Development of a tool for modeling snowmobile and snowcoach noise in Yellowstone and Grand Teton National Parks

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The National Park Service (NPS) develops winter use plans for Yellowstone and Grand Teton National Parks to help manage the use of Over-Snow Vehicles (OSVs), such as snowmobiles and snowcoaches. The use and management of OSVs in the parks is an issue because of potential environmental impacts and because of actions by environmental, recreational, and commercial groups. The U.S. Department of Transportation, Research and Innovative Technology Administration, John A. Volpe National Transportation Systems Center (the Volpe Center) supported the NPS by modeling the acoustical environment in the parks associated with potential modeling alternatives as well as current and historical conditions. The modeling considered a number of alternatives for inclusion in the NPS's winter use plans. These alternatives affect the type and number of OSVs that are allowed to operate in the parks and where they are allowed to travel. The acoustical modeling was performed by using the Federal Aviation Administration's (FAA) Integrated Noise Model (INM), adapted for use with OSVs. INM adaptation included the development of an over-ground sound propagation model to account for propagation over snow-covered terrain. The Volpe Center also developed a new OSV noise database, which defined OSV noise as a function of speed and source-to-receiver distance, based on previously published OSV acoustical studies and winter 2005-2006 measurements. Vehicle types modeled included two- and four-stroke snowmobiles as well as two- and four-track snowcoaches.

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1 INTRODUCTION

Three National Park Service (NPS) units; Yellowstone National Park, John D. Rockefeller Jr. Memorial Parkway, and the Grand Teton National Park (the Parks) form a contiguous region of land managed by the National Park Service. These parks include a wide range of flora, fauna, and geothermal activity, and also provide scenic vistas for visitors to the parks. Motorized Over-Snow Vehicles (OSVs) allow large numbers of visitors to enjoy the parks but may adversely impact park resources and the experience of visitors who may desire minimal human-made sounds in the parks. The first use of OSVs by visitors in the parks occurred with snowplanes[6] in 1948. In 1955, park vendors began offering snowcoach[7] tours of Yellowstone and snowmobiles first entered Yellowstone in January 1963. Over the years, OSV travel has increased in the parks from about 150 vehicles annually circa 1948 to about 795 vehicles daily in the late 1990s [1].

In general, with the increased number of OSVs in the parks, the associated noise level has increased in the vicinity of the OSV travel corridors. The NPS has a mandate to manage the noise level in the parks in order to protect park resources. The NPS also has a mandate to provide for visitor access and enjoyment. With the growth of OSV use, the NPS began evaluating methods to manage the winter use of OSVs in the parks. Management methods included using quieter OSVs and limiting the number and location of OSV use in the Parks and using commercial guides. Quieter snowmobiles' peak A-weighted sound pressure levels are required to be 5 dB lower than standard snowmobiles [2]. Winter use studies, assessments, and plans continue to be commissioned in response to litigation introduced by interested parties such as environmental groups, OSV manufacturers, the State of Wyoming, and others. A recent, Winter Use Plans Final Environmental Impact Statement [3], relied on noise modeling that was conducted by the United States Department of Transportation John A. Volpe National Transportation Systems Center's Acoustics Facility (Volpe), who designed and developed a modified version of the Federal Aviation Administration's Integrated Noise Model (INM). In this article, the authors discuss the enhancements made to INM in order to model OSVs in the parks. There are several models that can be used to compute transportation related noise including: ISO 9613-2 [4], Nord2000 [5–9], Harmonoise [10,11], SoundPLAN [12], DataKustik's CadnaA [13], Wyle Laboratories' Noise Model Simulation (NMSim) [14], the Federal Highway Administration's Traffic Noise Model (FHWA's TNM) [15,16], and the Federal Aviation Administration's Integrated Noise Model (FAA's INM) [17–20]. However, modeling OSV noise in the National Parks combines several challenges in a unique manner including the modeling of: (1) snow-covered ground surfaces, (2) unique vehicle reference source noise, (3) detailed operation schedules, and (4) advanced noise metrics. All of these challenges were considered during the model selection process and the authors determined that no existing model addressed all of these challenges without modification. Further, only NMSim, TNM, and INM had source code that the authors could modify. Since the authors have extensive experience with both the TNM and INM source code, since both TNM and INM can be modified to meet the stated challenges, and since both TNM and INM have been extensively tested, validated, and used by their respective communities [16–20], these two models were selected as initial candidates for modification to develop a tool to model OSV noise in the National Parks. The discussion that follows examines the relative merits of TNM and INM with respect to each of the challenges listed.

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[6] Snowplanes are hybrid vehicles which are supported by skis and are propelled by a (typically) rear mounted propeller. The cockpit of a snowplane may or may not resemble that of a small propeller driven aircraft. These are not as prevalent today and were not included in the modeling effort.

