Truck Stop Electrification as a Strategy To Reduce Greenhouse Gases, Fuel Consumption and Pollutant Emissions

by

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ABSTRACT

Extended truck idling is a very large source of fuel wastage, greenhouse gas emissions, and pollutant emissions. The focus of this research was on assessing the effectiveness of truck stop electrification (TSE) as a strategy to reduce these negative effects and to produce prediction methodologies to devekio these assessments. Before and after surveys were performed at three TSE sites that were implemented by IdleAire Technologies Corporation under contract by the Texas Transportation Institute. The study focused on occupancy rates (percentage of the lot occupied), idling rate (percentage of trucks idling) and TSE utilization rate (percentage of TSE spaces utilized).

Based on observed before and after TSE implementation data, it was found that the percentage improvements in fuel consumption, greenhouse gases, and pollutant emissions range from just over 5 percent to almost 44 percent for the three truck stops. Prediction models were developed based variables such as time of the day and temperature to predict occupancy rates, idling rates, and TSE utilization rates. These models predicted similar improvements due to TSE implementation (7 percent to 59 percent). It was shown that a truck stop with TSE can reduce daily fuel consumption by 167 gallons, oxides of nitrogen (NOx) emissions by 24.5 kg, and carbon dioxide (CO_2) emissions by 2.1 tons. The paper provides both observed and modeled results to substantiate these findings and to serve as basis for estimation of other TSE implementations.

INTRODUCTION

Background

The economy of the U.S. is strongly reliant on heavy-duty diesel trucks to move a vast array of goods across the country. Currently there are close to 3 million heavy-duty trucks operating in the U.S. (*1*). The U.S. Department of Transportation mandates that truck drivers rest 10 hours for every 14 hours of driving (*2*). This results in extended periods of time that drivers spend resting and sleeping in the cabs of their trucks. As a consequence, most long-haul truck drivers idle their vehicles for close to 10 hours per day to operate heating systems and air conditioners, generate electricity, charge their vehicle's batteries, and warm up the engines (*3,4,5*).

A typical long-haul truck is on the road for an estimated 250 to 300 days per year, resulting in an average annual idling duration of 2,100 hours per truck (*6,7,8*). At an idling fuel consumption rate of 0.9 gallons per hour, it can be shown that more than 12 million gallons of fuel is wasted on a daily basis nationwide due to extended idling (*1*). In addition, about 140,000 tons of carbon dioxide (CO_2) and 2,000 tons of oxides of nitrogen (NOx) are emitted every day due to extended idling in the U.S. In addition to fuel wastage and emissions, extended idling also results in a considerable wear on the truck engines.

Several methods have been developed to reduce extended truck idling. These methods can be divided into stationary and mobile technologies; the former refers to stationary equipment that can connect to the truck, and the latter refers to equipment on-board the truck, both reducing the need for extended idling. The focus of this research is on stationary equipment where the installations include external heating, ventilation, and air conditioning (HVAC) unit at each truck parking space. HVAC is delivered to the truck by a microprocessor-controlled system that mounts in a window on either side of the truck. The unit contains temperature controls, credit card reader, display, and keypad. Temperature control is provided through an air conditioner duct. The unit also provides 110 volts of electric power for appliances inside the cab as well as television, local telephone, and Internet service. An additional 110-volt outlet mounted on the outside of the control console provides an external power hookup for engine block heating (*9,10*).

The Texas Transportation Institute (TTI) received a $3 million grant from the U.S. Environmental Protection Agency (EPA) to develop a national deployment strategy for truck stop electrification, deploy several truck stop electrification sites, and to monitor the utilization of the deployed sites. The goal of this paper is to assess the effectiveness of truck stop electrification (TSE) as a reducer of fuel wastage, greenhouse gases, and pollutant emissions. Three test locations were installed by IdleAire Technologies Corporation under contract with TTI along the I-80 corridor in Ohio and Indiana.

Onsite surveys were performed of before and after installation conditions and prediction models were developed to estimate truck stop occupancy rates, truck idling rates, and TSE utilization rates. Finally, the potential fuel, greenhouse gas, and pollutant emissions benefits were estimated as a result of TSE applications. The paper is divided into the following six sections: introduction, description of the test sites, methodology, survey results, prediction models, and concluding remarks.

