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Shuttle Bus vs. Shuttle Van

A Cost-Benefit Analysis of Hope College Transportation

Introduction

At the beginning of the 2008-2009 academic year Hope College changed its transportation system to use a single shuttle bus instead of multiple shuttle vans. This switch was similar to that previously undergone by the Max bus system of Holland, Michigan in the following way. Under both of the previous systems, riders could be picked up from their residences and transported to a destination of their choice. The system now used by both the Hope College shuttle bus and the Max bus is a fixed-stop route that runs constantly during operational hours.

The new shuttle bus system at Hope College has met with some resistance, as was expected from the experience that the Max bus transition had. At the beginning of the school year, students were protesting this new fixed route system and many refused to ride it. After some changes in the route the boycott ended, however the present ridership of the shuttle bus is still a fraction of what the shuttle vans had experienced. A drop in ridership was expected from the administration.

In light of the large changes in ridership and substantial infrastructural changes to the system itself, we wanted to investigate which option was more economically and environmentally friendly to the community and college. Our research took a comprehensive look at several relevant factors. These included differences in noise, particulate and gaseous pollution produced by the shuttle van and shuttle bus, and the cost of operation for both systems, including per-rider costs. Finally, we examined public opinion of the new system.

Sound Pollution

One of the common areas of concern expressed by students was the sound produced by the new shuttle bus which was of little concern under the shuttle van system. The single larger diesel engine seemed to be making substantially louder noise at a lower frequency that could shake windows, and there were complaints about loud and high-pitched brake sounds. As a result, we sought to find a method to quantify and compare the sounds produced by the shuttle bus and shuttle vans.

Total Sound Produced

First, we used a simple sound meter to determine the amplitude of sound produced by the two vehicle types while accelerating, braking and idling and the sound inside of the vehicle. A 'max-hold' feature that recorded the highest decibel level during the test was used for the first three, and a 'slow' feature that recorded an average decibel level was used for the reading inside of the vehicle. The brake noise recording was taken at a marked bus stop as the bus approached, which ended up approximately 2 meters from the bus. The accelerating recording was taken as we exited the bus and then stood at the marked bus stop while the bus accelerated. The idling recording was also taken at a marked bus stop while the bus was not moving. Finally, recording inside the vehicle was taken from the time the bus started moving until it stopped, resulting in an estimate of the average decibel level during a ride. The equivalent measures were reproduced for the vans by the same procedures and at the same distances.

Decibels	Van	Bus
Accelerating	74.2	90.8
Braking	68.3	84.4
Idling	69	74.2
Inside	65.4	68.3

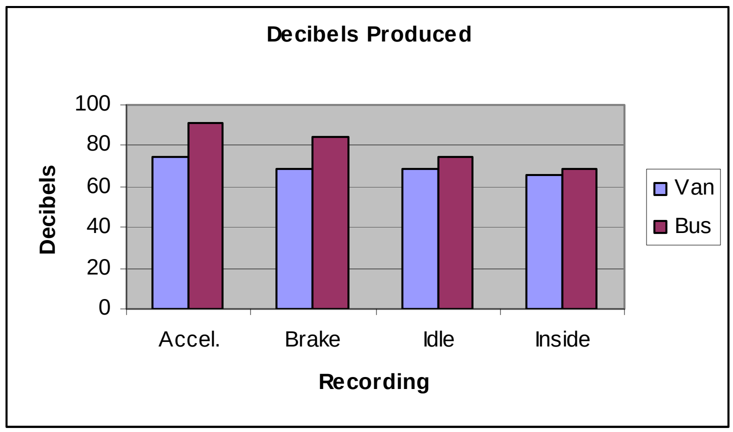


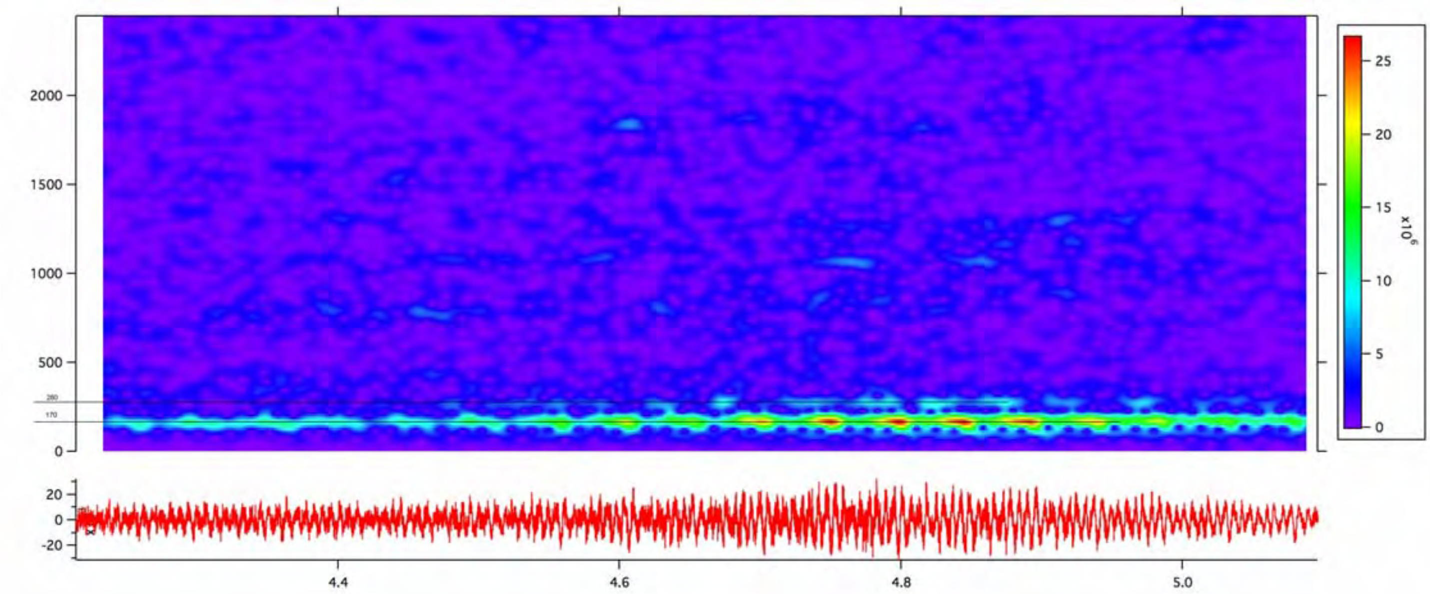
Chart 1 and Figure 1: Decibel levels recorded during different parts of a vehicle's route.