[7] Snowcoaches are multi-passenger vans or small buses on tracks. Some are purpose built (typically Bombardiers") and others are seasonally adapted to oversnow use. (The wheels are taken off and replaced by tracks or tracks and skis.)

1.1 Snow-Covered Ground Surfaces

By definition, the source-to-receiver propagation path for OSVs occurs entirely over snow. Modeling the effects of snow-covered terrain can either be accomplished by the implementation of a theoretical model or by use of empirical data. Modeling snow-covered terrain is an atypical situation for TNM and INM, although TNM has provisions to model different ground cover. TNM utilizes a theoretical model based on the work of Embleton, Piercy, and Daigle [21–23] while INM utilizes more empirical functions to account for ground effects. INM’s algorithms are based on propagation over grass-covered surfaces and these algorithms do not support over-snow propagation.

1.2 Unique Vehicle Types

Different engine types and operating conditions as well as the presence of tracks and skis generate sounds that are significantly different in character from other vehicles. Regardless of which model was selected, unique vehicle types would have to be added. Both TNM and INM have functionality to allow for custom vehicle types.

1.3 Detailed Operation Schedules

Detailed operation schedules are required to model OSV noise in the Parks because OSV traffic varies over the course of the day depending on location. For example, park entrances/egresses have higher traffic in the morning and afternoon, while points of interest, such as Old Faithful, have higher traffic around midday. These operational schedules are best modeled by data that can vary from hour-to-hour.

Both TNM and INM can accept hourly operations; however, INM’s scenarios are more flexible allowing hour-to-hour differences to be more easily modeled. In order to account for hourly differences in TNM, separate runs must be developed, which would require additional post-processing of the results.

1.4 Advanced Noise Metrics

The preferred noise-related metric for many parks is Audibility [18], which is a metric that predicts whether a given sound will be audible to the human auditory system. This metric was developed to predict the audibility of sounds based on the source and ambient sound pressure levels in each one-third octave band centered from 50 Hz to 10,000 Hz. Audibility accounts for the noise inherent in the auditory system by use of the Equivalent Auditory System Noise (EASN) which is represented by a curve similar to the free-field threshold of hearing as given by ISO 389-7 [24]. See Fig. 1. In order for a source to be considered audible, the sound due to the source in at least one one-third octave band must be greater than the combined EASN and ambient noise in that one-third octave band. The final determination for Audibility of a source using this method is given by:

$$D' L_{total} \geq 7 \text{ dB} \tag{1}$$

where,

$$D'L_{total} = 10 \log_{10}\left(d'_{total} / d'_{ref}\right) \tag{2}$$

$$d'_{ref} = 1 \tag{3}$$

$$d'_{total} = \left(\sum_{band=17}^{40} d'^{2}_{band} \right)^{1/2} \tag{4}$$

$$d'_{band} = 10^{D'L_{band}/10} \tag{5}$$

$$D'L_{band} = \left(L_{signal,band} - L_{noise,band}\right) + 10\log_{10}\left(\eta_{band}\right) + 5\log_{10}\left(bandwidth\right) \tag{6}$$

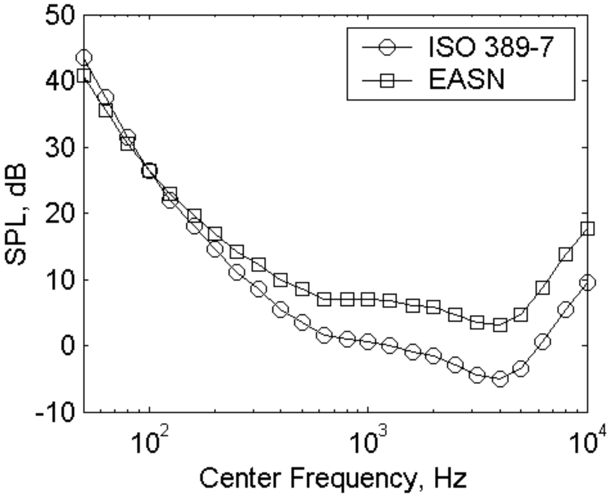

Figure 1: Comparison of free-field threshold of hearing (ISO 389-7) and Equivalent Auditory System Noise (EASN)

Equation (4) is iterated over the one-third octave bands from band 17 (50 Hz) to band 40 (10,000 Hz). $L_{signal,band}$ is the sound level due to the source of interest, $L_{signal,band}$ is the sound level due to all noise sources including the ambient and the EASN, η_{band} is the efficiency of the auditory system,[8] and b*andwidth* is the bandwidth for the specified one-third octave band.

While both TNM and INM compute the most common noise metrics, only INM computes Audibility directly based on vehicle operations and ambient data. TNM would need to have an Audibility algorithm implemented or Audibility would need to be computed during a post-processing stage if TNM were to be used for the current study.