DESCRIPTION OF TEST SITES

The project team identified and prioritized a total of 15 major truck corridors along the interstate system of the U.S. using criteria such as corridor length, major activity centers, truck volume, truck growth rates, nonattainment areas, existing TSE sites, number of truck stops, average temperatures, and major intersections. Each corridor was divided into sections or zones of approximately 20 miles in length that were also prioritized using the same criteria. Based on zone rankings and spacing criteria, a set of primary and secondary zones were identified for installing TSE facilities along each corridor. The corridor stretching from New York to Minneapolis was identified as the most important corridor for implementing TSE and five primary zones were identified along the corridor and three of these were selected for implementation. A full description of this analysis is documented elsewhere (*11*).

The three locations that were deployed along the corridor were: Toledo, OH - Travel Centers of America (TA87) truck stop located at the intersection of I-80 and I-280; Youngstown, OH - Travel Centers of America (TA58) truck stop located at the intersection of I-80 and Canfield Niles Road; and Lake Station, IN - Travel Centers of America (TA219) truck stop located on I-80/I-94 at exit 15B. Figure 1 shows the truck corridor and the locations of the primary and secondary zones as well as the TSE installations.

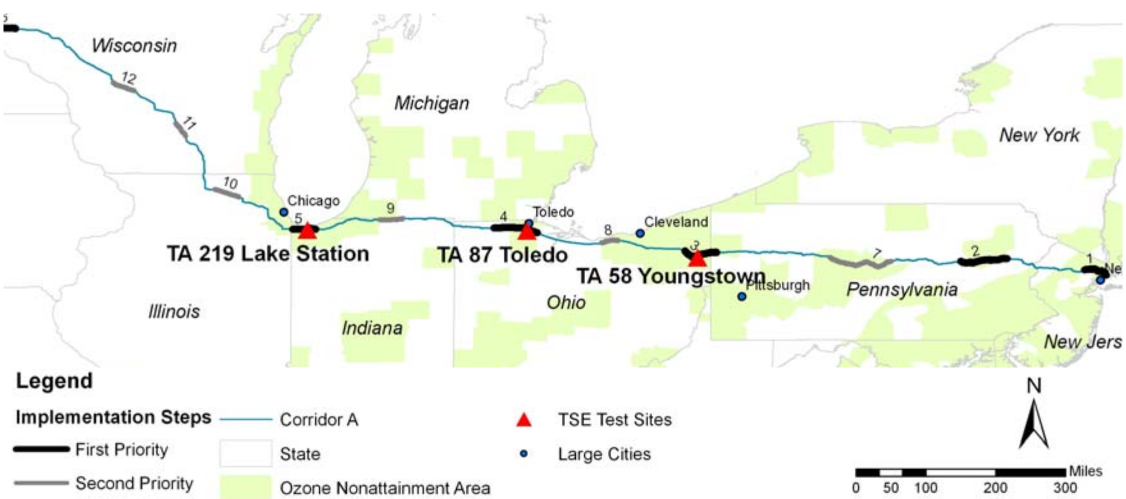


Figure 1. Primary and secondary zones as well as installations along corridor.

Figure 2 shows photographs of trucks using TSE at one of the facilities as well as the console that is inserted through the truck window to provide the HVAC and other amenities.

Figure 2. Photographs showing trucks using TSE as well as the console unit.

Table 1 shows the number of truck parking spaces and TSE spaces before and after installation. The table shows that, except for the Lake Station facility, the number of truck parking spaces was reduced slightly due to the implementation of TSE. This is due to configuration changes to accommodate the TSE equipment. Additionally, note that the number of TSE spaces is just over 30 percent of the total available spaces in all the cases.

Table 1. Number of truck and TSE spaces.

Location	Total spaces before TSE	TSE spaces	Total spaces after TSE
Toledo, OH	200	61	196
Youngstown OH	158	54	153
Lake Station, IN	245	86	245

METHODOLOGY

Two sets of 72 hour surveys were conducted from Thursday at 8:00 a.m. until Sunday at 8:00 a.m. at each of the three locations. The before survey (without TSE installations) was conducted in September, 2006 and the after survey (with TSE installed) in September, 2007. The same months were selected to minimize seasonal differences between the before and after surveys. During the 72-hour periods, hourly counts were performed of the number of trucks on the lot, number of trucks idling, number of trucks with their engines off, and the number of trucks that are using the TSE facilities. Other secondary information was also collected such as number of dropped trailers, trucks with no sleeper cabs, trucks with refrigeration units, and trucks with pulled curtains in their sleeper cabs.

