CORSIM Application of Alternative Fuels for Transit Buses

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ABSTRACT

Alternative fuel use is increasing in bus transit in the United States as transit agencies recognize the need to switch from conventional diesel. Although agencies have been using more alternatives over the past ten years, there are still uncertainties related to the advantages and disadvantages of each alternative fuel. Most of the bus data is collected from real-world case studies performed by the National Renewable Energy Laboratory (NREL) and the Department of Energy (DOE). This real-world data is then applied to traffic simulation software to model a particular fuel along any type of route.

There are limited programs available that offer the opportunity to fully model an alternative fuel bus, however, CORSIM provides an extensive simulation process to conduct a comprehensive analysis. The alternative fuels that are analyzed are biodiesel, compressed natural gas (CNG), liquefied natural gas (LNG), ethanol, methanol, hydrogen, and hybrid-electric. Each of these fuels is compared using the following parameters: service reliability, fuel economy, and environmental effects.

Once the input data is changed, parameters related to the bus operation are altered to represent extreme cases in which the bus is traveling. Extreme cases of volumes, number of stops, and bus headway are examined. Also, a test is performed that compares highway versus city travel. The compilation of tests shows that low-floor buses show great advantages with respect to travel times, delay times, and average travel speeds, however, hydrogen buses outperform all others in terms of fuel economy and environmental effects.

INTRODUCTION

As a result of the environmental hazards and energy security issues related to the intense use of conventional diesel, the Energy Policy Act of 1992 (EPAct) recommended that the United States begin experimenting with alternative fuels for transportation needs. The EPAct established fleet percentage requirements for government fleets mandating that a certain amount of the vehicles run on alternative fuels [1]. Since alternative fuel buses are expected to become more prevalent within public transportation, there must be a method to model these buses within a network. The model must be able to evaluate fuel economy, emission rates, travel times, and other parameters that are associated with bus operations. Transit agencies that are interested in implementing a particular fuel must know the advantages and disadvantages of each fuel within dynamic networks.

Currently, there is a lack of traffic software that can extensively and efficiently model alternative fuel buses. Transportation programs that can report data such as fuel economy or emission rates are available, however, they are not designed to evaluate a bus' ability to provide transportation services. Similarly, there are few programs that allow the user to create and evaluate a bus network. CORSIM allows the opportunity to fully model a bus operation on any type of network modeling any fuel to be used.

CORSIM simulation software is used to conduct the comparative analysis of diesel, biodisel, compressed natural gas (CNG), liquefied natural gas (LNG), ethanol, methanol, hybrid-electric, and hydrogen. Data from the National Renewable Energy Laboratory (NREL), the Department of Energy (DOE) case studies, and the Altoona Bus Research Center is applied to the CORSIM software to evaluate the necessary parameters.

Purpose and Objectives

The purpose of this paper is to provide accurate information describing the effectiveness of a particular fuel for a bus operation. It is not necessarily intended to declare an optional fuel to implement, rather it will provide a simulation process comparing different type of fuels within a particular bus network. This synthesis answers the following questions:

- How do the alternative fuels compare to diesel in terms of service reliability, fuel economy, and environmental effects?
- How can a traffic simulation program be used to develop reliable data for an alternative fuel bus?
- How can the network within the software be adjusted to reflect the extreme cases (i.e. volume increase/decrease) in which a bus will be operating?

The comparative analysis is performed using both real-world applications and theoretical computer networks. In order to provide the analysis, the following objectives will be met:

- Obtain data from real-world case studies comparing alternative fuel and diesel buses.
- Apply the real-world data to traffic simulation software.

- Manipulate the input data within the software to represent an alternative fuel.
- Provide results that accurately reflect bus operations with changes in the network.

Parameters Analyzed and Evaluated

As mentioned, the parameters used in this analysis are service reliability, fuel economy, and environmental effects. After the bus data is entered into CORSIM, a series of tests are conducted in order to compare the fuels in terms of these parameters.

Service reliability focuses on the operations provided by the bus along its specified route. Therefore, the travel time, delay time (D/T), and average speed of the bus are the main elements provided by the service. These three elements are directly related to the headway, the amount of time between bus arrivals at a station. The fleet size is then determined from the headway and travel time.

The fuel economy of the bus is relatively straight forward. It is the number of miles that can be traveled by the bus per gallon of fuel. The gallon of fuel is a No. 2 diesel gallon equivalent since the fuels each possess different energy contents. This parameter is expressed as miles per gallon (MPG).

Perhaps the most common parameter used when comparing alternative fuels is environmental impact. In this analysis, three types of emissions are compared: hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NO_x). These three are selected because they are the only emissions that can be measured within CORSIM [2]. They are expressed in grams per mile.

