Operations & Technology Working Group
Call #4 Meeting Notes (FINAL)

TOPIC: SNOWCOACH EXHAUST EMISSIONS / PERFORMANCED-BASED EMISSIONS SPECIFICATION

Call Date & Time: Tuesday, May 20, 2014, 11:00 AM - 12:30 PM MDT (1-2:30 PM EDT)
Access Information: 1 (877) 638-1989 Passcode: 8955346#

Present:

Name	Affiliation
Bruce Austin	Public
Don Bachman	Public
Scott Carsley	Alpen Guides
Ed Klim	ISMA
David McCray	Two Top
Scott Meirs	Michigan Tech
Alicia Murphy	Yellowstone Nat'l Park
Molly Nelson	Yellowstone Nat'l Park
Kim Rapp	Trails Work Consulting
Randy Roberson	Buffalo Bus
Wade Vagias	Yellowstone Nat'l Park
Travis Watt	Three Bear/See Yellowstone

Not Present:

Name	Affiliation
Bart Melton	NPCA
Kennedy Brown	Two Top
Philip Frankovic	Jackson Hole SM Tours
Bill Howell	Yellowstone Arctic Cat
Jason Howell	Yellowstone Arctic Cat
Jamie McCray	Two Top
Clyde Seely	Three Bear/See Yellowstone
Dan Stusek	Steve Daines' Office
Jack Welch	Blue Ribbon Coalition

Review and approval of 4/28/2014 Conference Call Notes on Speed Limits:

No comments on the speed limits notes from the group.

Background on Developing a Performance-based Specification for Snowcoaches (please also see notes from 1st call (3/10/2014) pertaining to this topic):

- Wade briefly defined what is meant by a "performance-based specification exhaust emission standard (aka "specification"). He described how the final Rule relies upon a technical standard for snowcoach exhaust (air) emissions (based on model year). This is primarily because it has proven difficult to develop performance-based exhaust emission standards for snowcoaches because of the many variables and different types of snowcoaches currently in operation in addition to the fact that snowcoach exhaust emissions are likely significantly affected by road gradient, snowfall, snowroad density, rolling resistance, horsepower, torque, gearing, etc. It can also be very expensive to undertake exhaust emission testing (it cost approximately $40,000 to test five snowcoaches and two snowmobiles in March 2012). Nevertheless, it is also expensive to refurbish machines if they are still performing adequately.
- The park and OSV concession contractors remain interested in learning more about performance-based standards and what it would take to develop such standards.

Introduction of Scott Miers, Assistant Professor, Michigan Tech University

(From Scott's bio): Dr. Miers joined the ME-EM Department at Michigan Tech in August of 2008. He was previously employed by Argonne National Laboratory in the Engines and Emissions Research section where his research focus was on internal combustion engine efficiency, emissions, and performance. He was also closely involved with alternative and renewable fuels research investigating how the unique chemical compositions affect both engine and vehicle operation. His research interests and expertise centers on experimental internal combustion engine research focusing on gasoline and diesel combustion including system efficiency and emissions reduction. He has experience with novel IC engine data acquisition techniques such as piston-mounted wireless microwave telemetry and minimally invasive combustion visualization. In addition, he has a significant interest in alternative and renewable transportation fuels and has worked with biodiesel, ethanol, butanol, and Fischer-Tropsch synthetic fuels in both spark-ignition and compression-ignition engines. Scott has been significantly involved in the Clean Snowmobile Challenge, both as a student and later a judge and advisor to the Michigan Tech team. Scott helped develop in-use emissions testing sleigh for snowmobiles. This is on-snow tailpipe emissions testing using a sleigh. The sleigh and test specs: Tested 10-15 snowmobiles in the challenge, 1.3 mile course with 4 laps and the same driver for each snowmobile, The sleigh behind the snowmobile carries the instruments on an aluminum frame to lessen its weight. Testing equipment is powered by lithium ion batteries. The sleigh has 2 skis, a hitch to attach it to the oversnow vehicle, and a cover to protect the instruments.

Question and Answer and General Discussion with Scott Miers of MTU:

Q#1: Wade asked Scott to describe what a pilot year study to better understand snowcoach exhaust emission performance would look like.

1. Scott Miers described the following:
    a. May be beneficial to transport guests during the test, which would be a good visitor education opportunity;
    b. Ideally we would test every snowcoach but for the pilot we should focus on one specific type of coach;
    c. Surface variability is clearly a part of the testing protocol as would be weather considerations;
    d. We may try to correlate on-snow results to chassis tests and extrapolate from there.'
2. Wade Vagias noted that one challenge is the large variability of snowcoach types—everything from vintage Bombardiers to vans on Mattracks to much larger coaches on agricultural track systems.

3. Scott Carsley said there is also variability within the testing field: temperature, elevation, snow consistency, moisture content, etc. If we could fit 1-4 snowcoach runs on multiple days on multiple conditions, we can try to find consistencies.
4. Scott Miers asked if we could we group the snowcoaches into generalized categories, such as engine type or Track and ski vs. all track?
5. Wade Vagias suggested that Bombardiers are the logical choice for a pilot study because they were made for oversnow use, there are small differences between individual coaches, and they all have the same new engines. Wade also mentioned its fairly easy to split snowcoaches into 3 to 5 classes or categories.
6. Ed Klim mentioned that the weight of the rider is important for snowmobile testing, is this as important for snowcoach test?
7. Scott Miers replied that additional weight will increase the power required to make the coach go but the air/fuel ratio should be consistent unless the pedal is on the floor. Wade notes that all previous emissions tests was conducted with sandbags on board to approximate the weight of a typical passenger load.
8. Ed Klim followed up with asking what the snowcoach use-cycle is compared to a snowmobile?
9. Scott said this would be easier to determine because this is a relatively controlled use/speed for snowcoaches in Yellowstone (as opposed to the many different ways snowmobiles are used across the country). The end goal is to measure in-use emissions.

Q#2: Ed asked if most of the fleet is diesel and does that make a difference?