The data from the survey sets were analyzed and summarized to develop trends and comparisons. In addition, statistical modeling was used to develop methods that can be used to predict the following parameters:

- occupancy rates (percentage of lot occupied) calculated as the number of trucks present on the lot divided by the number of available spaces on the lot;
- idling rate (percentage of trucks idling) calculated as the number of trucks idling divided by the total number of trucks on the lot; and
- TSE utilization rate (percentage of TSE spaces utilized) calculated as the number of TSE spaces utilized divided by the total number of TSE spaces.

The following section describes the results from the analyses.

SURVEY RESULTS

Even though the 2006 and 2007 surveys were both conducted in September to minimize variability in weather patterns, especially temperature, some differences in weather were still observed. Enough time was also allowed to ensure that the operations stabilize fully after TSE implementation. Because extended idling is strongly correlated with temperature, it is important to monitor temperature and consider it in the analysis. Table 2 shows the average temperatures during the two survey periods. The table shows that the average temperatures differ more than 10 percent between the 2006 and 2007 surveys with 2007 being considerably warmer. It was therefore important to develop prediction methods that incorporate the effect of temperature so that true comparisons can be made.

Table 2. Average temperatures during survey periods.

Location	2006 Average Temperature	2006 Standard Deviation	2007 Average Temperature	2007 Standard Deviation
Toledo, OH	61.1	7.1	70.0	9.3
Youngstown OH	60.6	7.9	68.6	9.9
Lake Station, IN	41.3	5.9	53.3	4.7

Observed patterns

Occupancy Rates

The first factor determined during the surveys was the occupancy rate or the percentage trucks present on the lot. Figure 3 shows the hourly occupancy rates for the three locations as well as the average occupancy rates for all three locations before and after TSE installation. This figure shows that the daily patterns are very consistent between the three locations. Around 3:00 p.m. trucks begin arriving and this trend continues until 11:00 p.m. after which the lots are fairly stable until approximately 4:00 a.m. when trucks begin leaving. The lots continue to empty out until about 3:00 p.m. when the process begins all over again. There is not much difference between weekdays and weekends except for Lake Station where there appears to be fewer trucks on the lot during the weekend.

The average occupancy rates for the three locations for the before and after TSE scenarios are 50.1 and 45.9 percent, respectively. The after TSE case, therefore, on average has 4.2 percent less trucks on the lot. This difference can be attributed to broader economic factors and might not be related to the fact that TSE has been installed on the sites.

