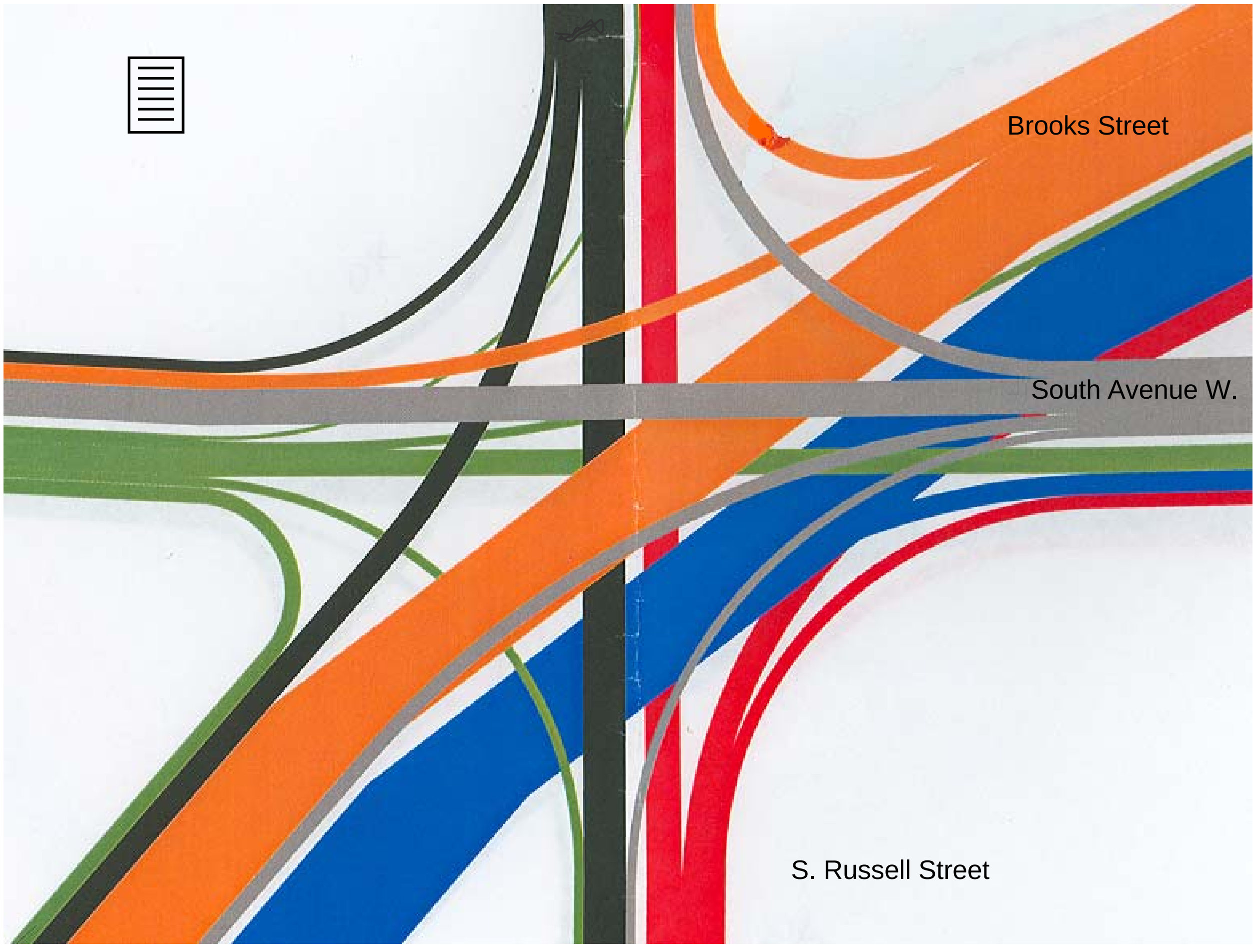
INTRODUCTION

This air quality analysis demonstration supports the redesignation of Missoula, Montana (MT), to attainment for carbon monoxide (CO) with respect to the 8-hour averaged CO National Ambient Air Quality Standard (NAAQS). This modeling demonstration focuses on the Brooks Street, South Avenue West, and South Russell Street intersection also locally known as “Malfunction Junction” and is referred to as the “B/S/R” intersection in this document. In addition, South Russell Street and South Avenue West are noted as S. Russell Street and South Avenue W., respectively.

This intersection is located in the center of the City of Missoula within Missoula County in west-central Montana. The primary source of CO in the Missoula area is vehicle exhaust and this intersection has historically had the highest annual average daily traffic (AADT) in the Missoula urban area. Brooks Street runs southwest to northeast bisecting the junction of South Avenue W. and S. Russell Street creating a six-way intersection.

Currently, the Montana Department of Transportation (MDT) classifies Brooks Street as a principal arterial; the other two roads are minor arterials. A Montana Department of Environmental Quality (MDEQ) CO monitor is located on the east side of S. Russell Street, south of South Avenue W. The Aerometric Information Retrieval System (AIRS) number for this monitor is 30-063-0005. Figure 1 displays the current intersection configuration provided by the MDT.

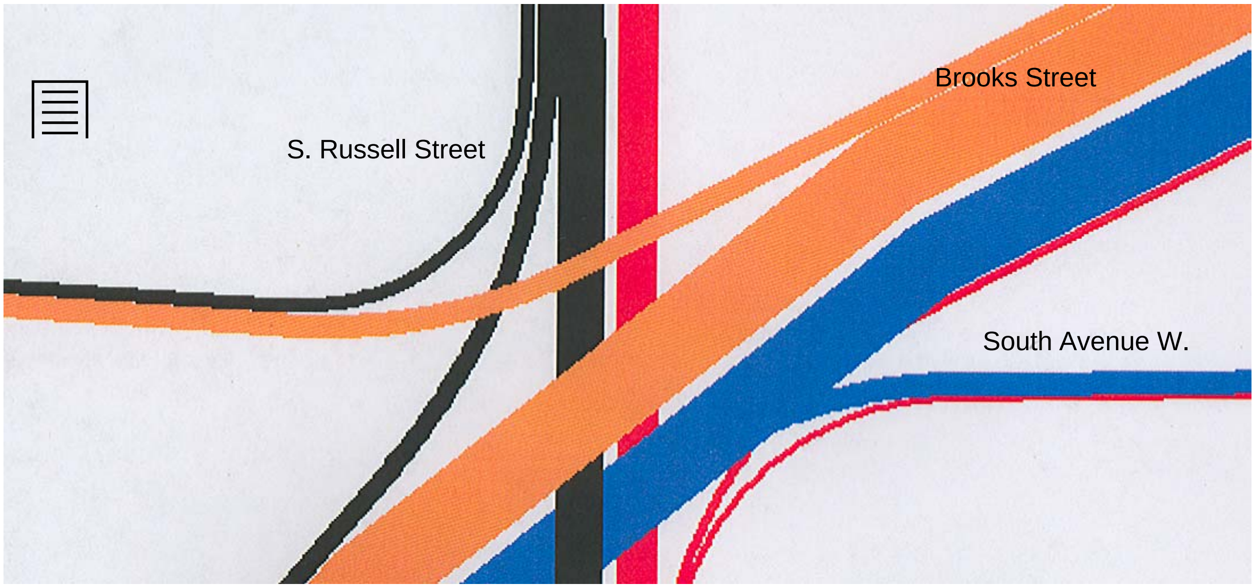
FIGURE 1: B/S/R INTERSECTION CURRENT CONFIGURATION



The Montana State Implementation Plan (SIP) requires a wintertime oxygenated fuels program in the Missoula urban area.[1] However, the Missoula City-County Health Department (MCCHD) requested this modeling demonstration compare the effects of oxyfuel.

The MDT intends to reconstruct the intersection in mid-2005 to reduce congestion and improve air quality. To compare the ambient CO concentrations from the vehicle emissions before and after the reconstruction, the following years were analyzed: 2000 (base year), 2005 (before reconstruction), 2010 (after reconstruction), and 2015 (future outlying year). Figure 2 displays the redesign of the intersection also provided by the MDT.

FIGURE 2: B/S/R INTERSECTION REVISED CONFIGURATION



The MDT provided the traffic volumes entering and departing the intersection on each road for each analysis year. The Urban Planning Section, MDT, used a transportation model called TransCAD (version 4.5). Important characteristics of the entire Missoula urban area facility (road) transportation network are stored in the model supported by Geographic Information Systems (GIS) capabilities. This transportation model predicts the traffic volumes and flow based on the most efficient routing patterns considering the land characteristics in that immediate area.

One of the model outputs was the annual average daily traffic (AADT) or simply, average daily traffic (ADT). The MDEQ modified these traffic volumes to represent the peak hourly volumes for a winter weekday. The MDEQ considers this weekday as a CO season day. The CO season is the 3-month period when CO violations occur. The MDEQ has selected January, February, and December as the CO season for the State of Montana.

Generally, wintertime is when CO violations occur from vehicle exhaust in Missoula. Wintertime temperatures prolong the “cold start” period of a vehicle engine. The length of a cold start depends on the ambient air temperature. Cold starts can last up to five minutes when ambient temperatures are below -29 degrees Centigrade (-20 degrees Fahrenheit).[2] Pollution outputs are much higher after a cold start until both the vehicle’s catalytic converter and oxygen sensor are sufficiently heated to control the optimum air to fuel ratio for a gasoline vehicle engine. Another factor is whether the vehicle even has this equipment and they are properly maintained. The first catalytic converters and sensors were available on the 1975 and 1976 model year vehicles, respectively.

Carbon monoxide from vehicle exhaust is released very close to the ground and remains near the surface during the wintertime. Low sunlight intensities and cool temperatures discourage atmospheric mixing during the wintertime. To clarify, the mixing height is the height at which vertical mixing occurs.

This demonstration required extensive information including vehicle and intersection data. The vehicle data included the age, type, and fuel use (gasoline or diesel) of the vehicle fleet traveling the roads. Passenger cars and light-duty trucks are examples of the vehicle type. Intersection data included the physical configurations before and after the reconstruction, and signalization parameters.

The latest U.S. Environmental Protection Agency (EPA) mobile emissions computer model, MOBILE6.2 (dated 09/24/03), calculated the onroad CO emission factors for each facility and analysis year. The resulting CO emission factors were in grams per mile and depended upon on the vehicle travel speeds, but were also influenced by other factors such as the sulfur content in the gasoline that will change over time.

Another EPA model, CAL3QHCR (dated 041181), incorporated the CO emission factors and traffic volumes with local airport meteorological data. This model is specifically used to model chemically inert air pollutants such as CO released from motor vehicle at roadway intersection. The model outputs included the 8-hour averaged CO concentrations (in parts per million) estimated along the roadways. The 8-hour concentrations were compared to the state and federal standards called the National and Montana Ambient Air Quality Standards (NAAQS and MAAQS, respectively). In this case, these standards are identical (Administrative Rules of Montana 17.8.710(2)).

An 8-hour CO NAAQS exceedance is an 8-hour running averaged concentration that has exceeded 9.0 parts per million (ppm) more than once during one calendar year (50 FR 37501, September 13, 1985; 40 CFR § 50.8). Running (or rolling) means the concentration was calculated using an eight-hour block of time such as hour 1 through hour 8 that moved as a block of eight hours from one hour to the next consecutive hour (hour 2 through hour 9). This 8-hour period can overlap two consecutive calendar days, but no more than two hours of invalid data is acceptable during that sampling period.