Table 1 summarizes how TNM and INM compare for four important features for modeling noise due to OSVs in the National Parks. Because both INM and TNM offer advantages for modeling OSVs, it was decided to develop a hybrid model by combining the capabilities of both tools. The hybrid model was developed using INM as the starting point since INM would require fewer modifications.

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[8] 10 $\log_{10}(\eta_{band})$increases monotonically from −6.96 for band 17 to −3.56 for band 26, is constant to band 30 where it begins to decrease monotonically to −6.86 for band 40.

Table 1: Comparison of TNM and INM OSV Modeling

	More Suitable		
Feature	TNM		INM
Snow-covered ground surfaces	yes		
Unique Vehicle Types		equal	
Detailed Operation Schedules			yes
Advanced Noise Metrics			yes

2 MODIFICATIONS TO THE INTEGRATED NOISE MODEL

As stated previously, the over-ground propagation function in INM is empirical. It is based entirely on measurements of an aircraft/engine source over grass covered terrain. In order to create the hybrid model using INM as the foundation, these empirical algorithms needed to be replaced with a similar function that was based on OSV sources and propagation over snow-covered terrain.

2.1 Noise Source Modeling

The Integrated Noise Model was originally intended for modeling aircraft noise, initially in the vicinity of airports. INM's functionality and scope has since been extended to allow for modeling of aircraft noise in the parks [18]. INM has a large aircraft noise source database, however, in order to adapt INM to model OSVs, the database needed to include OSV noise source levels and related spectra. One-third octave band data were already available for a number of snowmobiles and snow coaches measured in the parks [25, 26]. Therefore these data were processed for inclusion in the INM source database.

OSVs were categorized into classes based on the acoustic and operational characteristics of the OSVs as illustrated in Fig. 2. The five main classes were: two-stroke snowmobiles, four-stroke snowmobiles, purpose built snowcoaches, and four-track and two-track customized van snowcoaches. In addition to the two snowmobile classes, snowmobile noise levels were also modeled based on group size ranging from five to seventeen snowmobiles per group. Group sizes were determined by the NPS based on typical group sizes for each alternative to be modeled. For example, groups of five snowmobiles were modeled for historical conditions while groups of seven were modeled for “current” conditions.

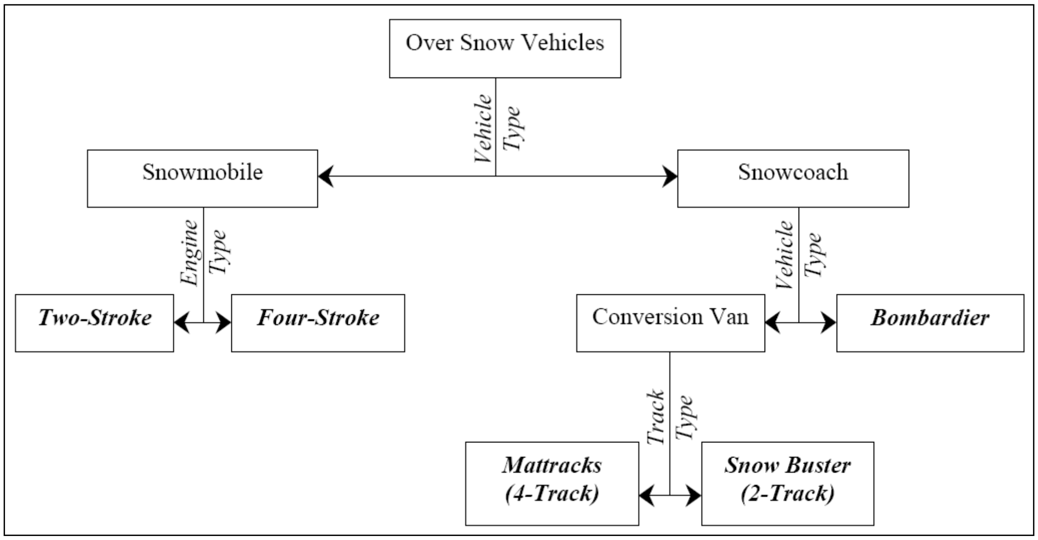

Figure 2: Categorization of over snow vehicles.

2.1.1 Events that overlap in time

When two vehicles pass by a location in the park, INM counts the full Audibility duration for each vehicle even when they travel right next to one another, thus the duration of audible events can be overestimated when vehicles travel in groups. One way to compensate for this is to model groups of snowmobiles as a single source at the center of the group with an increased sound pressure level of $10\log_{10}(N)$ dB, where N is the number of snowmobiles in the group. Close to the source, this type of modeling will lead to an overestimation of the sound pressure level, however, close to the source the group of snowmobiles will certainly be audible, so the over prediction of the sound pressure level at nearby locations does not significantly affect the modeled Audibility. At far distances the single source approximation produces sound pressure level results very similar to a distributed source model, so at far distances the single source approximation will produce nearly identical Audibility durations.

