METHOD OF INVESTIGATION OF THE EFFICIENCY OF ROAD TRAINS ON HIGHWAY THROUGH AN ADVANCED COMMUNICATION SYSTEM

Abstract: A method of investigation of the efficiency of road trains on highway which is distinguished from the known that the parameters as velocity, altitude, road slope, gear at the gearbox, fuel consumption, engine working conditions, are given by the use of an advanced communication system.

Keywords: ROAD TRAIN, EFFICIENCY, ROAD TESTS, GPS, GPRS

1. Introduction

Freight road trains with great capacity for long distance and international services, called “road trains” are widespread because they allow the application of modern high technologies in the organization of road transport.

The efficiency of use of road trains is determined by the achieved performance of the transport process, which in turn substantially depend on the degree of correspondence between their operational characteristics and specific road operating conditions.

To assess the effectiveness of the use of road trains, a complex technical indicator named ‘relative productiveness on fuel consumption’ or ‘transport efficiency’

\[
W_Q = \frac{W}{Q_s} = \frac{q_n \gamma s v_{av}}{Q_s} \left[ \frac{100 \times t \times km}{l \times h} \right],
\]

is applied, which represents a ratio between the transport productivity

\[
W = q_n \gamma s v_{av} \cdot \left[ t \times km / h \right]
\]

and the fuel consumption \( Q_s \) in liters per 100 km run at average speed \( v_{av}, [km/h] \).

The transport efficiency \( W_Q \) represents a complex criterion for the efficiency of the road vehicles because it characterizes their transport productivity, received per unit fuel consumption and gives an account of the major components of the cost of transport.

By \( q_n [t] \), in relationships above the nominal cargo capability of the road train is denoted and \( \gamma s \) is the coefficient of static use of the nominal cargo capability, the value of which for a course is equal to the value of dynamic use of the nominal cargo capability \( \gamma d \).

\[
\gamma d = \gamma s = \gamma
\]

The value of the coefficient of static use of the nominal cargo capability is

\[
\gamma s = q_f / q_n,
\]

where, \( q_f \) is the payload of certain type in [t], which can be loaded down on the body (bodies) of the tractor, semitrailer or the trailer (trailers).

On the other hand, reducing fuel consumption leads not only to increasing the efficiency, but to reducing the air contaminations by the pollutants.

Real conditions to raise the transport efficiency have being established by the modern communication technologies.

Abroad, and laterally in our country, GPS/GPRS technologies and systems are put into practice by mounting into the transport vehicles. They deliver to the owners of companies and specialists information in real time and in archive. However, these systems only collect and transmit data about the position of vehicles and some units and systems, so they are not systems improving the efficiency and are good in dispatching duties.

As a result of the collaboration under contract No. ДДВУ 02/51 on 20.12.2010 with a subject ‘Application of advanced communication system for testing and improving the efficiency of road trains on highway’, an advanced communication system is in a process of building up, which includes three subsystems: 1) for tracking the road train, 2) for giving an account of fuel consumption, and 3), for managing the efficiency.

The former two subsystems collect and transmit data in real time (on-line subsystems).

The third subsystem consists in a program for calculation and it uses the data of the first and the second subsystems and determines these conditions of engine work and number of gear of gear box, when the fuel consumption should be the least at certain route by a technical and economical criterion. To be able this subsystem to work, it is necessary a method to exist for receiving data from the first and the second subsystems. Such a method at the present moment is not known.

The aim of the work is a method of investigation the efficiency of road trains on highway through an advanced communication system to be created, which to permit to increase the efficiency of road trains on highway conditions.

2. Preconditions and means for resolving the problem

An important condition for successful work of the advanced communication system for improving the efficiency of road trains is the received information to be objective and at real time. It depends especially on the accuracy of sensors and on the correct preparations of the road tests.

2.1. Choice of sensors and installation on the tested road train

2.1.1. Choice of sensors for the subsystem for tracking the road train

The subsystem for tracking the road train serves to find its position, gather and transmit in real time data to the parties concerned. Its work bases on using GPS technologies.

2.1.2. Choice of sensors for the subsystem for giving an account of fuel consumption

This subsystem serves for giving an account of fuel consumption of the vehicle, the conditions of work of engine and
The use of this subsystem leads to determining cases of irrational manipulation of the vehicle: overloading, moving not at sparing speed, outage etc. As a sensor in this subsystem, a Flowmeter of liquid fuels should be used, for instance the ‘RTG-2’, created and produced at the Educational and Research Laboratory on designing, investigation and using the transport vehicles at the Institute of scientific instrument-building at the Research and Development sector at the University of Ruse, Bulgaria.

