EVALUATION OF TRAFFIC MANAGEMENT STRATEGIES CONSIDERING FUEL CONSUMPTION

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ABSTRACT

A component of Environmentally Sustainable Transportation (EST) is global emission which is correlated to fuel consumption. In the transport sector, the concept of sustainable development is promoted as one of the key solutions to environmental and energy problems. The focus of this study is the recording and analysis of microscopic data (speed per second, acceleration per second, longitude and latitude per second, etc.) and the introduction of fuel consumption criterion in the evaluation process of traffic management strategies in the country. To demonstrate the use of an on-board instrument and the introduction of fuel consumption criterion in the evaluation process of traffic management strategies, a case study on the comparison of a signalized intersection and a U-turn scheme is presented.

1. INTRODUCTION

The growing number of vehicles in major cities around the world has presented a number of problems. The rising automobile population has led to the decrease in available land for use in transportation. Finite energy resources are rapidly nearing annihilation. Vehicles have become one of the chief sources of harmful emissions that endanger not only our health, but the very existence of the next generation. The threat of global warming is now inevitable. In reaction, all sorts of counter-measures are applied and new ones are thought up all the time. Sustainable development is one of the trends that will help combat energy problems and global warming. Sustainable development has come a long way since its conception. Now, even transport systems can be assessed in the hopes of becoming more efficient. The concept is to apply the concept of sustainable development in designing and/or evaluating transport systems and strategies. Factors that take priority are fuel consumption and efficiency which can be translated into lower emission levels.

The U-turn traffic scheme aims to free up an intersection from queuing up behind traffic lights. It intends to increase the flow rate by applying U-turn slots a bit ways from the intersection itself. In effect, vehicles will have to constantly move in order to pass an intersection. Vehicles must make more maneuvers including left or right turns and lane weaving. In unison, no left or right turns are applied since parts of the intersection are closed in order for the U-turn scheme to work. The traditional signalized intersection scheme utilizes traffic lights in order to manage the order of lanes passing thru the junction. A certain amount of time is set for the green cycles of each lane. Queue length is the main factor that affects a green cycle's duration. The research was conducted to show the difference in fuel consumption between the two traffic management strategies. This study is limited to the investigation and quantification of fuel consumption confined in the two study areas. This research also focused on the effects of traffic management schemes which influence the fuel flow of the test vehicle that was used in both study areas. This in turn, presents the comparison of fuel consumption between the two areas of study. Other factors regarding traffic flow in general were not subjected to further discussions in this study.

Concept of Sustainability

To date, there are over 60 definitions of sustainability, but the idea contains at least one of the following important components: concern with the long-term health of the environment; apprehension about the welfare of future generations; condemnation of rapid population growth and awareness over the possibility to maintain economic growth in the face of resource scarcity. Despite the variety of ideas on sustainability and broad discussions on the perspectives of economic growth, general meaning of sustainable development supposes economic development to be within certain ecological limits *(Van Kooten and Bulte, 2000).* Sustainable development is development that meets the needs of the present without compromising the needs of future generations to meet their own needs *(Brundtland, 1987).* According to Dr. Jean-Paul Rodriguez, the concept of sustainability can be divided to three points: (1) Social equity; (2) Economic efficiency; and (3) Environmental responsibility. Social equity relates to conditions favoring a distribution of resources among the current generation based upon levels of productivity. Economic efficiency pertains to conditions permitting higher levels of economic efficiency considering resource and labor usage. Lastly, Environmental responsibility is concerned with the supply of resources and the different forms of wastes.