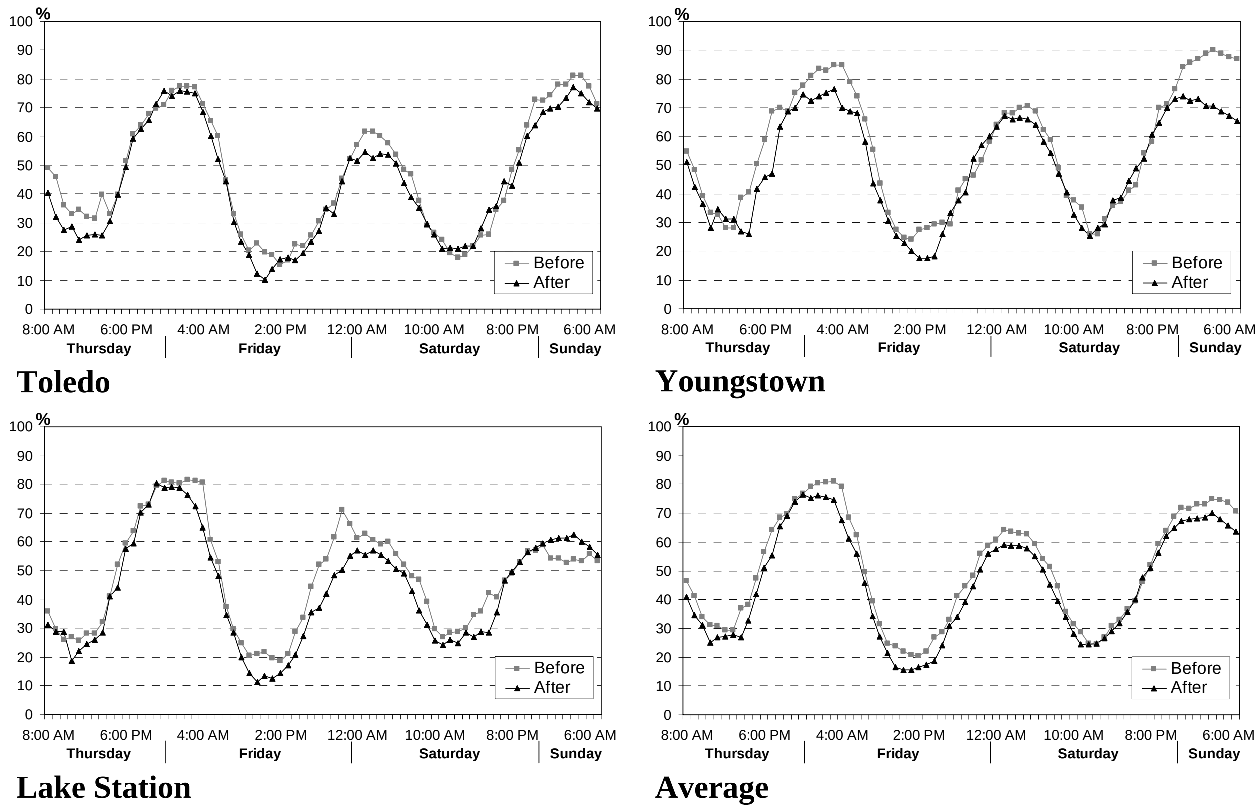
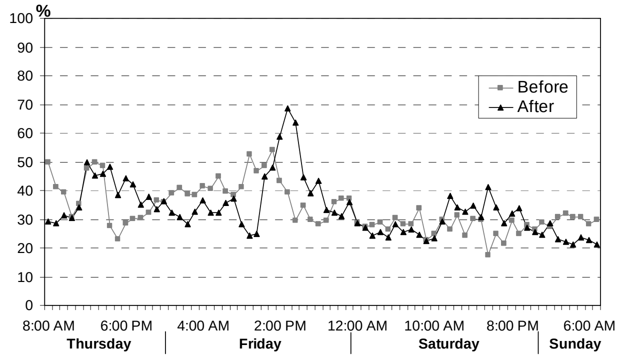


Figure 3. Hourly occupancy rates for the respective truck stops.

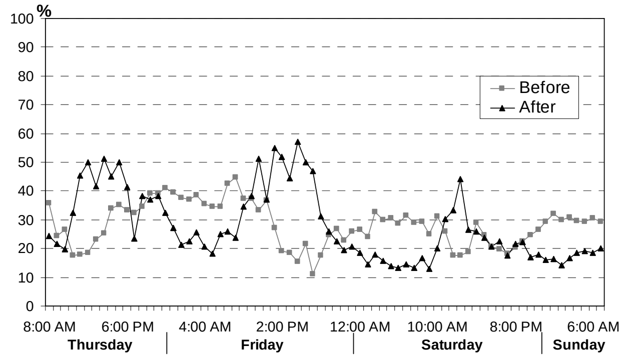
Idling Rates

The second factor determined during the surveys was the idling rates or the percentage trucks idling on the lot. Figure 4 shows the hourly idling rates for the three locations for the before and after TSE cases as well as the average idling rates for all three locations before and after TSE installation. This figure shows that the idling rates do not follow a clear pattern as the occupancy rates and that the patterns for the three facilities are quite different. There is, however, a tendency for more idling to occur during the nighttime when truck drivers want to sleep. Note that the before TSE idling rate is generally higher than the after TSE rate during the nighttimes. This is expected because this is the time when truck drivers want to sleep and are most likely to use TSE.

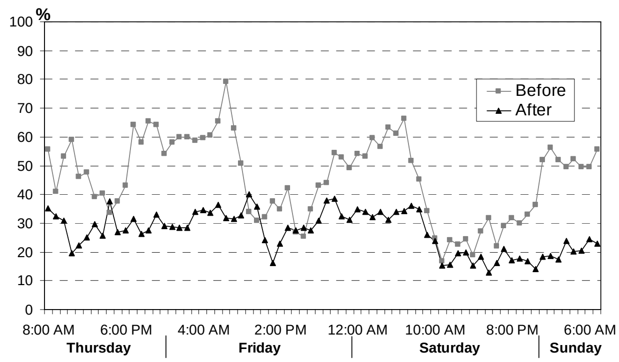
The average idling rate before TSE installation was found to be 36.0 percent and the average idling rate after TSE installation was found to be 29.6 percent. The reduced idling rate for the after TSE scenario (6.4 percent) can be attributed to truck drivers using the TSE facilities.