CORSIM SOFTWARE

CORSIM is a traffic simulation program produced by the Federal Highway Administration [2]. Within the software the user can create a network in order to model traffic behaviors. Surface and freeway networks can be created which encompass a wide range of variables such as signal timings, traffic volumes, and roadway geometry. Most importantly for this analysis, CORSIM can also model a bus network. Bus data such as its length, occupancy, headway, fuel economy, and acceleration/deceleration rates can be explicitly entered [2]. Bus station data can be entered in terms of capacity, dwell time, and location [2]. A network can be created along a corridor or throughout a city in order to determine various levels of output. Given the network and conditions such as volumes or number of stops, CORSIM provides output such as travel time, delay, speed, fuel economy, and emission rates. The output is given for each link, allowing the user to analyze specifically where delay or the lowest speed may occur. CORSIM is quite detailed in terms of output, and therefore is an appropriate tool for this analysis.

Unfortunately, CORSIM does not differentiate between the types of fuels that a vehicle is using. There are default values that report data such as fuel consumption and emission rates, however, the code within CORSIM can be manipulated in order to represent any fuel to be used.

It is assumed that within CORSIM the fuel and emission characteristics are intended to represent diesel. However, even the diesel fuel input data is updated based on the case studies. The software was originally developed in 1995, however, since then there have been improvements in diesel bus efficiency. Similarly, due to environmental standards, new technologies have been adopted that require diesel buses to emit fewer pollutants. The objective is to determine what fuel type characteristics will change how the bus operates. The four parameters of bus operation that will be input based on the case studies are fuel consumption, emission rates, acceleration rates, and dwell time.

Fuel consumption and emission rates can be entered into the software dependent upon the speed and acceleration rates of the vehicle. For a given network, CORSIM will then produce output of the actual fuel consumption and emissions rate that occurred throughout the network.

Similarly, acceleration rates can be entered as a function of speed. They are entered for speeds from 0-110 ft/sec at 10 ft/sec intervals. Travel time and delay associated with the constant acceleration from a bus station or a signal will be dependent on the input acceleration rates.

Dwell times can be established depending on whether the bus is low-floor or high-floor. The bus station data can be explicitly manipulated in terms of the amount of time the bus spends at each station. Within CORSIM, this time variable typically depends on the arrival rates of the passengers. However, in this analysis, this time will depend on whether the bus is low or high-floor. This will have a direct effect on the travel time that the bus experiences throughout the network.

CORSIM Models

Two types of networks are utilized within CORSIM. One is a model that is provided with the program (CORSIM City) and the second is a model that has been created to replicate the campus of the University of Delaware [2]. CORSIM City is a much larger network that encompasses both surface and freeway networks. The campus network is on a smaller scale and only utilizes a surface network.

Although this network is based on an actual University bus route, it does not entirely replicate the real-world conditions. While the links in which the bus travels, the link lengths, bus stop locations, and intersection control are consistent with the actual route, other parameters such as volumes, lane geometry, signal timings, and phasing are not consistent with the actual conditions. Therefore, the network is designed on a theoretical basis in order to model changes that would normally be fixed within the real world.

CORSIM allows the user to input bus station characteristics including the capacity, station type, mean dwell time, and bypass percentage. The capacity is the number of buses that can be operating at the bus station at one time [2]. The station type signifies the arrival rate of passengers to the station, however, this parameter is ignored in this analysis [2]. The mean dwell time is the time the bus spends at the station while passengers are boarding [2]. The bypass percentage is the percentage of time that the bus will not stop at the station [2]. This is set to zero so that the bus will make every stop.

The University network has a headway of one bus per 20 minutes which can be explicitly entered into the model [3]. In the CORSIM City model, the headway is set at 5 minutes, and as a result 32 bus trips are made over the course of the simulation. While the University network only analyzes surface travel, the purpose of the CORSIM City network in this analysis is to demonstrate the differences between surface and freeway travel. The freeway results also incorporate the effect of the ramps as the bus accelerates and decelerates to the appropriate speeds.

CORSIM Input Data Manipulation

As previously mentioned, four types of data will be entered into CORSIM in order to represent a bus using a particular fuel. These four inputs are fuel consumption, emission rates, acceleration rates, and dwell time. Once these inputs are entered into the software, a series of tests can be conducted with the resulting output of travel time, D/T, speed, MPG, and emissions.

Fuel Consumption

The NREL/DOE studies collected data on the fuel economy of alternative fuel buses. Since some of the alternative fuels were used in various case studies, an average value is taken for each fuel. Unfortunately, a simple MPG input is not available within CORSIM. Instead, an MPG must be entered based on the speed and acceleration rate of the bus. The units of the fuel economy also must be converted to gallons per second. Speed within CORSIM has the units of feet per second and the MPG must be entered for speeds of 1-110 feet per second. This value is then multiplied by 100,000 to be entered into the simulation file because decimals cannot be entered. Also, CORSIM requires that this value be entered for a given acceleration rate (0-10 ft/sec^2). For simplicity, the same rate is entered for each acceleration. Therefore, the gallons per second rate is the same for both quick and slow acceleration scenarios. This process is then conducted for all eight fuels and typed into the simulation file in CORSIM. Table 1 shows the MPG used for this input process for each fuel from the NREL/DOE case studies.