1. Wade replied that about 20% of the fleet is diesel but that the NPS anticipates it may grow to up to 30%. Existing Mattrack systems are known to fail prematurely under the torque produced by diesel-powered snowcoaches.
2. Scott Miers said that diesel runs globally leaner than gas.
3. Wade mentioned that there are temperature and torque on tracks problems with diesel. All diesel snowcoaches have to be MY2010 or newer so they all have pollution control devices by December 15, 2016.
4. Randy Roberson offered that diesel fueled snowcoach generally has greater horsepower and torque and is likely turbo charged which can help counter the effect of higher elevations. He has also gone to track systems that offer 30% less rolling resistance so fuel consumption is reduced. Randy also noted that many coaches operate at WOT (wide open throttle) in the park, which leads Scott to believe that those emissions may be higher since official testing doesn’t use WOT.
5. Scott Carsley pointed out that there is the potential for a big variation between the lab vs. oversnow testing. Scott Miers agreed but they may not be inconsistent differences, which would be good. Snow does make a tricky variable, but we would

hope to find consistent differences. Scott also mentioned that the Bombardiers have never been on a dynamometer. Wade added that the bombardiers are completely repowered, and usually involves a complete "frame up" restoration.

6. Scott M agreed and added that an additional diesel coach would be good for a pilot test.

Q#3: Wade stated that one of the central questions is the concept of a ten-year life expectancy. The Rule says after 10 years, the machine has to be replaced, but can Bombardiers or other coaches last longer without an increase in the amount of harmful tailpipe pollutants? They would be a good place to start as a testing group.

1. Bruce Austin said that it is encouraging to see progress towards straight-forward testing and results. He would like to see a larger testing group. What are the testing costs?
   a. Wade responded that the NPS can work with universities through the CESU program, which allows the Federal Government to partner with educational institutions.

Q#4: Wade asked Scott to estimate costs for a one-year pilot study.

Scott Meir's estimated the costs for a 1-season pilot would be ~$75-$100k and would include:

- Scott's time
- PhD student's time over at least a semester to support tuition, analysis, test prep
- Multiple vehicles tested—he would need info on those vehicles ahead of time so he could adapt the sleigh's hitch.
- Several weeks or longer in the park conducting multiple tests on multiple vehicles over multiple days
- Sleigh rental from MTU

Wade mentioned that this figure is not a surprise to the Park Service. Previous testing (March 2012) to test 5 snowcoaches and 2 snowmobiles over a one-week period cost $40-$50k.

Q#5: Scott Miers asked how long an average snowcoach trip is.

1. Wade replied that they are mostly day-long trips, mostly from West Yellowstone to Old Faithful and then back, 8-5. It may be possible to test a snowcoach from West to Old Faithful and move the sleigh (measuring device) to a different coach for the return trip, although there is more of a climb on the way to Old Faithful than on the return trip.
2. Scott Carsley added that there is a good climb right after Madison and that Gary Bishop's tests just went to that climb and then turned around. Scott added that snow conditions are hugely impactful—that can make the difference from 2 to 10 mpg for some coaches.

3. Randy Roberson agreed, noting that fuel usage can vary by 400% even within the same vehicle due to snow conditions, and in 2 weeks of testing, we're not going to see all snow conditions.
4. Scott Miers hopes to be able to extrapolate trends and rely on fuel consumption and temperature records to make some assumptions. Otherwise, we may need to do 2 tests over the winter with the same machines.

Q#6: Ed Klim asked if E-10 or E-15 fuel matters

1. Scott Miers replied that E-10 should not make a difference.

Q#7: Wade Vagias asked if anyone is interested in volunteering for the study. We are trying to get beyond the 10 year window for snowcoaches.

1. Alpen Guides – yes
2. Buffalo Bus – yes
3. Bruce offered an original Bombardier engine to Scott Miers for testing if it would be helpful and Scott will think about it but that because it has the original carbureted engine, it probably wouldn't be overly beneficial to test.

Q#8: Scott Carsley asked how important maintenance and upkeep is over time.

1. Scott Miers said he will send some research results to the group. For road vehicles, engine wear over time generally stabilizes at approximately 1-2%.
2. Wade would like to see this data, especially for heavy duty vehicles since most of the snowcoach fleet is oversnow in the winter and then over road all summer.

Q#9: Bruce Austin asked about the impact of low temperature starts on engines.

1. Scott Miers replied that in lab testing, 90% of emissions happen in the first 40 seconds of running. Therefore, the industry focuses intensely on cold starts for overall low emissions.
2. Wade Vagias asked if the catalyst stays lit even in extremely cold temps? Scott Miers said yes, if the engine can move the catalyst is lit.
3. Scott Carsley noted that all winter starts are cold starts.

Q#10: Scott Miers asked the group to contact him with any other questions.

Post-call notes:

Randy Roberson: to come to a quantifiable conclusion of performance baselines, ("in use emission measurements") I believe there are too many snow condition variables on a daily basis, to also evaluate multiple generations of vehicles. Because of this, I support a "technical based definition standard" as a starting place, but feel strongly that a performance base standard needs to be considered. Within the rule, it offers another important tool, "functional equivalent", that may allow the NPS to tweak the technical based standard for improved OSV use in Yellowstone.

Below, I have listed vehicle attributes and conditions that affect snowcoach exhaust emissions into two categories…Principles and Conditions that will have significant impacts on emissions, and those that will have minimal impacts on emissions. The relevance of a measurable outcome of these assumptions would be based on all other things being equal (vehicles with the same fuel and emission management technologies):

Significant

- Snow conditions…Mother Nature including new snow, soft snow, snow density, and temperature. And man-made snow conditions… grooming technique, lack of grooming, lack of compaction.
- Propulsion system…Type of track system, track ski system, tires.
- Available engine torque and at what RPM peak torque occurs.

Less significant (but relevant non-the less)

- Vehicle gearing (although this could be under the significant category in tough snow conditions, because of WOT operation)"wide open throttle"
- Modification's to assist with vehicle cooling (helps engine torque)

Because changing snow conditions dramatically affect performance throughout the winter season (thus emission's) I would think it difficult to come to quantifiable conclusions for "in use" tail pipe emissions, unless you could comprise a way to do it for the entire season… all conditions, all destination's, all passenger loads. (Probably not practical, or affordable).

With this said (assuming all vehicles met the same fuel and emission management technology's), and that there is a correlation between fuel use and emission's, perhaps the most practical (affordable) method to compare tailpipe emission output of vehicle and track system types would be with annual fuel usage by vehicle, with number of passengers included (miles per gallon per passenger) .

Please consider for future discussion the following regarding "functional equivalent" as stated in the winter use rule.

Although we didn't touch on "functional equivalent", I have offered a few examples and thoughts here, and encourage other operators to offer examples of where and how the functional equivalent rule may apply to their situation:

- Some gasoline vehicles met the 2008 Tier Two standards before the 2008MY (because of certification costs, those pre-2008 vehicles may have not been "retro certified".
- Ability to upgrade emission components necessary to meet tier two standards. Example… If a 2005 gasoline vehicle only needed a different O2 sensor to be the equivalent of a 2008 certified tier two vehicle, then why not?
- Some diesel vehicles may have met 2010 certification standards prior to the 2010 MY… same as bullet one above, because of certification costs, pre 2010 vehicles may have not been "retro certified".
- Other examples from the members?