Exceedances are based on air quality monitoring data. Comparisons to the 8-hour NAAQS are made in relation to integers with fractional components of 0.5 ppm or greater rounding up; in other words, values of 9.5 ppm or greater (one decimal place) are considered an exceedance of the standard. Table 1 lists the ten highest non-overlapping 8-hour averaged CO concentrations measured at the B/S/R intersection from 1999 to 2002 in descending order. These years represent the maintenance period for the Missoula CO redesignation demonstration.

A variety of people will examine this document with different technical backgrounds including laypeople. For informational purposes, the following is a general discussion on the automotive gasoline combustion process and oxyfuel.

Gasoline is primarily composed of molecules with only hydrogen and carbon arranged in chains (hydrocarbons). Gasoline molecules have from seven to 11 carbons in each chain. The optimum air to fuel ratio for combustion of an automotive gasoline engine is 14.7:1 (on weight basis). The primary source of CO from vehicles is the incomplete combustion of gasoline in the engine cylinders. The combustion (fuel oxidation process) is the conversion of the fuel to lower molecular weight hydrocarbons to eventually CO, and finally, carbon dioxide (CO_2). The initial reactions are faster than the final conversion of CO to CO_2. Incomplete conversion of fuel carbon to CO_2 results in part from insufficient oxygen in the combustion mixture (fuel rich conditions) and insufficient time for conversion to CO_2.

An oxygen sensor continuously measures the amount of oxygen in the exhaust and signals the engine computer to adjust the air to fuel for complete combustion. A sensor is usually placed before and after the catalytic converter. Carbon monoxide emissions by diesel vehicles are minimal, primarily due to the excess air used in the diesel combustion cycle and diesel fuel has a wide combustibility range so there isn't an ideal air to fuel ratio for these engines.

Oxygenates in gasoline (oxyfuel) can either boost the octane rating, make the fuel burn cleaner by increasing the oxygen content, or a combination of both. Octane rating is important for gasoline vehicles without computerized fuel injectors (engines built before the mid-1980s). These engines have carburetors that regulate the mix of fuel to air ratio, but without the programmed efficiency of computers.

TABLE 1: TEN HIGHEST 8-HOUR AVERAGED CO CONCENTRATIONS RECORDED AT B/S/R INTERSECTION: 1999 TO 2002

Year	Month	Day	CO Concentration (ppm)[a]								
			Ending Hour 1	Ending Hour 2	Ending Hour 3	Ending Hour 4	Ending Hour 5	Ending Hour 6	Ending Hour 7	Ending Hour 8	8-Hour Average
2001	January	4/5[b]	4.2 (1800)[c]	4.9 (1900)	6.1 (2000)	7.0 (2100)	6.6 (2200)	5.7 (2300)	5.3 (0000)	4.4 (0100)	5.5
1999	January	6	4.1 (1700)	4.5 (1800)	5.8 (1900)	6.0 (2000)	5.2 (2100)	4.6 (2200)	5.0 (2300)	4.2 (0000)	4.9
2002	November	7	3.4 (1700)	3.9 (1800)	5.2 (1900)	5.7 (2000)	5.1 (2100)	4.7 (2200)	4.6 (2300)	3.9 (0000)	4.6
1999	January	11	4.2 (1300)	4.6 (1400)	3.7 (1500)	3.6 (1600)	3.9 (1700)	4.6 (1800)	5.3 (1900)	5.1 (2000)	4.4
2000	December	27	3.5 (1500)	3.9 (1600)	4.2 (1700)	4.3 (1800)	4.9 (1900)	4.4 (2000)	3.3 (2100)	3.0 (2200)	3.9
2001	January	3/4	3.4 (1800)	4.6 (1900)	4.8 (2000)	4.1 (2100)	3.9 (2200)	3.5 (2300)	3.6 (0000)	3.2 (0100)	3.9
2001	November	14/15	3.3 (1800)	3.7 (1900)	3.6 (2000)	3.9 (2100)	4.1 (2200)	4.6 (2300)	4.2 (0000)	3.6 (0100)	3.9
2001	November	16/17	NA[d] (1800)	2.9 (1900)	3.7 (2000)	4.1 (2100)	4.1 (2200)	4.0 (2300)	3.9 (0000)	3.7 (0100)	3.8
1999	November	11/12	3.9 (1900)	4.1 (2000)	4.0 (2100)	4.0 (2200)	3.9 (2300)	3.7 (0000)	3.4 (0100)	3.1 (0200)	3.8
2001	January	10/11	3.0 (1800)	3.1 (1900)	3.6 (2000)	3.9 (2100)	4.6 (2200)	4.6 (2300)	3.5 (0000)	3.1 (0100)	3.7

[a] ppm = parts per million.
[b] Highest 8-hour averaged CO concentration occurred over two consecutive days.
[c] Ending military hour; midnight = 0000.
[d] NA = Not Available; no data was collected due to sampling error (null code).

None of these 8-hour averaged CO concentrations approached the 8-hour averaged NAAQS/MAAQS. Generally, the highest 8-hour CO concentration for each year was about half of the 9.5 ppm monitoring threshold for a NAAQS/MAAQS exceedance. Specifically, these concentrations were approximately 52, 41, 58, and 48% of the exceedance value (9.5 ppm) for the consecutive years during the 1999 to 2002 period. All of these events, except for one, began in the late afternoon or early evening.

During 2001, periods of relatively high 8-hour averaged CO concentrations occurred: January 3 – 5 and November 14 – 17. In all probability, the meteorology such as low wind speeds and mixing heights contributed to the accumulation and persistence of CO.

COMPUTER MODELS

The two EPA computer models used to calculate the ambient CO concentrations from the vehicle exhaust emissions from the B/S/R signalized intersection were MOBILE6.2 and CAL3QHCR. The first model, MOBILE6.2, was the latest EPA mobile emissions model to derive the CO emission factors. The corresponding user's guide and technical documentation supported the modeling applied in this phase of the investigation.[3, 4] The calculated emission factors were the estimated amounts of carbon monoxide from the vehicle fleet exhaust based on various factors such as the fleet speeds, including idling, during the signalization process. The units of the emission factors were in grams of CO per mile (g CO/mi.).

The CO emission factors developed by the MOBILE6.2 model were inserted into the other EPA computer model, CAL3QHCR. This model included a line source dispersion model (CALINE-3) and a traffic algorithm for estimating vehicular queue lengths at signalized intersections using one complete year of local meteorology. The model output included estimated 8-hour averaged ambient CO concentrations from the motor vehicle exhaust at various points next to the intersection roadways. These points, called receptors, represented where the general public can travel during the time period of interest, eight hours in this case. The Analytical Services Section, MDEQ, primarily defined these point locations. The modeling process and the selection of the model inputs strictly adhered to this model's guidelines.[5, 6, 7]

The CAL3QHCR model required information about the physical layout of the intersection. A transportation technical report had the current intersection configuration for CAL3QHCR input; this report was developed for the City of Missoula.[8] The WGM Group, Inc., Missoula, MT, is responsible for the intersection redesign and supplied a computer aided drawing (CAD) file of the intersection reconfiguration.

To determine this configuration for CAL3QHCR input, the CAD file was imported into the Environmental Systems Research Institute, Inc. (ESRI) ArcExplorer 4.0. The dimensions of this intersection configuration were measured by two methods: ArcExplorer measuring tool and ruler measurements from printed hard copies of the ArcExplorer file. With the measuring tool, the dimensions were measured three times then averaged. The hand measurements were performed once. The differences between these two methods were within 2% so the average of the measurements from both techniques determined the final dimensions.

A variety of sources provided the model inputs for both models. The *2000 Missoula, Montana, Carbon Monoxide Emission Inventory* supplied some of the MOBILE6.2 inputs and were adjusted for a particular analysis year.[9]

For this model input, the selected vehicle fleet speeds were 5.0 miles per hour (mph) less than the authorized (posted) road speeds. These estimated CO emission factors represented the emissions from the traffic moving during the green signal phase (free flow). Using 2.5 mph as model input, the idling CO emissions were calculated, which represented the delayed (queued) vehicles during the red signal phase until the next green signal.

The MDT Urban Planning Section provided the ADT data that entered and departed the intersection for the four analysis years. The MDT developed these volumes using a transportation model called TransCAD with GIS capabilities. The MDEQ adjusted all of the daily volumes to simulate peak hourly traffic volumes during a CO season day (winter weekday). The MDT Traffic and Safety Bureau provided all of the signalization characteristics (red/yellow/green cycle times) for all four years of interest.

MOBILE6.2 INPUTS TO CALCULATE THE CO EMISSION FACTORS

Some of the MOBILE6.2 model inputs used for this study were obtained from the *2000 Missoula, Montana, Carbon Monoxide Emission Inventory* and adjusted to a particular analysis year. Furthermore, many of these model inputs were also applied in the modeling demonstration to support the Missoula CO transportation conformity for the 2004 update of the Missoula transportation plan.[10] The EPA required consistency among SIP-related projects and transportation conformity.

The distribution of the vehicle age and type was required for model input. The Missoula County vehicle registration for 2000 was obtained from the Department of Justice, State of Montana. As an assumption, the vehicle distribution was identical in the Missoula urban area as in the Missoula County for the same year. In accordance to this model guidance, the same registration data was used for the other analysis years. The vehicle registration data included the vehicle model year, make, type, length, and/or gross vehicle weight (GVW). Unfortunately, the 2000 Missoula County vehicle registration did not provide sufficient information to separate the data into the required sixteen vehicle classes for MOBILE6.2 input. The sixteen classes were light-duty passenger cars, four types of light trucks, eight types of heavy-duty trucks, two types of buses (school and transit), and motorcycles; vehicle weight determined the truck class. Therefore, the registration data was divided into the eight primary vehicle classes as designated by the EPA MOBILE5.0 emissions model, an earlier version of MOBILE6.2 model. These classes were light-duty gasoline passenger cars, two light-duty gasoline trucks, heavy-duty gasoline trucks, light-duty diesel passenger cars, light-duty diesel trucks, heavy-duty diesel trucks, and motorcycles; vehicle weight established the truck class.

For each vehicle class, the data was further delineated into twenty-five years of vehicle age. The 2000 model year (MY) vehicles were grouped as Age Class 1 and the remaining model years were segregated in the appropriate age classes with the 1976 and older MY vehicles as Age Class 25. These eight sets of data were entered into a MOBILE5b utility program to develop the sixteen classes of vehicles for MOBILE6.2 input; the EPA MOBILE5b emissions model was a later version of MOBILE5.0 model. The Sierra Research, Inc. created this utility software, which was provided during MOBILE6.0 training classes supported by the EPA.

Two vehicle types were treated differently: recreational vehicles (RV) and motorcycles. Both types of vehicles have reduced usage during the wintertime when driving conditions are hazardous in Montana so the data was modified to reflect this reduced usage.

A RV that was 30 feet or less was classified as a light-duty truck (LDT) unless the GVW indicated it was a heavy-duty truck (HDT). If a RV was classified as gas light-duty truck, it was categorized as a light-duty gas truck-2 (LDGT2). If a motor home had insufficient information to determine whether it is a LDGT2 or HDT, 30% of them were categorized as LDGT2 and the remaining 70% were classified as HDT. After the data was manipulated in this manner, the total number of HDT RVs was reduced by 90% to represent wintertime usage. These various truck acronyms were defined in the MOBILE6.2 user's manual. The motorcycle fraction was set to zero since climatic conditions in the City of Missoula during the wintertime are rarely conducive towards this mode of transportation.