An important question is: does the sound level overestimation due to the single point approximation become small before audibility becomes uncertain? The effect of modeling a group of snowmobiles as a single source can be understood by considering an example case with ten snowmobiles. The ten distributed sources are spaced 50 feet apart, forming a line 450 feet long. Figure 3 shows the overestimation of the sound pressure level for a single source augmented by 10 dB and ten distributed sources for free-field propagation as a function of distance from the center of the snowmobile group. It can be seen that the over-estimation due to the single source approximation is less than 0.5 dB at distances larger than 400 feet. At this distance, the group of ten snowmobiles is still audible, so the sound level overestimation error will not significantly influence the Audibility calculation. This indicates that snowmobile grouping can be satisfactorily modeled by single sources using a $10\log_{10}(N)$ dB level adjustment.

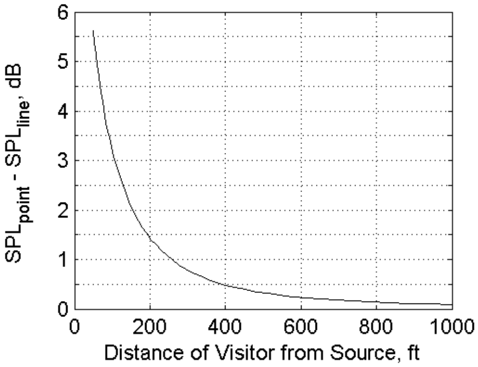

Figure 3: Over estimation of the sound pressure level at a visitor location due to using a point source to model a 225 foot long group of 10 snowmobiles.

2.1.2 Noise database

In order to compute sound pressure levels at various distances from the noise source, INM utilizes tabulated noise data for each vehicle class. These tables: (1) are derived from one-third octave band noise data (see Fig. 4); (2) provide the noise level as a function of distance; and (3) account for free-field divergence as well as atmospheric absorption in accordance with SAE AIR 184527. Normally, each set of noise versus distance data corresponds to a different vehicle power output, however, speed is a more useful operational parameter for snowmobiles, so noise versus distance data were generated for a range of operating speeds instead of power. The data used here are a combination of existing data, see Ref. 28, and new data measured for this study. Sample noise data tables are given in Table 2 for two-stroke snowmobiles. As mentioned previously, groups of snowmobiles were modeled as single sources but with an increase of $10\log_{10}(N)$ dB to account for group size. An example of the adjustment for group size can be seen in the second set of data in Table 2, where the difference between the single snowmobiles and the groups of five snowmobiles is 7 dB. The full OSV noise database can be found in Ref. 28.

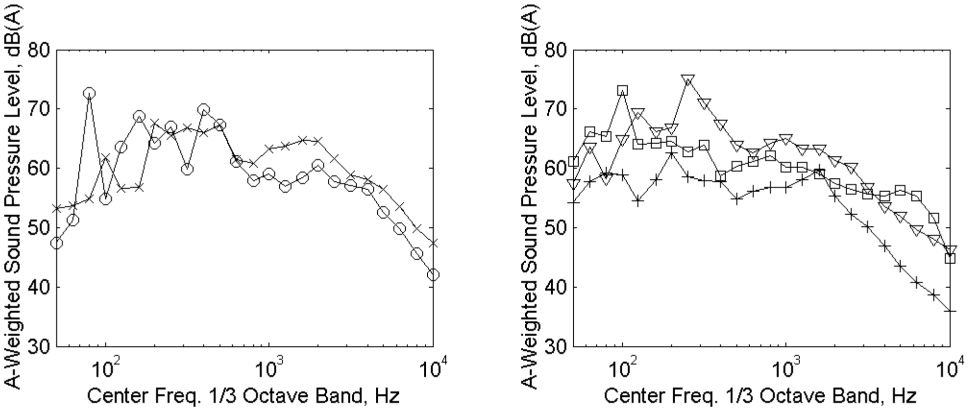

Figure 4: Sample one-third octave band noise spectra (LAmax at 50 feet) used for modeling OSV noise sources for (A) four-stroke snowmobiles at 30 and 40 mph and (B) two-track snowcoaches at 15, 20, and 35 mph.

2.1.3 Spectral classes

A spectral class in INM is a one-third octave band representation of the spectral shape of a group of acoustically similar vehicles at their maximum sound level. In addition to using spectral classes to determine effects of atmospheric absorption, spectral classes are also required in order to properly account for line-of sight blockages in INM. The same five classifications as shown in Fig. 2 were used, namely two-stroke snowmobiles, four-stroke snowmobiles, purpose built snowcoaches, and four-track and two-track customized van snowcoaches. The spectral classes were generated from energy-averaged one-third octave-band noise data measured at 50 feet [25, 26] and then propagated out to INM's reference distance of 1000 feet in accordance with procedures described in SAE AIR 1845.