Concept and Definition of Sustainable Transport System

A sustainable transportation system is one that allows the basic access needs of individuals and societies to be met in a manner consistent with human and ecosystem health, and with equity within and between generations; is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy; and limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, and minimizes the use of land and the production of noise *(Centre for Sustainable Transportation 2002).* Transportation is linked to sustainability. Sustainable transportation considers the economic, social and environmental impacts of a country and develops parameters and criteria to create an efficient transportation system. "Sustainability in the transport sector optimizes the use of the transportation systems to achieve economic and related social and environmental goals, without sacrificing the ability of future generations." *(Qureshi & Huapu, 2007).*

Energy Demand Statistics of the Philippines and the World

Energy demand in the transport sector covers fuel consumption. Petroleum products like gasoline, diesel and fuel oil are commonly used in the transport sector. Dependency of oil in the Philippines can be seen on transport use (Salire Jr., 2007). According to International Energy Agency (2008), the world also depends on the usage of oil products. The July average-to-date price of Asian Dubai crude increased by about $11/bbl compared to the June average. Likewise, gasoline and diesel rose by about US$5/bbl and US$9/bbl, respectively, over the previous month levels.

World oil prices hit new record highs last week as the US' EIA, the countries' statistical arm, reported a bigger than expected drop in the countries supply inventory. The threat of conflict with Iran also weighed on prices driving Dubai crude and petroleum products higher by about $5 to $7 a barrel over the preceding week average. The Energy Information Administration reported crude oil supplies to have fallen by 2 million barrels last week, or about 800,000 barrels more than the energy research firm Platts predicted. However, the report offered a mixed picture of energy use by the world's thirstiest oil consumer. Gasoline supplies unexpectedly grew by a considerable amount, and demand continued to slide, suggesting that record fuel prices are prompting a real shift in American's driving habits. Energy analysts are of the opinion that inventory was only one of the factors in the week's oil rally. The market worries on tight supplies, weak dollar, lingering pipeline attacks in Nigeria and conflict between Iran and Israel remain as the key factors that have been influencing the market. Specifically, traders are worried that Tehran could try to halt shipments and seize control of the strategically important Strait of Hormuz if attacked by Israel or United States. About 40% of the world's tanker traffic passes through the Middle Eastern choke-point.

Light, sweet crude for August delivery fell $3.92 or about 2.7% to settle at $141.37/bbl on the New York Mercantile Exchange. Earlier of the day, the contract sank to as low as $139.50/bbl. In London, Brent crude futures fell $2.55 to settle $141.87/bbl on the ICE Futures Exchange. Meanwhile, the July average spot price of WTI and Brent rose by about 8% and 7%, respectively, over their June averages. *(OIL MONITOR As of July 8, 2008 Philippine Department of Energy Official Website).*

Development of On-Board Diagnostics (OBD)

A modern OBD system is capable of monitoring a number of sensors to determine whether they are working as intended. It can detect a malfunction or deterioration of various sensors and actuators, usually well before the driver becomes aware of the problem. The sensors and actuators, along with the diagnostic software in the on-board computer comprise the On-Board Diagnostics or OBD system. In California, On-Board Diagnostics I (OBD I) was California's first set of OBD regulations that required manufacturers to install OBD systems that monitored some of the emission control components on vehicles. Although OBD I systems were required on all 1991 and newer vehicles sold in California, these OBD I systems were not particularly effective because they only monitored a few emission-related components, and they were not calibrated to a specific level of emission performance. In addition, the computer software coding and the OBD connection hardware were not standardized (Bordoff 2003, CARB 2003).

Global Positioning System (GPS)

The Global Positioning System (GPS) is a satellite-based navigation system (24 in operation and 3 backup in case one fails). The U.S. military developed and implemented this satellite network. GPS was originally intended for military applications, but in the 1980s, the government made the system available for civilian use. GPS works in any weather conditions, anywhere in the world, 24 hours a day. There are no subscription fees or setup charges to use GPS. (GARMIN)

Land-based applications are more diverse. The scientific community uses GPS for its precision timing capability. Surveyors use GPS for an increasing portion of their work. GPS offers an incredible cost savings by drastically reducing setup time. It also provides amazing accuracy, basic survey units offer accuracies down to one meter, and more expensive systems can provide accuracies to within a centimeter. (GARMIN)

METHODOLOGY

Information regarding the vehicle's fuel consumption and related factors was gathered from each traffic management strategy. Collections of data were selected for analyses; statistical procedures and interpretation were used for drawing conclusions and making implications.