The Flowmeter of liquid fuels consists of a sensor for measuring the fuel consumed by the engine and an electronic control unit for accounting the fuel consumption. The last serves to give an account of the period of working of the engine, the fuel consumption per hour and per kilometer, the instant fuel consumption etc.

2.1.3. Choice of a sensor for measuring the air speed
For experimentally determination the relative speed of the vehicle and air, an anemometer for measuring the air speed is used. The anemometer should be tuned up in a way to measure the speed of contrary wind. When the speed of wind is zero, the measured speed is equal to the speed of the vehicle.

2.1.4. Choice of sensors for measuring the angular velocity of the engine crankshaft and determining the number of gear at the gear box
A sensor of Hall is used to measure the angular velocity of the engine crankshaft. The same sensor is in use to measure the angular velocity of the secondary shaft of the gearbox or of the propeller shaft. The gearbox ratio can be calculated after dividing the angular velocity of the engine crankshaft by the angular velocity of the secondary shaft of the gearbox or of the propeller shaft. Having known beforehand the values of gear ratios, the number of engaged gear can be determined.

2.1.5. Choice of sensor for determining the position of the accelerator pedal
From the position of the accelerator pedal it can be judged about the working regime of engine – on full throttle or part load. That is why, a sensor should be used to take an account of the position of the accelerator pedal. Having known the number of the gear engaged, the angular velocity of crankshaft and load of the engine, the subsystem for managing the efficiency can calculate the optimal regime of work of the engine and number of gear at the gearbox, when the fuel consumption will be optimal for the certain part of route by a chosen exploitation criterion.

2.2. Preparation of road tests
To carry out the road tests in a successful way, their material and technical foundation should be prepared. Before this preparation has not been done, the road tests must not start.

The preparation of road tests includes actions, which divide into two groups:
- preparation of the test road section and instrumentation;
- preparation of the tested road train.

2.2.1. Preparation of the test road section and instrumentation
The test road section should be prepared for road tests by appropriate blazing, equipping with the necessary measuring instrumentation and to be secured.

2.2.2. Preparation of the tested road train
During preparation of the road train, should be done:
- admittance for road tests;
- technical preparation of the road train and delivering fuel and lubricating materials;
- initial running in of road train assemblies;
- maintenance during road tests;
- preservation and security;
- technical safety.

2.2.3. Preliminary measurements of the parameters of the road train
Particular attention should be paid to drawing up a detailed design and technical characteristic of the road train. Without knowing to perfection the special features of the construction of the road train units, it is not possible the road tests to be conducted methodologically proper and the conclusions from the experimental results to be adequate. For drawing up a design and technical characteristic, various sources, methods and means may be used: factory documentation, drawings, references and where necessary – measuring the parameters directly on the tested road train. When necessary, some units should be dismantled and their parameters to be measured.

By preliminary measuring the parameters of the road train by known methods [1], [4], [5], [6], [9], [10], [11], some basic parameters and characteristics can be determined, such as frontal area, coefficient of rolling resistance, factor of air resistance, free rolling parts of transmission, reduced to driving wheels, transmission efficiency [11], the lowest steady speed on each gear, forces of rolling resistance, resistance due to grade and air drag.

2.3. Experimental determination of fuel efficiency of a road train
The graph of fuel consumption \( Q_s [l/100 km] \), at constant road speed of an automobile with various values of the force of road resistance \( F_p \) is known as \([2] \ldots [9]\) ‘fuel consumption characteristic of the automobile', Fig. 2. The minimums of the curves specify the most economically steady speeds, called ‘economical speeds’ and the rightmost points – the fuel consumptions at the maximal speeds which are possible in different road conditions and vehicle loads on full throttle.

