FORECASTING OF FUEL CONSUMPTION
BY USING DEDICATED ONLINE SUPPORT SYSTEM

In this paper a dedicated online support system has been described. The system was developed to forecast a fuel consumption by buses and to support determination of fuel consumption standard. The system, based on route characteristics, vehicles parameters and information dealing with the driver style and skills, make it to forecast the fuel consumption possible. As a part of a study, formulas describing correction factors of fuel consumption and its forecasting have been estimated. The system has been developed in PHP environment, HTML, CSS technology and MySQL relational database.

INTRODUCTION

The fuel consumption forecasting is complex and difficult process to implement for the reason that there is no clear pattern defining the fuel consumption of vehicles of various types. On the market there are significant differences between the various types of vehicle operating conditions and other factors. To estimate the amount of fuel consumed by a vehicle, a number of factors and input data should be taken into account. Such factors are, for example [12, 13]:

- the length of the route,
- ambient temperature,
- changes in potential and kinetic energy of the car,
- the boundary traffic conditions,
- intensity of the direction of movement changes,
- thermal state of the engine,
- road surface,
- the degree of vehicle load,
- driving technique,
- the efficiency of the drive system [9],
- the state and the type of vehicle tires,
- the impact of wind speed and direction.

The amount of fuel consumed is influenced by many factors. The main of them include: maneuvering factors (forced stops and stream of traffic difficulties during the course such as entry and exit from the bus stop, parking, intersections, traffic jams and random events), resistance related to the movement of the vehicle and route, thermal stabilization of the engine, technical condition of the vehicle, experience of drivers and their driving technique [14, 15].

This article presents one of the possible methods of forecasting the actual fuel consumption by the vehicle. This method can be used in guidance systems designed to optimize the fuel consumption standards. The method of determining the mathematical model that maps the natural fuel consumption of the vehicle on a specified route has been discussed. A dedicated system for determining fuel consumption standards for the route, the vehicle and for driver has been developed.

1. MATHEMATICAL MODEL REPRESENTATION OF THE FUEL CONSUMPTION

Despite the fact that in the literature there is no formula that uniquely enables forecasting, you can attempt to formulate it in a way that is easy to implement in a computer-aided system. Individual steps of calculations that must be performed in order to estimate the fuel consumption are shown in Figure 1.

For each course of the vehicle, the calculations used to predict actual fuel consumption may be performed in the same way. In the first step the travel time, measured in minutes, has been calculated. Then, the information about route has been read off. Its length, amount of stops, the amount of light signals, amount of turns on the road, speed bumps amount and type of route which is associated with an appropriate correction factor. On the basis of the travel time and the length of the route, the average speed has been calculated and it is described by the formula:

\[ v_a = \frac{L_r}{t_t} \text{ [km/h]} \]  (1)

where:

- \( v_a \) – average vehicle speed [km/h],
- \( L_r \) – length of the route [km],
- \( t_t \) – travel time [min].

Then, the data about the vehicle has been read off: the fuel consumption at a standstill, the route of urban and extra-urban, weight and overall, vintage production and vehicle mileage. Based
on the previously calculations from the formula (1), average speed and fuel consumption for urban or inter-urban routes has been made.

Fuel consumption is affected by the technical condition of the vehicle, so the appropriate correction factor should be calculated to determine it. The simplest method is to establish an additional factor - the calculated correction factor of the fuel consumption relating to the technical condition of the vehicle (in this case, the value may be taken experimentally, and it is signed as \(c_s\) value can be taken for example as 0.02), and multiplying this factor by an estimated decrease of the feature values which describe the condition of the vehicle. Equation (2) describes the calculation of the correction factor for the technical condition.

\[
c_f = 1 + \left( c_1 \cdot (d_a - d_p) + c_2 \cdot \frac{p}{l_{pr}} \right) \cdot c_s
\]  

(2)

where:
- \(c_f\) – correction factor of fuel consumption, depending on the condition of the vehicle,
- \(c_1\) – coefficient relating to the level of use of the vehicle depending on the date of vehicle manufacture,
- \(c_2\) – coefficient relating to the level of use of the vehicle depending on the number of kilometers, where: \(c_1 + c_2 = 1\),
- \(d_a\) – current year,
- \(d_p\) – date of the vehicle production year,
- \(p\) – current mileage [km],
- \(l_{pr}\) – the estimated number of kilometers driven per year at low intensity of operation [km],
- \(c_s\) – correction factor depending on the state of the vehicle.