These results confirm that the bus is consistently louder than the van. To interpret whether or not this difference is problem, the decibel levels can be compared to a normal conversation's level of approximately 60-70 decibels and the level at which sustained exposure can cause hearing loss of about 90-95 decibels (Galen, 2007). OSHA permits up to 8 hours of exposure to 90 decibel noise per day (OSHA, 2006). Therefore, there is essentially no risk of hearing damage from the bus even with the increase in noise production over the vans. For obvious reasons, the level at which annoyance begins is entirely subjective and varies among people.

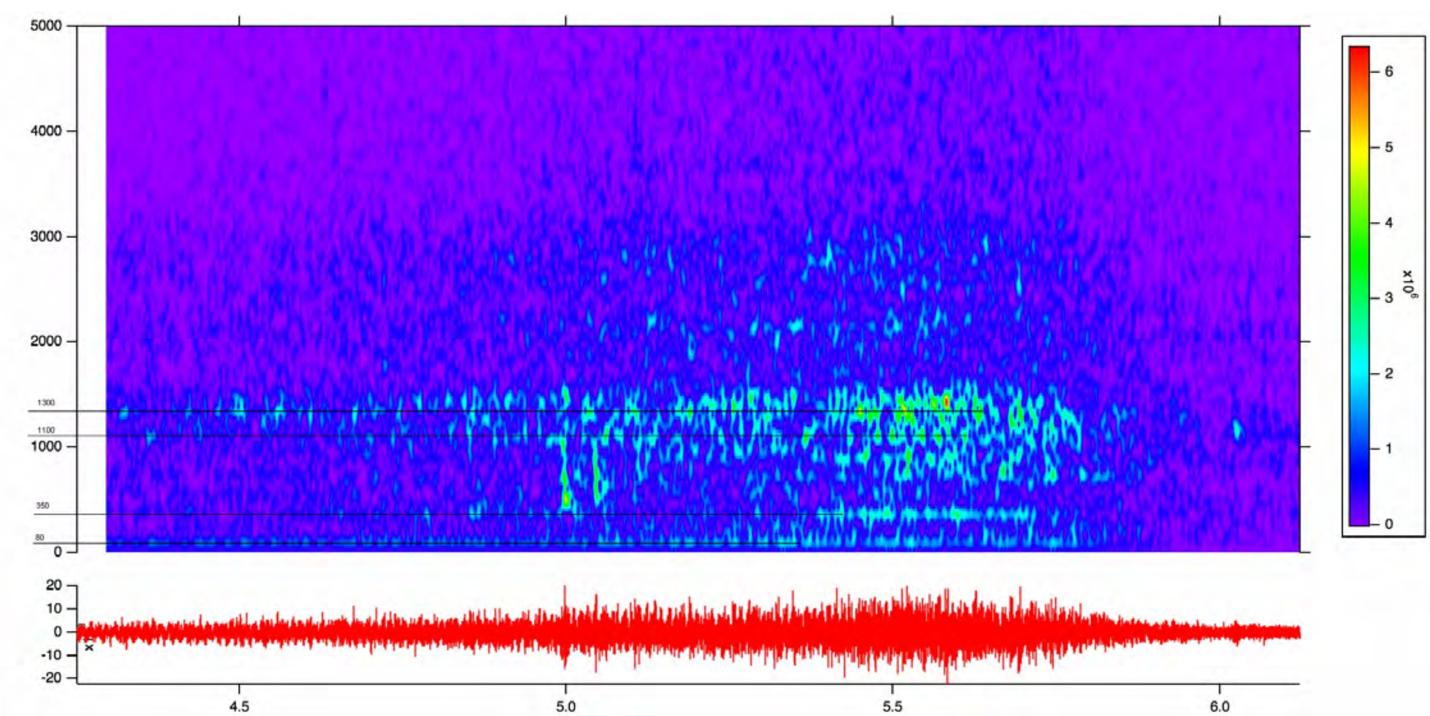
Sound Frequencies Produced

In order to further analyze the sound being produced, the bus and a van were digitally recorded accelerating and braking from approximately 3 meters away, and the loudest portion of the recordings were analyzed using IGOR Pro 6 sound analyzing software. Sonograms were created to compare the most intense frequencies being produced, with frequency in Hertz on the y-axis, time in the recording in seconds on the x-axis, and a color gradient for sound intensity:

