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Noise and Air Quality Implications of Alternative Transportation Systems: Zion and Acadia National Park Case Studies

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1. Introduction

The U.S. Department of Transportation, John A. Volpe National Transportation Systems Center's (Volpe Center) Environmental Measurement and Modeling Division prepared this letter report in support of Project Plan Agreement (PPA) HW-21M with the Federal Highway Administration (FHWA). The PPA provides for National Park Service (NPS) Transportation Program Support. The report presents the results of a technical study of the noise and air quality benefits associated with the introduction of visitor shuttle buses in place of a percentage of visitor personal occupancy vehicles (POVs) in both Zion National Park (Zion) and Acadia National Park (Acadia).

The primary objective of this study was to quantify the air quality and noise benefit associated with the replacement of a certain percentage of POVs with tour buses in both Zion and Acadia. A secondary objective was to develop the methodology, including the analytical tools to facilitate similar studies in other parks.

Section 1 of this letter report presents an introduction and objectives. Section 2 discusses the air quality analysis. Section 3 discusses the noise analysis. Section 4 presents the conclusions of the study. Section 5 presents references.

2. Air Quality

This section overviews the air quality analysis that was undertaken for Zion and Acadia National Parks. Section 2.1 overviews the input data and assumptions, Section 2.2 outlines the methodologies employed for the analysis, and Section 2.3 presents results as well as a discussion of those results.

2.1 Input Data and Assumptions

The following sections list all of the major data and assumptions used in the analysis. All of the data and assumptions for the Zion analysis were obtained from an emissions inventory report developed by the University of California at Riverside (UCR)[1].

2.1.1 Zion National Park

- The analysis was conducted for 2000 from May 23 to October 9 ("Summer").
- The on-road fleet mix was assumed to consist of:
  - Visitor vehicles = MOBILE5b composite.
  - Tour buses = 100% HDDV.
  - Government vehicles = 50% (of 5) LDGV, 50% (of 5) LDGT, 50% (of 85) LDDV, and 50% (of 85) LDDT.
  - Liquefied petroleum gasoline (LPG) shuttle buses.
- The total VMTs for the different vehicle types are:
  - Visitor vehicles (w/shuttle bus usage) = 839,968 miles/month
  - Extra visitor vehicles avoided by shuttle bus usage = 326,310 miles/month
  - Tour bus = 11,321 miles/month
  - Government vehicles = 73,440 miles/month (gas) and 12,720 miles/month (diesel)
  - Shuttle buses = 54,810 miles/month
- Shuttle bus emission factors were obtained from the manufacturer and are not dependent on speed:
  - VOC = 3.44 g/mile

    - CO = 0.3 g/mile
    - Nox = 9.85 g/mile
- Average vehicle speed of 16.7 mph as determined from "car following" field measurements, conducted by the University of California at Riverside, for the *after-bus-implementation* case.
- MOBILE5b modeling assumptions and data:
    - Used the basic Utah inspection/maintenance (I/M) program with technician training credits (TTC).
    - Used fleet mix and registration data obtained from field measurements.
    - No effects of anti-tampering or refueling losses were modeled.
    - No corrections for air conditioning usage, extra vehicle load, trailer towing, and humidity were assumed.
    - Used the default Federal Test Procedure (FTP) hot and cold mode fractions.
    - Used percent oxygenates in gasoline similar to programs in Weber and Utah counties.
    - The ambient temperature was assumed to be 80°F and the daily minimum and maximum temperatures were assumed to be 65°F and 100°F, respectively.