Replacing a vehicle prematurely because of a simple emission component upgrade, or a vehicle that is functionally the same as a newer vehicle that was certified, will ultimate lead to higher operating costs to the concessioners, and ultimately to the visitors.

I believe the ten year sunset rule, for the power plant and emission system as a whole, is overkill. With proper maintenance and care, these vehicles have a much longer serviceable life, especially if that vehicle is used for winters only, example… My original Vanterra, purchased new in 2001 on a Chevrolet chassis has well under 100,000 actual miles.

Because of the volume of fuel use, the gasoline catalytic convertor, and the diesel DPF could/should be replaced at an accelerated schedule.

I applaud the NPS for adding the "functional equivalent" to the rule, and recognizing snowcoaches are custom built vehicles that perhaps cannot or do not conform to EPA road based regulations and standards.

Attachments:

1. Profile of road elevations in Yellowstone National Park
2. Exploring the fuel efficiency of oversnow vehicles in Yellowstone National Park

Supplemental Reading Material

Yellowstone Over-snow Vehicle Emission Tests – 2012: Summary Vehicle Data and Fleet Estimates for Modeling. Natural Resources Technical Report NPS/NRSS/ARD/NRTR—2013/661 (available here: http://www.nps.gov/yell/parkmgmt/winter_monitoring.htm)

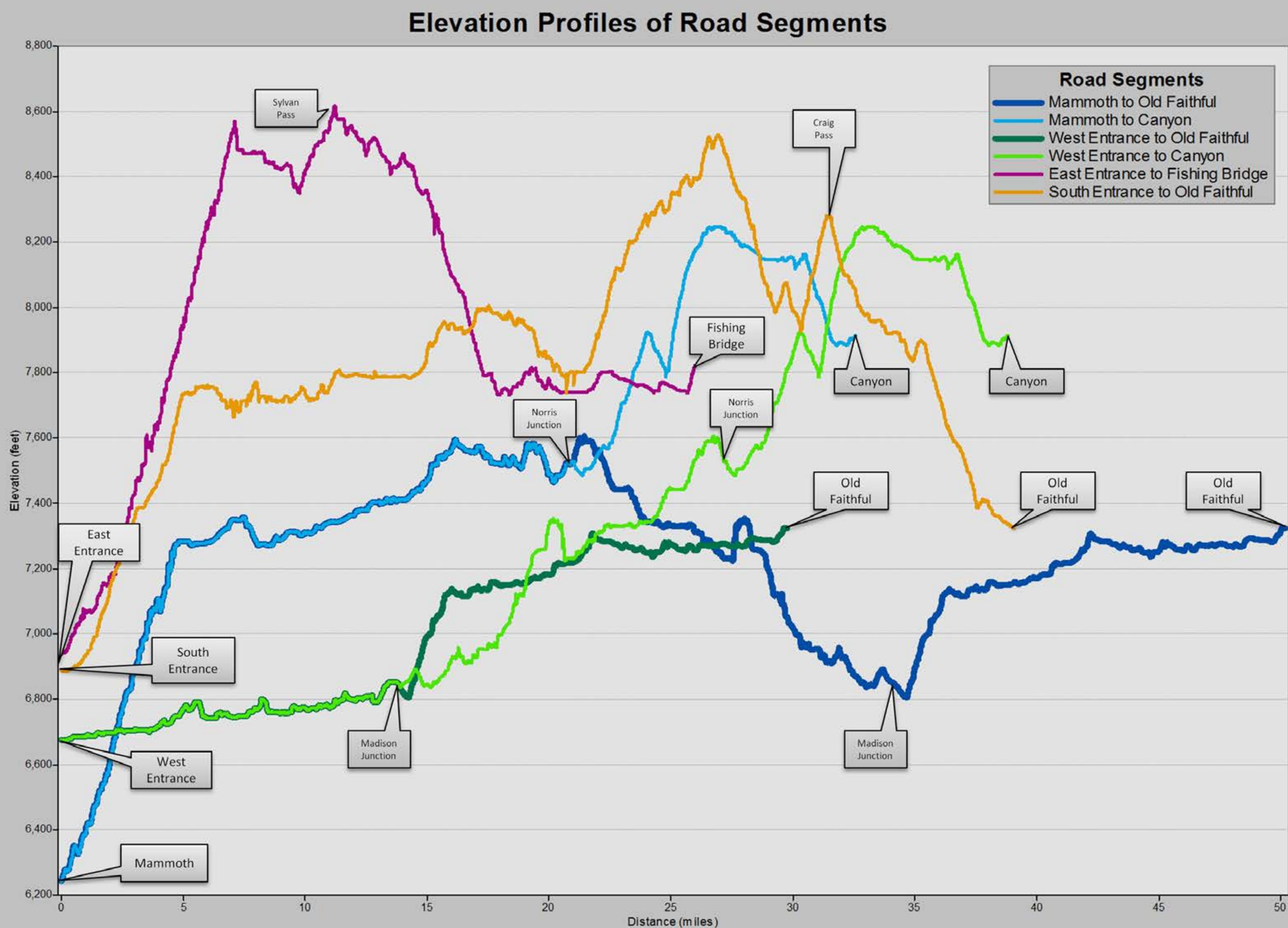
Final Rule for Winter Use (available here: http://www.nps.gov/yell/parkmgmt/currentmgmt.htm)

Actions:

1. Wade will distribute the draft notes for snowcoach exhaust emissions to the group by the end of the week (5/23/2014).
   Status: Draft Notes emailed to group on 5/23/2014
2. Comments and edits on snowcoach exhaust emissions need to be returned to Alicia Murphy (Alicia_Murphy@nps.gov) by Thursday, May 29, 2014.
   Status: Open for comment through Thursday 5/29/2014
3. Wade sent out a Doodle poll for the next meeting of the Operations and Technology Working Group to discuss interior noise abatement for snowcoaches and Sylvan Pass (both will be discussed on the next conference call).
   Status: Email out on 5/23 with poll closing on Friday, 5/30/2014; next meeting: June 17, 2014 11:00 a.m. MDT.
4. Please send discussion questions or agenda items to Wade on the topic of interior noise abatement for snowcoaches and Sylvan Pass by Friday, May 30th.
   Status: Currently accepting discussion questions and agenda items