Using local information to estimate the fractions of diesel sales was optional for projects concerning SIPs and transportation conformity so the defaults were used. The county vehicle registration also did not contain sufficient information about the annual mileage accumulation rates to further characterize the fleet, and the natural gas fraction of the registration data was also extremely small. For all of these cases, the MOBILE6.2 defaults were used.[4]

Another model command that incorporated the vehicle fleet characteristics was the AVERAGE SPEED command. The MDT recommended using the vehicle speeds that were 5.0 mph less than the authorized (posted) legal speeds of the roads entering and departing the intersection. Currently, both Brooks and S. Russell Streets have 30.0 miles per hour (mph) posted travel speeds whereas South Avenue W. has a 25.0 mph posted speed. After the intersection reconstruction, all three roads will have a 30.0 mph posted speed except for the traffic on South Avenue W. traveling west to enter Brooks Street to proceed northeast. In this case, a stop sign will control the traffic. However, the MDT TransCAD model did not predict any traffic executing this pattern of traffic flow for the two outlying analysis years (2010 and 2015). As explained by the MDT TransCAD modeler, the future transportation projects including the B/S/R intersection redesign will prevent traffic from traveling this route as modeled by TransCAD model (personal communications, Al Vander Wey, Urban Planning Section, MDT, June 10, 2004). In particular, a major project just north of the B/S/R intersection involving Brooks Street and adjacent streets will divert traffic away from South Avenue W. east of the intersection and subsequent flow onto Brooks Street. For further information on this event, contact the MDT Urban Planning Section.

The MOBILE6.2 model does not directly calculate idling CO emission factors since the idling emissions are already incorporated proportionally into the normal driving emission factors. A method recommended in the technical MOBILE6.0 documentation was employed to develop these factors. For each analysis year, a vehicle speed of 2.5 mph was used as model input and the resulting CO emission factors (g CO/mi.) were multiplied by the average speed (2.5 mph) to produce the idling CO emission factors as shown in the following equation.

$$(\textit{CO Emission Factor @ 2.5 mph})\,(\textit{2.5 mph Average Speed}) = \textit{CO Idling Emissions}$$

To summarize, the AVERAGE SPEED command was used with the following vehicle speeds for each analysis years: 2.5, 20.0, and 25.0 mph.

Additional model commands that incorporated the vehicle fleet characteristic included the VMT (vehicle miles traveled) FRACTIONS, VMT BY FACILITY, and SPEED VMT. The VMT fractions for the two types of arterials for each year were developed from data obtained from the MDT Traffic Data Collection Section for the Missoula urban area and the EPA national defaults. The MDT Traffic Data Collection Section developed heavy-duty vehicle fractions representative for 2000 for both minor and principal arterials in the Missoula urban area. Table 4.1.2 in the EPA technical guidance was applied for the light-duty vehicles categories (LDV, LDVT1, LDT2, LVDT3, and LTDV4). These national defaults represented the month of January and varied by year. By incorporating both sets of the data, the VMT fractions were developed; the fractions must equal 1.0 to encompass the total composition of the vehicle fleet. The motorcycle fraction was set to zero since climatic conditions in the City of Missoula during the wintertime are rarely conducive towards this mode of transportation. This procedure was reviewed and accepted by a Federal Highway Administration (FHWA) employee (Jim Carlin, MDEQ Air Quality Specialist, personal communications, Jeff Houk, FHWA, February 19, 2004). The VMT BY FACILITY and SPEED VMT commands were replaced by the AVERAGE SPEED command.

The effects of the weekday and weekend vehicle activities such as the number of starts per day were unknown, and the daily and diurnal activities such as the soak distribution/activity were also not included as model inputs due to lack of data. In these cases, the model defaults were applied.

Other model input parameters involved the fuel characteristics, which were influenced with the addition of oxyfuel. The MCCHD requested this demonstration compare the effects of oxyfuel so the OXYGENATED FUELS command was included. The Missoula area distributors have agreed to use only ethanol, not MTBE (methyl tertiary butyl ether), to oxygenate the fuel in the Missoula area.[11] The oxygen percent in ethanol was 2.7% by weight according to the MCCHD air quality regulations and was not expected to change.[12] A volatility waiver did not exist to allow splash blending of alcohol-based oxygenated fuels.[11] This would have allowed the Reid Vapor Pressure (RVP) to exceed the RVP requirements; however, a waiver was used as recommended by the EPA MOBILE guidance. A RVP value between 12.0 and 15.0 is satisfactory for the Montana winter season for MOBILE modeling as recommended by the EPA staff.[13] A RVP value of 12.5 was utilized, which was also used in previous CO inventories.[9]

The amount of sulfur in gasoline was also an important fuel consideration since sulfur, a natural component of gasoline, reduces the effectiveness of catalytic converters. As previously mentioned, the first catalytic converters were available in the 1975 MY vehicles. These devices chemically convert CO to CO_2 in the exhaust. The gasoline sulfur content will change nationally in 2004 due to the Tier 2/sulfur regulations program.[14] With the FUEL PROGRAM command, the "Conventional Gasoline West" category was selected as the fuel program. This selection was appropriate for the State of Montana since the State is considered a special "geographic phase-in area" (GPA), which allows a phasing-in of the sulfur limits in gasoline (66 FR 19296, April 13, 2001). The model defaults to gasoline sulfur content applicable for this special region.[3] Table 2 summarizes the changes in the gasoline sulfur content over time that were incorporated into the MOBILE6.2 modeling and other gasoline characteristics.

TABLE 2: OXYGENATED FUEL MARKET SHARE, GASOLINE OXYGEN AND SULFUR CONTENT USED IN MOBILE6.2 MODELING

Reconstruction	Year	Oxygenated Fuel Ether Blend Market Share (%)	Alcohol Blend Market Share (%)	Average Oxygen Content Of Ether Blend Fuels (%)	Average Oxygen Content Of Alcohol Blend Fuels (%)	Sulfur Content Tier 2 (ppm)[a, b]
Before	2000	0.0	100.0	0.0	2.7	300
	2005	0.0	100.0	0.0	2.7	160
After	2010	0.0	100.0	0.0	2.7	30
	2015	0.0	100.0	0.0	2.7	30

[a.] ppm = parts per million.
[b.] MOBILE6.2 defaults for the "Conventional Gasoline West" category.

State vehicle emissions programs also were considered including inspection and maintenance, or anti-tampering. Neither of these programs existed in Montana during 2000 nor were expected in the future.[11]

External environmental conditions were also required for model input including the month of analysis, absolute humidity, and altitude. The MDEQ previously selected the following months as the CO season (wintertime period): December, January, and February.[9] Therefore, the month of January was selected as the month of evaluation. The model defaults were applied for the absolute humidity in addition to other parameters that influenced the use of the vehicle air-conditioner such as the solar load since the period of interest was the wintertime. For clarification, high absolute humidity during periods of warm ambient temperatures increases the use of air-conditioning. The low altitude was selected as required by the EPA since this agency did not classify the altitude of the Missoula County as high (40 CFR § 86.094-30 (a) (5) (iii) and (iv)).

The model also required ambient temperature information. For a general emission inventory, the minimum and maximum ambient temperatures are obtained from the days when the ten highest 8-hour averaged CO concentrations occurred during the last three years.[15] However, for this project, the temperature data was determined from the period selected for the Missoula CO attainment maintenance demonstration (personal communications, Kerri Fielder, EPA Region VIII, March 3, 2004). The MCCHD selected 1999 to 2002 period, which contained eight quarters of CO monitoring data since monitoring was conducted from January to March, and October through December. Therefore, the minimum and maximum temperatures were determined from the days with the ten highest 8-hour CO concentrations within this period. If the 8-hour CO concentration occurred over two consecutive days, the ambient temperature data from both days were included for the final calculations. Table 3 lists the dates, CO concentrations, and daily minimum and maximum ambient temperatures measured at the Missoula International Airport (MIA) collected by the National Weather Service (NWS).[16]

TABLE 3: TEN HIGHEST 8-HOUR CO CONCENTRATIONS AT B/S/R INTERSECTION, AND DAILY MINIMUM AND MAXIMUM AMBIENT TEMPERATURES RECORDED AT MIA, 1999 TO 2002

Year	Month	Day (Sampling Period)[a]	8-Hour Averaged CO Concentration (ppm)[b]	Daily Minimum Temperature (F)[c]	Daily Maximum Temperature (F)
2001	January	4 (1800 – 0000)	5.5	20.0	38.0
		5 (0100)		27.0	47.0[d]
1999	January	6 (1700 – 0000)	4.9	31.0	39.0
2002	November	7 (1700 – 0000)	4.6	20.0	49.0
1999	January	11 (1300 – 2000)	4.4	31.0	44.0
2000	December	27 (1500 – 2200)	3.9	20.0	35.0
2001	January	3 (1800 – 0000)	3.9	14.0	28.0
		4 (0100)		20.0	38.0
2001	November	14 (1800 – 0000)	3.9	33.0	56.0[d]
		15 (0100)		26.0	53.0
2001	November	16 (1800 – 0000)	3.8	30.0	50.0
		17 (0100)		35.0	46.0
1999	November	11 (1900 – 0000)	3.8	35.0	56.0
		12 (0100 - 0100)		33.0	73.0[d]
2001	January	10 (1800 – 0000)	3.7	15.0	30.0
		11 (0100)		12.0	27.0

[a] Sampling period in military hours; midnight = 0000.
[b] ppm = parts per million.
[c] F = Fahrenheit.
[d] Temperature extreme for the month.

The overall average minimum and maximum ambient temperatures were 25.1 and 44.3 degrees Fahrenheit (F), respectively.

Table 4 lists the MOBILE6.2 commands and corresponding model inputs. The application of MOBILE6.2 defaults listed in this table generally indicated the 2000 Missoula County vehicle registration data did not contain sufficient information pertaining to those parameters and the MOBILE6 guidance recommended the use of model defaults in these cases.

TABLE 4: MOBILE6.2 COMMANDS AND INPUTS TO CALCULATE THE CO EMISSION FACTORS

MOBILE6.2 Command	User Input	MOBILE6.2 Input
Absolute Humidity (& Other Air-conditioner Variables)	No	Defaults; Unimportant for Wintertime Conditions
Altitude	Yes	User Input: Low (1)
Anti-Tampering Program	No	Not Used
Average Speed	Yes	User Input: 2.5, 20.0, and 25.0 mph
Calendar Year	Yes	User Input: 2000, 2005, 2010 and 2015
Diesel Sales Fractions	No	Defaults
Distribution of Vehicle Registration	Yes	2000 Missoula County Vehicle Registration; MOBILE5b Utility Assisted
Evaluation Month	Yes	User Input: January (1)
Fuel Program	Yes	User Input: Conventional Gasoline West (3)
Fuel Reid Vapor Pressure (RVP)	Yes	User Input: 12.5
Inspection/Maintenance Program	No	Not Used; None Existed and None Expected
Mileage Accumulation Rates	No	Defaults
Minimum/Maximum Temperature	Yes	User Input: 25.1 44.3
Natural Gas Fraction	No	Defaults; Very Insignificant Fraction
Oxygenated Fuels	Yes (W/ Oxyfuel) No (W/Out Oxyfuel)	User Input; Yes (W/ Oxyfuel) No (W/Out Oxyfuel)
Soak Distribution/Activity	No	Defaults
Speed VMT[a]	No	Replaced by AVERAGE SPEED Command
Starts/Day or Distribution During the Day	No	Defaults
Sulfur Content	Yes	Defaults (Table 2)
VMT By Facility	No	Replaced by AVERAGE SPEED Command
VMT Fractions	Yes	User Input; 2 Sets/Analysis Year: Minor Arterial and Principal Arterial
Weekday/Weekend Information	No	Defaults

[a] VMT = vehicle miles traveled.