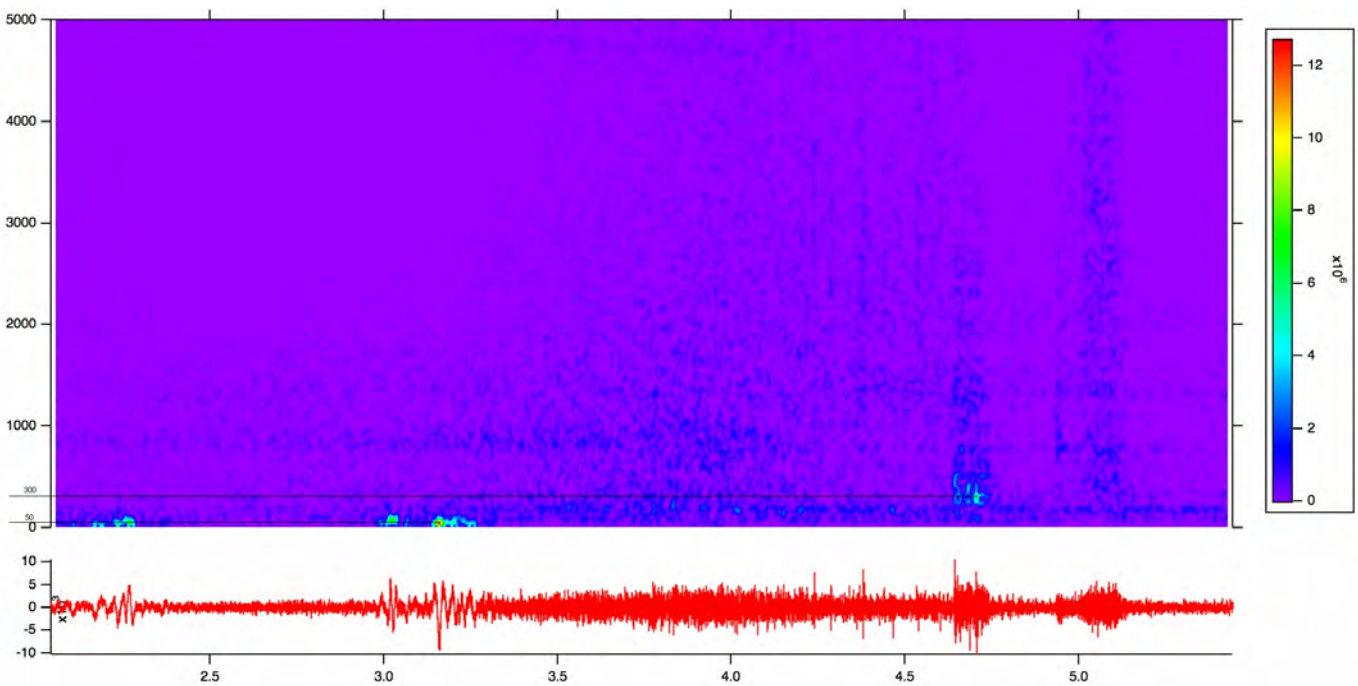
Van Accelerating



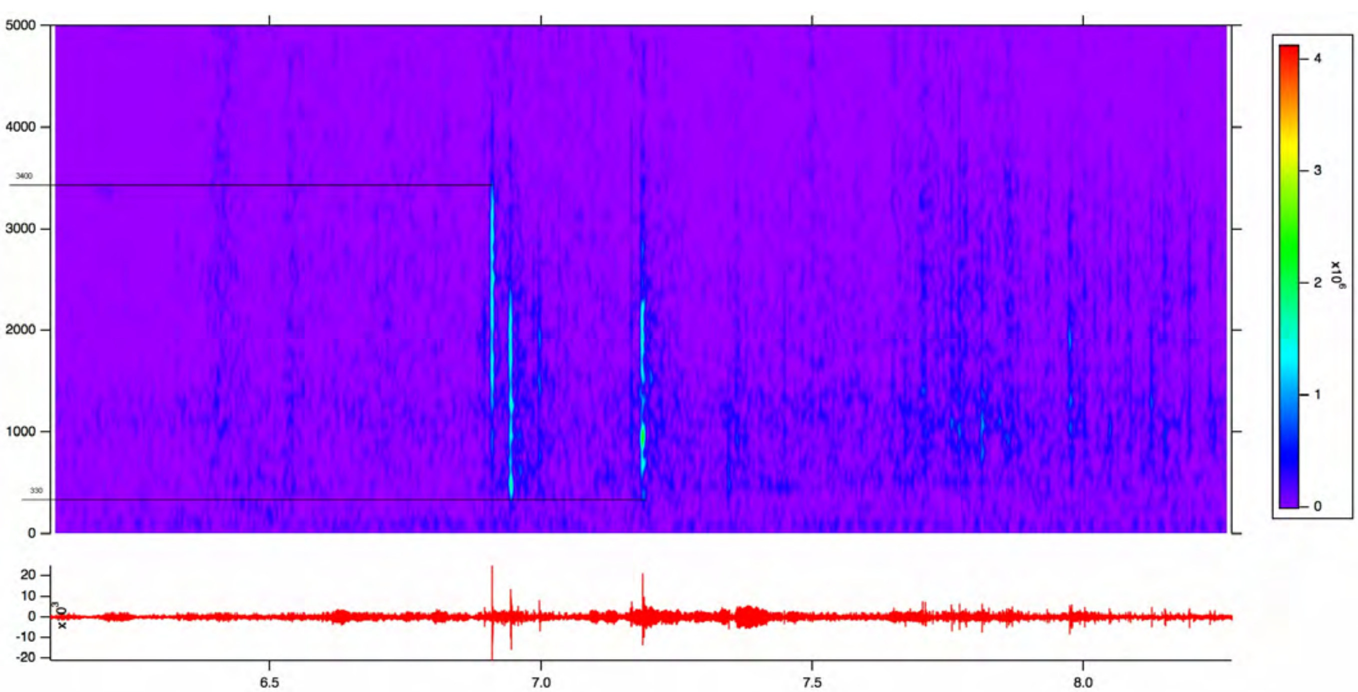
Bus Accelerating



Van Braking



Bus Braking



Recording	Frequency (Hz)	Notes
Van Acc	167	*~Dominant Frequency*
	278	
Bus Acc	80	*Many harmonics present*
	353	
	1093	
	1327	
Van Brake	47	*Noises appear to be tires and suspension, not brakes*
	300	
Bus Brake	327	*Frequencies range smoothly over this range*
	3400	

Chart 2: Sonogram analysis with dominant frequencies produced for accelerating and braking recordings of the van and bus.

The hypothesized areas of interest were the lowest frequencies produced by the accelerating bus in comparison to the van and the higher frequencies produced by the bus braking. The bus did in fact produce a lower frequency in accelerating, though the more notable difference was the number of harmonics produced. These additional frequencies being could increase the chances of a window rattling because different types of windows can have different exciting frequencies that cause them to rattle, as well as having multiple exciting frequencies per window type (Kitamura et al., 2006). The noise produced by the van braking was minimal, and what was recorded were primarily sounds from the tires slipping or moving loose gravel and the suspension. However the recording of the bus braking clearly had squealing brakes that resulted in sounds that spanned a large range of frequencies, including much higher frequencies than anything of substantial amplitude in the van recordings. This confirms the observation of dominant high pitches from the bus that did not occur with the vans.

Exhaust Pollutants

Exhaust Gas Analysis

It is obvious that a single large diesel engine should emit exhaust with a different composition than the smaller gasoline engine of a van. In order to analyze the health and environmental effects of the exhausts of the two systems, a few important gases were chosen – carbon dioxide, methane, NO and NO_2 – and the exhausts were collected from a van and bus while the engines were cold and warm. This was done by attaching a Mylar bag to the exhaust pipe via a funnel and rubber tubing. The samples were then analyzed using FTIR spectroscopy and compared against standard curves we created for the equipment to determine the partial pressures of these four gases within each sample.

Sample	CO_2 (2360)	CO_2 (2338)	CH_4	NO_2	NO
Bus Cold	28	26	0.058	B.D.L.	B.D.L.
Bus Warm	29	27	0.042	B.D.L.	B.D.L.
Van Cold	46	43	0.11	B.D.L.	B.D.L.
Van Warm	43	42	0.025	B.D.L.	B.D.L.

Chart 3: Partial pressure of CO_2 (based on two different wavenumbers), CH_4, NO_2 and NO. Numbers are percent composition of exhaust. Both NO and NO_2 were beyond the detection limit of our equipment.

Both samples of bus exhaust demonstrated substantially lower partial pressures of carbon dioxide, which was measured based on two different wavenumbers for greater certainty. Methane had the highest partial pressure in the exhaust of the cold van engine and lowest in the warm van engine. On average, the bus and van produced similar amounts of methane, but none of the samples contained enough methane to be a large concern. Both NO_x gases were present in even lower concentrations, if at all, as we could not discern any peaks at the expected wavenumbers above background noise. Therefore, this portion of the experiment showed an important difference in exhaust makeup only in CO_2, where the van produced about 60% more CO_2 per unit exhaust volume.