Operating Principles

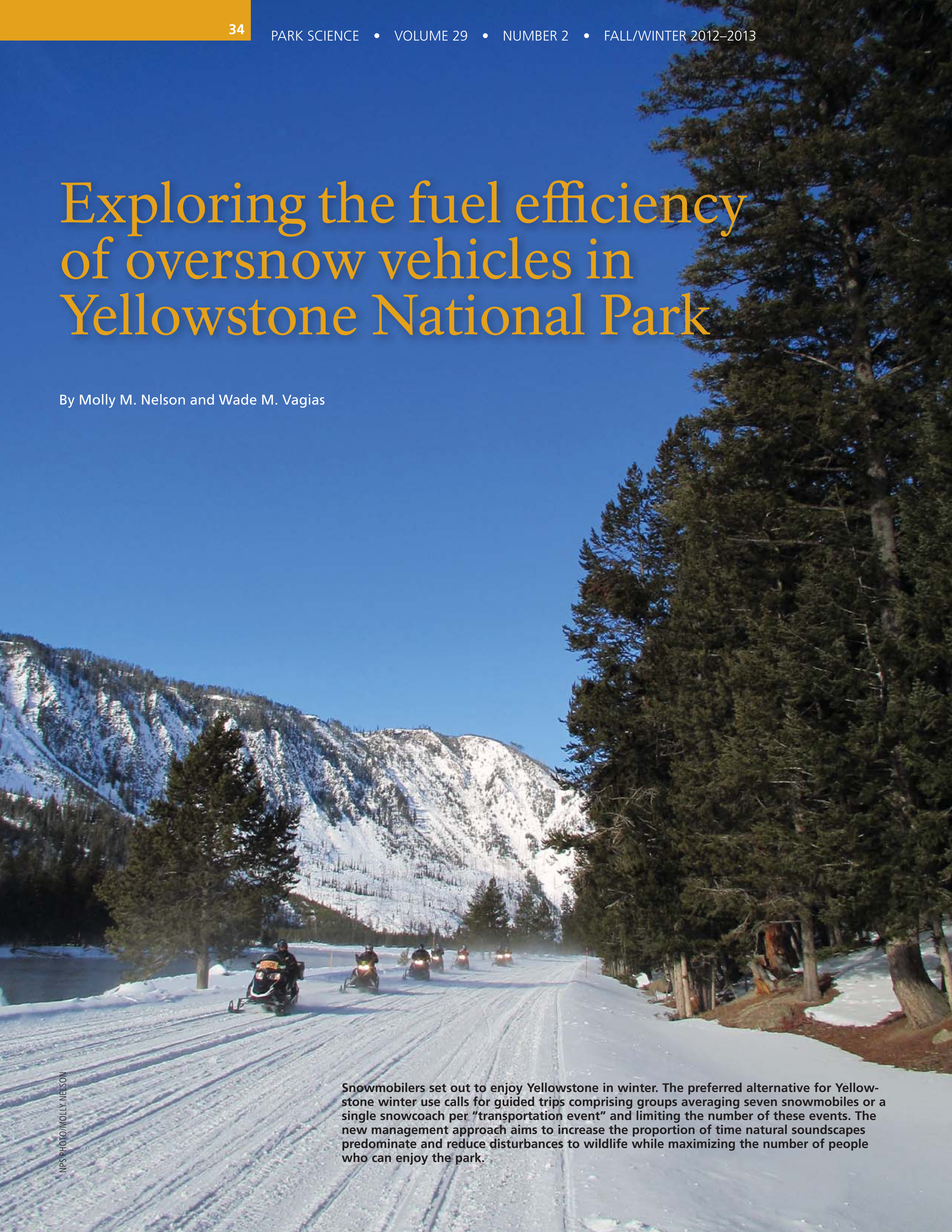
1. The Adaptive Management Program will be consistent with the framework contained within the final Plan/SEIS, the Record of Decision (ROD), and the final Rule;
2. This working group is a portal to encourage creative ideas and insights on how to best encourage and develop new and innovative ideas for winter use in Yellowstone as related to operations and technology;
3. We will be respectful of all ideas and each other and will entertain new possibilities and consider how they might work;
4. We'll ask tough questions;
5. The National Park Service is the final decision-making body for the Winter Use Adaptive Management Program.



Elevation Profiles of Road Segments
Road Segments
Mammoth to Old Faithful
Mammoth to Canyon
West Entrance to Old Faithful
West Entrance to Canyon
East Entrance to Fishing Bridge
South Entrance to Old Faithful
Elevation (feet)
Distance (miles)
8,800
8,600
8,400
8,200
8,000
7,800
7,600
7,400
7,200
7,000
6,800
6,600
6,400
6,200
0
5
10
15
20
25
30
35
40
45
50
Sylvan Pass
Craig Pass
Fishing Bridge
Canyon
Canyon
Norris Junction
Norris Junction
Old Faithful
Old Faithful
Old Faithful
East Entrance
South Entrance
West Entrance
Madison Junction
Madison Junction
Mammoth

Exploring the fuel efficiency of oversnow vehicles in Yellowstone National Park

By Molly M. Nelson and Wade M. Vagias



NPS PHOTO/MOLLY NELSON

Snowmobilers set out to enjoy Yellowstone in winter. The preferred alternative for Yellowstone winter use calls for guided trips comprising groups averaging seven snowmobiles or a single snowcoach per "transportation event" and limiting the number of these events. The new management approach aims to increase the proportion of time natural soundscapes predominate and reduce disturbances to wildlife while maximizing the number of people who can enjoy the park.

Abstract

Winter use planning for Yellowstone National Park is one of the most contentious issues in the National Park Service, with the debate primarily centered upon the impact of oversnow vehicles (OSVs, or snowmobiles and snowcoaches) on park resources including wildlife, air quality, and natural soundscapes as well as the visitor experience. Recently, several conservation advocacy groups have suggested that snowcoaches are more fuel efficient at the per-person level than snowmobiles. The purpose of this research was to assess fuel efficiency for a representative cross section of oversnow vehicles from Yellowstone's commercial tour operators' fleet regarding two primary metrics: miles per gallon (MPG) and person-miles per gallon (PMPG). Our analysis shows snowcoaches to have fuel efficiency averages ranging from 1.7 to 5.3 MPG (0.72 to 2.3 kilometers per liter) and 15 to 45 PMPG (6.4 to 19 passenger-kilometers per liter) and snowmobiles to have averages of 14 to 25 MPG (6.0 to 11 kilometers per liter) and 16 to 30 PMPG (6.8 to 13 person-kilometers per liter). Average fuel efficiency rates vary considerably among different models of snowcoaches and snowmobiles, but for the most popular models of OSVs in use in the park, neither category is decidedly more fuel efficient than the other at the PMPG level.