MOBILE6.2 CO EMISSION FACTORS

The CO emissions factors developed from the MOBILE6.2 modeling for all analysis years with and without oxyfuel, using three fleet speeds are recorded in Table 5. The bold emission factors were used in the CAL3QHCR modeling phase; the other factors were listed for informational purposes. As a reminder, South Avenue W. and S. Russell Street are classified as minor arterials and Brooks Street is considered a principal. Before and after the intersection reconstruction, the posted speed limit for both S. Russell and Brooks Streets will be 30 mph; all of these factors affected which values were bolded vales in this table.

TABLE 5: MOBILE6.2 CO EMISSION FACTORS WITH AND WITHOUT OXYFUEL

Reconstruction	Year	Arterial	Vehicle Speed								
			2.5 mph[a] (Idling)			20.0 mph			25.0 mph		
			With Oxyfuel (g CO/mi.)[b]	No Oxyfuel (g CO/mi.)	Emissions Reduction W/ Oxyfuel (%)	With Oxyfuel (g CO/mi.)	No Oxyfuel (g CO/mi.)	Emissions Reduction W/ Oxyfuel (%)	With Oxyfuel (g CO/mi.)	No Oxyfuel (g CO/mi.)	Emissions Reduction W/ Oxyfuel (%)
Before	2000	Minor	**325.4**	**387.3**	16.0	**48.4**	**57.5**	15.8	**46.5**	**55.3**	15.9
		Principal	**322.6**	**383.8**	16.0	48.0	57.1	15.9	**46.2**	**55.0**	16.0
	2005	Minor	**237.1**	**274.9**	13.8	**33.1**	**37.5**	11.7	**31.7**	**36.0**	11.9
		Principal	**235.7**	**273.3**	13.8	32.9	37.3	11.8	**31.6**	**35.8**	11.7
After	2010	Minor	**153.2**	**171.9**	10.9	25.1	27.8	9.7	**24.2**	**26.9**	10.0
		Principal	**152.9**	**171.5**	10.9	25.0	27.8	10.1	**24.2**	**26.8**	9.7
	2015	Minor	**117.8**	**129.2**	8.8	20.7	22.4	7.6	**20.1**	**21.7**	7.4
		Principal	**117.7**	**129.0**	8.8	20.7	22.4	7.6	**20.0**	**21.7**	7.8

[a] mph = miles per hour; resulting CO emission factors with the application of previous equation.
[b] g CO/mi. = grams of CO per mile.

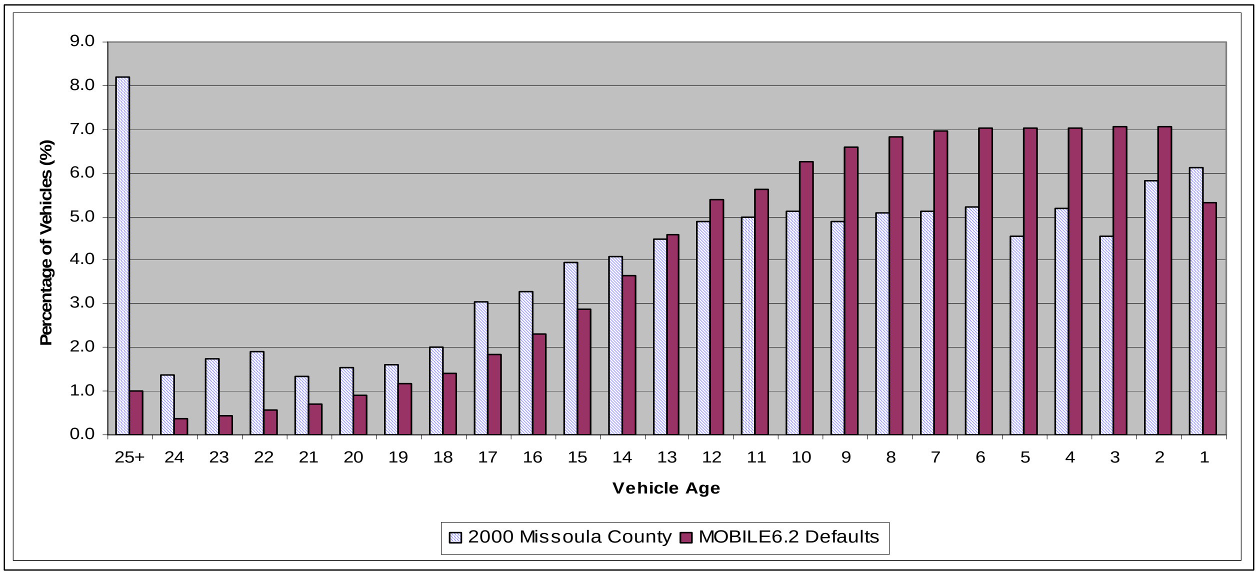
The idling CO emissions factors were significantly higher than the factors for the traveling speeds, over five to seven times greater, with or without the application of oxyfuel. Comparatively, the CO emission factors generated by the 20.0 and 25.0 mph vehicle speeds were not significantly different, with or without oxyfuel, or analysis year.

In this analysis, the inclusion of oxyfuel generally decreased the CO emission factors by approximately 16, 12, 10, and 8% for the 2000, 2005, 2010, and 2015 analysis year, respectively. According to an EPA MOBILE6.0 sensitivity analysis report, the effect of oxygenated fuels is less than 5%.[17]

The 2000 base year had the highest CO emission factors, which decreased with time. Relative to this year, the CO emission factors overall decreased at least 27, 47, and 56% for the 2005, 2010, and 2015 analysis years, respectively. The fleet turnover to better air emissions control technology probably was the most significant factor. The reduction of sulfur in the gasoline for better catalytic converter performance may have also been a factor although the same EPA sensitivity results found only a 5% effect.[17]

The vehicle age distribution of the 2000 Missoula County registration probably impacted the CO emission factors; this distribution was not typical of the national distribution that the sensitivity report was based upon. The following figure compares the vehicle age of the 2000 Missoula County vehicle registration and the MOBILE6.2 default vehicle distribution. These MOBILE6.2 default vehicle registration fractions were estimated from a graph in the report since the actual values were not documented in the report. [17]

FIGURE 3: VEHICLE AGE COMPARISON BETWEEN THE 2000 MISSOULA COUNTY VEHICLE REGISTRATION AND NATIONAL DEFAULTS



The 1976 model year and later vehicles (25 plus age group) were a significant fraction in the 2000 Missoula County registration data. The Missoula County registration had about eight times (8.1%) more vehicles that were 25 years and older than the MOBILE6.2 defaults (~1.0%). The weighted vehicle average of the MOBILE6.2 default registration was approximately 8.6 years old whereas the 2000 Missoula County vehicle registration was about 11.1 years or 2.5 years older. To reiterate, this age distribution of the 2000 Missoula County registration was also applied to the MOBILE6.2 modeling of the future years. After five years (2000 to 2005), the 25 plus age group encompassed 1981 MY and older vehicles so as a function of time, some of the 1975 and later MY vehicles in the 2000 analysis year were retired as newer models entered the fleet. Some of the older models (1975 MY plus) would have had catalytic converters, but the more sophisticated three-way catalysts with onboard computers and oxygen sensors were not introduced until 1981. The continued use of relatively high sulfur gasoline for the 2005 analysis year may have also reduced the effectiveness of the catalytic converters. For the 2010 and 2015 analysis years, the sulfur concentration in the gasoline was dramatically reduced according to the Tier 2/sulfur regulations and would have allowed the emission control equipment to function properly.

An interesting association was revealed in Table 5. Within a given travel speed and year, the minor arterial CO emission factors were generally a little higher than the principal arterial factors; the differences were not significant, but noticeable. The VMT fractions were the only major difference between the MOBILE6.2 model inputs for these two roads. The minor arterial distribution of VMTs had more gasoline vehicles and fewer diesels than the corresponding principal arterial VMT fractions. Since diesel engines emit less CO than gasoline, the higher percentages of diesel vehicles in the principal fractions caused comparably lower CO emission factors.

CAL3QHCR INPUTS TO CALCULATE THE 8-HOUR CO CONCENTRATIONS

Two approaches are allowed with the CAL3QHCR model. One method uses one complete year of meteorology with one hour of signalization and traffic volume data. The second method allows a diurnal pattern of signal and traffic information for an entire week. For this demonstration, the first approach was used, but the model was run five times for each analysis year, using a different year of local airport meteorological data each time. In each case, peak hourly CO season weekday traffic volumes were applied with the signalization phases that controlled maximum traffic volumes.

The CAL3QHCR model estimated the 8-hour averaged CO concentrations at specified locations called receptors. Using an x-y-z (z equals the height) coordinate system, these receptors were placed where the general public had (or will have) access to over the 8-hour period. The receptor locations were in the vicinity of the intersection, but not on the roadways. As specified by the EPA intersection modeling guideline, the receptors were placed at the required 10 ft (3 m) beyond the traveled roadways.[6] This placement avoided the mixing zone where the vehicle exhaust emissions are considered uniform due to the turbulence of the moving vehicles and thermal turbulence from the vehicle hot exhaust.

Also recommended by the model guidelines, the majority of the receptors had a height of 5.9 ft (1.8 m), the minimum acceptable height for this model. This height represented an adult male. One receptor was placed where the CO monitor is located at the B/S/R intersection; this location was not expected to change after the reconstruction. The height for this receptor was 12.5 ft (3.8 m) corresponding to the CO sampling probe inlet height. Receptors were also positioned at the following locations:

- At the vehicle stop line of each intersection road
- 82 ft (25 m) from the stop line receptor
- 164 ft (50 m) from the stop line receptor
- mid-block

If a receptor was positioned too close to another, it was relocated to avoid redundancy. The maximum number of receptors, sixty, was used for each model run.

The MDT TransCAD model developed the annual average daily traffic information for the arterial roadways. This daily traffic information was adjusted to represent the peak (maximum) hourly winter weekday traffic entering and departing each road of the intersection in the following manner.

Two permanent MDT automatic traffic recorders (ATR) were identified within the City of Missoula limits. Using the MDT station descriptions, these locations were Stations A-67 (Van Buren Street, south of Poplar Street) and A-37 (east end of the Orange Street Bridge). These ATR stations were classified as urban minor and principal arterials, respectively. In a MDT 2002 data report, the daily to peak hourly volumes for several years were documented for these sites.[18] Three recent years (1997 – 1999) that were common to both stations were selected to calculate the percentages necessary to convert the average daily traffic to peak hourly volumes; this information is listed in Table 6. Data were incomplete for Station A-37 for the year 2000 so this year was not used.

TABLE 6: 1997 – 1999 DAILY AND PEAK HOURLY TRAFFIC VOLUME DATA FOR TWO MISSOULA URBAN ARTERIALS

Year	Minor Arterial (Station A-67)			Principal Arterial (Station A-37)		
	Average Daily Traffic (ADT)[a]	Peak Hourly Volume	Percentage (%)	Average Daily Traffic (ADT)	Peak Hourly Volume	Percentage (%)
1997	9,440	1,100	11.70	20,509	2,408	11.70
1998	9,596	1,105	11.50	21,621	2,480	11.50
1999	9,957	1,199	12.00	20,207	2,245	11.10
Average	9,664	1,135	11.73	20,779	2,378	11.43

[a] ADT = average daily traffic.