2.1.2 Acadia National Park

- The analysis was conducted for 2000 from June 23 to September 2 (72 days in summer period) which represents the shuttle bus usage period.
- 2000 visitor traffic count data were obtained from a NPS traffic reports[2]. 1994 VMT data (specific to sections of roadways) were scaled using the aforementioned traffic count data[3]. Shuttle bus count and VMT data were obtained from bus schedules available on the internet[4].
    - Total visitor vehicle VMT = 4,160,647 miles/summer period.
    - Total visitor vehicle VMT reduced (from bus usage) =2,034,606 miles/summer period.
    - Total shuttle bus VMT = 193,481 miles/summer period.
- The Zion LPG bus emission factors were used as a surrogate for Acadia "propane" buses.
- Total visitor vehicles reduced (57,900) by implementation of shuttle buses were based on ridership of 193,000 from the Acadia web site and vehicle load factors from an NPS memorandum[5].
- Emission factors were modeled using MOBILE5b for Maine, New Hampshire, and Massachusetts. It was assumed that these states represent the bulk of the tourists who travel into Acadia. Typical MOBILE5b input files were obtained from each of the state's department of environmental protection (DEP); these take into account various parameters such as inspection/maintenance, anti-tampering, technician training credits, fuel volatility, etc. The composite emission factors were weighted based on population in each state[6].
    - Maine population = 1,276,961
    - New Hampshire = 1,239,881
    - Massachusetts = 6,357,072
- A conservative average speed of 25 mph was determined from conversations with Acadia park officials. No difference in average speed was assumed between the baseline and after-bus-implementation cases.
- Future emissions projections were scaled based on a conservative estimate of 6% visitor growth rate and did not include the implementation of any future regulations.

2.2 Methodology

The analyses for Zion and Acadia were kept separate due to the different data that were available for the two parks. Both were conducted based on measured and estimated VMT data as appropriate.

For this assessment, the Environmental Protection Agency's (EPA's) model, MOBILE5b, was used to develop emissions inventories for the baseline and after-bus-implementation cases. Dispersion analysis was not deemed necessary because emission factors are directly proportional to concentration values when comparing identical receptor locations. Therefore, comparisons of concentrations would have produced the same results as comparing emissions. MOBILE5b was used rather than the newly released MOBILE6 because UCR used MOBILE5b; this provides consistency between the UCR and Volpe analyses, and it is in keeping with EPA's guidelines on the continual usage of MOBILE5b if furthering an existing study that used this model.

Promulgated by the EPA, MOBILE5 (encompassing MOBILE5a, MOBILE5b, etc.) is a computer model used to estimate emission factors for various gaseous pollutants. The model takes into account different vehicle types (eight) and fuel (gasoline and diesel) under "various conditions such as ambient temperatures, average travel speed, operating modes, fuel volatility, and mileage accrual rates"[7]. The calculation procedures are based on those presented in Compilation of Air Pollutant Emission Factors – Volume II: Highway Mobile Sources[8]. As mandated by the Clean Air Act Amendments of 1990, MOBILE5 is typically used by states to generate base year inventories of air emissions due to highway (on-road) mobile sources.

MOBILE5b provides results for eight vehicle types: light duty gas vehicles (LDGV), light duty gas trucks 1 (LDGT1), light duty gas trucks 2 (LDGT2), heavy duty gas vehicles (HDGV), light duty diesel vehicles (LDDV), light duty diesel trucks (LDDT), heavy duty diesel vehicles (HDDV), and motorcycles (MC). The LDGT1 and LDGT2 categories are often aggregated into a single category (LDGT). For modeling purposes, the light duty gas vehicles and trucks categories are similar to the "automobile" category as defined in the FHWA's Traffic Noise Model (TNM), as discussed in detail in Section 3.

The basic methodology for determining total emissions is as follows:

1. Determine traffic counts and fleet mix characteristics.
2. Determine VMTs for each vehicle type.
3. Run MOBILE5b and/or obtain emission factor data.
4. Calculate total emissions as follows for each vehicle type:

$$TE = EF \times TV \times VMT$$

where TE = Total Emissions (g/month)
EF = Emission Factor (g/mile-vehicle)
TV = Traffic Count (vehicles/month)
VMT = Vehicle Miles Traveled (miles)

2.3 Results and Discussion

Using the methodology discussed in Section 2.2, total emissions were determined for each of the vehicle types including the population of vehicles that was avoided by the shuttle buses. The predicted changes in emissions due to the use of shuttle buses are shown in Table 1 by average speed of the baseline case (no shuttle buses) for Zion.

