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Fuel Consumption Evaluation of 1.5 Liter Engine using "Intelligent Start-Stop System" Technology

Yusupov Sarvarbek Sodikovich

PhD student, Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan

Abstract: In this article analyzed the fuel consumption in spark ignition engine, as well as ways of using modern information technologies in them and the possibility of using intelligent transport systems in the design of vehicles. It suggested test methods and requirements using an "intelligent start-stop system" based on 1.5-liter engines of local vehicles. According to experimental calculations, using an "intelligent start-stop system" is expected to reduce the operating time of the internal combustion engine by about 30%, by saving 8, 25 % of fuel in urban conditions.

Keywords: intelligent transport system, start-stop, density, microcontroller, mode, synergy, sigma, variation series, experimental, statistical.

Introduction

Nowadays development of the transport network in our country is faced with the need to solve certain problems related to it in the future.Tashkent's population and vehicles have increased during the last 10 years, the number of vehicles in Tashkent has doubled from 250,000 to 510,000. Additional new roads, bridges and subways are under construction. However, there is a lot of traffic on the streets of the capital city, and there are enough problems in traffic regulation. The research the densityof traffic and flow passengers through the geoinformation system revealed the presence of more than 500 major intersections in Tashkent. Of these, about 200 intersections have traffic signal control problem. This situation can lead to traffic jams or restrictions on movement.On the basis of such a complex analysis, a preliminary draft master plan for the improvement of road infrastructure and public transport in Tashkent has been developed.In particular, it was calculated that the optimizing 24 major traffic intersections in the capital might reduce the average number of stops by 71% and time by 48%, congestion by 64% and fuel consumption by 34% [1].

Scientific and practical researches are being conducted by experts in the field to improve the energy efficiency of road transport in the world, receiving real-time data from the elements of road infrastructure, ensuring traffic safety through the interaction of vehicles with elements of intelligent transport systems(ITS), increasing fuel economy, and improving environmental performance. In this direction, special attention is given to the development of software to ensure the interoperability of road infrastructure elements with the vehicle design based on new mathematical models in changing dynamic conditions.

In the experience of developed countries, by applying innovative ideas into the road transport network, ITS are created, which are efficient in solving modern transport problems [2]. Today, all vehicles manufactured on the basis of electronically controlled systems. ITS allow vehicles to communicate with everything related to these technologies. This is why, the communication with each other of innovative technologies of the 21st century determines the relevance of today.

Modern engineers emphasize that all types of technology should be not only single-functional, but also multifunctional. Although research in the field of ITS is increasing, the field itself is still new and its potential has not been fully explored.Based on this, there is a volume of application of appropriate ITS technologies in our country, which leads to the effective solution of road safety problems [3].

The technology is available and offers many different options for solving future problems, and in that respect, ITS comes first [4-5].

Methods.

Traffic congestion depends on the quantity of movement and the throughput of intersections.The quantity of movement is a variable indicator to years, months, days of the week, and hours of the day, as well as road sections.The change in the quantity of movement on automobile roads during the day often depends on the direction of driving, the days of the week, and the importance of the road. It is mainly observed rising three times a day (morning, lunch and evening).The quantity of movement during such hours is called “rush”. Correct organisation of traffic at these times is an essential factor to ensure safety.

Congestion increases traffic time, fuel consumption, air pollution and reducing efficiency or exploitation of road infrastructure [6].

The movement of vehicles on city streets always requires the synergy of infrastructure with vehicles.This is because infrastructure is a set of key facilities and systems that serve a country, city, or other region and cover the services and facilities needed for the economy [7-8].Synergy of vehicle-to-Infrastructure (V2I) helps vehicles to establish a wireless connection and optimize traffic between the environment’s static infrastructure joints, road signs, traffic lights, and others.

When the engine is running in idle mode, the amount of emission gases released into the environment is higher than in other modes. Because in this mode the engine runs on an enriched mixture ($\alpha<1$) so that it does not shut down. We consider that it is necessary to increase the vehicle's fuel economy and improve environmental performance in this mode. There are several methods to save fuel. One of these methods is to use the ISSS in the component of “vehicle-to-infrastructure” of the ITS in the idling mode of the vehicle. Because saving fuel in this mode has not been researched in our country. Theoretically, it is possible to ensure the fuel economy of the engine in the idle mode of the driving modes.