The average percentages of the peak hourly to daily traffic volumes for the minor and principal arterials were 11.73 and 11.43, respectively. Therefore, the ADTs entering and departing the B/S/R intersection were multiplied by these percentages depending upon the arterial type to estimate the annual peak hourly volumes. These percentages were applied regardless of the analysis year. For comparison, the MDT uses 10% as a rule-of-thumb to adjust the ADTs to peak hourly volumes (personal communications, Al Vander Wey, MDT, June 27, 2003).

The next step was to adjust the annual peak hourly volumes to a peak hourly CO season day (winter weekday) volumes. As discussed, the MDEQ currently defines the three-month CO winter season as January, February, and December. Table 7 lists the information necessary to compute the CO season day adjustment factors in order to adjust the peak hourly volumes to the peak hourly CO season day volumes for both types of arterials. The year 2000 was selected to correspond to the 2000 Missoula Vehicle registration and the data was obtained from the same MDT publication used for Table 6.

TABLE 7: 2000 MISSOULA TRAFFIC VOLUMES TO COMPUTE THE CO SEASON DAY ADJUSTMENT FACTORS

Facility (Station)	2000 January		2000 February		2000 December		Annual Average Weekday	CO Season Day Adjustment Factor
	Average Weekday Count	Percent Monthly Daily Average (%)	Average Weekday Count	Percent Monthly Daily Average (%)	Average Weekday Count	Percent Monthly Daily Average (%)		
Minor Arterial (A-67)	9,444	0.9371	9,839	0.9763	9,354	0.9282	10,078	0.9472
Principal Arterial (A-37)	20,582	0.9374	21,266	0.9686	20,924[a]	0.9530	21,956[b]	0.9530

[a] Average of January and February.
[b] Average of January through September.

The calculated averages were 0.9472 and 0.9530 for the minor and principal arterials, respectively. The percentages listed in Table 6 and 7 were multiplied to the B/S/R intersection ADTs depending upon the type of arterial (minor or principal); the results are listed in the Table 8. In this table, “Bound” roughly approximates the direction the traffic is traveling towards relative to a compass. For clarification, the “Enter” and “Exit” are in relation to the intersection (i.e., entering the intersection).

TABLE 8: B/S/R INTERSECTION CO SEASON DAY PEAK HOURLY TRAFFIC VOLUMES

Reconstruction	Year	Brooks Street NE Bound[a]		Brooks Street SW Bound		South Avenue W. E Bound		South Avenue W. W Bound		S. Russell Street N Bound		S. Russell Street S Bound		Total	
		Enter	Exit	Enter	Exit	Enter	Exit	Enter	Exit	Enter	Exit	Enter	Exit	Enter	Exit
Before	2000	1,136	1,311	1,217	1,390	700	596	620	564	691	678	706	531	5,070	5,070
	2005	1,189	1,360	1,278	1,446	730	614	645	583	737	748	749	577	5,328	5,328
After	2010	1,427	1,249	1,580	1,512	0	518	0	413	805	570	1,091	641	4,903	4,903
	2015	1,451	1,270	1,580	1,543	0	546	0	434	848	595	1,197	688	5,076	5,076

[a] Roughly approximates compass directions: NE = Northeast; SW = Southwest; E = East; W = West; N = North; and S = South.

In comparison to the 2000 base year, the total peak hourly winter weekday 2005 traffic volume increased about 5%. After the reconstruction of the intersection, the 2010 total peak hourly winter weekday volume decreased around 3% compared to the 2000 volumes, but slightly increased by less than 1% for the 2015 analysis year. After reconstruction, South Avenue W. was unusual since this road will be modified to primarily divert traffic away from the intersection. The largest percentage increase in traffic occurred on S. Russell Street. From the year 2000 to the year 2010, the total traffic increased by around 19% and another 8% by 2015. However, the largest increase in peak hourly winter weekday volumes occurred on Brooks Street.

The CAL3QHCR required an arrival type of the platoon traffic. A platoon of road traffic is defined as a set of vehicles traveling together as a group due to the road signal control, road configuration, or other factors. The selected arrival type was normal before and after the intersection reconstruction. The MDT Traffic and Safety Bureau provided this information.

The model also required information on the type of signalization. In both cases, the signalization type was semiactuated meaning the traffic control signal operation has at least one, but not all of the signal phases controlled through the operation of a sensing detector. The sensing device is used to determine the presence or passage of vehicles or pedestrians. The MDT Traffic and Safety Bureau supplied this information.

The signalization process in 2000 and 2005 had four distinct phases: (1) Brooks Street; (2) S. Russell Street; (3) South Avenue W. eastbound; and (4) South Avenue W. westbound. After reconstruction, only two phases were integrated in the signalization process by the MDT, completely eliminating South Avenue W.: (1) Brooks and (2) S. Russell Streets. For this demonstration, peak hour signal cycles were selected as a conservative assumption.

The length of the signalization cycle often changes during the day to reflect the traffic volumes. Shorter cycles times generally occur during low traffic flow periods whereas longer times coordinate higher volumes.

With constant traffic volume, the amount of idling CO emissions during the signalization process is dependent on the length of the red light times; the longer the red time, more idling CO exhaust is emitted and higher ambient CO concentrations result due to the high CO emission factors. According to the MDT, the cycle times changed dramatically after the intersection reconstruction, but remained constant thereafter. Table 9 lists the peak hour total signal cycle and red times for each road before and after the intersection reconstruction. The “Bound” notations roughly approximate the directions of the traffic flow relative to a compass.

TABLE 9: PEAK HOUR TOTAL SIGNAL CYCLE AND RED TIMES BEFORE AND AFTER B/S/R INTERSECTION RECONSTRUCTION

Intersection Reconstruction	Total Cycle Time (s)[a]	Red Time (s)					
		Brooks Street		South Avenue W.		S. Russell Street	
		NE Bound[b]	SW Bound	E Bound	W Bound	N Bound	S Bound
Before	180	133	133	144	144	133	133
After	120	48	48	Eliminated	NA[c]	68	68
Time Difference (s)	60	85	85	144	134	65	65
Percentage Reduction (%)	33.3	63.9	63.9	100.0	NA[c]	48.9	48.9

[a] s = seconds.
[b] Roughly approximates compass directions: NE = Northeast; SW = Southwest; E = East; W = West; N = North; and S = South.
[c] Not Available; a stop sign will restrict the flow of traffic; the MDT and the EPA did not provide any estimation nor guidance.

After the reconstruction, the total cycle time decreased over 30%. For Brooks Street, the red times decreased over 60%. The elimination of the signalization process for South Avenue W. obviously caused a significant decrease in the signalization times. Almost a 50% reduction in the red times was projected for S. Russell Street.

Atmospheric conditions were another model input parameter. With the CAL3QHCR model, one complete year of local meteorological (met) is used, preferably, collected on-site. As an alternative, five years of consecutive National Weather Service (NWS) met data representative of the area being modeled is also acceptable.[5]

The latest five years of surface met data on the EPA SCRAM Web site (http://www.epa.gov/ttn/scram/) collected at the Missoula International Airport was from 1987 to 1991. To represent the upper atmosphere, the Great Falls, MT, International Airport data was used for the same period. The annual met data was composed of hourly wind direction (degrees), wind speed (meters per second), ambient temperature (Kelvin), atmospheric stability class (A-F), and rural and urban mixing heights (meters). All of these parameters, except for the temperature, are incorporated in the CAL3QHCR model mathematical dispersion equations.

The atmospheric stability class categories are based on surface wind speeds (speeds at 10 meters). Mixing height refers to the depth of the atmospheric layer through which ground level emissions will eventually reach; “A” represents very unstable atmospheric conditions compared to class “F” which is extremely stable.

The “Rural” switch was applied based on the classification scheme developed by Auer that defines an area as rural or urban.[19] This method focuses on the use and structure of the land, and the percentage of vegetation in the surrounding 3 kilometers.

Other model input parameters included the settling and deposition velocities. These variables were set to zero. The gravitational settling and dry deposition velocities were not factors since carbon monoxide is a gas with little mass and the model does not consider precipitation.

Another variable was the source release height. This was also set to zero to represent the tailpipes. The surface roughness, 108 centimeters, was selected to represent a suburban area. Currently, the Missoula County Fairgrounds is located adjacent to the B/S/R intersection. It is to the east and south of Brooks Street and South Avenue W., respectively, but more than 50% of the surrounding area is suburban and includes offices and shopping malls; the selected surface roughness reflected all of these characteristics.

The surface roughness conveys the roughness of the nearby area, but is not the actual overall height of the structures since CO is released at ground level. It is based on how an obstruction influences the vertical and horizontal dispersion of pollutants released at ground level, and the intensity of mechanical turbulence from this obstruction.

HOURLY CO BACKGROUND CONCENTRATIONS

Hourly background CO concentrations were included as input into the CAL3QHCR model to account for sources not explicitly accounted for. For a CO season day in the City of Missoula, these sources include emissions from wood stoves burning wood for heat or pleasure, but primarily, emissions from vehicles traveling the roads surrounding the B/S/R intersection. The following table summarizes the background concentrations used in this analysis; these values were reviewed and accepted by an EPA staff (personal communications, Kerri Fielder, EPA Region VIII, May 12, 2004). These concentrations were equivalent to the 8-hour averaged CO background concentrations since the hourly concentrations did not change.

TABLE 10: CO SEASON DAY HOURLY CO BACKGROUND CONCENTRATIONS

Intersection Reconstruction	Year	Hourly CO Concentration (ppm)[a]
Before	2000	1.1
	2005	1.0
After	2010	0.8
	2015	0.6

[a.] ppm = parts per million.

The background CO concentrations decreased over time due to the primary source, the vehicle fleet outside the B/S/R intersection. Newer, cleaner vehicles with better emissions control technology will replace the older, dirtier vehicles thereby decreasing the overall background ambient CO concentrations.

In the past, higher background CO concentrations would be estimated due to the more pervasive residential wood burning in the City of Missoula. However, with the success of the MCCHD air pollution control program by restricting the types of wood stoves in the Missoula urban area has reduced the background CO concentrations.

CAL3QHCR 8-HOUR AVERAGED CO CONCENTRATIONS

Table 11 displays the highest and second highest 8-hour averaged CO concentrations from the CAL3QHCR modeling using the five different years of meteorology. The predicted concentrations at the CO monitor location are also listed. All concentrations included the background CO concentrations. The bolded second highest concentrations are compared to the 9.5 ppm NAAQS/MAAQS to determine violations. The results for all sixty receptors are included in the appendices.