The study was conducted to determine the effects of each traffic scheme on the test vehicle's fuel consumption and driving behavior. The test was done by means of an on-board system of devices setup to record data from the test vehicle's sensors. The tests were done in the intersection of Quezon Avenue and Araneta Avenue, and the intersection of Aurora Boulevard and Araneta Avenue. Tests were conducted during the morning peak hours (7AM – 10AM) of Tuesday, Wednesday and Thursday from June 11 to June 19 2008. The device used for obtaining data regarding fuel consumption was an Elmscan 5 unit. In order for the device to function, the test vehicle must be OBD-II compliant. For our experiment, we utilized a Ssangyong Actyon 1.6. To log coordinates of the test route, a Holux GPS unit was used. Information from the two devices were logged and recorded into the laptop for processing. After gathering information on the test runs of both study areas, data analysis was followed. For fuel consumption analysis, the researchers used the Scan XL program for direct data extraction. Values of fuel consumption and run duration were obtained from each run. GPS data were also retrieved from the Holux device. The researchers then exported data from each Elmscan log file into an Excel spread sheet for statistical treatment. Fuel consumed and other factors such as velocity for each run were computed. Additional data were derived from initial data and further analysis was performed. Data recorded from the Elmscan device were processed and fuel consumption data were extracted. Log files from the Elmscan device were exported into Excel. Fuel flow rate was in liters per hour. This was converted into liters per second and the average was computed. Velocity was in kilometers per hour. This was also converted into meters per second for easier analysis. Duration of the run was extracted and converted into seconds (unit). Runtime was multiplied with average fuel consumption per second to come up with the fuel consumed for the run. This resulted into the total fuel consumed for each run in each study area. Further data were derived from velocity. These include acceleration and deceleration. Simple acceleration formula is used in order to come up with additional data from velocity and time. The succeeding acceleration data are statistically treated in order to produce different factors which include number of changes in acceleration and deceleration. Time proportion for acceleration, deceleration and idling are also produced from the velocity data. A questionnaire produced a behavior and attitude scale which was measured by Linear Regression and Pearson's R to determine if hypothesis was accepted or rejected. With these data, comparison between two traffic management strategies and correlating it with the behavioral test it is possible through the evaluation of the fuel consumption rates developed by these strategies.

RESULTS AND DISCUSSION

The data revealed many factors concerning fuel consumption. By regression analysis, velocity and revolutions per minute data were found out to be strongly correlated to fuel consumption. Through the velocity profile, acceleration data was derived. Further analyses tell that fuel consumption is shown to have a directly proportional relationship with fuel consumption.

In the tests performed the results as shown in Figure 1 show that the U-Turn traffic system management scheme consumed a significantly higher amount of fuel as compared to the Signalized Intersection.

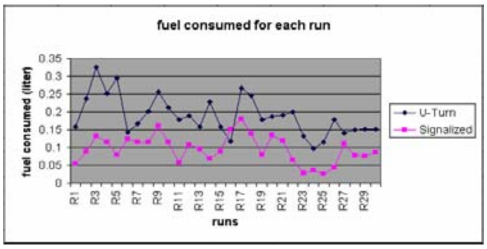

Figure 1 Fuel consumed per run per study area

In order to identify factors that affected the consumption of fuel, other data such as velocity and rpm were treated with regression analysis. It was found out that they are strongly correlated. This result leads to further analysis.

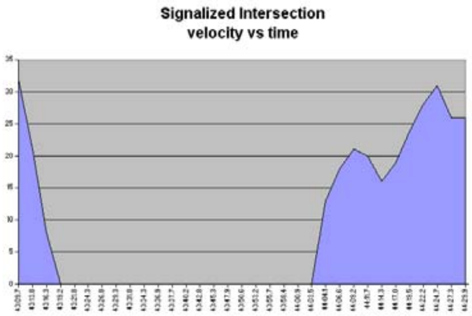

Figure 1 Sample Velocity Profile for Signalized Intersection Run

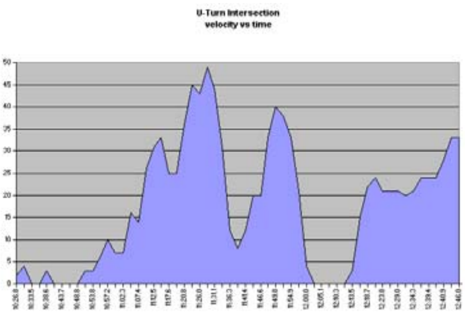

Figure 2 Sample Velocity Profile for U-Turn Intersection Run

Figure 2 and 3 reveals that the behaviors of velocity and fuel flow rate are similar. The spikes' appearances in the velocity graph are consistent with the spikes in fuel flow rate. These spikes represent increase and decrease in velocity and fuel flow rate. Higher RPM values results to higher fuel flow rate.