Key words

fuel efficiency, oversnow vehicles, snowmobiles, snowcoaches, Yellowstone National Park, winter use

WINTER USE IN YELLOWSTONE NAtional Park (Wyoming, Montana, and Idaho) has been the subject of ongoing public debate for more than 75 years. Since the 1930s the National Park Service (NPS) and interested stakeholders have debated if and how the park should be accessed in winter. The sidebar below explains the laws that necessitate special winter planning. The past decade of winter use planning and associated rulemaking efforts have been particularly contentious, with debate primarily centered upon the impact of oversnow vehicles (snowmobiles and snowcoaches, collectively OSVs) on wildlife, air quality, and the natural soundscapes. To help address these questions, since 1997 Yellowstone has completed four environmental impact statements (EISs)—a fifth is currently in development—and two environmental assessments (EA) and promulgated three long-term rules, only to have those regulations overturned by federal courts. The 2001 rule to phase out snowmobiles from Yellowstone, signed off on the last day of the Clinton administration in January 2001, was delayed by the incoming Bush administration and eventually vacated by the U.S. District Court of Wyoming. Subsequent EISs were completed in 2003 and 2007, both of which were vacated by the U.S. District Court for the District of Columbia (see Yochim 2009 for a discussion of winter planning use in Yellowstone).

Need for special rule to authorize oversnow vehicle use

The necessity for a special rule to authorize oversnow vehicle use in national parks stems from Executive Orders (EO) 11644 and 11989, which together require off-road vehicle use to immediately discontinue if such use will cause "considerable adverse effects on the soil, vegetation, wildlife, wildlife habitat, or cultural or historic resources of particular areas or trails of the public lands" (snowmobiles are considered off-road vehicles by the orders) and such areas must remain closed until the agency implements measures to prevent those adverse effects. Colloquially, this is known as the "closed unless open" rule.

Not surprisingly, given the role of Yellowstone National Park in the conservation movement and the American psyche, the ongoing debate about what is best for Yellowstone in winter has polarized stakeholders and elevated the issue to the national spotlight. Organizations including the Greater Yellowstone Coalition (GYC), National Parks Conservation Association (NPCA), Sierra Club, and Coalition of National Park Service Retirees (CNPSR) have, for more than a decade, advocated for the abolition of snowmobiles in favor of a snowcoach-only transportation paradigm. The GYC describes its goal as "to phase out snowmobiles in Yellowstone in favor of cleaner, quieter, more efficient snowcoaches" (Greater Yellowstone Coalition 2012). Access-oriented organizations and stakeholders including the Blue Ribbon Coalition, International Snowmobile Manufacturers Association, and various state-level snowmobile clubs have advocated for continued access by snowmobiles, but have not advocated for the elimination of snowcoaches.

Stakeholders' substantive observations and comments have elevated the level of discourse throughout the numerous winter use planning processes that have transpired over the past 15 years. This continual external examination of data and analyses has worked effectively alongside the park's own, raising important questions and helping ensure fidelity to the law, use of the best available science, and management decisions that are in the long-term interest of the park and the American people. All the while, new management strategies and OSV technologies introduced in the past decade have served to significantly improve resource conditions.

For instance, requiring best available technology (BAT) snowmobiles eliminated the “blue haze” that was common in the park in the 1990s and capped the maximum noise output of a snowmobile (currently the loudest commercial OSVs in the park are snowcoaches). The requirement that all trips be led by guides greatly reduced instances of wildlife harassment.

As resource conditions have improved, some stakeholder groups have sought new reasons to support their respective positions. A concern recently brought to the attention of winter use planning staff is the relative fuel efficiency of OSVs in use in the park. In comments received during the scoping process for the 2012 Winter Use Plan/Supplemental Environmental Impact Statement, the CNPSR, GYC, Natural Resources Defense Council, Sierra Club, and Winter Wildlands Alliance expressed interest in comparing the two different forms of winter transportation modes (snowmobiles and snowcoaches) using “per-visitor” impacts, contending that such analysis “might be most revealing in the context of fuel efficiency and emissions” (emphasis added) (Coalition of National Park Service Retirees et al. 2012). The working assumption is that because snowcoaches hold more people, they are more fuel efficient at the per-person level than snowmobiles.

Previous OSV fuel use studies

Our review of the literature and the administrative record found few instances of data or analyses to support the contention that snowcoaches are more efficient at the per-person level than snowmobiles, and the data that were present were not convincing. Those few analyses evaluated fuel efficiency peripherally, usually as a minor subset of tailpipe emission studies (see Bishop et al. 2006 and 2007, and Ray et al. 2012). Furthermore, those studies have been limited by small sample sizes, varying fuel efficiency estimation methods, or have used fuel efficiency estimations provided by manufacturers. These limitations reinforced the need for more thorough analysis of the fuel efficiency of OSVs in use in winter in Yellowstone National Park.

The 2012 Yellowstone Final Winter Use Plan/ Supplemental EIS

The preferred alternative in the 2013 Final Winter Use Plan/Supplemental Environmental Impact Statement (SEIS) is to manage OSV access by “transportation events,” defined as one snowcoach or a group of seven snowmobiles (averaged seasonally and with a daily maximum of 10 snowmobiles per event) traveling together within the park (Final Winter Use Plan/ SEIS 2013). This approach differs from previous management alternatives that were based on managing by absolute numbers of OSVs rather than managing by groups (or transportation events). The rationale for the shift is based on the empirical evidence that impacts on soundscape and wildlife resources stem from transportation events rather than absolute numbers of vehicles. By packaging traffic into transportation events and limiting the total number of transportation events allowed access into the park each day, the park is able to lessen disturbances to wildlife and improve natural soundscape conditions, in addition to allowing more visitors to see the park in winter. Data collected and analyzed during the 2012 SEIS process indicates that snowmobile and snowcoach transportation events have comparable adverse impacts on Yellowstone’s resources and values. However, greater insight into the fuel efficiency of OSVs could shed additional light on the comparability of the two types of transportation events. We also note that fuel efficiency is distinct from tailpipe emissions and air quality as an impact topic, and is therefore not directly under evaluation in the SEIS. Nevertheless, this issue has been raised by stakeholders commenting on the current planning process, could influence the vehicles that commercial tour operators and the park choose to use, and provides insight into the amount of fossil fuels required to power OSVs in Yellowstone.