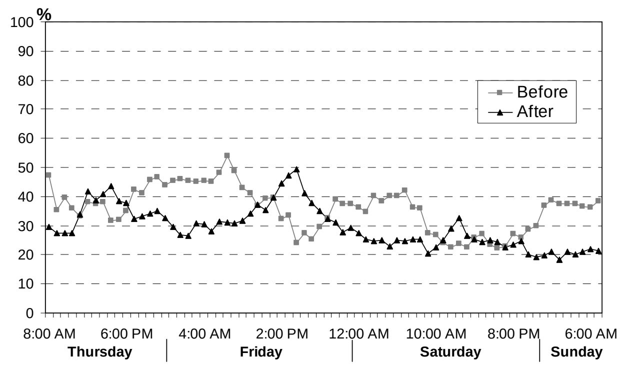
Toledo



Youngstown



Lake Station



Average

Figure 4. Hourly idling rates for the respective truck stops.

TSE Utilization Rates

The third factor determined during the surveys was the TSE utilization rates or the percentage of TSE spaces that are actually being used by the trucks. Figure 5 shows the hourly TSE utilization rates for the three locations along with the hourly temperatures as well as the averages for all three locations. The figure shows that the hourly utilization rates follow the hourly truck occupancy rates discussed earlier. This is expected because the more trucks you have on the lot the more likely it is that TSE will be utilized. It also confirms the notion that truck drivers prefer to use TSE at night when they want to sleep. The temperature patterns are almost the inverse of the TSE utilization patterns. This is also expected because the highest temperatures are during the day when the least amount of trucks are present and the opposite is true for the nighttime. The average TSE utilization rate for the three facilities was found to be 25.7 percent.

Additionally note in Figure 5 that the temperature variation at Lake Station was not as great as with the other two locations. Also, the temperature at Lake Station was quite a bit lower than for the other locations. This factor is likely the reason why the idling rate at Lake Station is different than the other locations as discussed in the previous section.