Table 1. Percent Change in Emissions from Implementation of Shuttle Buses at Zion National Park

Baseline Speed (mph)[b]	After-bus Implementation Speed (mph)	Percent Change in Emissions[a]		
		VOC	CO	NOx
6	16.7	-60.7	-62.4	-4.2
8	16.7	-50.5	-53.6	1.6
10[c]	16.7	-43.7	-46.0	5.9
12	16.7	-37.2	-39.2	9.3
14	16.7	-30.6	-33.1	12.2
16.7[d]	16.7[d]	-21.4	-25.9	15.2

[a]Percent change = [(after – baseline) / baseline] x 100%
[b]Possible average speed of the baseline (no shuttle bus) case.
[c]Reasonable estimate of average speed due to congestion from absence of shuttle buses.
[d] This assumes that the average speeds are identical for both cases and was the basis for the UCR study. The percent changes at this speed are different than those in the UCR report because UCR used the after-bus-implementation case as the basis for the percent change calculations: i.e., percent change = [(after - baseline) / after] x 100%.

Although the same UCR MOBILE5b input data were used, the analysis was conducted for various other average speeds in an effort to quantify the effects of congestion-relief due to the use of shuttle buses. The last row shows the scenario under which the UCR study was conducted. The 16.7 mph was determined by UCR through car-chasing field studies at Zion. UCR did not have any data to quantify the effects of traffic congestion that would exist in the absence of shuttle buses, and therefore, the air quality benefits (calculated as percent changes at 16.7 mph) are likely to be understated in that study. Several speeds between 6 and 14 mph were modeled as possible scenarios to represent this congestion. As shown in the table, heavy congestion (e.g., 6 mph) in the baseline case would correlate to significantly more emissions benefits from the usage of shuttle buses; the emissions reductions would be 60.7% for VOC, 62.4% for CO, and 4.2% for NOx. A more reasonable speed for the baseline case would probably be around 10 mph which corresponds to emissions reductions of 43.7% for VOC and 46% for CO with a 5.9% increase in NOx. These correspond to reductions of approximately 2.8 tons for VOC and 14.7 tons for CO with a 0.1 ton increase in NOx. As noted in the UCR report, the increase in NOx is due to the fact that the LPG shuttle buses emit much higher levels of NOx than the other vehicle types.

Unlike the Zion analysis, vehicle counts and VMT estimations from NPS traffic reports were used to determine the emissions benefits from using shuttle buses in Acadia. Since fleet data was not available, composite vehicle emission factors were used for all vehicle types. The results of this analysis are shown in Table 2.

Table 2. Percent Change in Emissions from Implementation of Shuttle Buses at Acadia National Park

Baseline Speed (mph)[b]	After-bus Implementation Speed (mph)	Percent Change in Emissions[a]		
		VOC	CO	NOx
6	25	-72.6	-77.3	-34.6
8	25	-65.9	-71.9	-30.7
10	25	-60.5	-66.9	-27.6
12	25	-55.5	-62.4	-24.9
14	25	-50.7	-58.3	-22.7
16.7	25	-44.4	-53.2	-20.1
20[c]	25	-36.4	-47.0	-17.9
25[d]	25[d]	-25.2	-32.8	-17.1

[a]Percent change = [(after – baseline) / baseline] x 100%
[b]Possible average speed of the baseline (no shuttle bus) case.
[c]Reasonable estimate of average speed due to congestion from absence of shuttle buses.
[d]This assumes that the average speeds are identical for both cases.