Emission Rates

The same process performed with the fuel consumption is done with the emission rates. For each pollutant, HC, CO, NO_x, the grams per second emitted at each speed is entered for the acceleration rates of 0-10 ft/sec^2. Emissions data is taken from the NREL/DOE studies and applied to the software. The emissions rate is multiplied by 1,000 and entered into CORSIM at every speed.

This process is then conducted for all eight fuels and typed into the simulation file in CORSIM. Table 1 shows the emission rates used for this input process for each fuel. The hydrogen bus in the studies is a zero emissions vehicle. The LNG bus has an extremely low HC emissions rate which is too small to enter into CORSIM.

TABLE 1 MPG and Emission Rate Input Data

Fuel	MPG (No. 2 diesel equivalent) (gal/sec)	HC (gram/mi)	CO (gram/mi)	NO_x (gram/mi)
Diesel	3.54	1.4	6.21	30.21
Biodiesel	4.27	1.48	3.9	35.2
CNG	3.20	8.38	5.5	12.23
LNG	2.85	0	0.234	21.25
Ethanol	3.25	7.05	23.15	11.45
Methanol	3.00	1.05	6.25	7.35
Hydrogen	11.50	0	0	0
Hybrid	3.05	0.46	1.73	27.43

Acceleration Rates

The data for acceleration rates is obtained from both the NREL/DOE studies and the Altoona Research Center [4]. The studies only report acceleration rates at certain speeds. Because CORSIM requires that the acceleration rates be entered for speeds of 0-110 ft/sec at 10 ft/sec increments, the data is extrapolated in order to obtain the acceleration rate at speeds up to 110 ft/sec. It should be noted that since data for biodiesel buses is not available, biodiesel and diesel buses were assumed to have the same acceleration rates because of their similar fuel properties. Also, methanol and ethanol were assumed to have the same acceleration rates.

Dwell Time

The dwell times are based on a study published by the Transportation Research Board. TCRP Report 41 provides data from a national study of dwell times for low-floor versus high-floor buses. The study explains that on average, a low-floor bus has a dwell time of 28 seconds and a high-floor bus has a dwell time of 47 seconds [5]. Out of the eight types of fuels used in the study, only the hydrogen, hybrid, and CNG buses are low-floor, and therefore will have a lower dwell time.

COMPARATIVE ANALYSIS

This section evaluates the service reliability, fuel economy, and environmental effects of each bus based on the tests previously described. The service reliability compares travel time, D/T, average speed, and fleet size. The fuel economy compares the miles per gallon (MPG). Finally, the environmental effects compare the emission rates of HC, CO, and NO_x.

Service Reliability Comparison

The first parameter analyzed using the CORSIM software is service reliability. The volume and headway tests are used to evaluate the service reliability. Only the University network is utilized in this analysis.

Volume Test for Service Reliability

The volumes within the network are changed to reflect the performance of each fuel. The point at 0% represents the base volumes. The travel time, D/T percentage, and average speed are compared individually with changes in volume. Figure 1 shows the change in travel time with volume. When the volumes are increased by 45%, the network becomes unstable as the traffic has reached a gridlock condition. Only three of the buses, LNG, ethanol, and methanol, are able to complete the eight trips in the gridlock scenario that are predetermined in the network with a headway of 20 minutes.