There are different aspects in the coverage of this dissertation. Turning off the vehicle engine at the traffic light through “Intelligent start-stop system” in the limited time of traffic red light (if the red light is more than $t_r>10$ s, otherwise the engine will not turn off) and after a particular time during the engine restarting process in yellow light (t_y = 1 ... 3 s) or green light (t_g = 1 ... 30 s) the effect on engine parts, to the battery, to the starter, to the alternator resources is not studied. Because of the high degree of quality and reliability of technology used in the manufacturing of mechanical and electrical parts of modern vehicles ensures that they do not breakdown during vehicle operation.

Idling at traffic lights is a waste of fuel, and with the increased focus on economy and pollutants, it makes logical sense to turn off your engine.According to experts, about 30 % the engine life cycle is consist of idle times.In the world experience, drivers and passengers lose an average of 30 minutes a day by stopping at a red traffic lightin the cities [9].We consider that it is necessary to ensure the fuel economy and environmental performance of vehicles in its driving modes by analyzing the component V2I of ITS.

The driving modes of vehicles are following (Fig.1):

1. Idle speed engine or stop mode ($V_a=0$; $\omega_e=\omega_{ise}>0$; $S=0$; $t>0$);
2. Acceleration mode ($j_a>0$; $V_k>V_n$; $S>0$; $t>0$);

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3. Constant speed driving mode (j_a=0; V_k=V_n; S>0; t>0);
4. Deceleration mode (j_a<0; V_k<V_n; S>0; t>0).

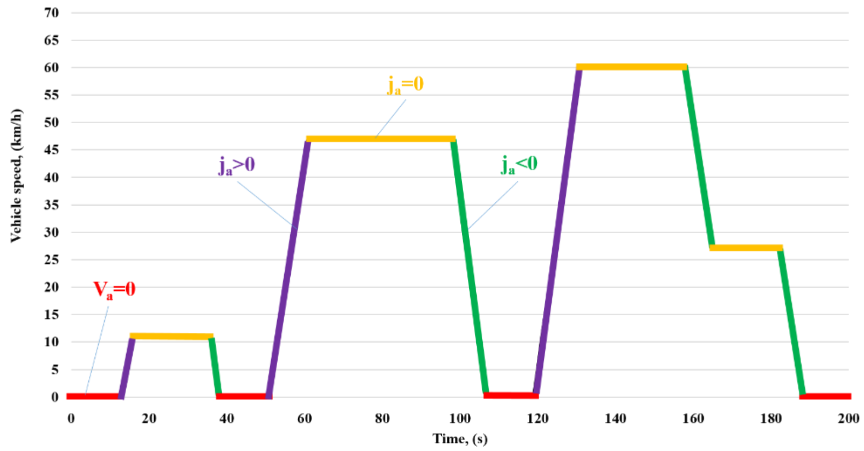

Fig.1. Drive cycle of Tashkent city [10]

The efficiency of this system is determined by turning off the vehicle engine at the red light of the traffic lights depending on time, and saving fuel consumed during this time.In addition, this system reduces the idle time of the engine and increases its efficiency and resource.To do this, the data transmission and reception processes between the vehicle and the traffic light are performed via the ESP8266 microcontroller.One of the main functions of the microcontroller is that it has the ability to send and receive information wirelessly.The distance of wireless information exchange is up to 300 meters.

Analyzing the conditions of exploitation of vehicles, and taking into account the density of traffic, the city of Tashkent was selected as the object of research.On the Drive cycle of the Tashkent city we used a Chevrolet Nexia. The statistics data were collected using the experimental method in a small ring road with a high traffic intensity on the central streets of the city at the tight time, which is a distance of 25-30 km long and passing 45-50traffic lights (Fig.2).Given that the operation of the system depends on a microcontroller setted on the traffic light, during the test, when the vehicle stopped at the red light, by using simulation its engine was stopped and started.

Fig.2. Research processes by using "Intelligent start-stop system" at the traffic lights to determine the lost times

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Results and discussions.

In the urban driving cycle, the idle engine phase of the vehicle's driving modes was separately analyzed and synthesized.We analyzed at this process in detail because as we aim to reduce engine idling to reduce fuel consumption.

Using the scanmatic diagnostic device were obtained vehicle speed on driving mode of the vehicle through OBD-II CAN on board the electronic control system of the engine. In this case, $t_1^{tr}, t_2^{tr}, \dots, t_n^{tr}$ are represented by the stopping times at traffic lights (Fig.3).