Considering that the combustion of the fuel in both engines appears to be mostly complete (as evidenced by the low methane levels), this number may be less important than expected. It is likely a result of the differences in compression ratio, fuel/air mixture and other design specifications between gasoline and diesel engines. Exhaust concentration is not a good indicator of total CO_2 output unless combined with exhaust volume to determine total CO_2 volume. As we had no safe way of measuring exhaust volume during operation, total CO_2 volume is impossible to determine. A stand-in for total CO_2 output in lieu of direct measurement is fuel consumption, because the fuel consumed will produce consistent amounts of carbon dioxide as it burns. As will be discussed later, it was found that the van consumes slightly more fuel by volume than the bus (610 gallons vs. 600 gallons per month). However, because diesel is more energy dense than gasoline, producing 38.6 MJ/l to gasoline's 34.9 MJ/l (Oak Ridge National Laboratory), total hydrocarbon consumption of the bus is approximately 9% higher than that of the van. Considering the rather crude methods used to arrive at fuel consumption, however, this small amount is well within experimental error and we must conclude that the two systems produce similar amounts of carbon dioxide.

Particulate Pollution

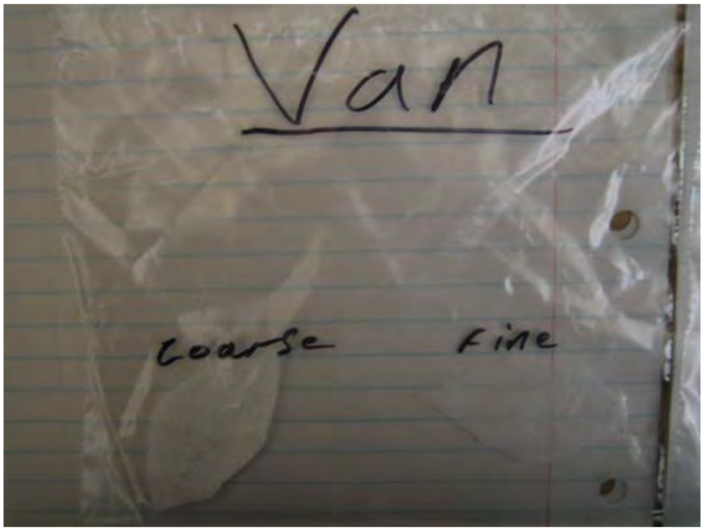
Scientific research since the 1970's (Lave and Seskin, 1973) has consistently demonstrated the deleterious health effects of atmospheric particle aerosols. These pollutants are emitted by internal combustion engines in the course of their operation due the incomplete oxidation of their fuel. Particulate pollution is estimated to cause at least 22,000 deaths per year in the United States alone (Mokdad et al. 2004). Small particles less than 10 μm in diameter are the most dangerous because of their ability to bypass the body's natural filtering mechanisms and pass deep into the lungs. Some can even progress further into the bloodstream. Particles can damage tissues, reducing lung function and contributing to asthma and cardiovascular disease (epa.gov). They can also carry carcinogenic or toxic components adsorbed onto their surfaces.

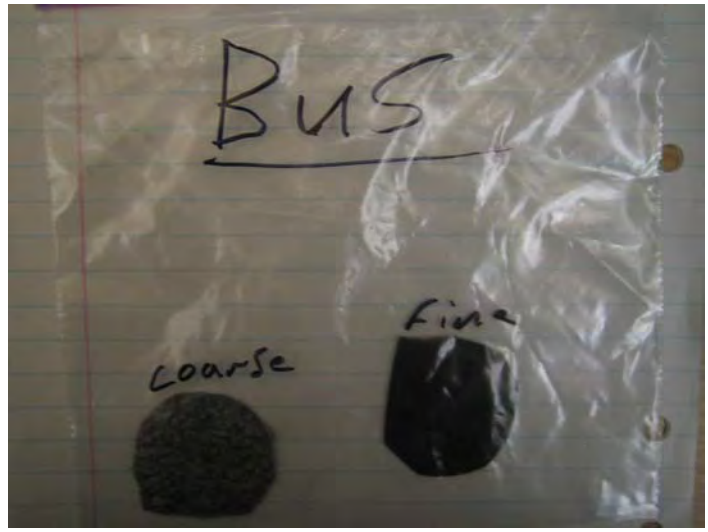
In addition to its health implications, particulate pollution is detrimental to the public welfare. It is the major cause of reduced visibility (haze) in many parts of the country. When they do settle out of the atmosphere, particles can damage crops, acidify bodies of water and stain or damage public structures, such as buildings and monuments.

For these reasons, the USEPA regulates particle emissions as required by the Clean Air Act. Particles are mainly classified by size. Those larger than 10 μm usually settle out of the air fairly quickly and if inhaled are stopped by the bodies defenses before reaching the lungs. "Inhalable coarse particles" or PM_{10} have a diameter of 2.5-10 μm, while "fine particles" or $PM_{2.5}$ are smaller than 2.5 μm. Fine particles are the most problematic (epa.gov). They are the most likely to enter the bloodstream, most difficult to remove from the body, have the most surface area to adsorb chemicals and take the longest to settle out of the atmosphere.

In order to determine the relative amounts and types of particulate matter produced by the shuttle bus and the shuttle vans, we sampled them both during cold operation. We temporarily attached a commercially available NIOSH N95 rated respirator mask, rated to remove at least 95% of airborne particles, to the tailpipe of each vehicle.

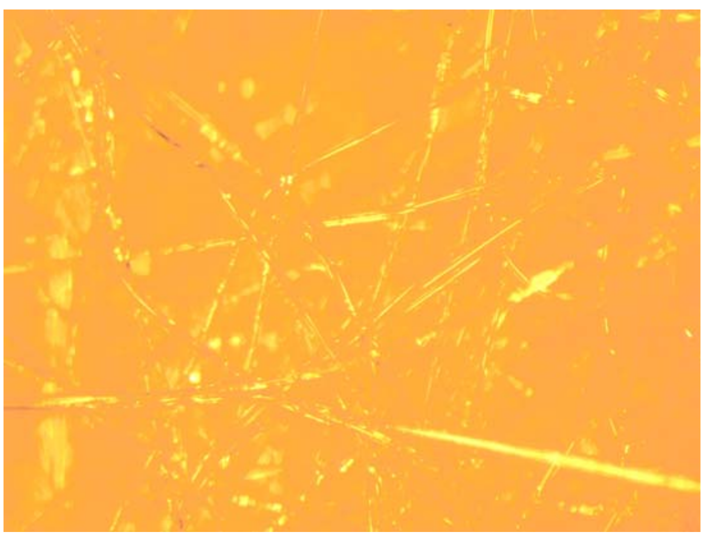
We also attempted to sample warm engines during operation. Unfortunately, the large volume of exhaust produced by the bus during acceleration defeated any method of filter attachment, so only cold-start samples were analyzed. The engine was started and allowed to run for 1 minute with the filter attached. The N95 respiratory filters we used had several layers. The top layer consisted of coarse fibers apparently intended to trap larger particles. A second layer with denser weave of smaller fibers successfully trapped smaller particles. The photographs below show samples of both layers cut from our experimental filters. For reference, both layers were completely white before exposure to exhaust.