Because the force of road resistance \( F_p, [N] \), is a product of...
the coefficient of road resistance \( \nu \) and the weight of automobile \( G \).

\[ F_w = \nu G, [N] \]

the change of load necessary for plotting curves can be made by three methods:

- by movement on different test road sections having different
coefficients of road resistance (angle of climbing, quality of road),
keeping constant along the test road section and with constant load of
the road train.
- on the same test road section, but with different loads –
beginning from movement without load and finishing with full legal
load. Because the force of road resistance is a product of the
coefficient of road resistance and the weight, it is without
importance if it is being gained by changing the coefficient of road
resistance or by changing the weight of the automobile. On the
other hand, it is difficult to find sections of road with the necessary
lengths and parameters remaining unchanged throughout their
length. This defines as more appropriate to carry out the road tests
on one test section but with different loads.
- on the same test road section, but a special dynamometric cart
to be used to vary the load. At first, the curves of the fuel
consumption characteristic on a gear without the dynamometric cart
should be determined. Then, the dynamometric cart should be
hitched and the same curves should be plotted with different loads,
by determining them through adjusting the brake moment of the
brake mechanism of the dynamometric cart. We should have in
mind, that simultaneously with varying the speed, the forces of road
and air resistances of the dynamometric cart and respectively the
force acting to the road train change too. This means that the
dependencies of the road and air resistances of the dynamometric
cart and the law of adjusting of the brake moment of the brake
mechanism of the dynamometric cart should be preliminary
determined, which complicates the method for testing and delivers
conditions for more mistakes.

The unsettled operation of the engine influences the fuel
consumption, but for road trains moving at highway conditions this
influence is negligible and can therefore not to be countered.

The experimental determination of each point of each curve of
the fuel consumption characteristic of the road train is carried out
by moving on the test road section with a given steady speed and a
given constant load and constant gear of the transmission. After
plotting the curves relating to one gear, another gear may be shifted
and the same may be done at it.

The speeds at which the tests are conducted should be at
interval of 5-10 km/h, beginning from the lowest steady speed \( v_{min} \)
and finishing at the highest steady speed \( v_{max} \) on given gear. The
road train accelerates until the speed of task is reached in a way to
reach it at 200-500 m before the beginning of the test road section
and lasts to move with it until covers its distance, which is 1000 m.
Runs are carried out in two opposite directions at least three times
and, to plot the respective point of the curve, the results should be
averaged. The real speed in one direction \( v' \) and in the opposite
direction \( v'' \) distinguish from the speed of task \( v_{task} \) and should be
calculated on the base of the overall time of covering the test road
section of 1000 m in respective direction. The real speed of motion \( v \) with given load is obtained as an average of the speeds \( v' \) and \( v'' \).

Because the readings of Flowmeter of liquid fuels are in liters,
\( Q_s, [l] \), and the length of the test road section is 1000 m (1 km),
the fuel consumption \( Q_S \) in \( l/100km \) will be received by the
dependence

\[ Q_S = \frac{Q_s / \emptyset}{1/100} = Q_s \times \emptyset, [l/100km] \]

From the other hand, to determine the fuel consumption
analytically, the next equation is in use:

\[ Q_S = \frac{\emptyset m}{360 \rho_f \emptyset} (F_w + F_{w_x} + F_p + F_{p_{dn}}), [l/100km] \]

where, \( g_f, [g/kWh] \) is the specific fuel consumption, \( \rho_f, [kg/l] \) -
the density of the fuel, \( F_{w_x}, [N] \) - the force of air resistance,
\( F_p, [N] \) - the force, which is necessary to be applied to the
periphery of the driving wheels to overcome the moment of
parasitic losses and \( F_{p_{dn}} [N] \) is the force which is necessary to be
applied to the periphery of the driven wheels to overcome
the moment of friction in the bearings of the driven wheels [11].

It is seen that to be possible the subsystem for managing the
efficiency to determine analytically the fuel consumption \( Q_S \), it is
necessary the value of the specific fuel consumption \( g_f, [g/kWh] \),
to be known. The last depends on the speed and load regime of
the engine. From (7) it comes, that

\[ g_f = \frac{\emptyset m}{360 \rho_f \emptyset} (F_w + F_{w_x} + F_p + F_{p_{dn}}) = \frac{36Q_S \rho_f \emptyset}{F_L}, [g/kWh] \]

For more convenience, the test results are arranged in Table 1.
Such a table should be filled in for each curve of the fuel
consumption characteristic of the road train.

The tests should be made firstly at direct drive for a road train
without load and then, by the same method, with load increment of
20 % to the full legal load.

For the complete results of the tests, the fuel consumption
characteristic of the road train on direct drive should be plotted. It
allows to assess the optimal speed of the road train at certain road
and load conditions from the point of view of fuel efficiency.

To compare the fuel efficiency of the road train at other gears,
the fuel consumption characteristic on these gears should be plotted.
This forces tests in the same content, but with another gear shifted
and another loads, to be conducted.