Unlike Zion, no changes in average vehicle speed were assumed to have occurred at Acadia due to the implementation of shuttle buses (i.e., no noticeable congestion was known to have existed in Acadia prior to shuttle bus implementation). Therefore, reductions in vehicular emissions (as modeled in this study) are only due to the reduction of visitor traffic. With an average speed of 25 mph for both the before and after cases, the emissions reductions are 25.2% for VOC, 32.8% for CO, and 17.1% for NOx. These correspond to reductions of approximately 2.4 tons for VOC, 25.2 tons for CO, and 2.3 tons for NOx. Note that the emissions for NOx decreases as opposed to the increase seen in the Zion analysis. This is largely due to the greater amount of visitor traffic VMT avoided by the use of shuttle buses.

In order to relate the emissions reductions to equivalent traffic growth, an iterative analysis of the post-processing calculations was performed assuming an average speed of 10 mph (Zion) and 25 mph (Acadia) for the baseline cases and using the measured 16.7 mph (Zion) and the same 25 mph (Acadia) for the after-bus-implementation cases. The equivalent traffic growth percentages are: 91.4% (VOC) and 94.1% (CO) for Zion; and 34.5% (VOC) and 48.8% (CO) for Acadia. This means that with the current bus implementation, visitor traffic in Zion could be increased by over 90% before emission levels of both VOC and CO becomes equivalent to the baseline levels. Similarly, visitor traffic in Acadia could be increased to nearly 35% for VOC and nearly 50% for CO before emission levels become equivalent to the baseline levels. Equivalent traffic growth percentages for NOx were not calculated due to the increase in NOx with shuttle bus usage for Zion. The uncertainties involved in the data would preclude any definite conclusions concerning NOx since the percent changes are relatively small.

Conservatively assuming a 6% annual visitor growth rate (assuming the same vehicle growth rate per year) with all other factors held constant over time, these equivalent traffic growth percentages correlate to about 15 years for Zion and about 7 years for Acadia before emission levels of CO equate to those of the baseline case.

3. Noise

This section overviews the noise analysis that was undertaken for Zion and Acadia National Parks. Section 3.1 overviews the input data and assumptions, Section 3.2 outlines the methodologies employed for the analysis, and Section 3.3 presents results as well as a discussion of those results.

Input Data and Assumptions

In addition to the assumptions cited in Section 2.1 for air quality, the following assumptions apply for the noise analysis:

- Daily traffic data for the air quality analysis were converted to hourly data assuming a 12-hour day (i.e., all vehicles were spread evenly over 12 hours).
- Zion traffic count data are based on year 2000 data with shuttle bus service.
- Acadia traffic count data are based on year 2000 traffic data using an average of the three most heavily traveled roadways.
- The vehicle mix data (fractions) for Acadia are derived from the final mixes of the Zion data.
- The number of visitor vehicles avoided by use of shuttle buses in Acadia were obtained by using the ridership information from the Acadia website and reasonable load factors for vehicles and buses.
- The number of shuttle buses for Zion were based on an average trips through a roadway.
- The number of shuttle buses for Acadia was based on schedule and route information from the Acadia National Park website.
- The "worst" case data for Zion corresponds to August 2000; the ADT derived from these monthly data is therefore an average day for that month.
- The fleet mixes for Zion were derived per the following MOBILE5b fleet mix assumptions:

LDGV	0.701
LDGT1	0.138
LDGT2	0.106
HDGV	0.008
LDDV	0
LDDT	0.003
HDDV	0.016
MC	0.028

- Zion's MOBILE5b fleet mix was used as a surrogate for Acadia.
- The translation from MOBILE5b to TNM vehicle categories is shown below. The translation was based on weight categories as defined by the two models.

LDGV	Auto
LDGT1	Auto
LDGT2	Auto
HDGV	50%MT, 50%HT
LDDV	Auto
LDDT	Auto
HDDV	50%MT, 50%HT
MC	MC

- Vehicle counts correspond to a composite roadway since data for each of the different roadways were averaged. Data for the roadways were insufficient to model each of them separately.