Table 2: Sample noise data tables

Distance	Two-stroke Snowmobile, dB(A)		
feet	10 mph	20 mph	30 mph
200	54.5	59.2	62.1
400	47.9	52.4	55.4
630	43.3	47.7	50.9
1000	38.4	42.6	46.2
2000	30.5	34.3	38.8
4000	21.8	25.0	30.9
6300	15.9	18.7	25.4
10000	10.1	12.4	19.1
16000	4.3	6.0	11.9
25000	-1.5	-0.5	3.7

Distance	5 Two-stroke Snowmobile, dB(A)		
feet	10 mph	20 mph	30 mph
200	61.5	66.2	69.1
400	54.9	59.4	62.4
630	50.3	54.7	57.9
1000	45.4	49.6	53.2
2000	37.5	41.3	45.8
4000	28.8	32.0	37.9
6300	22.9	25.7	32.4
10000	17.1	19.4	26.1
16000	11.3	13.0	18.9
25000	5.5	6.5	10.7

2.2 Ground Effects

When a direct and a reflected sound wave combine coherently, interference patterns, such as the one shown in Fig. 5, are formed due to phase differences caused by the air-to-ground boundary and the path length difference between the two waves. For acoustically soft ground, this interference pattern results in a reduction in the source level. Although an advanced database has been developed for a research version of INM to account for ground effects under a wide range of ground-cover conditions [29], the database has not yet been implemented into the mainstream model, and in particular the version of the model that computes Audibility. At present, INM models acoustically soft ground effects with an empirical curve based on field grass (150 cgs Rayls[9]) which does not sufficiently represent the highly absorptive ground effects associated with modeling propagation over granular snow (40 cgs Rayls).

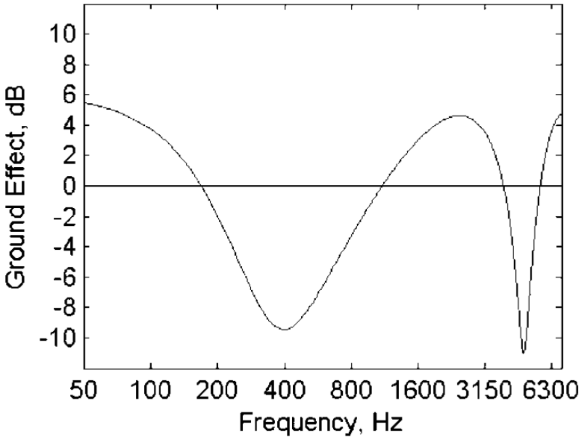

Figure 5: A sample ground effect's interference pattern for a four-stroke snowmobile over snow (40 cgs Rayls). Source height = 1.5 feet. Receiver height = 4 feet.

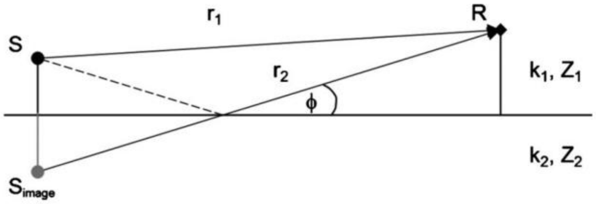

Figure 6: Sample of direct and reflected sound wave geometry

2.2.1 Ground effects theoretical basis

In order to account for the ground effects that are expected for propagation over snow, the fundamental ground effects theory found in the FHWA's TNM was used to generate two new ground effects curves [29], one for snowmobiles and one for snowcoaches, both for granular snow. The theory is based on the work of Embleton, Piercy, and Daigle of the National Research Council of Canada. Their model is well documented by Embleton [21–23], Lawhead and Rudnik [30] and ingard [31] briefly

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[9] INM quantifies a ground type's acoustic impedance by using effective flow resistivity in cgs Rayls, where 1 cgs Rayl equals 1 dyn s $\text{cm}^{-3.}$

summarized here. The basic geometry is shown in Fig. 6. The sound pressure, *p*, at the receiver location, *R*, relative to the sound pressure at a reference distance of 1 meter, p_0, is given by:

$$\frac{p}{p_0} = \left(\frac{e^{ik_1 r_1}}{k_1 r_1}\right) + R_p\left(\frac{e^{ik_1 r_2}}{k_1 r_2}\right) + \left(\frac{(1-R_p)F(\omega)e^{ik_1 r_2}}{k_1 r_2}\right) \qquad (7)$$

where k_1 is the wave number in air, r_1 is the direct wave path distance, r_2 is the reflected wave path distance, and R_p is the plane wave reflection coefficient given by:

$$R_p = \frac{Z_2 sin\phi - Z_1(1-k_1^2/k_2^2\cos^2\phi)^{1/2}}{Z_2 sin\phi + Z_1(1-k_1^2/k_2^2\cos^2\phi)^{1/2}} \qquad (8)$$

where Z_1 is the characteristic impedance in air, Z_2 is the specific normal impedance of the ground surface, ϕ is the angle between the reflected sound ray and the ground surface, and k_2 is the ground wave number. The ground wave reflection parameter, *F*, is given by:

$$F(\omega) = 1 + i\pi^{\frac{1}{2}}\omega^{\frac{1}{2}}e^{-\omega}erfc(-i\sqrt{\omega}) \qquad (9)$$

where *erfc* is the complimentary error function and ω is the numerical distance given by:

$$\omega = i\frac{2k_1 r_2}{(1-R_p)^2}\left(\frac{Z_1}{Z_2}\right)^2\left(1-\frac{k_1^2}{k_2^2}\cos^2\phi\right) \qquad (10)$$

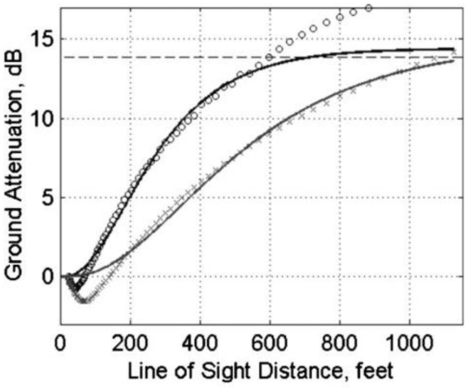

Figure 7: Theoretical ground effect attenuation for granular snow (40 cgs Rayls) for snowmobiles (o) and snowcoaches (x); curve fits (-); and INM's limit on ground effect (- -)

2.2.2 Development of ground effects for over-snow vehicles

In order to adapt INM to account for ground effects for snow covered terrain, ground effect curves were computed for each OSV spectral class by using an EFR of 40 cgs Rayls. The receiver height for all computations was set to 4 feet while the source heights were set to 1.5 feet for snowmobiles and 3 feet for snowcoaches. The source heights were chosen based on qualitative analysis of snowmobile and snowcoach source heights by NPS and Volpe Center personnel. Ground effects were computed for 79 distances spaced equally on a logarithmic scale between 25 and 1200 feet. The theoretical ground effect attenuations for the overall levels are shown in Fig. 7.

A curve fit was developed to approximate the theoretically computed ground effect attenuations in INM. The curve fit was chosen to be of the form:

$$GE(x)_{vehicle,\ source\ height} = a(\ 1 - e^{-bx})^3 \tag{11}$$

where x is in feet. A nonlinear regression was used to determine the coefficients, a and b, in this function.

When comparing the ground effect results for each vehicle class as a function of distance, it was observed that there was a clear difference between the ground effects for snowmobiles and snowcoaches. Therefore, it was decided that two ground effects curves should be added to INM, one for snowmobiles and one for snowcoaches.

For snowmobiles, the curve is given by:

$$SM(x)_{1.5ft} = 14.41(1-e^{-0.006094x})^3 \tag{12}$$

For snowcoaches, the curve is given by:

$$SC(x)_{3\,ft} = 14.77(1-e^{-0.003224x})^3 \tag{13}$$

It can be seen in Fig. 7 that the two areas of deviation from the theoretical relationship occur near the source and far from the source. At distances very near the source, the theoretical ground effects indicate that there should be a slight increase in sound level due to the ground reflections. A satisfactory equation was not developed to model this behavior, however, at these close distances, the source will always be audible when present, so the effect of this shortcoming is negligible. At far distances empirical evidence indicates that ground effects asymptote to approximately 12 to 20 dB [32]. In INM, the limit is set to 13.9 dB. This limit was also used for the present modeling. This is shown as the dashed line in Fig. 7. It can be seen that the regression does follow the theoretical ground effects up to this limit.

3 MODELING OVER-SNOWVEHICLE NOISE IN THE PARKS

Over-snow vehicles operate in the Parks during the winter months, traveling along groomed corridors which go through forested, grass- and shrub-covered flat and mountainous regions. The temperature and relative humidity change over the course of a day and over the course of the season. Wind blows across open regions and through mountain corridors. Snow ranges from freshly fallen powder to snow that has melted and crusted over forming an icy surface. The Parks require that visitors using OSVs be led by commercial guides, which has had the effect of grouping visitors more. Although the pattern and timing of visitor use is relatively consistent, over the course of a given day, the number, type, and location of OSVs in operation varies depending on when visitors enter and exit the park and when they break to visit sites such as Old Faithful.