In the next step the maneuvering fuel volume has been calculated. In this step, information about the route describing its course, such as the number of stops, the amount of traffic, number of bends, the number of bumps and estimate the amount of fuel consumed on individual traffic flow difficulties, has been used.

In the publication [3] the author describes the amount of fuel assigned to individual maneuvering activity. It can be assumed that the period of time spent at each stop is an average of 10 seconds while at crossroads with traffic lights 15 seconds. On this basis, the model calibration in real conditions and selection factors presented in the formula (3) determining the volume of fuel falling on performed maneuvers has been made [10, 12]:

\[
G_m = 0.02\,dm^3 \cdot q_s + 0.01\,dm^3 \cdot q_s + 0.0026\,dm^3 \cdot (q_t + q_{sb}) + \frac{f_s}{6} \cdot (q_s + 0.5 \cdot q_{sb})
\]  

(3)

where:
- \(G_m\) – maneuvering fuel volume [dm³],
- \(q_s\) – the number of stops,
- \(q_t\) – the number of traffic lights and subordinated intersections,
- \(q_{sb}\) – the number of turns on the road,
- \(f_s\) – the amount of consumed fuel during one minute stop [dm³].

Calculation of the amount of fuel used to run with greater mass than expected producer during the tests (included only vehicle weight and mass of the rider) is based on a calculation of the maximum load capacity of the vehicle and its average filling. Sometimes it happens that sometimes the vehicle is running almost empty, and sometimes overloaded, but on average, the unloaded routes vehicle is not fully charged. Assuming the filling level of the vehicle, an additional mass of the vehicle can be calculated from the formula (4).

\[
w_{add} = f \cdot (w_i - w_p - w_d)
\]  

(4)

where:
- \(w_{add}\) – additional weight [kg],
- \(w_i\) – total vehicle weight [kg],
- \(w_p\) – vehicle weight [kg],
- \(w_d\) – the weight of the driver [kg],
- \(f\) – filling level of the vehicle, where 0.00 is an empty vehicle and 1.00 is fully loaded vehicle.

Additional weight based on of calculated formula (4) were used. The volume of consumed fuel attributed for each additional 100 kg, while driving loaded vehicle, has been calculated. This value was set at 0.5 dm³ / 100km [5]. For the entire length of the route this volume can be calculated by the formula:

\[
G_k = \frac{w_{add} \cdot 0.5}{100\,kg} \cdot \frac{dm^3}{km} \cdot \frac{L_r}{100}
\]  

(5)

where:
- \(G_k\) – the volume of fuel consumed on the whole route driving loaded vehicle [dm³],
- \(w_{add}\) – additional weight [kg],
- \(L_r\) – length of the route [km].

However, in relation to the vehicle or the driver, the formula referring to the distance 100 km takes the following form:

\[
G_k = 0.5\,dm^3 \cdot \frac{w_d}{100\,kg}
\]  

(6)

where:
- \(G_k\) – the volume of consumed fuel for a driving loaded vehicle [dm³],
- \(w_d\) – additional weight [kg].

Taking the values resulting from the formula (5) or (6), the consumption can be ultimately estimated on the basis of the equation:

\[
g_c = s \cdot c_t \cdot c_{md} \cdot c_s + G_m + G_k
\]  

(7)

where:
- \(g_c\) – forecasted fuel per unit consumption [dm³/km],
- \(s\) – vehicle fuel consumption by the producer [dm³/km],
- \(c_t\) – correction factor for the type of the route,
- \(c_{md}\) – correction factor for the method of driving,
- \(c_s\) – correction factor of fuel per unit consumption, depending on the vehicle technical state,
- \(G_m\) – maneuvering fuel volume [dm³],
- \(G_k\) – the fuel volume of fuel per unit consumed to drive a loaded vehicle [dm³/km].

Formula (7) consists of all the most important factors affecting the quantity of consumed fuel. However, the impact of thermal stabilization of the engine and the vehicle, and the ensuing extra fuel, can be ignored. It can be done because these do not have a significant impact on changing the fuel consumption of the vehicle moving on long distances.

In the initial period of system implementation it is not recommended to determine the standards but spend this time to input data into system. The more data there is in the database the more accurately the system can certainly determine the standard.