Study purpose

We sought to advance understanding of the relative fuel efficiency of a representative cross section of OSVs used in Yellowstone in winter for two primary metrics:

- Miles per Gallon (MPG): The number of mile(s) a vehicle travels using one gallon of fuel; calculated as miles traveled divided by gallons of fuel expended on a trip. Miles per gallon is commonly used to describe the fuel efficiency of a vehicle but does not provide insight into fuel efficiency on a per-person basis. It is also expressed in kilometers per liter (KPL).

- Person-Miles per Gallon (PMPG): Fuel efficiency on a per-person basis; calculated as miles traveled times the number of persons on board divided by fuel expended. The person-miles per gallon metric is often used to compare fuel efficiency of various mass transit systems and allows for a more appropriate comparison of relative rates of fuel consumption. It is also expressed in person-kilometers per liter (PKPL).

Methods

Data collection

Five commercial OSV tour operators based in West Yellowstone, Montana, and one commercial OSV tour operator based in Jackson, Wyoming, were asked to record fuel consumption during the 2011–

2012 winter season for a variety of OSVs from their respective fleets. The goal was to generate a fuel consumption data set for a representative cross section of OSVs currently in use in the park. We provided each operator with a standardized data input form that requested information related to the date of each trip, the type of OSV (including associated engine and ski/track configuration), a description of the trip (origin, destination, and number of miles traveled), the number of persons per vehicle for the trip, and the total amount of fuel consumed.

Our *unit of analysis* was a single OSV; we used this term to denote either a specific snowcoach in the commercial fleet or all snowmobiles of a certain make, model, and year. For example, the "2011 Ford" is a single snowcoach owned by a single operator in West Yellowstone. A "2012 Ski-Doo GT1200" represents data from many individual snowmobiles of this particular make, model, and year that were reported separately but averaged together. Our *level of analysis* (a "data point") was a single OSV making a single roundtrip from a known point of origin to a known destination and back. We analyzed trips to the most popular destinations in Yellowstone: between West Yellowstone and Canyon Village, between West Yellowstone and Old Faithful, and from the South Entrance to Old Faithful and back. Filters were applied to ensure that all data used in the fuel efficiency calculations were as reliable and representative as possible and not unduly influenced by outlying cases. We retained for analysis only OSVs with six or more reported trips. We included trips with passenger loads falling within two standard deviations of the arithmetic mean for each individual snowcoach and did not use trips with outlier-load characteristics like those in which an OSV towed a luggage trailer. We did not take out any snowmobile trips based on outlier ridership as ridership for a snowmobile is always between 1 and 2, and both values are common. We retained 1,249 snowmobile and 137 snowcoach data points (individual roundtrips by a single vehicle) after data filtering and processing.

The person-miles per gallon metric is often used to compare fuel efficiency of various mass transit systems and allows for a more appropriate comparison of relative rates of fuel consumption.

NPS PHOTOS (3)

Figure 1. Four of the snowcoaches represented in the data set, clockwise from top left: 1956 Bombardier, 2011 Chevrolet, 2011 Turtle Top, and 2001 Chevrolet.

Distance and passenger estimates

When available, exact roundtrip distances for snowmobile trips were used; these ranged from 63 to 71 miles (101–114 km) for West Yellowstone to Old Faithful and 106 to 115 miles (171–185 km) from West Yellowstone to Canyon Village. When exact mileage data were not provided, the arithmetic mean for known trip mileage events (equal to that used for snowcoaches) or the operator-estimated mileage (in the case of South Entrance trips) was used. We did not use snowcoach odometer readings because the circumference differences between track systems and standard tires rendered the values invalid, and we were not in a position to fit OSVs with GPS tracking devices to record total mileage. Roundtrip distances for all snowcoach trips were estimated at 65 miles (105 km) for West Yellowstone to Old Faithful and 111 (179 km) miles for West Yellowstone to Canyon Village. Roundtrip distances from the South Entrance to Old Faithful were estimated at 94 miles (151 km) during December and 100 miles (161 km) January through March, the difference owing to additional site visits in the Old Faithful area later in the season when road conditions improved. These estimates were based on conversations with operators and

Table 1. Attributes of analyzed oversnow vehicles

	Study Name	Data Points	Vehicle Year, Make, Model	Engine Size (cylinders/liters displacement)	Fuel	Track Type	Max. Capacity	Gate of Origin
Snowcoaches	1956 Bombardier	14	1956 Bombardier B-12	8 cylinders, 5.3 L	Gas	Bombardier Skis/Tracks	11	West
	2001 Chevrolet	9	2001 Chevrolet Express Van Terra	8 cylinders, 8.1 L	Gas	Mattracks 150, YS3-175*	15	West
	2011 Chevrolet	28	2011 Chevrolet Passenger Van	8 cylinders, 6.0 L	Gas	Mattracks 150	15	South
	2006 Ford	6	2006 Ford E-350 Passenger Van	8 cylinders, 5.4 L	Gas	Mattracks 150	15	West
	2010 Ford	7	2010 Ford E-350 Passenger Van	8 cylinders, 5.4 L	Gas	Mattracks 150	15	West
	2011 Ford	24	2011 Ford E-350 Van Terra	10 cylinders, 6.7 L	Gas	Mattracks 150; YS3-175*	15	West
	2011 Turtle Top	49	2011 Ford F-550 Turtle Top	8 cylinders, 6.7 L	Diesel	GripTrac	31	West
Snowmobiles	2012 Arctic Cat TZ1	58	2012 Arctic Cat TZ1	2 cylinders; 1,056 cm^3	Gas	NA	2	West
	2011 Arctic Cat TZ1	89	2011 Arctic Cat TZ1	2 cylinders; 1,056 cm^3	Gas	NA	2	West
	2012 Ski-Doo GT1200	24	2012 Ski-Doo GT1200	3 cylinders; 1,170.7 cm^3	Gas	NA	3**	West
	2012 Ski-Doo GT600 ACE	130	2012 Ski-Doo	2 cylinders, 600 cm^3	Gas	NA	2	West
	2011 Ski-Doo GT600 ACE	948	2011 Ski-Doo	2 cylinders, 600 cm^3	Gas	NA	2	South

*YS3-175 tracks are experimental tracks used by one operator out of West Yellowstone; they are intended to improve vehicle operation in several ways, so trips using these tracks are specifically noted in the data.

**According to the manufacturer, this vehicle can hold three people. Operators usually only fill it to this capacity if the group consists of one adult and two small children.

reported snowmobile mileage (snowmobile odometers are correctly calibrated).