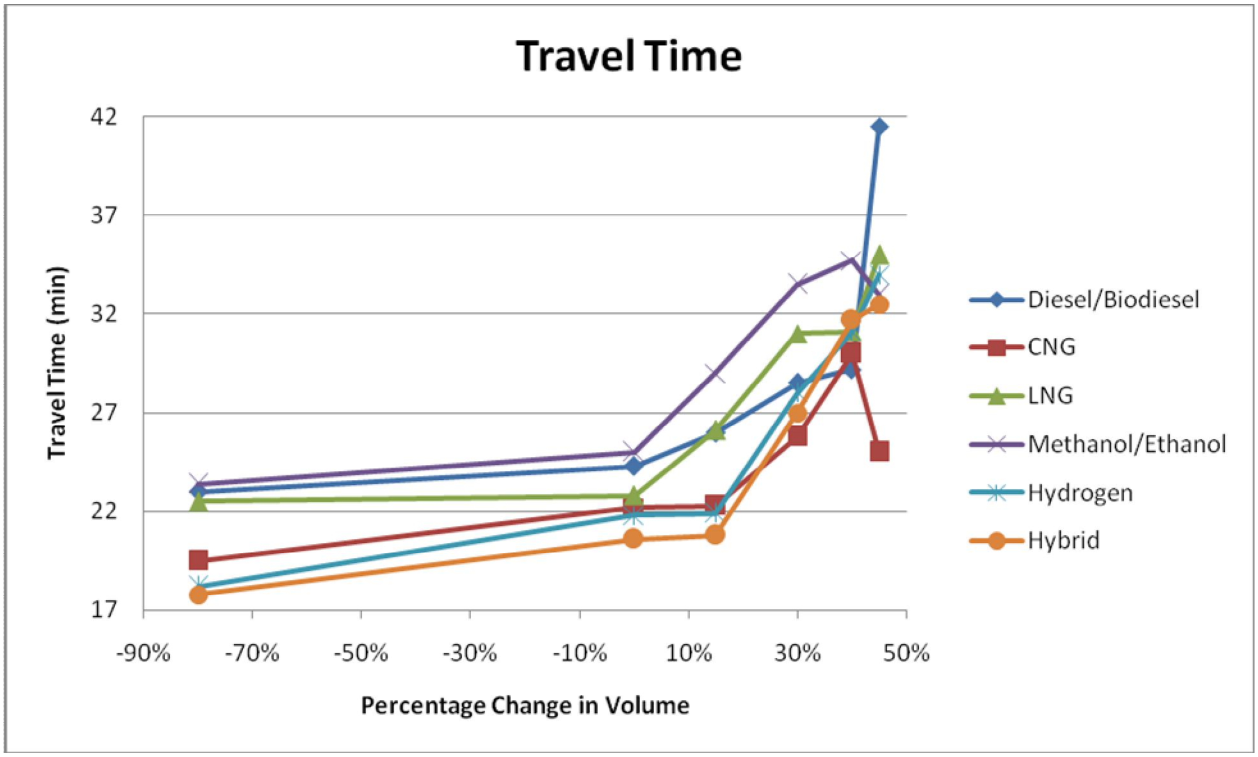

FIGURE 1 Volume Test for Travel Time

The travel time that is reported is the total travel time though the entire 9600 seconds of simulation divided by the number of bus trips. Therefore, it is an average time per bus trip. CNG, hydrogen, and hybrid perform the best because of their lower dwell time as a result of low-floors. Also, the hydrogen and hybrid buses have quicker acceleration rates at lower speeds, which further separate them from CNG. At the low volume extreme, these three buses clearly outperform the other five fuels. In fact, the travel time of these three buses remains below the high floor buses up until the gridlock scenario. Unfortunately, the data at the gridlock scenario is not completely reliable, however, it cannot be dismissed since all of the buses run on the same network, and experience the same gridlock. The diesel/biodiesel bus experiences a much higher travel time at the gridlock scenario, however at the previous data point of 40%, diesel/biodiesel has the lowest travel time. As the volumes are increased, the diesel/biodiesel bus increases at the smallest rate.

Figure 2 shows the D/T percentages for the volume test. The data follows the same trends as the travel time results. The low-floor buses, CNG, hydrogen, hybrid, experience less delay, especially at the low volume scenarios. As the volume increases above the base volume, the D/T increases at a greater rate. Once again, at a volume increase of 45%, the network is unstable. Although the low-floor buses experience on average 5% less delay than the high-floor buses at the lower extreme volume case, as the volumes increase, the different fuels tend to converge together. At -80% of the base volumes there is a difference of 11% between the highest and lowest D/T, while at +40% of the base volumes this difference is only 4%.