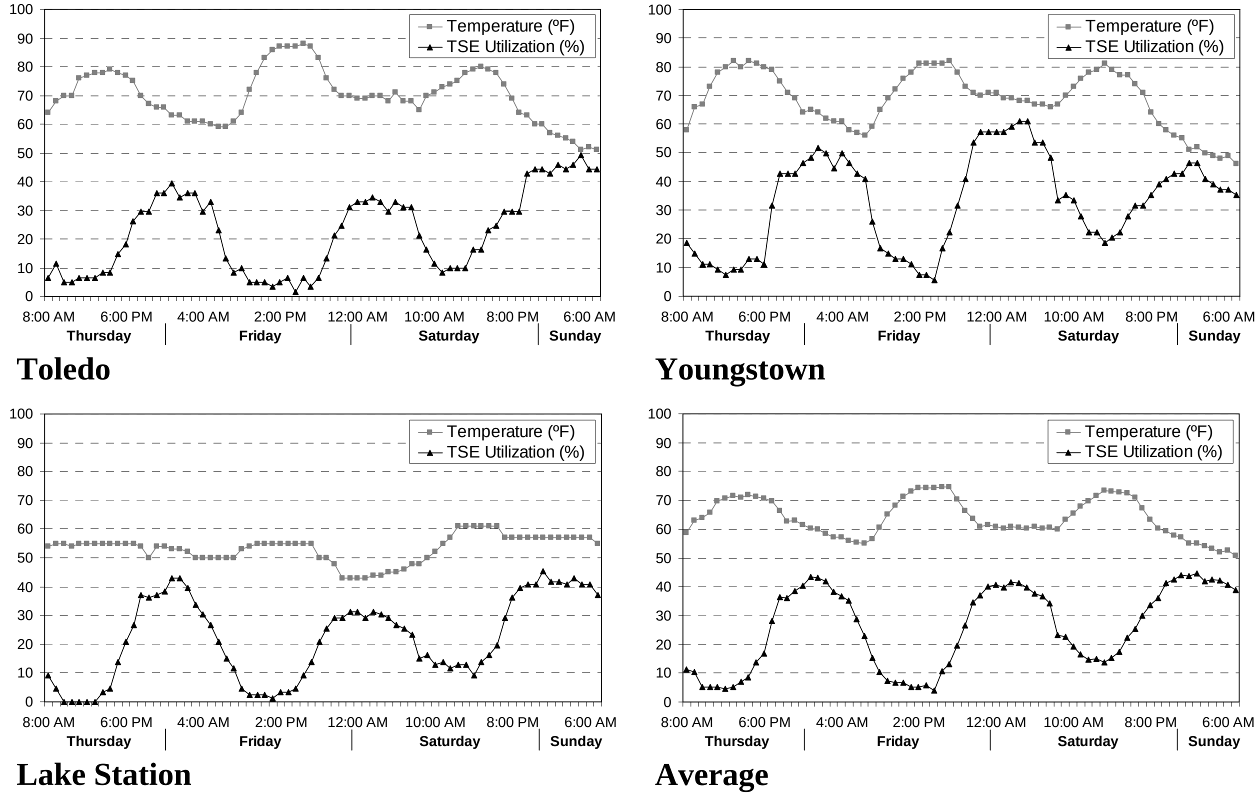


Figure 5. TSE utilization rates for the respective truck stops.

Estimated Fuel and Emissions Impacts

The observed patterns can be converted to hourly fuel consumption and emissions using previously determined fuel consumption and emissions rates developed for long-duration idling of heavy-duty diesel trucks. Table 3 summarizes the various rates as well as their respective references.

Table 3. Fuel consumption and emissions rates used for the analysis.

Factor	**Idling rate**	**Reference**
Fuel consumption	0.92 gal/hr*	Lutsey et al. (*12*)
NOx (Nitrogen oxides)	135 g/hr	EPA Guidance (*13*)
PM (Particulate matter)	3.68 g/hr	EPA Guidance (*13*)
CO_2 (Carbon dioxide)	9292 g/hr	Lutsey et al. (*12*)
CO (Carbon monoxide)	41 g/hr	Sierra Club, Maine Chapter (*14*)
THC (Total hydrocarbon)	8 g/hr	Sierra Club, Maine Chapter (*14*)

** Based on the assumption of 10.1 kg of CO_2 per gal of diesel burned.*
*** CARB – California Air Resources Board.*

Table 4 shows the findings from the fuel and emissions analyses. The hourly truck idling rates were multiplied with the hourly fuel and emissions rates to determine the hourly fuel consumption and emissions at each of the facilities. These rates were then divided by the number of trucks on the lot for that hour to determine normalized fuel consumption and emissions rates (per truck per hour).

Table 4 shows that TSE results in a reduction in fuel consumption, greenhouse gases, and pollutant emissions for each of the three locations. The percentage improvements range from just over 5 percent for the Toledo facility to almost 44 percent for the Lake Station facility.

Table 4. Savings due to TSE for fuel consumption and emissions using observed data.

Factor	Toledo		Youngstown		Lake Station	
	Before	After	Before	After	Before	After
Fuel (gal)	0.31*	0.29	0.27	0.23	0.45	0.25
NOx (g)	45.0	42.6	40.3	33.8	65.8	36.9
PM (g)	1.23	1.16	1.10	0.92	1.79	1.01
CO_2 (g)	3096.4	2934.8	2774.6	2323.8	4531.0	2541.6
CO (g)	13.7	12.9	12.2	10.3	20.0	11.2
THC (g)	2.7	2.5	2.4	2.0	3.9	2.2
% Improvement**	5.2%		16.2%		43.9%	

* *Numbers are per truck per hour.*
** *% Improvement = (After – Before) / Before * 100 (%).*

PREDICTION MODELS

The observed data provided a good basis for understanding occupancy rates, idling rates, TSE utilization rates, and potential fuel and emissions benefits of using TSE at truck stops. However, several factors play a role in these parameters and for prediction purposes it is important that these factors be considered. A number of factors were examined and it was found that time-of-day, day of week, temperature, and whether TSE has been installed on the facility have the greatest impact. Prediction models were developed using these variable to predict the required dependent variables.

Three model forms were investigated for this analysis – a negative binomial, Poisson, and ordinary least squares (OLS) regression models. As a result of the selection of the final predicted variables, it was found that the OLS models performed best for this application. The time-of-day variable was based on a modified time which is defined as the number of hours away from midnight, for example the modified time at 9:00 p.m. is equal to 3 and 3:00 a.m. is also equivalent to 3 and the modified time will never exceed 12. The addition of TSE caused two sets of models to be developed – one before TSE installation and one after TSE installation because it was found that it is statistically significant and more effective to split the models into before and after TSE installation.