Drive Cycle Factors	U-Turn	Signalized
Average Speed	3.928152771	2.861333696
Average Running Speed	5.489398094	5.79887758
Average Acceleration	0.582364896	0.61010012
Average Deceleration	0.646172894	0.618290155
No. of Acceleration Changes	28.53333333	11.86666667
No. of Deceleration Changes	21.1	7.466666667

Table 1 Drive Cycle Factors

The data in Table 1 show the values of various factors derived from velocity of both U-turn and Signalized runs.

As the frequency of acceleration and deceleration changes increase, fuel consumption also increases. This frequency of changes is noticeably higher in U-turn runs as compared to Signalized runs, as shown in the table above. The design of the U-turn run introduces a larger number of maneuvers that induces acceleration and deceleration compared to signalized intersection run wherein only a single left turn maneuver is required.

Since acceleration and deceleration are present during weaving maneuvers, U-turn slot approach, and queue approach, the complex trip route experiences a higher number of changes in acceleration and deceleration. During a U-turn run, all of these maneuvers are present. As opposed to a signalized run where the vehicle only experiences a stop once or twice before proceeding to move along during the green cycle.

Time proportions are also relevant in fuel consumption. First is the time proportion for idle. The longer the duration for the idle time, the more fuel it consumes without moving. Signalized runs experience a longer idle time since the vehicle is exposed to a prolonged period waiting when queuing for a green cycle. While in U-turn runs, idle time is almost non existent due to continuous vehicular flow. This factor has a larger impact on the signalized intersection compared to the U – turn. Another factor is the time proportion for acceleration and deceleration. It was mentioned earlier that changes in velocity affects fuel consumption, therefore, larger time proportion for acceleration and deceleration means larger effect on fuel consumption. The presence of driving maneuvers affects acceleration and deceleration. A U-turn route requires more driving maneuvers than a signalized intersection route. The results gathered from the analysis prove that this factor generally shows that more time is spent accelerating and decelerating during U-turn runs. Even though acceleration and running speed have major effect on fuel consumption, the variances of the results between U – turn and signalized intersection are shown to be small that they appear to be almost equal. Therefore, these results have the least priority in terms of analysis.

The following figures represent the generalized data for both u-turn and signalized intersections.