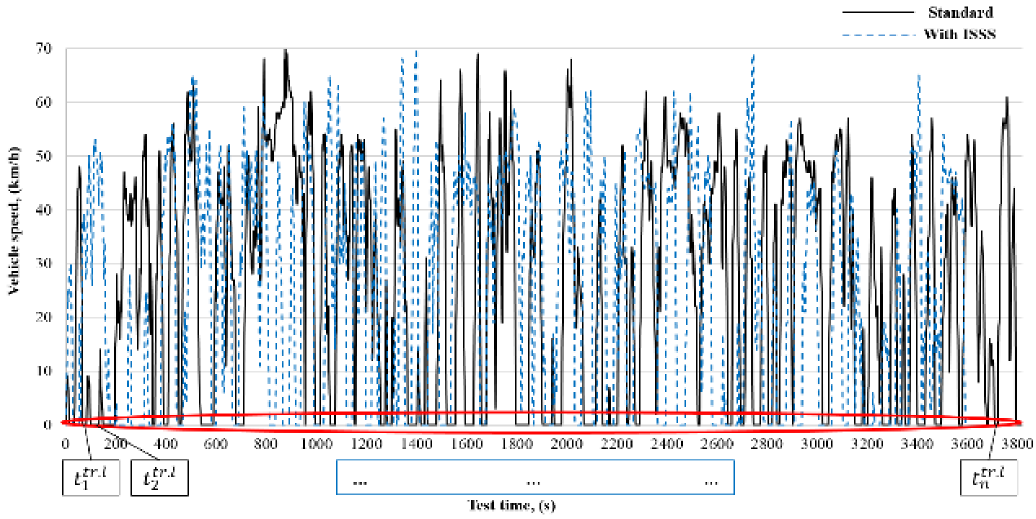

Fig.3. Changing in vehicle speed in the city driving cycle of Tashkent

In the test experiments, in the driving cycle "Intelligent start-stop system" was used on the idle engine mode $(t_1^i, t_2^i, \dots, t_n^i)$and engine stopped times $(t_1^{en.s}, t_2^{en.s}, \dots, t_n^{en.s})$were calculated (Fig. 4).These calculated times are statistically summed by random quantities of stopping times at a traffic light in the direction of test travel.

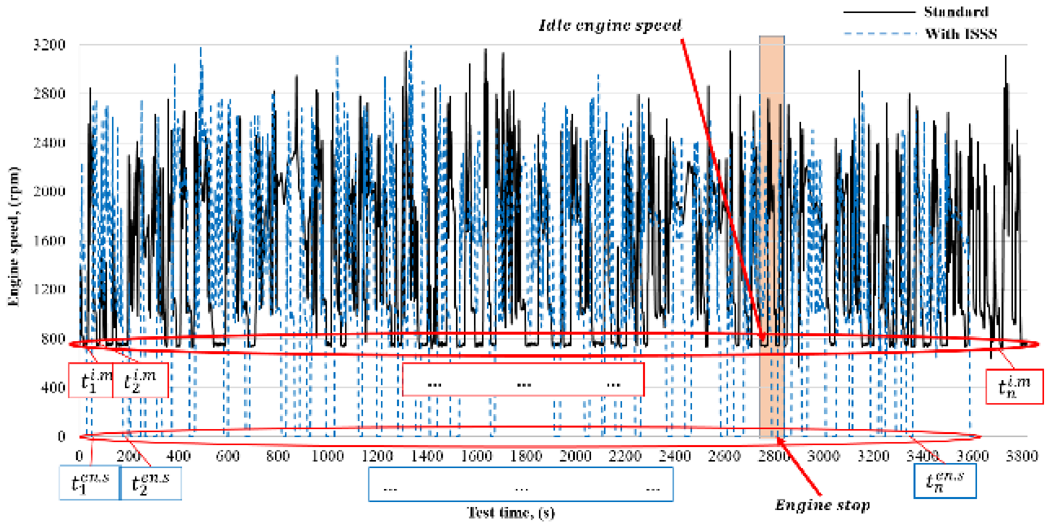

Fig.4. Changing in engine speed in the city driving cycle of Tashkent

The main parameters were calculated on the idle engine mode of the vehicle in the city driving cycle (Table 1).

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Table 1. The idle engine time parameters in the city driving mode of Tashkent.