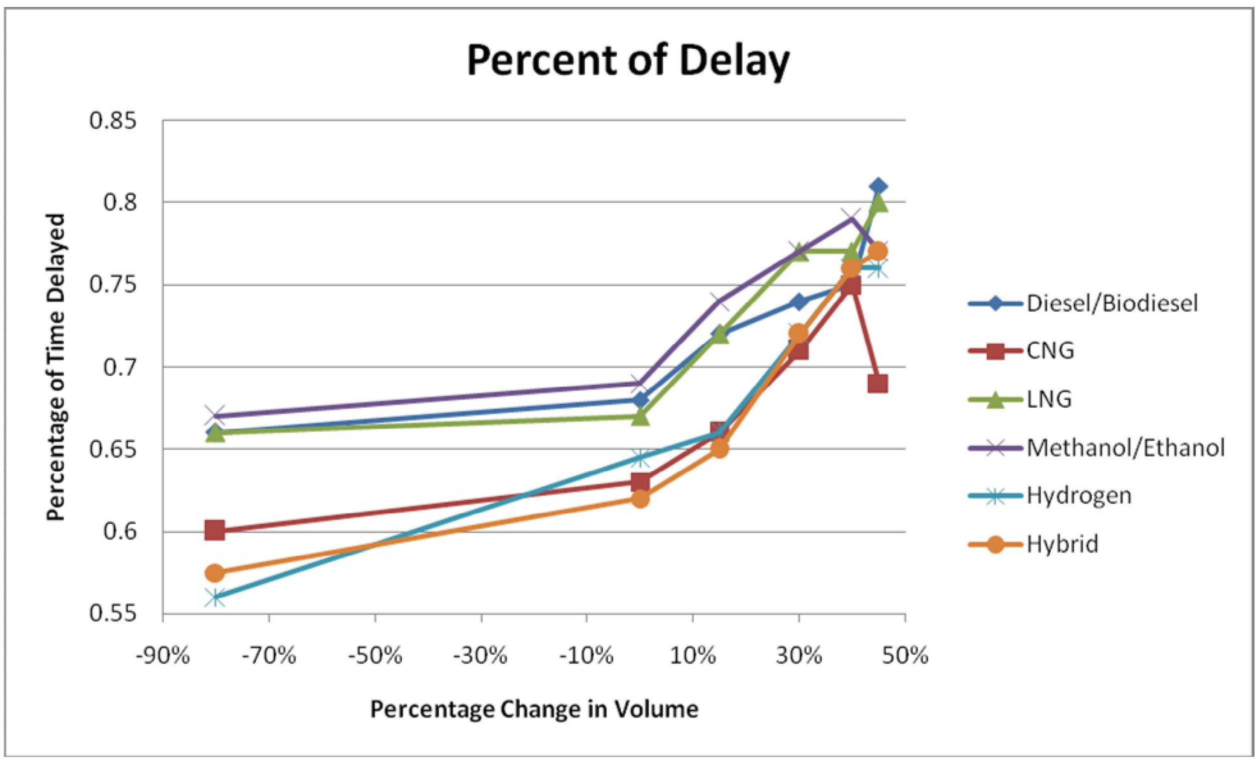

FIGURE 2 Volume Test for Percentage Time Delayed

As the volumes are increased, the speed follows a decreasing trend as expected. This trend can be seen in Figure 3. The low-floor buses are able to operate at a higher speed than the high-floor buses at each volume. Methanol and ethanol have the lowest speed at each volume because of their slower acceleration rate at lower speeds. This is a small network with low design speeds, therefore buses with poor acceleration rates at low speeds will perform at a lower average speed. Unlike the travel time and D/T, the decreasing rate in speed remains relatively constant from -80% to 45%. At -80% the speeds of each bus vary by the largest margin; there is a 3.2 mph difference between the highest and lowest speeds. The speeds do not converge at higher volumes, however at the base volumes the difference between the highest and lowest speed is only 1.9 mph. This reinforces the accuracy of the calibration process in that the base volume case provides a level playing field for each bus. In all, as in the previous two cases, the low-floor buses operate the best in terms of speed. The hydrogen and hybrid buses further separate themselves because of their higher acceleration rate at lower speeds.