- For Zion, government vehicles and tour buses were "counted" outside of the fleet mix.
- Government vehicles were assumed to be light-duty "autos."
- Consistent with a UCR assumption, recreational vehicles (RVs) were modeled as 50% buses and 50% "autos.
- Similar to the air quality analysis, the average speeds were modeled as:
  Zion: 10 mph (baseline) and 16.7 mph (after-bus-implementation
  Acadia: 25 mph (baseline) and 25 mph (after-bus-implementation

3.1 Methodology

Acoustic computations for this analysis were undertaken utilizing the Federal Highway Administration's Traffic Noise Model (FHWA TNM®). The TNM is a state-of-the-art computer program used for predicting noise impacts in the vicinity of highways. TNM was developed as a means for aiding compliance with policies and procedures under FHWA noise regulations. It uses advances in personal computer hardware and software to improve upon the accuracy and ease of modeling highway noise, including the design of effective, cost-efficient highway noise barriers.

The foundation around which the acoustic algorithms in the TNM are structured is its Reference Energy Mean Emission Level (REMEL) database. The TNM REMEL database was developed during the period from July 1993 through November 1995 by the Volpe Center as part of a national study entitled Highway Noise Model Database Development[8]. For this analysis, conventional bus REMEL data were used, given that no propane bus-specific REMEL data are known to exist. This sound level surrogate conservatively under-estimates any noise benefit.

In support of database development, measurements were conducted at 40 sites in nine states across the country. The states included in the study were California, Connecticut, Florida, Kentucky, Maryland, Massachusetts, Michigan, New Jersey and Tennessee. In total, over 6000 individual vehicle events were measured at speeds of between 0 (idle) and 80 mph. All data were grouped according to five standard vehicle types as follows: automobiles (A), medium trucks (MT), heavy trucks (HT), buses (BUS), and motorcycles (Mcycle), as defined in Reference 6. The national noise emission level database collected in support of TNM is the most comprehensive database of its type in the world. Figure 1 shows the final sound-level-speed relationships built into TNM for average pavement, level grade, and constant-flow traffic. The graphic depicts the emission level (in dBA at a distance of 50 ft) versus speed for each of the five vehicle types.