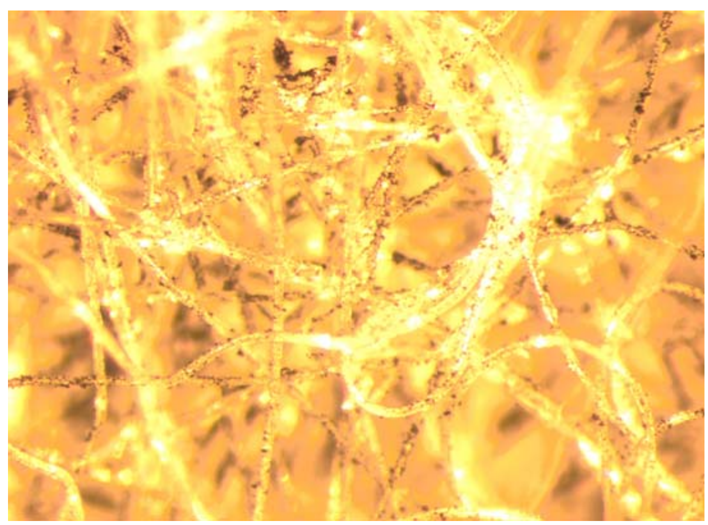


A clear difference between the vehicles can be seen with the naked eye. While the van filter appeared virtually identical before and after the test, the bus filter had turned almost black after 1 minute of exhaust filtration. The filter samples were taken back to the lab for microscopic analysis.

Photographs were taken of the surface of all filter layers using a dissecting microscope at 60x power. The following are of the coarse layer:



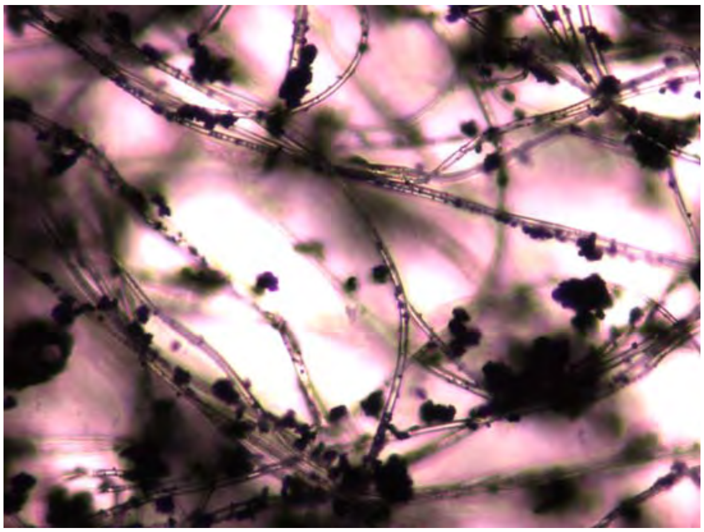
Van Filter – 60X Magnification



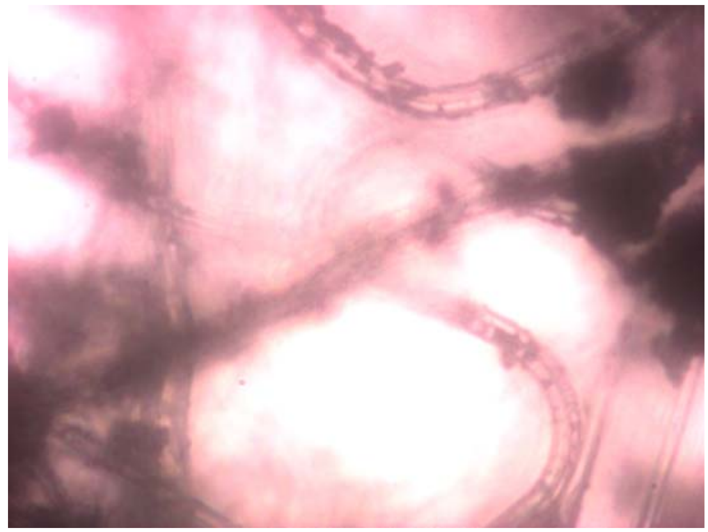
Bus Filter – 60X Magnification

Little to no particle accumulation is visible on the van filter while noticeable buildup is present on the bus filter. This pattern held on both the coarse and fine layers.

To obtain higher magnification, a small portion of fiber was removed from the fine layer of each filter and viewed under a compound light microscope equipped with a digital camera. Both photographs below are of a typical section on the bus filter. We have not included any more photographs of the van filter because it continued to demonstrate complete lack of particles attached to the fibers among randomly selected locations.



Bus Filter - 400X Magnification



Bus Filter - 1000X Magnification

These images of a representative section of fine filter fibers demonstrate a large amount of particle accumulation. Particle size in these images was determined by utilizing a stage micrometer. Particles or conglomerations of particles of size greater than 10 µm, PM_{10} and $PM_{2.5}$ were all abundant. A large number of particles were smaller than 1 µm. While the 1000x magnification image is cloudy because at this setting we are nearing the limit of optical microscopy, very small particles can be seen. This indicates that the particle distribution extends at least to the lower resolution limit of this microscope, just under 1 µm. Smaller particles may exist.

In conclusion, the amount of particulate produced by the shuttle bus is starkly higher than that produced by the old shuttle van system. While a few large particles were seen on the van filter, accurate quantitative comparisons between the two are impossible because of the extremely low amount of particulate produced by the van. It is clearly fair to say that particulate production by Hope College's vans is negligible and that the bus produces at least several orders of magnitude more particulate pollution than the van. This is true even taking into account that multiple vans would run per bus. Concerning type of particulate produced, the particulate produced by the shuttle bus varies widely in size, falling into all legal categories, including the most damaging $PM_{2.5}$ designation.

Fuel Usage and Costs

One of the several reasons Hope College cited for switching from a shuttle van (gasoline) system to a shuttle bus (diesel) system was reduction of cost. At the time of the switch, a similar price for the two fuels was presumed to provide an economic incentive for the college to use a diesel vehicle as opposed to gasoline-fueled vans. While fuel prices vary over time, we tested both systems to determine how much fuel was used by each.

Fuel Usage

The shuttle bus that Hope College currently uses is powered by diesel fuel. A constant route is set up around the campus. The shuttle bus only stops running on this route a few times a night for the driver to take a break (Transportation). During this route, the bus uses approximately three gallons of diesel fuel per hour (Transportation). Sunday through Thursday when the shuttle bus runs from 6:00 p.m. to 12:20 a.m. the next morning, the bus uses nineteen gallons of diesel fuel per night (Student Development). On weekends, Friday and Saturday night the bus runs for 6:00 p.m. until 2:20 a.m. using around twenty-seven gallons per night (Student Development).