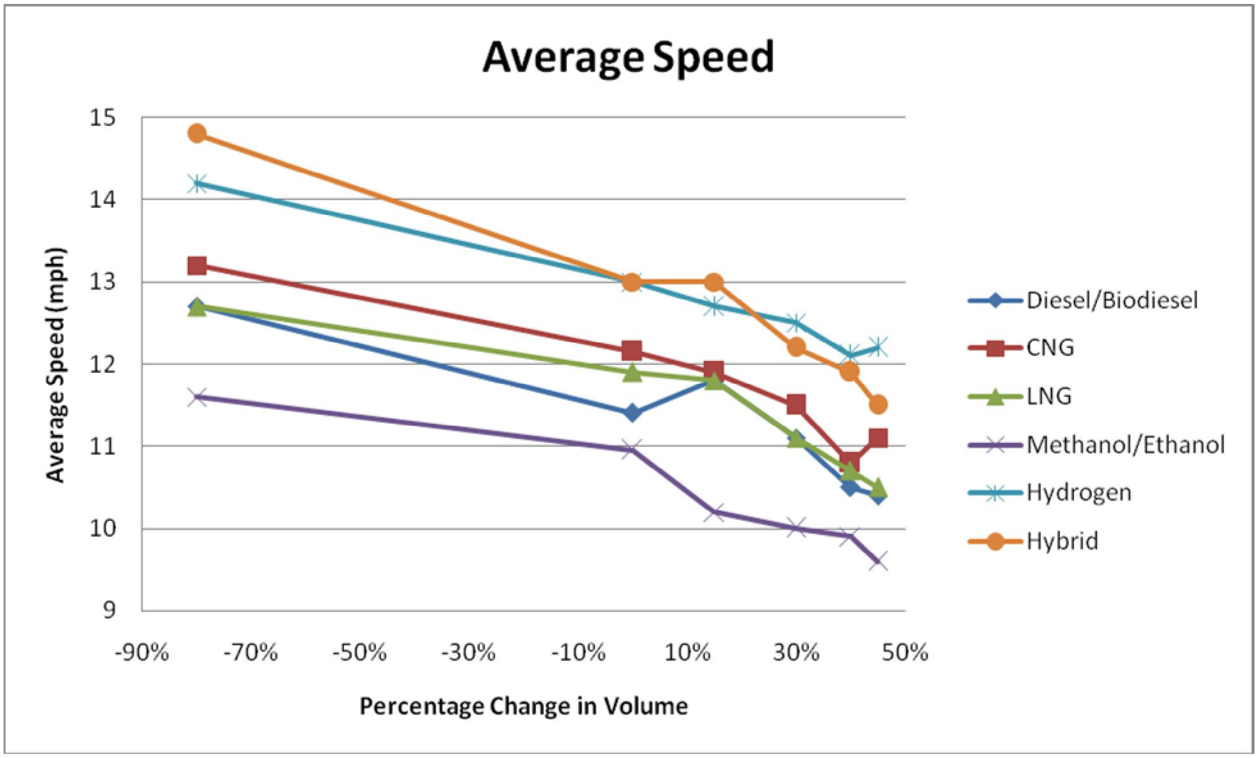

FIGURE 3 Volume Test for Average Speed

Headway Test for Service Reliability

In this test, the headways are increased and the travel time of the entire simulation duration is reported. The number of bus trips that are made is also documented. Therefore, with the travel time per bus trip and the headway known, the fleet size for the bus operation is calculated. Although the headways are changing, the simulation duration time remains at 9600 seconds. Therefore, as the headway increases, the total travel time will decrease because there is a longer amount of time between bus arrivals at each stop. Figure 4 shows these results. At the lower extreme case, 100 seconds, or one bus every 1.67 minutes, the travel times for each bus have a significant difference. At the high extreme case, 3200 seconds, or one bus every 53.3 minutes, the travel times are relatively closer together. Even though the travel times appear to be converging together, the relative difference between the points at each headway is not decreasing.

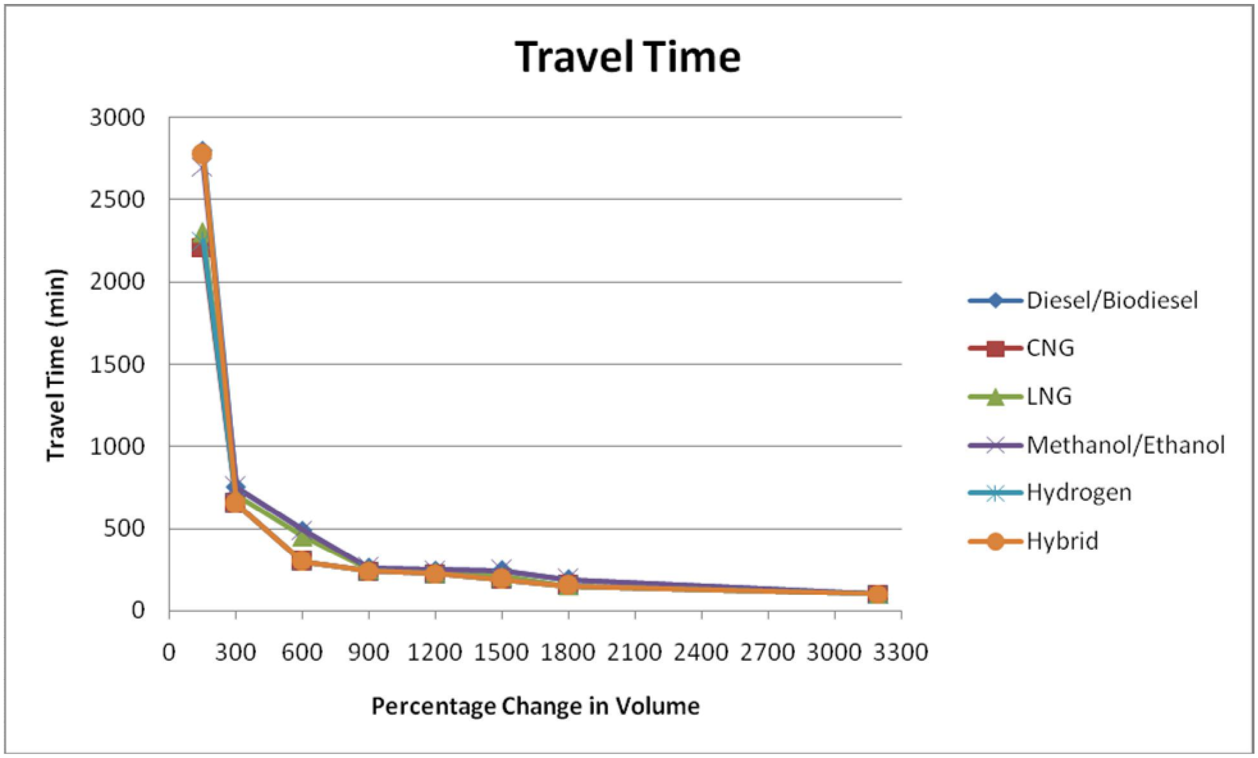

FIGURE 4 Headway Test for Travel Time

With the travel time per bus trip known at each headway, the number of buses needed at each headway is calculated. The number of buses is determined from the equation T = N*H, where N is the fleet size, T is the travel time, and H is the headway. This equation is taken from TCRP Report 41 [5]. The value of T is normally meant to represent not only the time traveling on the route, but also the layover time that the bus experiences at the bus facility. For simplicity, T will only represent the travel time along the route during the entire simulation process. Therefore, the output of the headway test is travel time and fleet size.