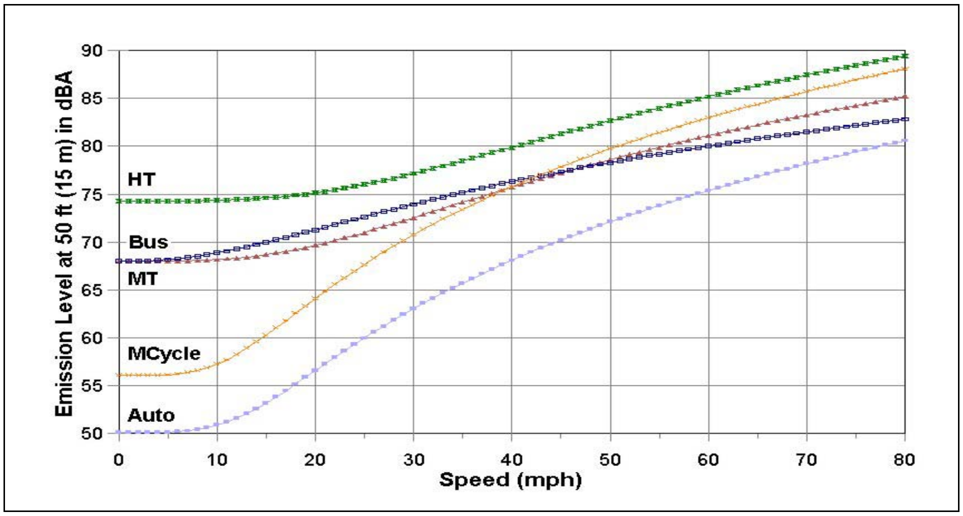

Figure 1. National Noise Emission Levels in FHWA TNM

3.2 Results and Discussion

Utilizing the UCR traffic data and the additional assumptions outlined above, sound levels were predicted at receiver distances of 50 feet from the roadway for both with and without (baseline) the implementation of the shuttle buses. Comparisons were made of the predicted peak-hour sound levels before and after the implementation. These comparisons are made utilizing standard vehicle noise modeling assumptions for both interrupted flow vehicles (prior to implementation of buses) and uninterrupted flow vehicles (assuming congestion relief due the elimination of some passenger vehicles). Similar to the Air Quality analysis, for completeness data are presented for multiple baseline speeds. The highlighted data represent those considered most representative of the actual baseline. Tables 3 and 4 present the noise benefit, or sound level difference data, for Zion and Acadia National Parks, respectively.

Table 3. Sound Level Benefit after Implementation of Shuttle Buses:
Zion National Park

Speed (mph)		Sound Level Difference (dBA)
Baseline[a]	After-bus Implementation	
6	16.7	9.2
8	16.7	9.5
10	16.7	9.6
12	16.7	9.5
14	16.7	9.3
16.7	16.7	8.6

[a]Average speed of the baseline (no shuttle bus) case.

Table 4. Sound Level Benefit after Implementation of Shuttle Buses: Acadia National Park

Speed (mph)		Sound Level Difference (dBA)
Baseline[a]	After-bus Implementation	
6	25	7.6
8	25	7.9
10	25	8.0
12	25	7.9
14	25	7.7
17	25	7.0
20	25	6.3
25	25	5.8

[a]Average speed of the baseline (no shuttle bus) case.

As seen in Tables 3 and 4, total noise benefits of approximately 9.6 and 5.8 dBA are realized as a result of the implementation of bus service in both Zion and Acadia National Parks, for the respective baseline cases. Noise reductions on this order of magnitude are considered quite substantial. A 10 dB reduction is readily perceptible to the human ear and would likely be easily noticeable to park visitors. 10 dB is also considered a reduction goal for the first row of houses behind a well-designed highway noise barrier[9]. In other words, the construction of a 12 to 15 ft tall highway noise barrier, at an approximate cost of $1,000,000 per linear mile alongside the study road in Zion might provide a comparable reduction in sound level to that which was obtained through the implementation of bus service in that park. The noise reduction achieved in Acadia is on the order of what would be achieved via the construction of a noise barrier which simply blocks the line-of-sight between automobiles and visitors along the roadways.

In order to relate the noise benefit to equivalent traffic growth in Zion, sound levels were predicted for future years assuming an average speed of 10 mph for the baseline case and using the measured 16.7 mph for the after-bus-implementation case. Similar future-year predictions were made for Acadia assuming a 25 mph average speed for both cases. Conservatively assuming a 6% annual visitor growth rate (assuming same vehicle growth rate per year) with all other factors held constant over time, the predicted sound levels indicate that it would take about 80 and 120 years at Zion and Acadia, respectively, for traffic noise levels to equate to those of the baseline case. This represents a significant benefit to the park as a direct result of implementation of the shuttle bus service.

4. Conclusions

The data and methods used by UCR to analyze air quality benefit for Zion appear to be very reasonable. However, UCR did not perform an analysis to determine the likely effects of congestion-relief due to the use of shuttle buses. Modeling several different average speeds for the baseline case showed that congestion-caused decreases in speed can have a significant effect on the percent reduction in emissions. From assuming a "medium" congested scenario, the results indicate that the percent reduction in CO and HC emissions offset approximately 15 years of growth in park visitors for Zion and approximately 7 years of growth for Acadia. Similarly, noise level results for this same scenario indicate that the benefit offsets approximately 80 and 120 years of growth at Zion and Acadia, respectively. A recommendation for future analysis may involve a more refined investigation into the effects of modal vehicle activity.

5. References

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