Under the old shuttle van system the van did not run on a fixed route, but rather was picking students up from any campus location and dropping them off at other campus locations (Fraker). According to the drivers, the van spent about half the night idling waiting to be dispatched to campus locations and waiting for students to load on and off the vehicles (Fraker). Due to this the vans were only driving about half of the time, although this varied by how busy the night was (Fraker). On slow nights there were two van running on campus and on busy nights such as weekends there would be three vans in use (Fraker). Like the shuttle bus, the vans ran on Sunday through Thursday schedules and had a weekend schedule of Thursday and Friday (Fraker). On weeknights, there would be two shuttle vans running and on weekends, there would be three vans running per night (Fraker). The hours that the shuttle van s were in-service were 6:00 p.m. to 2:00 a.m. the next morning every day of the week (Fraker).

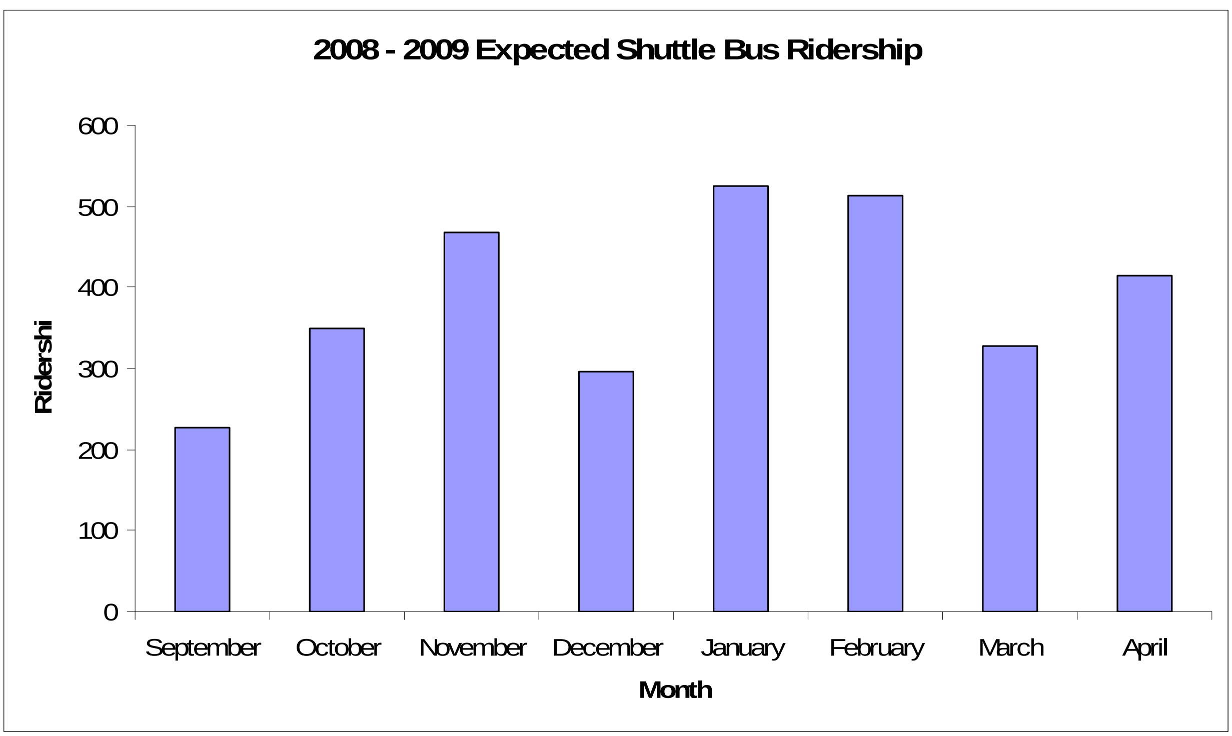
In order to determine the vans' fuel consumption it was necessary to test the vans' fuel usage per hour not only driving but idling as well. We took a van to a local gas station and filled the gas tank at a slow rate to ensure a consistent gasoline level in the tank. To test the fuel usage per hour when driving in a residential area and coming to complete stops often, we then drove the van for fifteen minutes and refilled the tank using the same method to see how much gasoline was used in this fifteen minute time period. We then multiplied this number by four to determine the amount of gasoline used in an hour of stop and go driving at no more than twenty-five miles per hour. This was about 1.2 gallons per hour. In order to test the amount of gasoline used per hour while idling we filled the gas tank, pulled the van to a parking spot a few feet away from the pump and let the car idol for fifteen minutes. We then pulled back into the pump and filled the tank again. From this process, we were able to find that the van uses almost as much fuel idling as it does driving at low speeds. In an hour of idling, the shuttle vans use 0.8 gallons of gasoline. Because the shuttle van idols for about half the night and drives for the other half, on average the van uses roughly one gallon of gasoline per hour. On weeknights, the shuttle van system used about sixteen gallons of gasoline per night. On weekends when there were three vans the van system used about twenty-four gallons of gasoline per night.