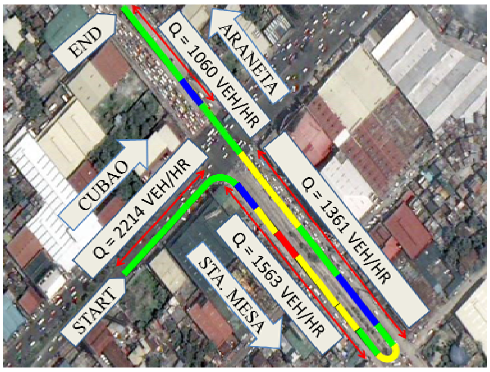

Figure 4. Generalized Representative for U-Turn Intersection Data

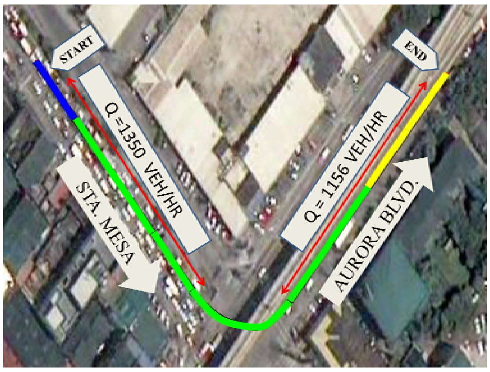

Figure 5. Generalized Representative for Signalized Intersection Data

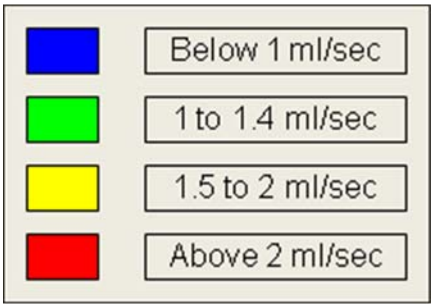

Figure 6. Legend for Generalized Representatives

As shown in the general representative data of both U-turn and Signalized Intersection runs, fuel consumption is significantly higher in the latter area due to the higher fuel flow rates it experiences.

FACTORS		UTURN		
Drivers Behavior	R^2	0.072575571	Weak Correlation	0.010785511+0.069793179X
	F	2.191139166		
Total Weight	R^2	0.066010442	Weak Correlation	0.000867093+0.131912008X
	F	1.978921879		
Velocity	R^2	0.435016445	Strong Correlation	(-0.005911639)+(0.272391876)(X)
	F	21.55896462		
RPM	R^2	0.264404758	Strong Correlation	(-6.94417^5)+(0.259570416)(X)
	F	10.06441153		

Table 2. Summary of Correlation for U-turn

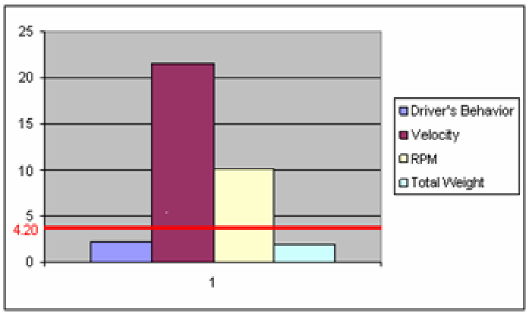

Figure 7. Bar Chart of Factors that affects Fuel Consumption in U-turn

FACTORS		INTERSECTION		
Drivers Behavior	R^2	0.017290473	Weak Correlation	Y= -0.0038+0.145x
	F	0.492651427		
Total Weight	R^2	0.030089502	Weak Correlation	0.00042+(-1.0491)x
	F	0.868643107		
Velocity	R^2	0.437701048	Strong Correlation	y=-0.003+0.13x
	F	15.16001932		
RPM	R^2	0.380033468	Strong Correlation	y=(-0.0001)+0.2420X
	F	12.43718264		

Table 2 Summary of Correlation for Signalized Intersection

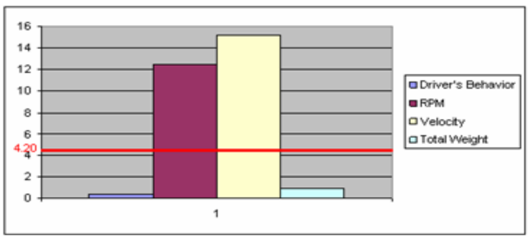

Figure 8. Bar Chart of Factors that affects Fuel Consumption in Signalized Intersection

The figures showed the four factors that correlated to fuel consumption comparing in two different traffic schemes. It clearly shows that the velocity and rpm gives the strong correlation with the fuel consumption because it surpasses the critical value of 4.20 compared to the driver's personality and total weight, it gives a weak correlation and does not significantly affect the fuel consumption. Using a different kind of statistical method to be able to determine the correlation between our X and Y variables, the researchers used the F-test. To arrive at an answer the mean of the X and Y variables was taken. Wherein Y being the dependent variable which was the fuel consumption and X being the independent variable. Independent variables considered were the driver's personality, total weight, velocity and revolution per minute. The regression results and the F-test results were computed from the four different kinds of factors used. First, was the fuel consumption and driver's personality the R-squared that resulted from the regression was statistically weak at 0.0725755712 which was about 7.3 percent only. Also, the correlation was proven to be weak because the F that was taken from the table was greater than the F computed. Same was applied to fuel consumption and total weight where R-squared came up with a regression model that was statistically weak because the regression is 0.06601044175 or about 6.6 percent in total. On the other hand the F-Test where the F computed was only 1.97 which was less than the F derived from the table which was 4.20. The third factor was the Fuel consumption and velocity where the regression value showed a good correlation between them since the R-squared was 0.4350164454 or about 43.5 percent. The F-test also showed a strong correlation between them because the F computed was larger than the F derived from the table. Last was the relationship between fuel consumption and revolution per minute where the R-squared was 0.264404758 which was about 26.4 percent. This showed a good model equation because when the F-test was done the F computed was 10.26 which were greater than the F given from the table at 4.20