Exact passenger numbers were provided for all snowcoach trips so no passenger number estimations were necessary. Exact passenger numbers were provided for many of the snowmobile trips and when known were used to inform calculations. When exact passenger numbers were unavailable (as with some of the data points starting at West Yellowstone), estimations were based on the average snowmobile ridership, 1.4 persons per snowmobile, from the 2009–2010 through 2011–2012 seasons' visitation data from the West Entrance (Yellowstone Draft Winter Use Plan/Supplemental Environmental Impact Statement 2012).

Results

Our data set contained data on 10 individual snowcoaches and three different makes/models of snowmobiles. We attempted to get a representative cross section of the park's OSV fleet and the majority of the vehicles in our data set are very popular models. Table 1 describes characteristics of each OSV retained for analysis and figure 1 (previous page) contains photos of four of the 10 snowcoaches we analyzed. Snowcoaches ranged from a repowered 1956 Bombardier B-12 to 15-passenger Ford, and Chevrolet vans up to a large 30+ passenger bus. During the winter of 2011–2012, approximately 27% (N = 21) of the snowcoaches used in the park were Bombardiers (primarily model B-12), while 47% (N = 37) were standard vans and SUVs (Ford E-350 15-passenger vans, Chevrolet Express), and 26% (N = 20) were small and mid-sized buses (Van Terra, Odyssey, Krystal). The three snowmobile models retained for analysis (Arctic Cat TZ1, Ski-Doo GT600, and Ski-Doo GT1200) are among the most popular makes and models in use in the park and all meet Yellowstone's best available technology (BAT) requirement.

Figure 2 presents the range of fuel consumption in miles per gallon for snowmobiles and snowcoaches. Overall, snowmobile fuel efficiency ranges from 14 to 25 MPG (6.0 to 11 KPL). Snowmobiles with smaller engines, such as the Ski-Doo GT600 ACE, which has a 600 cc engine, obtain nearly twice the MPG as those with larger engines, such as the Arctic Cat TZ1 and Ski-Doo GT1200. Ski-Doo GT 600 ACE snowmobiles based at the South Entrance, and traveling on the steep grade of the south entrance road, averaged 23 MPG (9.8 KPL), slightly less than the 25 MPG (11 KPL) the same snowmobiles originating at West Yellowstone averaged. In terms of fuel consumed per mile, the most efficient snowcoach was the 1956 Bombardier, which obtained 5.3 MPG (2.3 KPL) on average, and the least efficient was the Ford F-550 Turtle Top, which obtained 1.7 MPG (0.72 KPL) on average. The Bombardier is nearly twice as fuel efficient in terms of MPG as the next most efficient snowcoach, the 2010 Ford, which averaged 2.7 MPG (1.1 KPL).

Figure 3, shows person-miles per gallon for all vehicles tested, segmented into vehicles operating out of West Yellowstone and the South Entrance and ordered from most to least efficient. Table 2 (next page) gives additional statistics of person-mile per gallon calculations for each vehicle. Fuel efficiency at the PMPG level is not consistently different between snowmobiles and snowcoaches; however, it does vary considerably between different models of snowcoaches and snowmobiles. The top three vehicles out of the West Entrance in terms of PMPG efficiency are the 1956 Bombardier with a fuel-injected V-8 motor, which averages 45 PMPG (19 PKPL); the 2011 Ford F-550 Turtle Top snowcoach, which averages 38 PMPG (16 PKPL); and the Ski Doo ACE 600

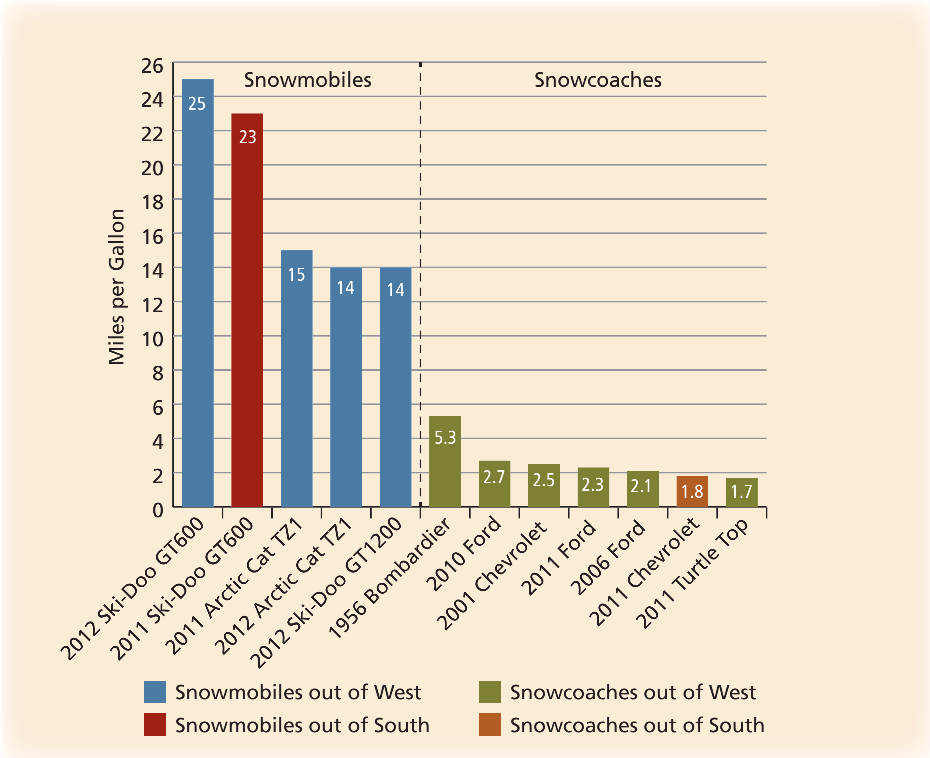


Figure 2. Miles per gallon for snowmobiles and snowcoaches, listed from most to least efficient and segmented by vehicle type.