Better clearness is obtained when the fuel consumption chart of
the internal combustion engine is used.

<table>
<thead>
<tr>
<th>Gear No.: ......................</th>
<th>( G = ...................... ) [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direction ( v_{task} )</td>
<td>( Q_S )</td>
</tr>
<tr>
<td>( [km/h] )</td>
<td>( [l/100km] )</td>
</tr>
<tr>
<td>( v_{min} )</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>( v_{max} )</td>
<td></td>
</tr>
</tbody>
</table>
3. Results and discussion

As an optimal regime of movement it should be understood that combination between the speed of movement and gear shifted in the gearbox, at which the road train with a certain load consumes minimal quantity of fuel.

3.1. Plotting the power balance of the road train moving at direct drive

Using the full set of test results with number of loads, arranged in Table 1, the Table 2 should be filled in, where the power consumption $P_c$, in [kW], should be calculated as

$$P_c = (F_w + F_{w_s} + F_{p_d})v/1000 = \frac{360Q_s \rho \eta_l \eta_f}{g_f}[kW].$$

$P_d$ in Table 1 denotes the driving power, i.e. the power of the engine, delivered to the driving wheels [11]. At steady speed it is equal to the power consumption.

Because the loads are different, the maximum speed for each load differs from the maximum speed attained for other loads. The power while moving at respective maximum speed is the power of the engine, delivered to the driving wheels with full throttle, i.e. at external engine characteristic.

The angular velocity of the engine crankshaft is

$$\omega_{\text{m}} = \frac{v}{r_k}[s^{-1}].$$

Using Table 2, the curves of power of resistances of motion of the road train at direct drive should be plotted, Figure 3. Curves $P_{c1}$ ... $P_{c5}$ on Fig. 3 denote the results achieved from tests with various loads: from a road train without load to a road train with full legal load with load increment of 20%. After connecting the highest points of curves $P_c$, denoted on Fig. 3 by squares, the curve of the power transmitted through the transmission from the engine to the driving wheels $P_d = f(v)$ at external engine characteristic should be plotted.

To plot the external engine characteristic $P_e = f(v)$ it is convenient to arrange the data for plotting the curve $P_d = f(v)$ in Table 3. After calculating by the formula

$$P_e = \frac{P_d}{\eta_f}, [kW]$$

and filling in the relevant column of Table 3, the curve $P_e = f(v)$ should be plotted on Fig. 3. So, Fig. 3 represents the power balance of the road train at direct drive.

The engine moment in Table 3 should be calculated as
3.2. Plotting the fuel consumption chart of the internal combustion engine

A practical application in determining the optimal condition of movement of the road train has the fuel consumption chart of the internal combustion engine. It represents, Fig. 4, an external characteristic of the engine moment together with lines of constant specific fuel consumption $g_f = \text{const}$. In addition, on the graph the curve of the engine moment with constant power $(P_d = \text{const})$ is to be plotted, which is necessary the road train to move at constant speed with different gears shifted. This curve represents a hyperbola $M_m = P_e / \omega_m, [Nm]$.

For plotting the lines of constant specific fuel consumption, the results of $g_f, [g/kWh]$ should be used, obtained for the respective speeds and loads by the help of Eq. (8) and filled in the last column of Table 1 or latter – for more convenience, in Table 2.

By using the points belonging to different curves for motion of the road train at a constant speed and gear, the load characteristic of the engine for the relevant angular velocity of its crankshaft may be plotted. Particularly, in Fig. 3 these are the points positioned vertically one above another at the speeds respectively of $v_{\text{min}}, 60, 70, 80, 90$ and $100 \text{ km/h}$. The same data is filled in the respective rows of Table 2 for the same speeds.

Having this in mind, Table 4 should be filled in. The values of engine power and moment are to be calculated by Eq. (11) and Eq. (12).

Table 3

<table>
<thead>
<tr>
<th>No. of load</th>
<th>$v$</th>
<th>$\omega_m$</th>
<th>$P_d = P_e$</th>
<th>$P_e = P_d / \eta_1$</th>
<th>$M_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1$</td>
<td>$v_{\text{min}}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m$</td>
<td>$v_{\text{max}}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4

<table>
<thead>
<tr>
<th>No. of speed</th>
<th>$v$</th>
<th>$\omega_m$</th>
<th>$P_{d1} = P_{e1}$</th>
<th>$P_{e1}$</th>
<th>$g_f1$</th>
<th>$M_{e1}$</th>
<th>$P_{d_m} = P_{e_m}$</th>
<th>$P_{e_m}$</th>
<th>$g_f_m$</th>
<th>$M_{m_m}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1$</td>
<td>$v_{\text{min}}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$n$</td>
<td>$v_{\text{max}}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(12) $M_m = P_e / \omega_m, [Nm]$.