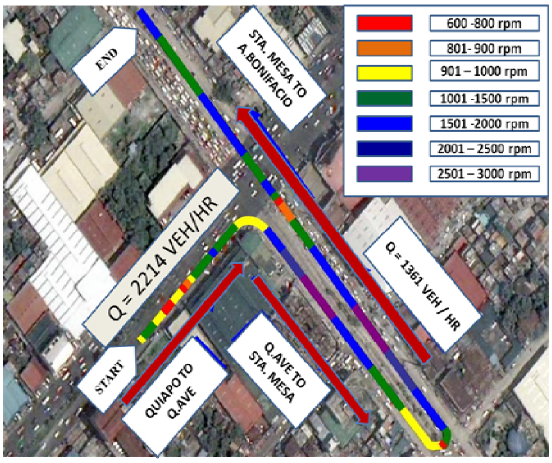

Figure 9. Mapping of U – Turn for RPM

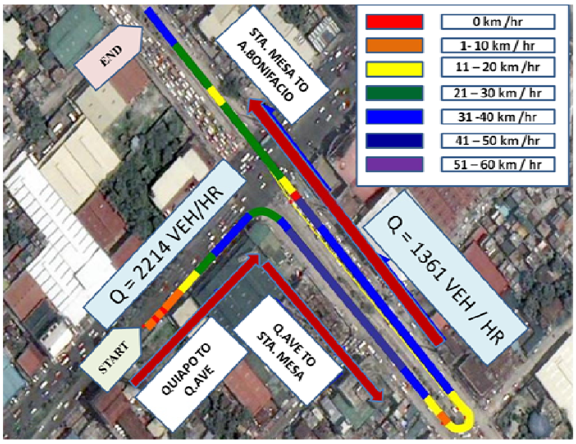

Figure 10. Mapping of U – Turn for Velocity

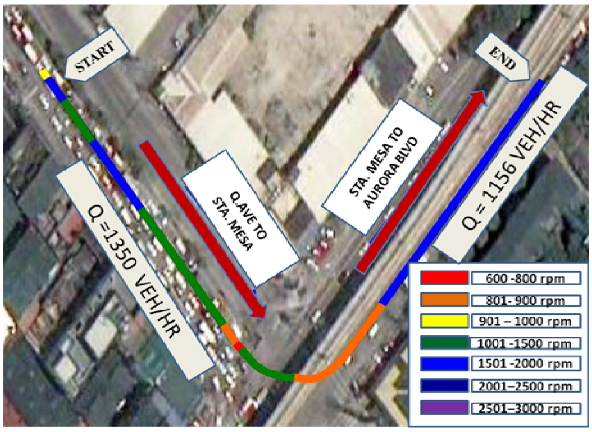

Figure 11. Mapping of Signalized Intersection for RPM

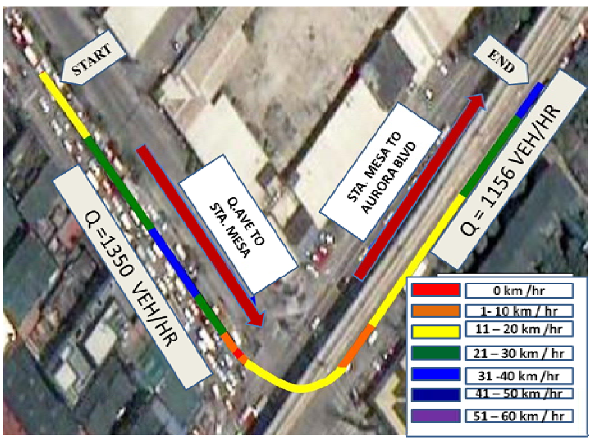

Figure 12. Mapping of Signalized Intersection for Velocity

The figures show the mapping representing all the conducted runs for u-turn and signalized intersection. It is apparent that in the U-turn section (Figure 4-5 and Figure 4-6), the rpm and velocity had a steady increase from rest until the vehicle turned left acquired in the data run number nine and twenty six and had an average fuel consumption of 0.001002L/sec. High consumption rates were not sustained for a long time. It was noticeable that high consumption rates were reached when the car starts from idle. From the experiments in the u-turn section, idle time occurred while the vehicle was waiting for its chance for u-turn and high fuel consumptions were attained while the vehicle was merging with the flow of traffic.

CONCLUSION

Traffic management strategies are designed to help regulate and if possible optimize an area's traffic flow. However, with the advent of the trend in sustainable development, these strategies have not put into consideration fuel consumption in its design. Many traffic schemes are currently in effect. However, the researchers chose to evaluate the fuel consumption of U-Turn and signalized intersection traffic management strategies. The Elmscan device proved vital to the completion of the study since it can provide direct fuel consumption data without the need for further computations which may lead to errors. By using the on board setup of equipment, the researchers obtained data of the fuel consumption from the two traffic management strategies. The data from each strategy were later compared against each other. It was now possible to establish which strategy has higher fuel consumption. After the statistical analysis of data acquired from the two traffic management strategies, the researchers have been able to conclude which has higher fuel consumption. Many factors can be attributed to this result. One of the main factors that were observed based from the data, was the run duration. The U-turn strategy has longer run duration because it redirects the normal flow of traffic. This translates into more fuel consumed compared against the signalized intersection strategy. Distance traveled per route also affects fuel consumption. U-turn runs travel 700 meters while signalized intersection runs travel only 230 meters from start to finish. Even though the signalized intersection has idle vehicle factor during red cycles, which still consumes fuel, the longer distance traveled in the U-turn strategy accounts for its higher fuel consumption rate.