The system standards are set individually for each route, vehicle and driver. They are recorded in a permanent way - there is no
possibility to undo a standard or delete it. You can only enter a new one. The aim of this solution is to maintain assigned archival values and to prevent cheating the system by editing the previous standards.

The system always proposes the same standard after the compilation. It is calculated, on the basis of the average of actual consumption and previous standards, using the formula (8).

\[ S_n = 0.5 \cdot \left( \sum_{i=1}^{n_c} F_c + S_o \right) \]

(8)

where:
- \( S_n \) – the new proposed standard [dm³/100km],
- \( n_c \) – number of courses,
- \( F_c \) – actual consumption for the course [dm³/100km],
- \( S_o \) – earlier standard [dm³/100km].

The use of the above method of calculating the new standard narrows the range of permissible limit of divergence, with every next step allows achieve the optimum. The proposed by the system standard is not the binding norm because it can always be changed by the system administrator. Its value can be increased - a lighter fuel policy and reduced - tough policy. At the same time, it is not recommended to reduce the value of standards, since this may result in the determination the standards, which are realistically impossible to achieve. Decisive is always the person managing the system which has to take a decision for the appropriate standard. The developed system is an auxiliary – advisory factor. It shows on what pay the attention, predicts the real-time fuel consumption and presents its results, while the final interpretation rests with the man.

The entire database structure is based on the relationship between the tables. They are related to each other by means of primary keys and foreign keys [2, 9]. In order to simplify the structure of the database a solution in which each record in the table has its own unchangeable ID has been used. ID number is automatically created by the MySQL database when every new data is input. This result was obtained by assigning the auto_increment values to fields like id_route, id_driver, etc. The database automatically completes the contents of the field by number 1 greater than the last. Thanks to this, the system does not need to generate the ID number by itself, check it or correct the removal of records from the database. During relationships creation between data from different tables the system reads the ID, in which is interested in, by referring in the newly created record. ID function as primary keys and foreign keys – it is why they are indexed data in the tables.

2. DESCRIPTION OF THE SYSTEM

As part of the study a system, whose aim was to standardize consumption of fuel in real-time, forecast fuel consumption on the specified routes for the individual courses and forecast the optimal standard based on the analysis of previously entered data, has been created. In additional, the program can be used to indicate vehicles abnormal fuel consumption, so it is possible to systematically select the fleet which is optimal for a given route.

Reporting module shows the drivers who distinguished themselves from the others, overvalued / undervalued fuel consumption, which in turn allows to choose who should be trained in the subject of efficient driving and people who might steal fuel. These are additional advantages of the proposed system.

Discussed system has a modular structure [1], work is more intuitive, and the system can be developed and new modules can be implemented in the future. The system consists of five basic modules further divided into sections. Figure 1 shows part of an interface, system menu with its modules.

2.1. Routes management module

This module allows describing the relevant information about the route. The first section, "types of routes" corresponds only with the introduction of an additional correction factor for the route. Additional, since it is not a factor determining the urban route or outside the city route (these types of routes are identified automatically by the system on the basis of the average speed, and allows to choose the fuel consumption specified by the manufacturer for a given speed), introduced in this section factor can accurately correct the forecasted fuel consumption. For example, if the vehicle runs within the city, the system automatically selects fuel consumption for urban driving, but there are additional factors affecting on fuel consumption, such as driving on a hill, the poor condition of roads, traffic jams, etc. Therefore, this type of route has to be additionally distinguished and an individual factor should be inserted for each of the route type. Such a solution allows to accurately calculated fuel consumption and each route will be individually monitored.

The second section of discussed module, the "Routes" module, describes its parameters. Here the most important route information such as name, length, number of stops and the data which accurately describe the route (the number of traffic lights, turns, speed humps) are introduced. The last parameter is the type of route and it refers to the correction factor from the previous section.

2.2. Vehicle management module

Vehicle management module is used to enter the information about company's fleet. "Vehicle Brands" section allowed to enter specifications of vehicles such as brand, fuel consumption at a standstill and in urban and extra-urban cycle, the vehicle weight and total vehicle weight. Section "Vehicles" was used to supplement the

![Fig. 1. Interface part - system menu with modules: 1 - Routes management module, 2 - Vehicle management module, 3 - Drivers management module, 4 - Courses module, 5 - Reporting module](image-url)
individual characteristics of the car such as production year, mileage, car registration number and, in additional, the number of seats and standing places. The last step was to select from previously entered brands, the one which determines the current introduced into the base vehicle.