TABLE 11: CO SEASON DAY HIGHEST AND SECOND HIGHEST 8-HOUR AVERAGED CO CONCENTRATIONS WITH CAL3QHCR MODEL

Reconstruction	Year	Met Year	Highest CO Conc.[a] (ppm)[b]		**Second Highest CO Conc. (ppm)**		CO Monitor			
							Highest CO Conc. (ppm)		**Second Highest CO Conc. (ppm)**	
			No Oxyfuel	With Oxyfuel	**No Oxyfuel**	**With Oxyfuel**	No Oxyfuel	With Oxyfuel	**No Oxyfuel**	**With Oxyfuel**
Before	2000	1987	14.0	11.8	**12.3**	**10.5**	7.0	6.1	**7.0**	**6.1**
		1988	13.4	11.5	**12.5**	**10.7**	8.1	7.0	**7.2**	**6.3**
		1989	12.2	10.4	**11.9**	**10.1**	7.7	6.6	**7.3**	**6.4**
		1990	12.5	10.7	**11.3**	**9.7**	7.3	6.4	**7.3**	**6.3**
		1991	12.7	10.8	**11.4**	**9.7**	8.0	6.9	**7.7**	**6.7**
	2005	1987	10.2	8.9	**8.9**	**7.8**	5.2	4.7	**5.2**	**4.7**
		1988	9.8	8.7	**9.1**	**8.0**	5.9	5.4	**5.3**	**4.8**
		1989	8.7	7.8	**8.5**	**7.5**	5.6	5.0	**5.4**	**4.9**
		1990	8.9	7.9	**8.2**	**7.3**	5.4	4.8	**5.3**	**4.8**
		1991	9.1	8.1	**8.2**	**7.2**	5.8	5.2	**5.6**	**5.1**
After	2010	1987	5.0	4.6	**4.7**	**4.4**	3.0	2.8	**2.9**	**2.7**
		1988	5.9	5.4	**4.6**	**4.2**	3.3	3.0	**3.1**	**2.9**
		1989	5.1	4.7	**4.7**	**4.3**	3.2	3.0	**3.1**	**2.9**
		1990	4.3	4.0	**4.3**	**3.9**	3.2	3.0	**3.1**	**2.9**
		1991	4.8	4.4	**4.3**	**3.9**	3.4	3.2	**3.1**	**2.9**
	2015	1987	4.0	3.8	**3.9**	**3.6**	2.4	2.3	**2.3**	**2.2**
		1988	4.7	4.5	**3.7**	**3.5**	2.6	2.4	**2.5**	**2.3**
		1989	4.1	3.8	**3.8**	**3.6**	2.6	2.4	**2.5**	**2.4**
		1990	3.5	3.2	**3.4**	**3.2**	2.6	2.4	**2.4**	**2.3**
		1991	3.9	3.6	**3.5**	**3.3**	2.7	2.5	**2.4**	**2.2**

[a] Conc. = concentration.
[b] ppm = parts per million.

Even with the application of oxyfuel, a violation of the NAAQS/MAAQS exceedance value (9.5 ppm) was predicted to occur at locations other than at the CO monitor during the 2000 base year. Compared to the average of the results of the five different met years, the second highest 8-hour concentrations were about 7 and 25% greater than the exceedance concentration with and without oxyfuel, respectively. At the CO monitor, the second highest CO 8-hour concentrations were around 23 and 33% less than the NAAQS/MAAQS exceedance value with and without oxyfuel, respectively.

Compared to the average of the results of the five different met years, for the 2005, 2010, and 2015 analysis years, the second highest 8-hour CO concentrations with oxyfuel were about 20, 56, and 64%, respectively, less than the exceedance concentration compared to corresponding 10, 52, and 62% without the gasoline additive. At the CO monitor, the relationship was 49, 70, and 76% (with oxyfuel) compared to 44, 68, and 75% (without). The following table displays the percentage reductions in the CO concentrations with the application of oxyfuel.

TABLE 12: 8-HOUR CO CONCENTRATION REDUCTIONS DUE TO OXYFUEL

Reconstruction	Year	Met Year	Highest CO Concentration Reductions[a] (%)	Second Highest CO Concentration Reductions (%)	CO Monitor	
					Highest CO Concentration Reductions (%)	Second Highest CO Concentration Reductions (%)
Before	2000	1987	15.71	14.63	12.86	12.86
		1988	14.18	14.40	13.58	12.50
		1989	14.75	15.13	14.29	12.33
		1990	14.40	14.16	12.33	13.70
		1991	14.96	14.91	13.75	12.99
		Average	14.80	14.65	13.36	12.87
	2005	1987	12.75	12.36	9.62	9.62
		1988	11.22	12.09	8.47	9.43
		1989	10.34	11.76	10.71	9.26
		1990	11.24	10.98	11.11	9.43
		1991	10.99	12.20	10.34	8.93
		Average	11.31	11.88	10.05	9.33
After	2010	1987	8.00	6.38	6.67	6.90
		1988	8.47	8.70	9.09	6.45
		1989	7.84	8.51	6.25	6.45
		1990	6.98	9.30	6.25	6.45
		1991	8.33	9.30	5.88	6.45
		Average	7.93	8.44	6.83	6.54
	2015	1987	5.00	7.69	4.17	4.35
		1988	4.26	5.41	7.69	8.00
		1989	7.32	5.26	7.69	4.00
		1990	8.57	5.88	7.69	4.17
		1991	7.69	5.71	7.41	8.33
		Average	6.57	5.99	6.93	5.77

With the application of oxyfuel and at locations other than the CO monitor location, the 8-hour averaged CO concentrations were reduced around 15, 11, 8, and 6% for the 2000, 2005, 2010, and 2015 analysis years, respectively. These reductions reflected the impact of oxyfuel on the CO emission factors. Comparatively, the reductions at the CO monitoring site were about 1% lower for the same analysis years.

The year of the met data used also affected the predicted 8-hour concentrations. Before the intersection reconstruction, the highest and second 8-hour CO concentrations were estimated using the 1987 and 1988 met year data, respectively. After the reconstruction, the impact of these two years was generally reversed. At the CO monitor, a pattern was less distinct, but overall, before reconstruction, the application of the 1988 and 1991 met years yielded the highest and second highest 8-hour concentrations, respectively, and the pattern was reverse after the rebuild.

Table 13 lists the receptor locations and dates (Julian day and ending hour) corresponding to the data in Table 11. The dates and locations (receptors) of the highest and second 8-hour averaged CO concentrations identified by the model were not identical for the analysis years. These changes were not surprising due to changes in the intersection design, traffic volumes, and signalization parameters.

TABLE 13: CO SEASON DAY RECEPTOR LOCATIONS AND DATES OF THE HIGHEST AND SECOND HIGHEST 8-HOUR AVERAGED CO CONCENTRATIONS

Reconstruction	Year	Met Year	Highest CO Concentration				Second Highest CO Concentration				CO Monitor			
			No Oxyfuel		Oxyfuel		No Oxyfuel		Oxyfuel		Highest CO Concentration		Second Highest CO Concentration	
											No Oxyfuel	Oxyfuel	No Oxyfuel	Oxyfuel
			Receptor	Date[a]	Receptor	Date	Receptor	Date	Receptor	Date	Date	Date	Date	Date
Before	2000	1987	8	251, 7	8	251, 7	43	125, 7	43	125, 7	93, 5	93, 5	74, 10	74, 10
		1988	4	237, 5	4	237, 5	8	272, 6	8	272, 6	336, 7	336, 7	27, 15	313, 16
		1989	45	293, 8	45	293, 8	45	327, 5	45	327, 5	71, 7	71, 7	20, 9	20, 10
		1990	4	315, 2	4	315, 2	8	301, 2	8	301, 2	64, 3	64, 3	306, 11	306, 11
		1991	48	140, 6	48	140, 6	38	350, 1	38	350, 1	350, 1	350, 1	12, 1	12, 1
	2005	1987	8	251, 7	8	251, 7	43	125, 7	43	125, 7	74, 10	74, 10	93, 5	93, 5
		1988	4	237, 5	4	237, 5	8	272, 6	8	272, 6	336, 7	336, 7	149, 7	27, 15
		1989	45	293, 8	45	293, 8	45	327, 5	45	327, 5	71, 7	71, 7	20, 10	20, 9
		1990	4	315, 2	4	315, 2	8	301, 2	8	301, 2	64, 3	306, 11	306, 11	64, 3
		1991	48	140, 6	48	140, 6	38	350, 1	38	350, 1	350, 1	350, 1	12, 1	12, 1
After	2010	1987	10	125, 7	10	125, 7	27	222, 5	27	103, 5	93, 5	93, 5	286, 3	201, 9
		1988	27	305, 1	27	305, 1	28	350, 24	27	303, 4	336, 7	336, 7	313, 15	313, 16
		1989	27	77, 4	27	77, 4	27	102, 5	27	102, 5	71, 7	71, 7	333, 8	333, 8
		1990	27	316, 2	27	316, 2	27	64, 3	27	64, 3	64, 3	63, 4	147, 6	147, 6
		1991	27	293, 3	27	293, 3	38	11, 23	27	319, 23	350, 2	350, 2	30, 10	30, 10
	2015	1987	10	125, 7	10	125, 7	27	103, 5	27	103, 5	93, 5	93, 5	201, 9	37, 17
		1988	27	305, 1	27	305, 1	27	303, 4	28	350, 24	336, 7	336, 7	313, 16	313, 16
		1989	27	77, 4	27	77, 4	27	102, 5	27	102, 5	71, 7	71, 7	135, 4	135, 4
		1990	27	64, 3	27	304, 3	27	279, 3	27	279, 3	64, 3	64, 3	147, 6	147, 6
		1991	27	293, 3	27	293, 3	27	319, 23	27	319, 23	350, 2	350, 2	12, 1	12, 1

[a] Date = Julian Day and the ending hour of the 8-hour period.

In general, the application of oxyfuel did not affect the locations and the dates of the highest and second highest 8-hour averaged CO concentrations. For a given met year, the same receptors and dates of these events were also identified depending on when the analysis year occurred in relation to the intersection reconstruction (before or after). This trend was also consistent regarding the dates for the receptor representing the CO monitor.

It is generally believed the meteorological conditions conducive to an 8-hour CO NAAQS/MAAQS violation occur midnight to early morning in the wintertime; however, some of the dates in Table 13 included during other seasons. Violations have been recorded at this intersection during the other periods than wintertime (spring, late summer, and fall months) in the 1970s before monitoring was limited to six months during the year although these 8-hour concentrations were never the highest or second highest 8-hour concentrations. With reduced vehicle CO emissions in the 1980s and 1990s, exceedances of the 8-hour CO NAAQS only occur in the winter when dispersion was poor.

These high 8-hour concentrations also occurred primarily during moderately to very stable atmospheric periods with low wind speeds and mixing heights. The atmospheric stability class is provided as part of the met data and affects the Gaussian mathematical calculations of the horizontal and vertical dispersion of the CO. An inverse relationship exists between CO concentrations and wind speed (lower the speeds, higher the concentrations). Even moderately stable atmospheric conditions can occur with surface wind speeds than less 3.0 meters per second (m/s) during the nighttime depending on the cloud cover. For clarity, nighttime is considered 1 hour before sunset to 1 hour after sunrise.