3.1 Modeling Assumptions

Modeling OSVs with variations for so many parameters is extremely challenging. Consequently, several simplifying assumptions were made in order to focus on the acoustic effects of changing the number, type, and location within the Parks of OSVs in operation (the primary management options for the NPS).

The following modeling assumptions were made: (1) no wind, (2) average winter temperature (16.8 °F) and relative humidity (73.9%), (3) vehicle operations distributed according to peak and off-peak hours, (4) vehicles operate at uniform speed along a specified travel corridor, (5) only visitor OSV use is modeled, (6) only one type of snow is modeled (snow at 40 cgs Rayls), (7) ambient sound levels can be characterized by a forested (15 dBA) acoustic zone and an open (22 dBA) acoustic zone as measured by the NPS,[10] and (8) snowmobile groups can be modeled as a single source. It is recognized that the assumptions made do not result in a perfect match to real conditions for any particular moment in time, however, they do allow for the analysis of the relative effects of number, type, and location of OSVs in operation over the course of an average winter day in the parks.

3.2 Modeling Alternatives

Modeling alternatives were developed by the NPS and these alternatives evaluated a full range of management options for winter use in the parks. The options ranged from allowing varied levels of snowmobile and snowcoach use to closing the park entirely to over-snow vehicle travel. Details of the modeling alternatives are given in Ref. 3.

3.3 Modeling Results

Sample operations for Alternative Z and Z1 for the 10:00 to 11:00 AM hour are given in Table 3. For these alternatives, snowmobiles are modeled as traveling in groups of 8 and in groups of 17, while snowcoaches travel through the park individually. The number of operations for each road section is indicated in the table, where each entry represents an average number of OSVs for the specified group size. For example, Alternative Z from Mammoth to Norris has 1.2 groups of 8 and 0.1 groups of 17 snowmobiles for a total of 11.3 individual snowmobiles.

The resulting Percent Time Audible contours from the modeling are shown in Figs. 8 and 9 for the two alternatives. The legend in each figure gives the Percent Time Audible in terms of a minimum criterion, for example, >10 indicates that for this area of the park OSV noise would be audible for at least 10% of this hour of operation, while, >50 would indicate that OSV noise would be audible at least 50% of this hour of operation. Note, that the 50% contour lies on top of the 10% contour, thus hiding some of the area associated with the 10% time audible contour, however, the total park area that is affected at least 10% of the time is quantified in the next column, that is, 7% for Alternative Z and 8% for Alternative Z1. Details of the modeling and results for the entire study are given in Ref. 28.

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[10] The sound level difference between these two acoustic zones is likely due, at least in part, to wind.

Table 3: Sample OSB Operations, Alternative Z and Z1, 10:00 to 11:00 AM

	Snowmobiles in Groups of 8		Snowmobiles in Groups of 8		Singel Snow Coaches	
YELL Road Segment	Alt Z	Alt Z1	Alt Z	Alt Z1	Alt Z	Alt Z1
Mammoth to Norris	1.2	1.2	0.1	0.1	4.1	3.7
West Entrance to Madison	4.2	4.2	0.2	0.2	4.9	5.2
Madison to Norris	0.0	3.5	0.0	0.2	0.0	5.2
Norris to Canyon Village	0.9	2.5	0.0	0.1	3.0	3.3
Canyon Village to Fishing Bridge	1.9	3.5	0.1	0.2	5.3	3.3
Fishing Bridge to Lake Butte	0.2	1.1	0.0	0.1	0.2	0.6
Fishing Bridge to West Thumb	2.2	1.7	0.1	0.1	4.6	1.2
Madison to Old Faithful	3.6	3.1	0.2	0.2	4.0	4.3
Old Faithful to West Thumb	2.4	1.7	0.1	0.1	3.0	2.5
West Thumb to Flagg Ranch	1.3	1.1	0.1	0.1	0.9	1.4

The NPS considered many issues in addition to noise when determining which alternative would be selected. These issues included: social and economic concerns, human health and safety, wildlife, air quality, visitor access and circulation and visitor experience3.

The noise modeling allowed the Parks to compare the relative noise effects of many scenarios, providing information that the NPS needed in order to evaluate the issues related to natural soundscapes and visitor experience.