2.3. Drivers management module

It consists of a section responsible for the driving style and section where information about driver can be input. "Driving style" section allows you to specify the style of driving and assign a correction factor. It is very important because the way of driving has the greatest impact on fuel consumption, and according to A. Ubysz [17, 18], correction factor varies between 0.9 - 1.3.

Therefore, the importance of the person skills of economical driving and the importance of this factor in the calculations which forecast fuel consumption can be seen.

The second section of discussed module focuses on personal driver data. It allows entering information such as name, address and date of issue a driving license, the number of collisions and others. It also allows link the driver with driving style which has been specified in an earlier section of the module.

2.4. Courses module

Courses module is a single section module, but it combines information from all earlier discussed modules. The purpose of this module is to entered information into a database about each course. This information is entered manually but, when the program will be more developed, automatic data transfer from the vehicle to the system after the completion of each course should be possible.

The module allows the data introduction to specify the date of course execution or departure and arrival time. The information about heating temperature or air conditioning, and the initial temperature in the vehicle and on the outside, it is information which can be entered to the system but not used in this version of the calculations. It will be possible to implement in the future developed system so this information will be used to calculate the time needed to thermal stabilization of the engine and vehicle heating.

Further information about the course are: stopping time (total time of forced stops of the vehicle with the running engine), and actual fuel consumption at the end of the journey. In the last step, there are introduced the data which defines the route, the vehicle and the driver. Therefore, relationship of the course with the previously entered data is taken - relational structure.

2.5. Reporting module

Reporting module is the main module which allows creating lists and assigning the fuel economy standards. When report for the route, the driver or the vehicle system is selected, a system displays a ready-made list. At the beginning of each report, they are given information such as: information about the selected route (its name), route type, length, number of stops and other information which describes it in more detail.

If the date and / or the time interval, for which you want generate a report, has been selected, that information will be displayed. Otherwise, information that the report applies to all courses that are in the database, regardless of the date and time, will appear. After displaying this information, the system will generate a table of the courses (Fig.3). This table contains the date, exact time of departure and arrival, vehicle registration number, information about the driver and the actual fuel consumption for the execution of the course.

The next column of the table contains the value of consumed fuel which is calculated by the system. In the last column of the table there is a standard entered by the user of the system. Already at the stage of generating tabulation system clearly indicates exceeded standards and indicate courses in which the actual fuel consumption is greater than forecasted.

In the column "calculated consumption" in green have been marked fields where the calculated fuel consumption are lower from the real. These fields are marked regardless of the established norm. It allows immediately notice possible overruns of the amount of used fuel. If the norm has already been introduced, the column marked as "actual consumption" is subjected to an automatic analysis and verification with the entered norm.

In the case of values exceedance, the table field is marked with

Fig. 2. Screenshot for routes management module, the section describing the route parameters
an appropriate color depending on the exceeded value. The more navy blue is the color the greater is exceeded standards. Values exceeding associated with colors are shown on a legend under the table:

- 0.2% overruns of the norm – sky blue color,
- 5% overruns of the norm – light blue color,
- 10% overruns of the norm - blue color,
- 20% overruns of the norm – dark blue color,
- 50% overruns of the norm – navy blue color.

Thanks to the determination of the color scale appearance of the compilation is more transparent, it can be quickly spot the most important norms exceeding and pay less attention to these which are marked by a lighter color.

In the case of small exceedances can be deduced that they were caused by additional difficulties during the vehicle movement or excessive driving dynamics. The exceedances marked in dark or

### Table 1: Summary of Route Exceedances

<table>
<thead>
<tr>
<th>Date</th>
<th>Start Time</th>
<th>End Time</th>
<th>Overrun</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>2023-01-01</td>
<td>06:00</td>
<td>07:30</td>
<td>0.3%</td>
<td>sky blue</td>
</tr>
<tr>
<td>2023-01-02</td>
<td>07:00</td>
<td>08:30</td>
<td>2.5%</td>
<td>light blue</td>
</tr>
<tr>
<td>2023-01-03</td>
<td>08:00</td>
<td>09:30</td>
<td>5.0%</td>
<td>blue</td>
</tr>
<tr>
<td>2023-01-04</td>
<td>09:00</td>
<td>10:30</td>
<td>10.0%</td>
<td>dark blue</td>
</tr>
</tbody>
</table>

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**Fig. 3. A sample screenshot of the route report**

**Fig. 4. A sample screenshot of the route report - fuel consumption graph**
nagy blue can indicate unusual problems such as forced stops, traffic jams, car crashes along the route, vehicle overload, excessive usage of heating or air conditioning or even a case of fuel theft.