№	Test parameters	Without ISSS	With ISSS
1.	Total test distance - S_t, (m)	$S_t = \sum_n^3 S_t^n = 75000$	$S_t = \sum_n^3 S_t^n = 75000$
2.	Total time for test - T_{tdt}, (s)	$T_{tdt} = \sum_n^3 T_{tdt}^n = 11580$	$T_{tdt} = \sum_n^3 T_{tdt}^n = 11760$
3.	Average speed of vehicle - V_{av}^T, (m/s)	$V_{av}^T = \sum_n^3 V_{av}^T = 6{,}47$	$V_{av}^T = \sum_n^3 V_{av}^T = 6{,}37$
4.	Idle engine time of vehicle - $T_{ie.m}$, (s)	$T_{ie.m} = \sum_n^3 t_{ie.m}^n = 2825$	$T_{ie.m} = \sum_n^3 t_{ie.m}^n = 2848$
5.	Share of the idel engine time over the total time - $T_{iet}^{\%}$, (%)	$T_{iet}^{\%} = \frac{T_{ie.m}}{T_{tdt}} = 24{,}39$	$T_{iet}^{\%} = \frac{T_{ie.m}}{T_{tdt}} = 24{,}22$

We define the statistical data obtained as a result of observations in the random state of $x_1^*, x_2^*, \dots, x_n^*$ as a sample. The statistical data was disorder.

To statistically verify this information we do these:

1)make the variation series;

$$x_1 \le x_2 \le \cdots \le x_n.$$

This sequence can be called the values of a variable (variation) series.To process the statistics, you first have to put a set of random numbers in ascending order. The values of the variation series of the sample were constructed. The minimum value of the variation series was 3 s and the maximum value was 59 s.These values were randomly determined in the example of the city of Tashkent in the framework of a cycle of variability t_r = 18 ÷ 90 seconds at the standard minimum and maximum illumination period (tact) of the red light of traffic lights.

2)composing the law of distribution of sample.

For this, we used the following formula because the sample size is large[11].

$$h = \frac{x_{max} - x_{min}}{k} = \frac{x_{max} - x_{min}}{1 + 3{,}31 \cdot lgn}; \quad (1)$$

where:

x_{max}, x_{min} - maximum and minimum waiting time at the red light of the traffic light, s;

k is the number of intervals divided into variational series (determined using the Starjess formula and taken in the range k=8-12 (Table 2.));

n is the number of experimental data.

Table 2. Values of the number and width of intervals of data obtained in the city driving cycle.

№	Parameters of variation series	Without ISSS	With ISSS
1.	Number of intervals - k	$k = 8$	$k = 8$
2.	Wirth of intervals- h	$h = 7$	$h = 6{,}75$

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In the next processing stage a number of private around the calculated average value or the variance value of the reliability index and the mean quadratic deviation changes were calculated (Table 3.).

Table 3. Average value and average quadratic deviation value.

№	Parameters of variation series	Formula	Without ISSS	With ISSS
1.	Average value - $\bar{X}$	$\bar{X} = \frac{1}{n}\sum_{i=1}^{k} m_i \cdot x_i$	$\bar{X} = 23$	$\bar{X} = 24$
2.	The value of the second-order moment -$\overline{x^2}$	$\overline{x^2} = \frac{1}{n}\sum_{i=1}^{k} m_i \cdot x_i^2$	$\overline{x^2} = 693$	$\overline{x^2} = 731$
3.	The variance of the sample -$\overline{\sigma^2}$	$\overline{\sigma^2} = \frac{1}{n-1}\sum_{i=1}^{k} (x_i - \bar{X})^2 \cdot m_i$	$\overline{\sigma^2} = 173$	$\overline{\sigma^2} = 141$
4.	Average quadratic deviation -$\bar{\sigma}$	$\bar{\sigma} = \sqrt{\overline{\sigma^2}}$	$\bar{\sigma} = 13,15$	$\bar{\sigma} = 11,87$

The results of the research have shown that the cost of developing ITS infrastructure should be proportional to the adaptation of ITS technology.

Statistical processing of experimental data was performed to determine lost time at traffic lights and congestion.During the calculations, it was found that the minimum value of the interval limit is $x_{min} = 3; 5$, the maximum value is $x_{max} = 58; 59$, the average value of the variation series is $\bar{X} = 23; 24$, and the average quadratic deviationis $\bar{\sigma} = 13,15; 11,87$.