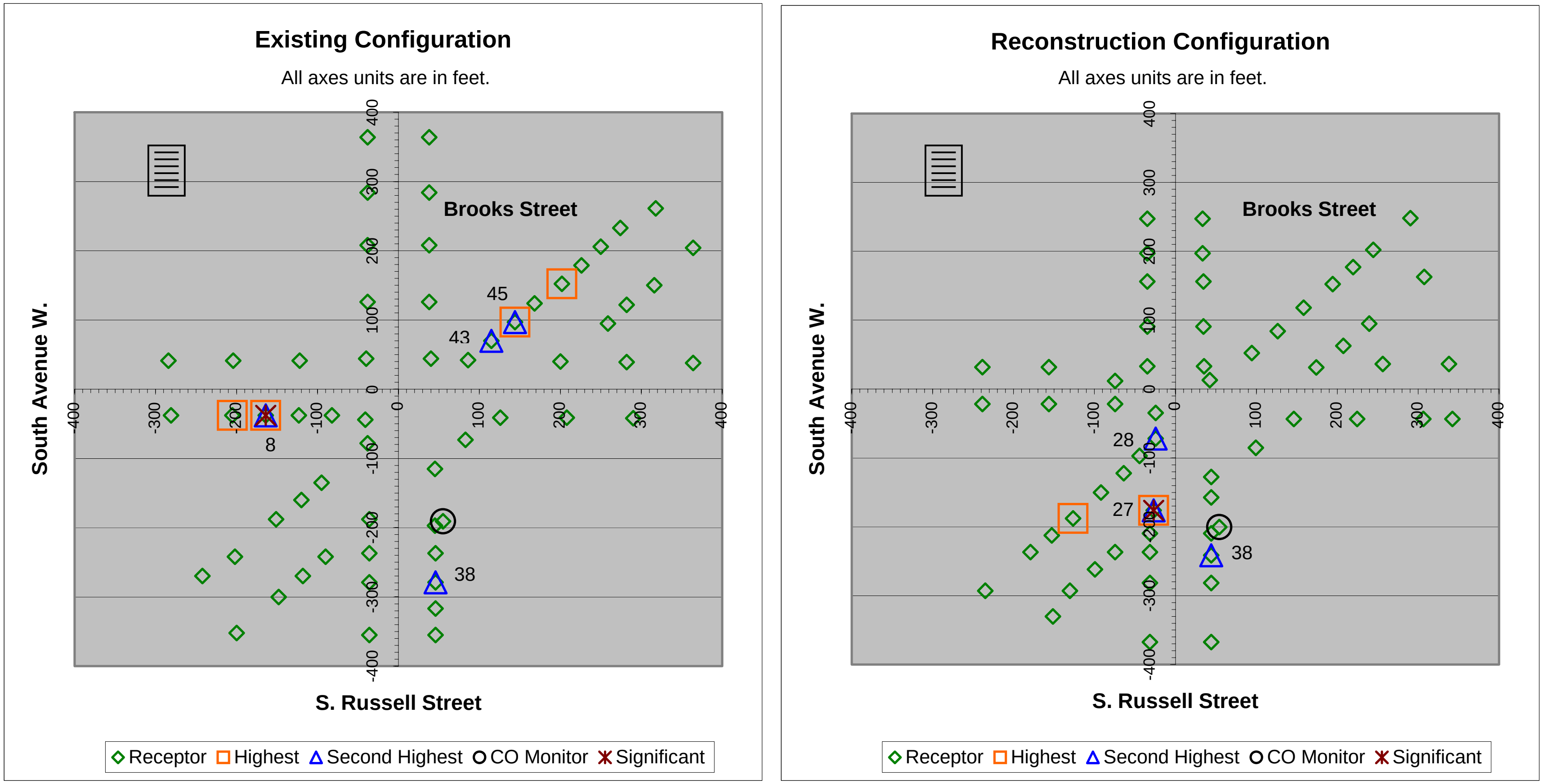
When a calm wind (less than 1.0 m/s) exists in the model input, the hourly concentration is set to zero and the hourly ambient background concentration is not used to calculate the 8-hour averaged CO concentration. The 8-hour averaged concentration is calculated by summing all of the non-calm 1-hour concentrations and dividing the total by the total number of non-calm hours or 75%, whichever is greater. Therefore, the model does handle hours of calm wind, but several hours of calm wind is not identical to long periods (days) of air stagnation when CO accumulates. In this case, the background CO concentration should be relatively large to represent air stagnation.

The process the CAL3QHR model determines the highest and second highest 8-hour averaged CO concentrations should also be elaborated. The model calculates nine highest 8-hour running concentrations for each receptor. Of these nine averages, one is the maximum and at least one of the other averages does not overlap one of the higher averages. The CAL3QHCR model outputs the highest and second highest running non-overlapping values for each receptor. The other seven values are either lower in value or overlap the higher values.

The consistency of the identified receptors revealed interesting information. Before the intersection reconstruction (2000 and 2005 analysis years), the highest 8-hour CO concentrations were predicted at the following receptors: 4, 8, 45, and 48 with Receptor 4 as the most prevalent. The second highest 8-hour CO concentrations were identified at the following receptors: 8, 38, 43, and 45; in this case, Receptors 8 was dominant.

After the reconstruction (2010 and 2015 analysis years), Receptor 27 was overwhelmingly the significant location; Receptors 10, 28, and 38 were also identified, but only sporadically. Figure 4 displays all receptor locations including the highest and second 8-hour averaged CO concentrations with the dominant receptors labeled as “Significant.” In this figure, the identification numbers of the receptors were not identical in both charts since the receptor information for each chart was obtained from different sources and the intersection changed shaped due to the redesign.

FIGURE 4: ALL RECEPTOR LOCATIONS FOR EXISTING AND RECONSTRUCTION INTERSECTION CONFIGURATIONS



The CAL3QHCR model outputs included the source contributions from the free flow and delayed (queued) vehicles to the predicted highest and second highest 8-hour concentrations. Before the intersection reconstruction and excluding the background CO concentrations, the emissions from the idling vehicles closest to those receptors of the highest and second highest 8-hour averaged CO concentrations contributed heavily, between 40 to 60%, except for the receptor representing the CO monitor. The red cycle light time on South Avenue W. was the longest, which probably caused the high concentrations estimated at Receptor 8 since the hourly traffic was relatively low. In contrast, the traffic volume on Brooks Street traveling southwest was the highest and when delayed produced the high concentrations predicted at Receptors 43 and 45. This same traffic when was in free flow (no delay) caused between 10 to 20% to these same 8-hour averaged CO concentrations.

These results indicate that the CO monitoring location is not the site of the highest or second highest 8-hour averaged CO concentrations at the intersection with the current configuration. These results were verified by a 1992 CO saturation study of the B/S/R intersection conducted by the MCCHD.[20] This bag sampling study identified the location of the highest 8-hour averaged CO concentration near Receptor 43.

After the reconstruction, the primary source to the highest and second highest 8-hour concentrations was from the vehicles approaching and departing the intersection without signal delay (free flow) on the adjacent roadway. These emissions contributed between 25 to 37%, excluding the background concentration. Receptor 27 was impacted by the traffic traveling northeast on Brooks Street without signalization delay, which contributed between about 25 to 35% to the 8-hour CO concentrations. The traffic volume on this road was not the highest so the only other potential contributing factor was the meteorology. The secondary source (10 to 25%) to the concentrations predicted at this receptor was from the vehicles traveling without delay on Brooks Street heading southwest.

The reconstruction did not affect the primary contributor to the concentrations predicted at the CO monitor receptor. The emissions from the delayed vehicles on the adjacent roadway (S. Russell Street) contributed between 15 to 45% to the highest and second highest 8-hour CO concentrations. Before the redesign and depending upon the met year, secondary contributors (about 15%) were the departing traffic on Brooks Street heading southwest, queued traffic on South Avenue W. (going east), and Brooks Street (proceeding southwest). After the rebuild, the secondary contributors were from the free flow traffic (around 15%) on Brooks Street.

COMPARISON OF CAL3QHCR RESULTS AND B/S/R MONITORING DATA

Table 14 lists the highest and second highest 8-hour averaged CO concentrations recorded at the B/S/R intersection in 1999 through 2003 monitoring period.

TABLE 14: HIGHEST AND SECOND HIGHEST 8-HOUR AVERAGED CO CONCENTRATIONS RECORDED AT THE B/S/R/ INTERECTION: 1999 - 2003

Year	Highest 8-Hour CO Concentrations (ppm)[a]	Second Highest 8-Hour CO Concentrations (ppm)
1999	4.9	4.4
2000	3.9	3.3
2001	5.5	3.9
2002	4.6	3.6
2003	4.3	3.6

[a] ppm = parts per million.

The highest and second highest 8-hour averaged CO concentration measured in 2000 at the CO monitoring site was 3.9 and 3.3 ppm, respectively. With the application of oxyfuel, the CAL3QHCR predicted the highest 8-hour CO concentrations at this location between 6.1 to 7.0 ppm, depending on the met year data; the overall average was 6.6 ppm. Therefore, the average of the highest predicted 8-hour averaged concentrations were about 40% greater than the measured concentration.

For the second highest predicted 8-hour averaged CO concentrations, the range was 6.1 to 6.7 ppm; the overall average concentration was 6.4 ppm. The estimated concentrations were about 48% greater than the observed concentration.

An EPA accuracy statistic was applied to analyze the performance of model. This statistic was also used by the State of Colorado for a combined Urban Airshed Model (UAM) and CAL3QHCR analysis to examine CO concentrations.[21] In that investigation, the accuracy statistic was used with the highest 8-hour CO concentrations greater than 5.0 ppm that were paired in space (same location) and time (same date). The cited maximum goal between predicted and observed 8-hour CO concentrations was 25 - 30%.

$$A = \frac{1}{n} \left| \sum \frac{Ce - C_O}{C_O} \right| (100)$$

A = Estimate Accuracy (%)
N = Number of Data Sets
C_e = Estimated Highest 8-hour Concentration at the CO Monitor
C_o = Observed Highest 8-hour Concentration at the CO Monitor

Unfortunately, the measured CO concentrations at the CO monitor during 2000 were less than the threshold concentration (5.0 ppm). So as an approximation, the observed 5.5 ppm 8-hour CO concentration measured in 2001 and the predicted CAL3QHCR concentrations for 2000 were applied using the previous equation. Substituting the available data from the CAL3QHCR modeling, the accuracy was about 16% (15.6%); this result indicated the CAL3QHCR model with the MOBILE6.2 CO emission factors performed adequately.

IMPACT OF METEOROLOGICAL DATA

An important factor in this modeling demonstration was the meteorological data. Although the data were not collected on-site, the numbers of consecutive hours of calm winds (<1.0 m/s) at the Missoula International Airport (MIA) were unusually large during the 1987 to 1991 period. In fact, the CAL3QHCR was recently modified to expand the array of this parameter from 200 to 2000 hours; before this modification, incorrect concentrations resulted. The following table displays the number of consecutive hours of calm wind; the sequence of number of consecutive calm wind hours in this table is not successive.

TABLE 15: FREQUENCY OF CONSECUTIVE HOURS OF CALM WINDS AT MIA: 1987 - 1991

Hours of Consecutive Calm Wind[a, b]	Frequency of Occurrence in Met Year				
	1987	1988	1989	1990	1991
1	540	460	463	487	542
2	179	163	160	166	184
3	93	69	63	74	93
4	35	33	39	58	43
5	18	15	14	29	37
6	9	8	11	12	12
7	8	8	3	16	9
8	1	6	4	6	11
9	2	2	4	7	5
10	2		2	6	5
11	1		2	1	3
12			1	2	1
15			1		
16					1
17			1	1	
18			1		
23				1	
Total	888	764	769	866	946

[a] The sequence of the number of hours is not consecutive.
[b] Calm wind is less than 1.0 m/s (2.2 mph).

The consensus of the MDEQ staff is recent climatological conditions throughout Montana, including the year 2000, have not been typical. The State including the City of Missoula has not had typical wintertime conditions conducive to carbon monoxide accumulation and persistence.