If the number of points to plot curves of powers $P_e = f(v)$ and $P_d = f(v)$ is less than $5 \ldots 8$ and so the information for plotting these curves is insufficient, it is recommended additional tests to be carried out at the top gear or again at the direct drive but with other loads and the result of them to be added to the available results. For instance, in Fig. 3 the curves $P_{e1} \ldots P_{e5}$ for the same load and gear, but with increased coefficient of rolling resistance $f_0$ on low speed are plotted.

Figure 4. Fuel consumption chart of an internal combustion engine [4]

Figure 5. Method of plotting the curves of the fuel consumption chart of an internal combustion engine
Then, for movement of the road train at constant speed, i.e. for each row of Table 4, the curve \( g_f = f(M_m) \) should be plotted, Fig. 5 a. After that, different values of the specific fuel consumption \( g_f \), for instance \( g_f = \text{const}_1, [g/kWh] \) should be set. For instance, from Fig. 5 a the values of engine moment \( M_{m1} \) and \( M_{m3} \), \( M_{m2} \) and \( M_{m4} \), and so on, of the cross points of curves \( g_f = f(M_m) \) and the horizontal line \( g_f = \text{const}_1 \) should be read. By using the values of engine moment \( M_{m1} \) and \( M_{m3} \), \( M_{m2} \) and \( M_{m4} \), and so on, then in the coordinate system \( M_m - o_m \) for different values of the angular velocity of engine crankshaft \( o_m \), the points 1 and 3, 2 and 4, and so on, which correspond to the constant specific fuel consumption \( g_f = \text{const}_1 \) should be put on, as it is shown in Fig. 5 b. After connecting these points, the line of constant specific fuel consumption \( g_f = \text{const}_2 \) should be plotted. The other lines of constant specific fuel consumption may be plotted in Fig. 5 b in the same manner, by using Fig. 5 a and setting another constant values of the specific fuel consumption.

Finally, the curve of external engine moment \( M_m = f(o_m) \) should be plotted in Fig. 5 b.

**3.3. Instructions for practical using of the fuel consumption chart of the internal combustion engine**

The so mapped fuel consumption chart of the internal combustion engine may be used for determining the optimal regime of movement of the road train on highway.

For instance, for a given speed of motion \( v \), firstly by Eq. (10) the angular velocities of the engine crankshaft at each gear ratio should be calculated. Then, having in mind the said above in p. 3.1, the effective engine power and by Eq. (12) – the external engine moment \( M_m \) should be determined for each of them.

After that, the sum of forces of resistance should be calculated:

\[
F_f = F_l + F_{w_x} + F_{p,dn} = F_w + F_{w_x} + F_{p,dn}[N].
\]

The power consumption \( P_w \), in \([kW]\), should be calculated by Eq. (9) and then by the dependence

\[
P_w = \frac{P_f}{\eta_f}, [kW],
\]

the required engine power \( P_m \), \([kW]\), should be determined. To be it possible the road train to move at a certain gear, the received here required engine power \( P_m \) should not exceed the external engine power, determined for the angular velocity of the crankshaft at this speed of motion.

Finally, by using Eq. (13), the values of the engine moment \( M_m \) at constant power \( P_m = \text{const}_1 \), required to overcome the losses of power in motion at the constant speed \( v \) relevant to each gear, should be calculated and these values should be plotted in the fuel consumption chart, see Fig. 4, in accordance with the instructions given in p. 3.2.

Optimal will be this regime of motion, when the curve \( M_m = f(o_m) \) passes the area with the lowest specific fuel consumption. For instance, in Fig. 4 this is the regime with coordinates \((o_m, M_m)\).

**4. Conclusions**

In this paper the structure of an advanced communication system for increasing the efficiency of road trains on highways and the type of sensors necessary for its successful operation are determined.

A method of investigation of the efficiency of road trains on highway on the base road tests through an advanced communication system is proposed, which makes it possible to increase the efficiency of road trains on highways.

**5. Acknowledgements**

The investigations in the paper are accomplished by virtue of the financing based on the Contract No. ДДВУ 02/51 on 20.12.2010 of Bulgarian Science Fund.

**6. References**