It found that the 3σ rule was appropriate for the random quantity being tested in determining the time lost at traffic lights and congestion. The time of standby at the red light of the traffic light without ISSS of the vehicle on the rule of 3σ is equal to [12]:

$\bar{X} + 3\sigma = 23 + 3 \cdot 13,15 = 62,45;$

$\bar{X} - 3\sigma = 23 - 3 \cdot 13,15 = -16,45.$

And with the ISSSof the vehicle is:

$\bar{X} + 3\sigma = 24 + 3 \cdot 11,87 = 59,61;$

$\bar{X} - 3\sigma = 24 - 3 \cdot 11,87 = -11,61.$

Based on the conclusion of three sigma (3σ), the time lost (random quantity) at the traffic lights proved to be subject to the Normal distribution (Fig.6). The Normal distribution function is written as follows:

$$F(x) = \frac{1}{\sigma\sqrt{2\pi}} \int_0^{\infty} e^{-\frac{(x-\mu)^2}{2\sigma^2}} dx \qquad (2)$$

The density function is defined as follows:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad (3)$$

where:

μ - mathematical expectation.

The theoretical frequencies determined according to formula (3) were calculated as follows.

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$$f(x)=\frac{1}{11{,}19\sqrt{2\pi}}e^{-\frac{(26{,}44-\mu)^2}{2\cdot 11{,}19^2}}=0{,}038\cdot e^{-\frac{(26{,}44-\mu)^2}{2\cdot 11{,}19^2}}$$

The calculated experimental and theoretical values of the normal distribution showed that they were obeyed to the normal distribution in randomly variable processes
(Figure5).

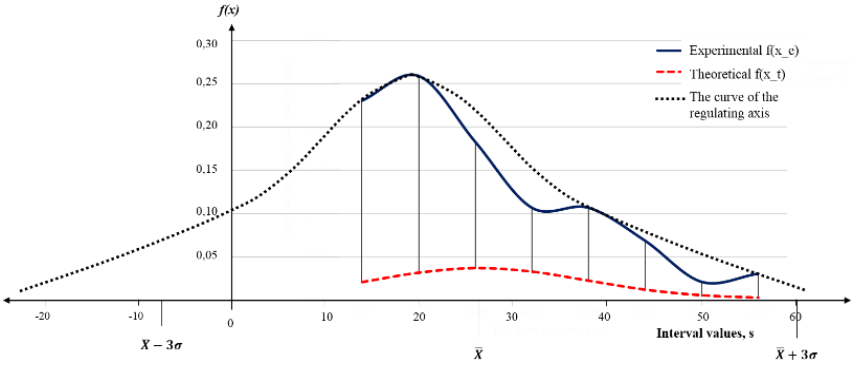

Fig. 5. Approximation graph of the theoretical and empirical distribution of selected values

According to practical calculations, it was calculated that within 75 km of the test conditions, the engine was switched off by ISST for an average of 45 minutes.

$$T_{i.m>10}=\sum_{i=1}^{m}T_{i.m}-\sum_{i=1}^{m}T_{i.m<10},\ (s) \qquad (4)$$

where:

$T_{i.m>10}$ – the engine idling time at red lights of traffic lights more than 10 seconds; $T_{i.m}$ – the total idling time of engine stopping at red lights of traffic lights, (s); $T_{i.m<10}$ - the engine idling time at red lights of traffic lights less than 10 seconds.

Fuel consumption of a vehicle with ISSS was calculated in *l/km* and the results are given in Table 4.

Table 4.

Vehicle model	According to technical description, *l/100 km*	Experimental fuel consumption, *l/75 km*		According to the description of the experiment, *l/100 km*		Difference, +/-, *l/100 km*		Percentage of fuel saved, % (*inl/100 km*)
		Without ISSS	With ISSS	Without ISSS	With ISSS	Without ISSS	With ISSS	
Chevrolet Nexia	8	5,99	5,52	7,98	7,32	-0,02	-0,658	8,25

Conclusion.
The average lost of time by a vehicle at a red traffic lights during a day was 45 minutes. The vehicle with the ISSS saved 8.25 percent of fuel per 100 km in urban conditions. In additional, by using practical and analytical methods, it was determined that one vehicle saved an average of 132 liters of fuel per year when traveling 20,000 km, and minimizes CO emissions by 8060 g, HC emissions by

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700 g, and NO_x emissions by 520 g. So, as we recommended the ISSS is characterized by 28-32% reduce idling time of engine at a trip of 100 km.

Numerous researches have shown that the “auto start-stop system” saved 5-10% of fuel in urban conditions and reduced emissions of the same amount of toxic gases into the environment.The results of our experiments showed that they are consistent with these indicators.

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