Table 5 shows the series of models developed for occupancy rates, idling rates, and TSE utilization rates for the before and after TSE conditions.

Table 5. Models developed for occupancy rate, idling rate, and TSE utilization.

Model Number	Description	Ordinary Least Squares Regression (1, 5)	Chi-Square	R^2
1A	Occupancy before TSE	$Y_1 = 83.95 - 4.59M - 0.12T$	222.8	0.64
1B	Occupancy after TSE	$Y_1 = 90.36 - 4.34M - 0.29T$	281.7	0.73
2A	Idling before TSE	$Y_2 = 80.4 - 0.78T - 0.35M$	166.71	0.54
2B	Idling after TSE	$Y_2 = 2.25 + 0.39T + 0.42M$	58.58	0.24
3	TSE utilization	$Y_3 = 47.2 - 3.58M$	211.2	0.62

Note:
(1) Y_1 is defined as the number of trucks present per lot capacity.
(2) Y_2 is defined as the number of trucks idling per the total number of trucks on the lot.
(3) Y_3 is defined as the number of trucks using TSE per available TSE spaces .
(4) Description of variable names, M = modified time, D = day of week, T = temperature.
(5) All variables were statistically significant at a 0.05 p-value

The models were applied to the three test sites and it was found that in general they have good predictability. For example, Figure 6 shows the observed versus estimated occupancy rates for Youngstown after TSE implementation. The figure shows that the estimated occupancy rates track fairly well with the observed occupancy rates.

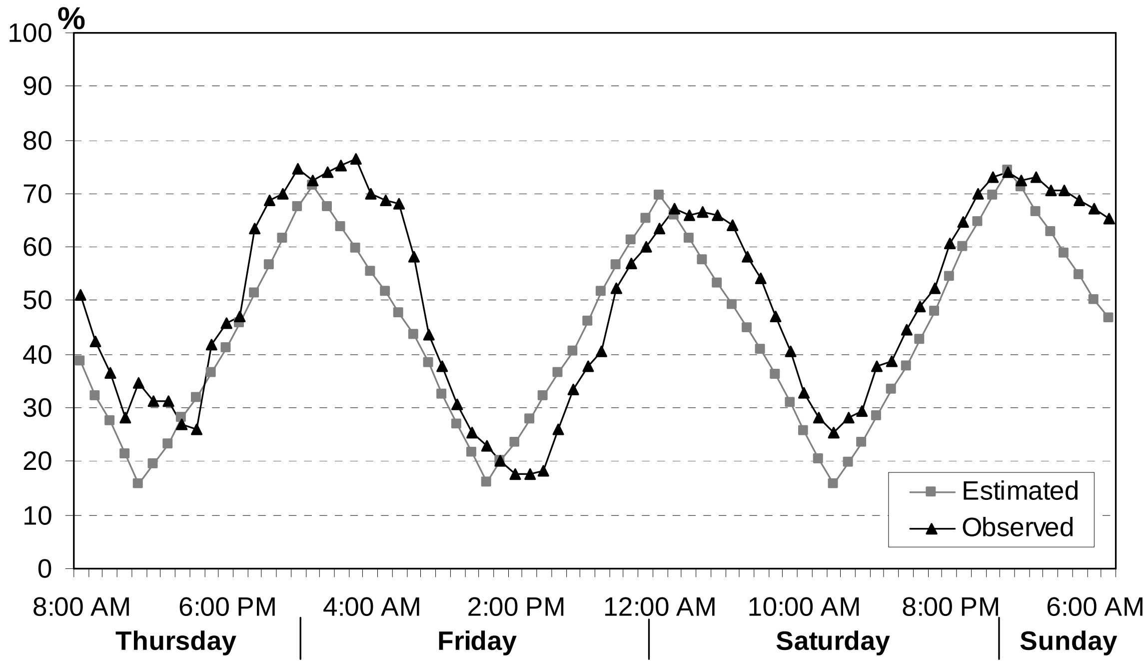


Figure 6. Observed versus estimated occupancy rates for Youngstown after TSE implementation.