Table 2 shows the results for each fuel. At a headway of 100 seconds, the largest difference in fleet size is noticed, and as the headway increases, this difference decreases. The table shows that at 100 seconds CNG only requires 18 buses as opposed to the 24 buses required by diesel/biodiesel. A difference of six buses results in hundreds of thousands of dollars saved by a transit agency. However, buses arriving every minute at a station are highly unlikely. The results do show that using a low-floor bus with quicker acceleration rates results in lower travel times, and potentially a smaller fleet size.

TABLE 2 Fleet Size at Each Headway

Headway (sec)	Diesel/Biodiesel	CNG	LNG	Methanol/Ethanol	Hydrogen	Hybrid
100	24	18	19	21	19	23
300	6	5	6	6	5	5
600	3	3	3	3	3	3
900	2	2	2	2	2	2
1200	2	2	2	2	2	2
1500	2	1	1	2	1	1
1800	1	1	1	1	1	1
3200	1	1	1	1	1	1

Fuel Economy Comparison

The second parameter analyzed in CORSIM is the fuel economy of the buses. In order to evaluate fuel economy, the surface vs. freeway test is conducted. This analysis uses the CORSIM City network. The MPG of each bus is evaluated in this analysis.

Surface vs. Freeway Test for Fuel Economy

The surface vs. freeway test distinguishes differences in a low speed versus high speed scenario. The difference in fuel consumption from one fuel to the next does not follow a particular trend. The MPG for the diesel bus remains almost identical between surface and freeway travel. The biodiesel and hydrogen buses experience better fuel economy on the freeway network. CNG, LNG, ethanol, methanol, and hybrid each experience better fuel economy on the surface network. Hydrogen experiences the best fuel economy overall, far surpassing biodiesel with the second best overall fuel economy. One trend that is apparent is the fuels with a higher fuel economy, biodiesel and hydrogen, have a higher MPG on the freeway, and fuels with a lower fuel economy have a lower MPG on the freeway. This is expected in CORSIM because of the nature in which the data is entered. The MPG is multiplied by 100,000 when it is entered. Furthermore, a fuel such as hydrogen uses very little fuel at low speeds. However, this number must be rounded to the nearest whole number and entered into CORSIM because decimals cannot be entered into the simulation file. Therefore, at low speeds, the hydrogen bus appears to be burning more fuel than necessary. Not until it reaches a higher speed can its high fuel economy be utilized in the CORSIM software.

Environmental Effects Comparison

In order to evaluate the environmental effects the surface vs. freeway test is conducted. This analysis uses the CORSIM City network. The emission rates of HC, CO, and NO_x are investigated in this analysis.

Surface vs. Freeway Test for Environmental Effects

The surface vs. freeway test shows a more significant change in the emission rates between the fuels. The data is summarized in Table 3.

With respect to HC, CO, and NO_x, the fuels emit more pollutants on the freeway network. Also, the relative changes between the fuels from the surface to freeway networks are fairly consistent from one fuel to the next. The only variation occurred for ethanol HC emissions. It can not be completely explained why the ethanol bus had lower emissions on the freeway network.

TABLE 3 Percentage Change in Emissions from Surface to Freeway Network

	HC	**CO**	**NOx**
Diesel	8%	9%	9%
Biodiesel	9%	9%	9%
CNG	12%	9%	12%
LNG	-	5%	10%
Ethanol	-36%	16%	16%
Methanol	15%	16%	16%
Hybrid	17%	17%	17%

SUMMARY OF RESULTS

In terms of service reliability, the low-floor buses significantly outperformed the high-floor buses. In the volume test, the low-floor buses have lower travel times, lower delay, and higher speeds. In particular, the hydrogen and hybrid buses are the optimal choice because of their quicker acceleration rates. In the headway tests, travel times fluctuated for each fuel, however, it is apparent that the low-floor buses perform better. In this case, the hydrogen and CNG bus operations result in low fleet sizes. The hybrid bus has a higher travel time in the headway test which results in a larger fleet size. In all, in terms of performance and consistency, the hydrogen bus is the best option for service reliability.

In terms of fuel economy, the hydrogen bus clearly has the best fuel economy, and therefore would be the optimal bus to choose. Biodiesel also has a comparable fuel economy to diesel. However, the remaining five fuels have a lower fuel economy than diesel. As a result of the CORSIM tests, there is not one fuel that operates better than others in terms of changes to volume because the MPG of each fuel does not experience a significant change. However, there is a notable difference in surface vs. freeway travel. The hydrogen and biodiesel buses perform well on the freeway network, where the bus is forced to accelerate to greater speeds. As shown in the volume test for MPG, hydrogen and biodiesel will operate more efficiently in terms of MPG at higher speeds. Thus where networks feature the use of freeways or higher speeds in general, these two buses are the best options.