Fuel Costs

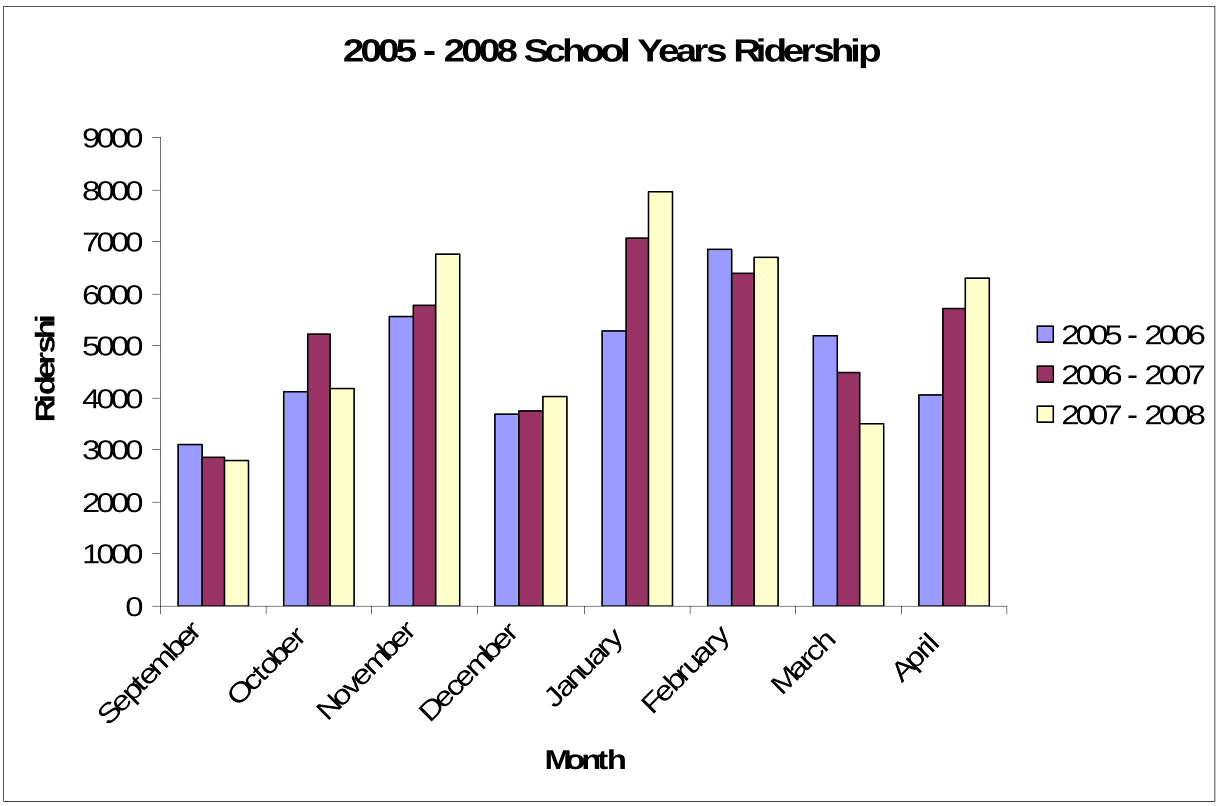
The cost to fuel the vehicles fluctuates with the economy and the price per barrel of crude oil. At times diesel fuel is more cost efficient than gasoline per gallon, such as a few months ago. At other times such as today, the cost of diesel fuel is much higher than that of gasoline. In a twenty-eight day month, the shuttle bus would use almost six-hundred gallons of diesel fuel. The shuttle vans would use almost six-hundred and ten gallons of gasoline. While the shuttle vans and bus use about the same amount of fuel, the total cost varies on how much the fuel costs. Currently the cost of gasoline is substantially less than the cost of diesel fuel. According to the Energy Information Administration the cost of gasoline is $1.70 per gallon on December 12, 2008, this means that in a month the cost of gasoline is around $1,000 (EIA). The cost of diesel for December 12, 2008 is $2.52 per gallon; for the month of bus operation the cost of diesel fuel is about $1,500 (EIA).

Ridership

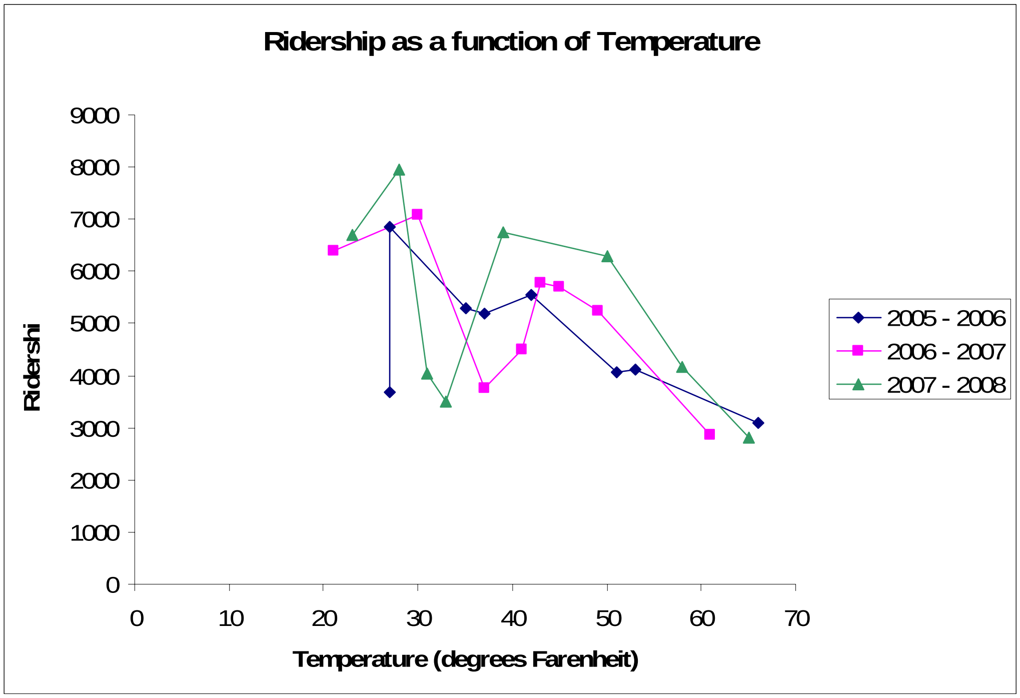
Ridership numbers for the shuttle bus have been difficult to determine for several reason. The first reason ridership has been difficult to determine is that there was a boycott of the initial bus system. During the boycott there were only a few riders per night at most and on some nights there were none at all (Transportation). Mid semester, the shuttle bus switched to a different route that was faster (Transportation). Once this switch to the new route occurred ridership increased substantially. As a result, we were only able to consult accurate ridership numbers for one month of the semester. We used a ratio for the month of November shuttle bus ridership to past November ridership numbers of the shuttle van system to predict what possible future ridership numbers could be. For the month of November 2008 the ridership was 467 riders for the shuttle bus (Transportation).



The shuttle van system had a low of around 3,000 riders for the month of September. The highest number of riders was most often seen in January and February, with 5,000-7,000 riders (Campus Safety). In December, ridership is nearly half of November and January (Campus Safety). This is because of Hope College closing for the semester and the vans only running for approximately two weeks of the month. Spring break occurs in March and the campus shuts down for a week. Because of the campus shutting down for a week the ridership numbers were smaller than if the van ran for the entire month.



There is a correlation between the temperature and ridership. As the temperature drops the ridership of the shuttle vans, not surprisingly, increased. Roughly, for every ten degrees Fahrenheit that the temperature drop there was a 1,500 rider increase for the shuttle vans.



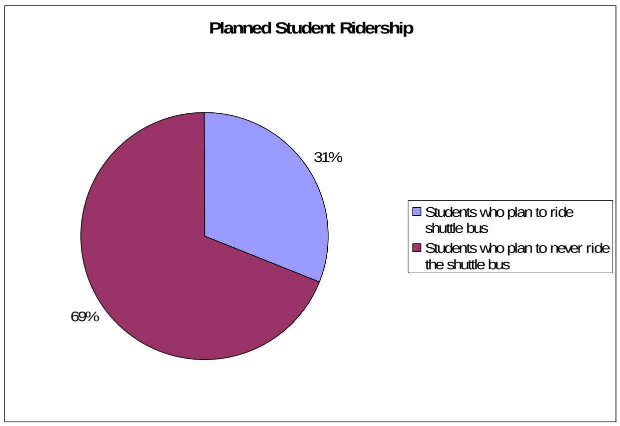
Cost to Operate

Currently the fuel cost per rider for the shuttle bus is about nineteen times the cost of the shuttle van. This is due to the low ridership levels that the shuttle van is experiencing. For the month of November the shuttle bus used about $1,500 in fuel and had about 450 riders (Campus Safety & EIA). The average cost per ride for this month was around $3.30. In previous years the ridership for November was almost 6,000 riders and the cost of fuel would be around $1,000 (Campus Safety & EIA). The cost per ride for the shuttle van would therefore be around $0.17 per ride. Because fuel costs are fixed for the shuttle bus, the cost per ride is expected to decrease as the winter months become colder and ridership increases.