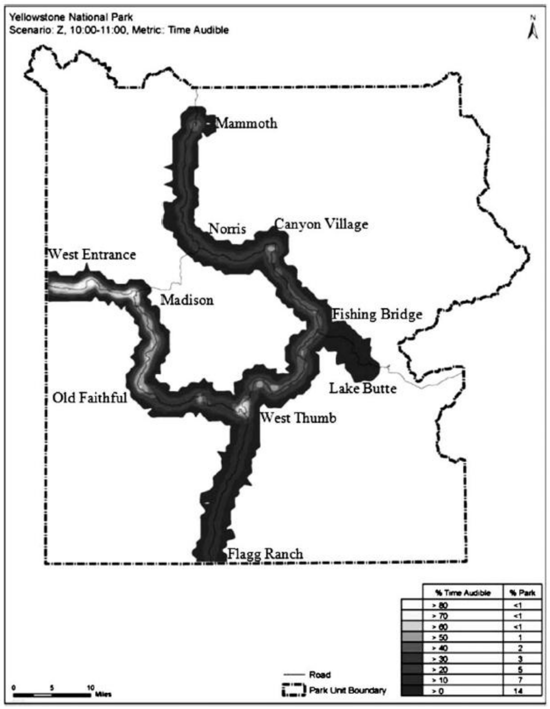

Figure 8: Percent time audible contours for Yellowstone National Park when modeling Alternative "Z" for the hour of operation 10:00 to 11:00 AM

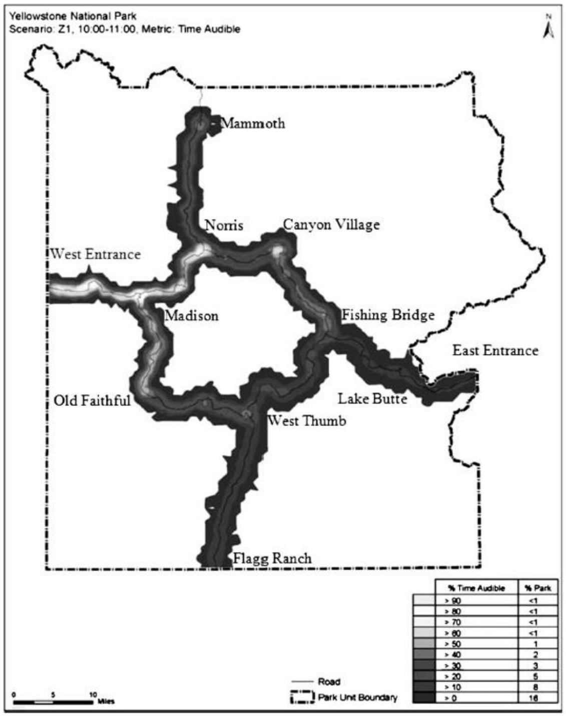

Figure 9: Percent time audible contours for Yellowstone National Park when modeling Alternative "Z1" for the hour of operation 10:00 to 11:00 AM

4 DISCUSSION

The modified version of INM described in this article, provides a tool for evaluating winter use management alternatives. It is intended for modeling typical conditions including typical hourly operations of typical OSVs. To this end, assumptions were made to simplify modeling to a practical level. These same assumptions limit the ability to predict specific real life conditions. For example, modeling a single four-stroke snowmobile in INM will not necessarily match the measured results from a specific snowmobile. Additionally, modeling using this tool will not accurately predict the maximum audible distance when wind, the ambient sound level, the temperature profile, humidity, or ground impedance varies from those assumed in the model.[11]

In order to evaluate more detailed alternatives, a greater range of OSVs could be measured and modeled. By accounting for the noise characteristics of each vehicle model separately in INM, alternatives can be refined to show the relative effects of the different OSVs being operated, for example diesel or gasoline snowcoaches, as well as standard and turbo-charged four-stroke snowmobiles could be modeled separately in the alternatives. The NPS and the Volpe Center have conducted additional measurements of snowmobiles, snowcoaches, and groomers for an additional two

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[11] Predicted audibility results were compared with some real life events. In some cases the predicted audibility was greater and in some cases the predicted audibility was less than the observed audibility. The variance is likely due in part to the deviations from these assumptions. For example, monitoring includes administrative oversnow vehicles, which have different travel patterns and may have different sound characteristics than the typical visitor oversnow vehicles that were modeled.

winter seasons [33]. These data have been processed but have not yet been incorporated into INM's noise database or ground effect equations.

In order to expand the range of parameters that can be compared in this tool, a greater set of ground effects could be developed. At present, there are only two ground effect curves for OSVs, one for snowmobiles and one for snowcoaches, both were developed for snow with an effective flow resistivity of 40 cgs Rayls. In reality, the snow cover can vary a great deal having, for example, effective flow resistivities ranging from 10 to 50 cgs Rayls or more [21]. In order to account for a more complex set of ground effects, it may be more appropriate to implement a ground effects database such as is proposed by Fleming et al. [29].

Although this hybrid tool has not been extensively validated by comparing long-term monitored sound levels to the modeled sound levels for the same distribution of OSVs, the hybrid tool was developed based on two programs that have been extensively validated by and used within their respective to communities [18–20]. It would be beneficial to conduct an extensive validation of the hybrid tool in order to optimize the acoustic algorithms to assure the highest degree of accuracy, however, in the meantime, it is expected that the results obtained from modeling using this hybrid tool will provide useful results for comparative studies of OSVs in the National Parks.

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