Clearly the hydrogen bus is the best selection in terms of environmental effects because it is a zero emissions vehicle. For the other alternatives, there is little consistency in terms of the amount of pollution that a fuel emits from one pollutant to the next. For example, LNG and hybrid emit a very small amount of HC and CO, however, their NO_x emissions are somewhat high. In the CORSIM analysis, it is important to note the relative change in emission rates as a result of changing speeds. On a freeway network, when buses are forced to accelerate to higher speeds, the bus is expected to emit more pollutants as shown in the surface vs. freeway test. Therefore, if a bus is required to use a freeway or travel at higher speeds, a LNG, methanol, or hybrid bus would be a clean option.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The comparative analysis provides useful results for using different fuels in bus transit operations. The CORSIM simulation program accurately models each fuel along two different networks. With the growing number of transit agencies that are implementing alternative fuels within their programs, a traffic simulation program is vital in providing a bus route model using different fuels. The conclusion will describe the originality within the paper and its advantages and disadvantages.

Summary

Diesel remains the dominant fuel source, however, it will not always be the most advantageous fuel to use within a particular bus network. The alternative fuels can provide a more beneficial bus operation in terms of service reliability, fuel economy, and environmental effects.

The CORSIM simulation proves that traffic software can be utilized to model any type of fuel. Although the data manipulation process is time-consuming, its detailed and extensive interface allows the opportunity to provide reliable results. Determining the types of data that can be modified in CORSIM is important in establishing an appropriate analysis tool. Fortunately, CORSIM allows the user to modify key characteristics that define the bus operations. Since the CORSIM models are theoretically based, the extreme conditions within various tests are easily observed. The ability to determine these extremes allows the user to find the principal differences between the effectiveness of each fuel.

Conclusions

The originality of this paper is derived from the computer simulation program. There have been few studies conducted that use a computer program to model an alternative fuel bus versus a diesel bus. CORSIM has been available over the past ten years, however, it is mostly used to model effects of increased volumes, adding lanes, or changing signal phasing/timings. As a result, the appropriate modifications can be made to the traffic network in order to ease the effect of the volumes in future years. CORSIM is, in contrast, rarely used to model a bus network.

Additional case studies are being developed throughout the United States, particularly by NREL and DOE. The characteristics of the fuels that are studied in these real-world examples can then be applied to computer simulations to model the bus using a different network. Various parameters can be changed in the model, such as volume and headway, in order to determine how the bus and its fuel characteristics will react to the dynamic conditions.

CORSIM is a very detailed program that allows the user to input a number of different variables. The user can create an original network or build an existing network consistent with lane geometry, signal control, and volume. Not all of the features can be explained in this discussion however the vastness of the program extends beyond the traffic characteristics. Even within the bus modeling, CORSIM allows the user to change the input of key variables related to alternative fuel buses, such as miles per gallon, emission rates, dwell times, and acceleration/deceleration rates. In addition, bus occupancy, length, jerk value, and maximum deceleration rates can be modified.

It is important to note the availability of data for alternative fuel buses. NREL and DOE have made a strong effort to provide detailed reports of alternative fuel buses. Using CORSIM to run the simulation program is only possible with accurate and reliable data. The real-world studies performed by NREL/DOE provide the empirical data that can be used within a theoretical network.

The CORSIM analysis does have its drawbacks. It is not a particularly user-friendly program for modeling the alternative fuels. The data input process is quite time-consuming because each MPG, emission rate, and acceleration rate must be typed explicitly into the software for each speed from 0-110 ft/sec at acceleration rates of 0-10 ft/sec. CORSIM also only accepts whole numbers within the software, and therefore very small numbers must be rounded to a value of one.

Recommendations

This section will discuss the general recommendations for transit agencies and future research. Transit agencies can take the lead role in stimulating the use of alternative fuel buses and future researchers can develop better methods to accurately model alternative fuels within bus operations.

By applying the CORSIM analysis to their own networks, transit agencies can observe that the alternative fuel buses have the potential to improve their bus operations. There will be higher costs associated with the operation, however, as the demand for alternative fuel use increases, the production costs are expected to decrease. As a result, costs associated with fuel, infrastructure, maintenance, facilities, parts, and equipment will decrease. Alternative fuels will then be more attractive compared to diesel. Also transit agencies can improve their public image by adopting alternative fuel buses within today's environmentally aware society. The type of fuel to use however is always negotiable.

In terms of computer simulation programs, future researchers can use CORSIM and the latest versions of SYNCHRO to model alternative fuel buses. Since CORSIM is such a large program, more complex networks and tests can be created to evaluate different fuels. A number of variables can be changed within the model. Only a select few of those variables were examined in this study.

NREL/DOE has been releasing their reports since 1996. The results are being updated as the alternative fuels are developing. The studies show that the buses are becoming more cost comparable to diesel. Also, the fuel economy is becoming more efficient. Therefore, data from new studies can be used and applied to CORSIM. Since CORSIM is relatively older software, using more recent software to model alternative fuels can be investigated.

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