To estimate the effect of TSE implementation the models were applied to the observed data for the before TSE implementation case. In other words, the occupancy rates and idling rates were observed during the before survey. It was then assumed that TSE is implemented for the three locations and model 2B was used to estimate the idling rate as if TSE was implemented. The estimated idling rate (with the assumption that TSE was employed) was then used to calculate fuel consumption and emissions and these results were compared with the results from the observed idling rates. This approach was used to eliminate all the factors that changed over a year with the before and after surveys, especially temperature.

Table 6 shows the findings from the fuel and emissions analyses based on the observed data before and the estimated data using the model and assuming that TSE is implemented. It can be seen that TSE again results in reductions in fuel consumption and emissions with Lake Station again being the greatest reducer of these effects. The percentage reductions using the prediction model are shown to be slightly more than the observed results (28 percent on average versus 22 on average based on observations). This result is expected because the average temperature in the after TSE installation case is higher than the before case which will require lower TSE usage and lower benefits for the observed case than the modeled case.

Table 6. Savings due to TSE for fuel consumption and emissions using prediction models.

Factor	Toledo		Youngstown		Lake Station	
	Before	After	Before	After	Before	After
Fuel	0.33*	0.27	0.30	0.28	0.49	0.20
NOx	48.34	40.03	44.70	41.39	71.95	29.55
PM	1.32	1.09	1.22	1.13	1.96	0.81
CO_2	3327.3	2755.2	3076.6	2848.7	4952.1	2034.1
CO	14.68	12.16	13.58	12.57	21.85	8.98
THC	2.86	2.37	2.65	2.45	4.26	1.75
% Improve-ment**	17.2		7.4		58.9	

* *Numbers are per truck per hour.*
** *% Improvement = (After – Before) / Before * 100 (%).*

Both the observed and modeled approaches indicate reductions in fuel consumption and emissions of more than 20 percent on average (22 percent for the observed case and 28 percent for the modeled case). At a conservative improvement rate of 20 percent, it can be shown that, for an average truck stop, TSE on average reduces fuel consumption by 167 gallons per day, NOx emissions by 24.5 kg per day, and CO_2 emissions by 2.1 tons per day. Over a one-year period these amounts balloon to 61,000 gallons for fuel consumption, 11 tons for NOx emissions, and 767 tons of CO_2 emissions per truck stop. If all the 1,000 truck stops (based on 2006 data) that have 100 truck parking spaces or more were implemented with TSE, it can be shown that on a daily basis 167,000 gallons of fuel, 31 tons of NOx and 2,100 tons of CO_2 emissions can be reduced.

CONCLUSIONS

Extended truck idling is a very large source of fuel wastage, greenhouse gas emissions, and pollutant emissions. The focus of this research was on assessing the effectiveness of TSE as a strategy to reduce these negative effects and to produce prediction methodologies to develop these assessments. Before and after surveys were performed at three TSE sites that were implemented by IdleAire Technologies Corporation under contract by the Texas Transportation Institute. The study focused on occupancy rates (percentage of the lot occupied), idling rate (percentage of trucks idling) and TSE utilization rate (percentage of TSE spaces utilized).

It was found that the daily occupancy patterns are very consistent between the lots with peaks occurring during the night. The average occupancy rate for the three locations was approximately 50 percent. The idling rate did not follow such a clear pattern and was clearly dependent on the temperature. The average idling rate before TSE installation was found to be 36 percent and the average idling rate after TSE installation was 30 percent. The average TSE utilization rate for the three facilities was 26 percent.

Based on observed before and after TSE implementation data it was found that the percentage improvements in fuel consumption, greenhouse gases, and pollutant emissions range from just over 5 percent for the Toledo facility to almost 44 percent for the Lake Station facility. Prediction models were developed based variables such as time of the day and temperature to predict occupancy rates, idling rates, and TSE utilization rates. These models incorporated the effect of temperature and predicted similar improvements due to TSE implementation (7 percent-to-59 percent).

It was shown that, on average, these truck stops reduce fuel consumption by 167 gallons, NOx emissions by 24.5 kg, and CO_2 emissions by 2.1 tons per day. Over a one-year period these amounts balloon to 61,000 gallons of fuel consumption, 11 tons of NOx emissions, and 767 tons of CO_2 emissions per truck stop. TSE is therefore a highly effective method for reducing fuel consumption, greenhouse gases and pollutant emissions. This paper provides both observed and modeled results to substantiate these findings. The observed rates and prediction models provide a basis for estimating such savings and to serve as a basis for future research.

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