CONCLUSIONS

The idling MOBILE6.2 CO emission factors were significantly greater than the factors for the traveling speeds, over five to seven times greater, with or without the application of oxyfuel. In comparison, the factors of two traveling speeds were not significantly different.

The 2000 base year had the highest CO emission factors, which decreased with time. Relative to this year, the CO emission factors overall decreased at least 27, 47, and 56% for the 2005, 2010, and 2015 analysis years, respectively. The fleet turnover to better air emissions control technology probably was the most significant factor. The reduction of sulfur in the gasoline for better catalytic converter performance may have also been a factor.

In this analysis, the inclusion of oxyfuel generally decreased the CO emission factors by approximately 16, 12, 10, and 8% for the 2000, 2005, 2010, and 2015 analysis year, respectively.

The Missoula County vehicle registration was different than the EPA national default registration. The 1976 model year and later vehicles (25 plus age group) were a significant fraction in the 2000 Missoula County registration data. The Missoula County registration had about eight times (8.1%) more vehicles that were 25 years and older than the MOBILE6.2 defaults (~1.0%). The weighted vehicle average of the MOBILE6.2 default registration was approximately 8.6 years old whereas the 2000 Missoula County vehicle registration was about 11.1 years or 2.5 years older.

In comparison to the 2000 base year, the total peak hourly winter weekday 2005 traffic volume increased about 5%. After the reconstruction of the intersection, the 2010 total peak hourly winter weekday volume decreased around 3% compared to the 2000 volumes, but increased by less than 1% for the 2015 analysis year.

The largest percentage increase in the peak hourly traffic volume occurred on S. Russell Street. From the year 2000 to the year 2010, this traffic increased by around 19% and another 8% by 2015. However, the largest increase in peak hourly winter weekday volumes occurred on Brooks Street. After reconstruction, South Avenue W. was unusual since this road will be modified to primarily divert traffic away from the intersection.

After the reconstruction, the total signalization cycle time decreased over 30%. For Brooks Street, the red times decreased over 60% compared to nearly 50% reduction of red signal times for S. Russell Street. The elimination of the signalization process for South Avenue W. obviously caused a significant decrease in the signalization times.

For the 2000 base year with the current intersection configuration, the CAL3HCR model predicted a violation of the 8-hour averaged CO NAAQS/MAAQS, with and without use of oxyfuel, but not at the location representing the CO monitoring station. The dominating source of the 8-hour CO concentrations was from the vehicles delayed (queued) on the adjacent roadway during the signalization process.

Before the intersection reconstruction, the locations of the second highest averaged 8-hour CO concentrations depended upon the year of the met data. However, the primary source of these concentrations was from the delayed (queued) vehicles during the signalization process. These vehicles contributed between 40 to 60% to these concentrations excluding the background CO concentrations. The extremely high idling CO emission factors relative to the traveling factors impacted these results.

With two out of the five years of met data, the location of the second highest averaged CO concentration was west of the B/S/R intersection on South Avenue W. This leg of the B/S/R intersection had the longest red cycle time with the highest traffic volumes traveling on this road; these volumes were about 40% less than the traffic on Brooks Street. With two other years of met data, the delayed high traffic volumes on Brooks Street traveling southwest caused the near-by receptors as the locations of the second highest 8-hour averaged CO concentrations.

After the reconstruction, the possibility of an exceedance of the 8-hour NAAQS/MAAQS was highly improbable even without oxyfuel. Therefore, based on these modeling results, the redesign of the intersection at Brooks Street, South Avenue W., and S. Russell Street will beneficially improve the air quality surrounding the area through 2015 (the final year of analysis). Concurrently, the urban background CO concentrations will also decrease.

The primary source to the highest and second highest 8-hour concentrations after the intersection reconstruction was from the vehicles approaching and departing the intersection without signal delay (free flow) on the adjacent roadway. These emissions contributed between 25 to 37%, excluding the background CO concentrations. The significant reductions in the signal cycle times influenced these results.

Based on an EPA accuracy statistic, the CAL3QHCR modeling with the MOBILE6.2 CO emission factors performed adequately. The following factors, in decreasing order of importance, contributed to the improvement, of the ambient 8-hour averaged CO concentrations at the B/S/R intersection:

- Vehicle fleet turnover of 1976 model year and older vehicles without catalytic converters or oxygen sensors to new, cleaner vehicles with better emissions reductions technology.
- Significant reductions in the red light cycle times for both Brooks and S. Russell Streets by almost 65 and 50%, respectively.
- Elimination of two signal phases controlling traffic on South Avenue W. which reduced the total signal cycles times over 30%.
- Reduction of the sulfur content in gasoline by federal mandate that poisons catalytic converters from 300 ppm to 30 ppm, a 90% decrease.

RECOMMENDATIONS

The following recommendations are suggested for verification of this modeling demonstration and for future analyses of the B/S/R intersection. When applicable, all data should be collected during the winter weekdays of the relevant years with sufficient replication for statistical analysis.

- Traffic Volumes: Verify the approach and departure volumes by placing automatic traffic counters across each leg of the intersection roadway during the years of interest. Ideally, data collection would occur on an hourly basis during the winter weekdays to establish the peak hour winter weekday volumes.
- Vehicle Travel Speeds: Confirm the vehicle travel speeds during the peak hour winter weekdays by traveling with the flow of traffic through the B/S/R intersection using stopwatches within pre-determined distances.
- Signalization Parameters: Validate the signal cycle times (red/yellow/red cycle times) with stopwatches.
- Vehicle Registration: Compare the 2000 Missoula County vehicle registration data with future year registration data to verify fleet turnover.
- VMT Fractions: Update this important MOBILE6.2 parameter with local information for future modeling analyses.
- Computer Models: Apply any updated EPA CO mobile emissions and signalized intersection models in addition to any MDT transportation model; models are continuously improved and updated.
- Guidance Development: The EPA should develop guidance to address alternative traffic control systems such as stop and yield signs.
- Met Data: Verify the CAL3QHCR results using met data for the years of interest from the Missoula and Great Falls International Airports with any updated model inputs.

REFERENCES

1. Federal Register. "Approval and Promulgation of Air Quality Implementation Plans, States of Montana and Utah; Oxygenated Gasoline Program." Federal Register 59: 55585. November 8, 1994.

2. Sierra Research, Inc. *Cold Start, Plug-in and Mid-Trip Idling CO Emissions from Light-Duty Gasoline-Powered Vehicle in Alaska.* Report No. SR99-06-01. Sierra Research, Inc. Sacramento, CA. 1999.

3. EPA. *User's Guide to MOBILE6.1 and MOBILE6.2: Mobile Source Emission Factor Model*. ONLINE. August 2003. EPA420-R-03-010. U.S. Environmental Protection Agency. Office of Transportation and Air Quality. Assessment and Standards Division. Available: http://www.epa.gov/otaq/m6.htm [September 2003].

4. EPA. *Technical Guidance on the Use of MOBILE6 for Emission Inventory Preparation*. ONLINE. January 2002. U.S. Environmental Protection Agency. Office of Air and Radiation. Office of Transportation and Air Quality. Available: http://www.epa.gov/otaq/models/mobile6/m6techgd.pdf [January 2002].

5. EPA. *Addendum To The User's Guide To CAL3QHC Version 2.0 (CAL3QHCR User's Guide)*. U.S. Environmental Protection Agency. Office of Air Quality, Planning and Standards. Technical Support Division. Research Triangle Park, NC. 27711. September 1995.

6. EPA. *User's Guide to CAL3QHC Version 2.0: A Modeling Methodology for Predicting Pollutant Concentrations Near Roadway Intersections*. EPA-454/R-92-006 (Revised). U.S. Environmental Protection Agency. Office of Air Quality, Planning and Standards. Technical Support Division. Research Triangle Park, NC. 27711. September 1995.

7. EPA. *Guideline For Modeling Carbon Monoxide From Roadway Intersections*. EPA-454/R-92-005. U.S. Environmental Protection Agency. Office of Air Quality, Planning and Standards. Technical Support Division. Research Triangle Park, NC. 27711. November 1992.

8. HNTB. *Intersection Air Quality Modeling Analysis Technical Report for the Brooks/South/Russell Intersection Transportation Improvement Project (South Avenue Realignment Alternation)*. May 1996.

9. Cain, Cyra J. *2000 Missoula, Montana, Carbon Monoxide Emission Inventory*. Permitting and Compliance Division. Air Resources Management Bureau. Montana Department of Environmental Quality. Helena, MT. 59620. July 2004.

10. Cain, Cyra J. *CAL3QHCR Modeling Analysis For Missoula, Montana, Redesignation To Carbon Monoxide NAAQS Attainment.* Montana Department of Environmental Quality. Permitting and Compliance Division. Air Resources Management Bureau. Analytical Services Section. Helena, MT. 59620-0901. July 2004.

11. Haines, Howard. Energy Specialist. Personal Communications. Montana Department of Environmental Quality. Pollution Prevention Bureau. Helena, MT. April 17, 2002.

12. MCCHD. *Missoula County Air Pollution Control Program. Oxygenate Blending Facility Requirements.* ONLINE. November 17, 2000. Missoula City-County Health Department. Air Quality Regulations. Available: http://www.co.missoula.mt.us/EnvHealth/AirQ/aqreg2000.pdf [January 2002].

13. Lee, Scott. U.S. EPA Region VIII. Personal Communications with Jim Carlin. Air Quality Specialist. Montana Department of Environmental Quality. Monitoring and Data Management Bureau. Helena, MT. October 1995.

14. Federal Register. “Control of Air Pollution From New Motor Vehicles; Tier 2 Motor Vehicle Emission Standards and Gasoline Sulfur Control Requirements; Diesel Fuel Quality Controls.” Federal Register 65: 6752. February 10, 2000.

15. EPA. *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources*. EPA-420-R-92-009. U.S. Environmental Protection Agency. Emission Planning and Strategies Division. Office of Mobile Sources and Technical Support Division. Office of Air Quality Planning and Standards. Research Triangle Park, NC. December 1992.

16. NOAA. *Climatological Data: Montana*. National Oceanic and Atmospheric Administration. National Environmental Satellite. Data and Information Service. National Climatic Data Center. Asheville, NC. 28801. 2000.

17. EPA. *Sensitivity Analysis of MOBILE6.0*. EPA420-R-02-035. ONLINE. December 2002. U.S. Environmental Protection Agency. Office of Transportation and Air Quality. Assessment and Standards Division. Available: http://www.epa.gov/otaq/models/mobile6/r02035.pdf [July 2002].

18. MDT. *Montana’s Automatic Traffic Counters 2002*. ONLINE. January 2002. Montana Department of Transportation. Traffic Data Collection Section. U.S. Department of Transportation. Federal Highway Administration. Available: http://www.mdt.state.mt.us/departments/transportation_planning/pdf/2002_atrbook.pdf [July 23, 2002].

19. Auer, Jr., A. H. *Correlation of Land Use and Cover with Meteorological Anomalies.* Journal of Applied Meteorology. 17(5): 636-643. 1978.

20. Schmidt, Benjamin. *Missoula, Montana Carbon Monoxide Saturation Study, December 5, 1992 to December 20, 1992*. Missoula City-County Health Department. Missoula, Montana. April 1993.

21. CDPHE. *Colorado State Implementation Plan For Carbon Monoxide, Technical Support Documentation, Chapter 6, Denver Metropolitan Nonattainment Area Element.* Colorado Department of Public Health and Environment. Air Pollution Control Division. 4300 Cherry Creek Drive South. Denver, Colorado. October 1994.