While the above difference in price appears staggering, fuel costs are only a small portion of the total operational costs of a transportation system. Many other costs such as paying drivers and other staff and insurance likely cost more. Maintenance is also likely to be less expensive for one vehicle than for three. While we were unable to determine the exact cost composition of these two alternatives, we do know from extensive interaction with the College's administration that the new bus-based system is less expensive to operate than the old system when all costs are considered together. This was in fact one of the main incentives for changing the system. While this provides a countervailing force decreasing the cost per rider, the approximately 13x fewer students now using the system represents a sizeable pull in the other direction. The new system would need to be 13x cheaper than the old in order to break even on cost per rider.

Public Opinion

In a recent survey done by Hope College Residential Life concerning the shuttle bus system, it was found that overall students have a negative view of the shuttle bus. The survey was a random sampling of 461 students on Hope College's campus (Survey). The survey was equally divided between Freshman, Sophomores, Juniors, and Seniors. From this survey it was found that of the 461 students sampled, only one thought that the shuttle bus system was a good system (Survey). Thirty-one percent of the students surveyed said they would be willing to ride the shuttle bus; however, sixty-nine percent said they would never ride the shuttle bus (Survey).



There are other concerns that students have about the shuttle bus system. These concerns were voiced in the survey taken by Hope College. One issue many students have is about the noise of the shuttle bus. A student said in the survey, "The brakes are very loud. There is a stop outside my cottage and my housemates and I actually wake up to the bus. The sound rivals the trains..." (Survey). From our research, we did find that there was a large amount of low frequency noise produced by the large diesel engine of the bus. From personal experience, one of us (McKinnie) has experienced this problem as well, when the shuttle bus stops across the street from her apartment, the windows rattle.

Another concern of the students relates to safety. Before when a student was receiving a ride from the shuttle vans, the vans would pick students up from any campus location and drop them off at another . There was not the need to walk to stops in the dark late at night. One student voiced her concern with this new situation by writing, "It is not safe for people to wait outside for the shuttle bus to come pick them up. You may have to wait a while and it could be dark, raining, or snowing and you could be by yourself. As a female, I would not feel comfortable waiting for the shuttle bus by myself at night" (Survey).

As stated earlier, this transition was expected to be viewed negatively by the system's patrons. Exchanging a more convenient system for a less convenient system is bound to be unpopular. While it remains to be seen how these opinions will change, it seems likely that as students get used to the new system and new students arrive that never new of the old one, flaring tempers will die down.

Discussion

In difficult economic times, reducing costs is often necessary. The ability to make difficult decisions to cut popular services is an essential characteristic of good leadership. However for every decision to be made, the cost of the action must be weighed against its benefits. Is the money saved on a less expensive transportation system worth the reduction in benefits of the service? For Hope College's transportation system, with a drop in ridership of 13x, that answer, for the present, appears to be no. It should be emphasized, however, that this conclusion is highly preliminary and more time will have to pass before anyone can know if it holds.

There are many other factors relevant to this transition that we were not able to investigate. If people are not happy with the shuttle bus service, for instance, they will probably use other means of transportation. Will they drive their own cars more? This seems likely. How much? It is difficult to say. Not using the provided transportation system and opting for other options is likely to increase total costs to the campus community. More students may choose to bring cars to campus. This could increase congestion in parking lots. Greater use of personal cars will increase fuel consumption, local traffic and pollution. What are the costs of these? What is the increased risk to personal safety of more people walking to get across campus instead of taking the shuttle system? How large are the undoubtable health benefits of doing so? All of these questions are extremely relevant to understanding the total cost of each system. Unfortunately they are just as difficult to answer and quantify. These are just examples, but the point is that infrastructural changes such as that recently undergone by Hope's shuttle system are likely to have numerous effects that are not only difficult to anticipate, but difficult to understand even after the transition.

With these uncertainties in mind, it is still useful to analyze those costs that we are able to in order to provide as much information to decision makers as possible. Understanding the largest and most discernible factors influencing a system is far better than having to make a decision about it based on no information at all. So how much exactly does each system cost? Here, also, a complete fiscal analysis of the college's myriad transportation-related expenses under both plans was beyond the scope of this investigation. Combined with the inherent difficulty in monetizing externalities such as particulate and noise pollution, this makes it impossible for us to provide a straight number value for each system. Instead we have attempted to provide relevant and detailed information about how much each system has been used to date as well as its external effects on the local community and beyond. Whatever the true costs, we do know that in order to break even on a per rider basis, right now those combined costs would have to be 13x lower for the new system than they were for the old one. This seems unlikely.

If reducing the college's costs is in fact this important, then it may be better to do away with the shuttle system entirely if ridership does not substantially improve. That's the cheapest option of all – it directly costs the college nothing. On the other hand, these conclusions are based on a system that has just barely transitioned. As people get over grudges, become more acquainted with the new system and the weather continues getting worse, the number of riders is almost certain to increase. How much is anyone's guess.

For a system with almost completely fixed and virtually no variable costs, like the shuttle bus, increasing the number of riders is paramount to improving the system's efficiency. It is ironic that by protesting the new system they consider worse than the old one, some students have actually helped to make it so. Public transportation systems are made or broken on public acceptance, and in this case a self-fulfilling prophecy seems all too likely. If more people start taking the shuttle bus, per rider costs could decrease sharply, far more quickly than they would have for the vans. At the same time, people will only ride any shuttle system if they need it, and the shuttle bus is likely never to be efficient in the warmer months when there is simply too little demand.

Under present conditions, the shuttle bus system is not an economically or environmentally efficient means of transportation for the Hope College community. Only time, and the extent to which students embrace the new system, will determine whether that remains the case.

Acknowledgements

We thank Dr. Graham Peaslee and Dr. T.J. Sullivan for their continuous assistance and substantial expertise. We also thank the Macatawa Area Coordinating Council.

Competing interests. It should be noted that one of the authors (Fraker) had extensive operational experience under the employ of Hope College Campus Safety as a van driver during operation of the old system. While this helped inform our research, we do not feel that it compromised the results in any way. This author has not worked for the shuttle service for over a year and a half, after leaving voluntarily to pursue other interests. This was over a year before the transition. As Hope College students, we all have the opportunity to use this service, implying the possibility of personal preference. However, as seniors with only one semester remaining, any possible systemic changes would likely take place after we have left the college.

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