Another factor is the behavior of the driver under different circumstances. In this case, under different traffic management strategies, drivers can react differently depending on their environment and situation. Acceleration and deceleration also impact fuel consumption rates. As shown in the test results, continuous change in vehicle speed consumes more fuel. The U-turn strategy has proven to be prone to more changes in vehicle velocity compared to the signalized intersection. This is due to the higher amount of driving maneuvers required to complete a U-turn run compared to a signalized intersection run. Taking into consideration these factors involved and comparing results from the data gathered from the experiments, the researchers were able to determine that the U-turn strategy has consumed more fuel than the signalized strategy.

This study brought out clearly that the driver's personality slightly affects his fuel consumption when crossing a signalized intersection on making U-turn. The Psychological test that was created had no greater effect with the fuel consumption because the effect was too weak to say that the behavior of driver can affect his fuel consumption while he was driving. In the psychological exam the questions was not a big factor in fuel consumption so that the analysis of fuel consumption and drivers behavior there was just a weak correlation made between them. On the other hand, is the analysis of fuel consumption and velocity it showed a strong correlation which means that there was a good relationship between them. Another thing that was considered was the fuel consumption against total weight where it shows weak correlation between them considering that other factors like the type of engine, model and year of the vehicle were not included last was the fuel consumption against the revolution per minute (RPM) wherein it showed a good positive correlation because it coincided with the velocity of the vehicle. The test questionnaire proved to be one of the important bases in evaluating the driving behavior of the respondents. In the beginning of the questionnaire shows the drivers profile where it will be easy to group them accordingly. It is important that the maturity of the respondents be evaluated, the younger the driver the more aggressive he is. With these types of questions, the respondents can easily be group. There are also questions that are meant to evaluate the respondent's reaction to different situations depending on his driving behavior. Based on the analysis the researchers deduced that there was actually an inter-correlation between and among the factors however the independent variable will not explain individually the correlation with the dependent variable.

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