In the case of repeated exceedances at similar hours, it is recommended to create an additional report limited by range of hours, so it can be more clearly visualize exceeded norms and determine if it is a repeatable process, resulting for example from rush hour, or if it was only several times when the norms were exceeded for other reasons.

In a report for the route, other possible problems of exceeded standards may appear. Different vehicle brands have various consumption of the fuel. This problem is illustrated in diagram (Fig. 4) which is also a part of the report.

A graph is always automatically generated for each report. In the attached example, significant differences in the amount of fuel consumed are shown. When compare these differences to vehicles and drivers, will be notice that the increased fuel consumption associated with another vehicle and the driver. In such a case it is recommended to interchange the drivers of the vehicles with each other and further observation of the results. If overruns of norms will still occurred with another vehicle, lack of skills of economical driving can be deduced. Otherwise, if the change does not show the difference, it is obvious that the reason of an overrun is vehicle, that may be in a bad technical condition. On the basis of these conclusions, appropriate steps such as driver training, vehicle repairs or buying new ones - more efficient, can be made.

In Figure 4, at course number 19, jump of actual fuel consumption of about 2 liters can also be seen. Such jumps can be important, because if it will repeat, for courses operated by the same driver, it can mean the fuel was stolen. A particular attention to this type of exceeds should be taken in such situations. It is good, in cases like this, to perform additional report for the driver and pay attention to its individual overruns, and then on the graph and in the table the jumping fuel consumption can be seen.

CONCLUSIONS

The task of discussed system is to determine the optimum fuel standards, assist in the management of these and locate the overruns or inaccuracies. Fuel consumption by vehicles has a high share in total costs incurred by transport companies, so it is essential to rational management and control of fuel consumption. Such control is even more important when dealing with the larger company. However, it is not possible to supervise this process, only by the man, because the amount of information that must be taken into account and the number of calculations that must be made in order to correctly estimation, the amount of fuel consumed by a vehicle is too high.

To supervise companies involved in public transport there would have to be a large department dealing just with problem of fuel consumptions. Current technology development can replace the work of many people thanks to advisory systems like presented one. Such systems offer the processing and analysis of input data in real time. Designed and discussed in this paper system shows one of the ways to optimize fuel consumption standards.

Analysis of the calculated combustion based on: route, vehicles, drivers and individual courses - the process of learning the database - to make forecasting calculations, what should be the fuel consumption of the vehicle and perform a comparative analysis of the calculated combustion real.

After data entering such as route, vehicles, drivers and individual courses (database learning process), the system allows making forecasting calculatins, what vehicle fuel consumption should be, and performing a comparative analysis of the calculated and real combustion. The system generates reports in real time according to the criteria specified by the user. This allows for constant control over consumed fuel. By using this system it is possible to draw appropriate decision-making conclusions and take reasonable steps to achieve them. It is also possible to improve the weakest links which contribute to increasing fuel consumption in the company. Other advantages of the system are:

- finding vehicles that consume too much fuel,
- determining the most economical vehicles configuration,
- finding drivers who cannot drive economically,
- pointing drivers characterized by the most economical driving,
- defining hours, in which there is the greatest crowding on routes,
- pointing of possible cases of fuel theft.

It can be seen there are many advantages of introducing such systems to the company, and for a longer period of usage it is possible to improve the operations of the company, optimize solutions and thus reduce the cost of the entire company.

BIBLIOGRAPHY

W niniejszym artykule opisano dedykowany system on-line, który został opracowany w celu prognozowania zużycia paliwa przez autobusy ibusy oraz w celu wspomagania doboru norm zużycia paliwa. System wykorzystuje charakterystykę trasy, parametry pojazdu oraz informacje o stylu jazdy kierowcy w celu prognozowania zużytego paliwa. W ramach przeprowadzonych badań wyznaczono wzory odpowiadające za ustalanie współczynników korekty zużytego paliwa wykorzystywanych podczas prognozowania. System został napisany w języku PHP przy wykorzystaniu technologii HTML, CSS oraz relacyjnej bazy danych MySQL.

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