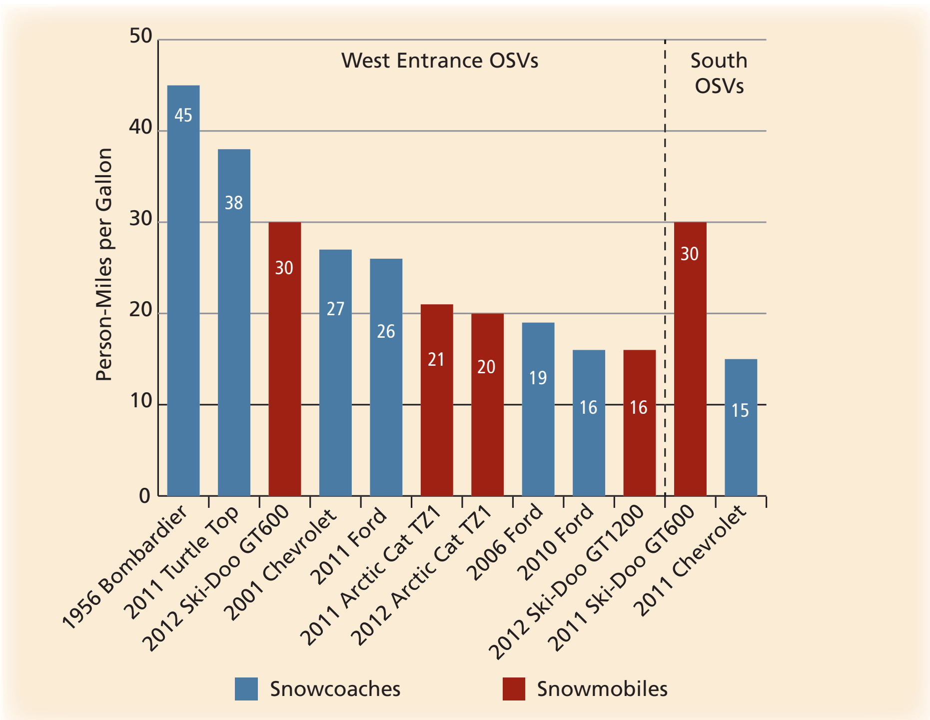


Figure 3. Person-miles per gallon for snowmobiles and snowcoaches, listed from most to least efficient and segmented by park entrance gate.

Table 2. Final MPG and PMPG values

Vehicle	Miles/ Gallon (avg.)	Persons/ Vehicle (avg.)	Person-Miles/ Gallon (avg.)	Min. PMPG	Median PMPG	Max. PMPG	SD PMPG
1956 Bombardier	5.3	8	45	26	42	82	14
2011 Turtle Top	1.7	22	38	14	40	60	12
2012 Ski-Doo GT600	25	1.2	30	19	29	49	6.8
2001 Chevrolet	2.5	11	27	17	26	38	6.9
2011 Ford	2.3	11	26	15	26	37	6.9
2011 Arctic Cat TZ1	15	1.4	21	15	20	38	4.3
2012 Arctic Cat TZ1	14	1.4	20	16	20	26	2.2
2006 Ford	2.1	9	19	11	20	26	5.8
2010 Ford	2.7	6	16	9.0	15	25	6.0
2012 Ski-Doo GT1200	14	1.2	16	10	13	48	7.9
2011 Ski-Doo GT600	23	1.3	30	13	28	74	10
2011 Chevrolet	1.8	8	15	7.9	15	26	3.9

snowmobile, which averages 30 PMPG (13 PKPL). For the South Entrance, the 2011 Ski Doo Ace 600 is two times as fuel efficient at 30 PMPG (13 PKPL) as the 2011 Chevrolet snowcoach, which averages 15 PMPG (6.4 PKPL). There appears to be no relationship between the model year of an OSV and its fuel efficiency.

Discussion and implication

Overall snowcoach fuel efficiency ranged widely, a fact likely attributed to varying track types, power-to-weight ratios, snow conditions, road grades, engine sizes, and differential gearing among other variables. Without question, the most fuel efficient OSV in our analysis at the PMPG is the repowered Bombardier snowcoach, which averages 45 PMPG (19 KPKL). This vehicle is purpose-built for over-snow travel and has a relatively long track design allowing it to stay at the top of the snow-road surface, a lightweight frame and body, and ample power from its V-8, fuel-injected motor. These attributes combine to afford it the ability to operate in higher gears while under power and cruising in the park. The second most efficient snowcoach at the PMPG level is the Ford F-550 Turtle Top at 38 PMPG (16 PKPL). Unlike the Bombardier, which has a relatively high power-to-weight ratio but only carries up to 11 people, the Ford is efficient at the PMPG level because it has a very large diesel motor and carries up to 31 people. Snowmobile fuel efficiency also varies widely. The Ski-Doo GT ACE with the 600 cc engine is nearly twice as fuel efficient at approximately 30 PMPG (13 PKPL) as snowmobiles with larger engines such as the Ski-Doo GT1200 and Arctic Cat TZ1, which averaged approximately 16 and 21 PMPG (6.8 and 8.9 PKPL), respectively.

Though limited, this study is informative. By analyzing OSVs in the current Yellowstone commercial operator fleet under a wide range of operating conditions and with various passenger loads, we have been able to ascertain fuel efficiency rates for a representative cross section of these vehicles. The repowered Bombardier and large Ford bus are considerably more fuel efficient at the per-person level than even the most efficient snowmobile we analyzed; however, both of these vehicles have significant limitations. Bombardiers have been out of production for decades, and acquiring replacement parts can be very difficult. Traveling in a "Bomb" (as they are affectionately called) is a unique experience and is one that does not appeal to all winter visitors to Yellowstone. The Ford F-550 Turtle Top also has significant limitations. Given its size and weight, this coach is only capable of making trips between West Yellowstone and Old Faithful and is unable to travel to the Canyon Village area or to the South, North, or East Entrances. There is also concern that snowcoaches of this size and weight may cause rutting of snow roads, affecting all winter vehicular travel, and pose safety risks to visitors in smaller snowcoaches and on snowmobiles.

The third most fuel-efficient OSV on a per-person level was the Ski Doo ACE 600, which was more efficient than five of the seven snowcoaches we measured. Interestingly, compared to the two other snowmobile models measured (the Arctic Cat TZ1 and the Ski Doo GT-1200), the Ski Doo Ace was approximately 65% more efficient in terms of miles per gallon. This is an important finding for commercial tour operators and for the park's administrative snowmobile fleet. In terms of fuel efficiency across the various OSVs in use in Yellowstone and given the known limitations of the various OSVs, we conclude there is insufficient evidence to support a compelling advantage for one type of OSV transportation mode over another.

Study limitations

This analysis has several limitations that could be addressed in subsequent evaluations. Data were self-reported by operators. Variables such as road and weather conditions may influence fuel efficiency for a given vehicle, and the ability to assess these potential effects could be insightful. Estimation of distance traveled would be more accurate if OSVs were fitted with GPS units.

The shift [in management tactics] is based on the empirical evidence that impacts on soundscapes and wildlife stem from groups rather than absolute numbers of vehicles.

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