INFLUENCE OF GPS TECHNOLOGY ON COST CONTROL AND MAINTENANCE OF VEHICLES

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***Abstract**: Quality control of vehicle costs requires the modelling of normed fuel consumption which expresses fuel quantity in regard to tracking indicators such as the engine operation, travelled path length and burden mass, for each unit of vehicles and a certain working task. How much the applied IT technology of satellite navigation, such as the Global Positioning System, can contribute to a reliable determination of effectiveness and efficiency parameters in city logistics systems? Especially for the parameters of vehicle running costs in the waste collection system. This paper gives a software model to determine the normed fuel consumption of the complex waste collection system based on the GPS application and logistics experience. Influence of the tracking parameters on the accurate determination of essential elements to assess the efficiency of process is shown. Also, the paper shows importance of the vehicle electric supply system for the exact calculation of efficiency indicators. The paper indicates advantages and imperfections of a chosen logistics system and how some imperfections can be overcome. Using the software obtained tracking parameters we can make the diagnostic decisions in maintenance and thus perform the quality maintenance management of refuse collection vehicles system.*

Keywords: *logistics system, tracking parameters, running costs, maintenance, refuse collection.*

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1. INTRODUCTION

The Global Positioning System (GPS) is universal logistic support for monitoring the moving objects in city logistics systems. It is also in the solid waste management system, especially in the waste collection process where moving objects are the refuse collection vehicles (RCV). GPS tracking parameters also contribute to detect the imperfections of technical systems on vehicles such as the system for battery charging (generator and voltage regulator). GPS diagnostics can be a significant support to a timely implementation of maintenance procedures as well as cost control of vehicles.

Life cycle costs can be generally divided to the purchase costs, running and maintenance costs. According to the research [1], the most important costs of vehicle life cycle are the running or operating costs and they are shown in the example of RCV. The operating costs take almost one half of total costs (Fig. 1) and they mainly contain the engine fuel costs, insurance and registration costs and costs of workers' salaries. In Fig. 1, one can see that the fuel costs are the most important singular costs after the purchase costs because they take almost a quarter of the total refuse collection vehicle costs. Therefore, the optimal management of running costs, especially fuel costs, is a permanent goal in the realization of efficient working process. The optimization of these costs requires answers to some questions. Which GPS tracking parameters should be chosen for the efficient control of running costs? Does the effective fuel consumption is the optimal one in the same time? How much reliable are the obtained tracking parameters for further use in the cost optimization process?

One aspect of the IT technology application (GPS tracking) is shown in this paper. It is the implementation of reliable key parameters in the vehicle tracking process. Some applications of GPS technology as a tool for vehicle diagnostics are shown also in the paper within several typical case studies.

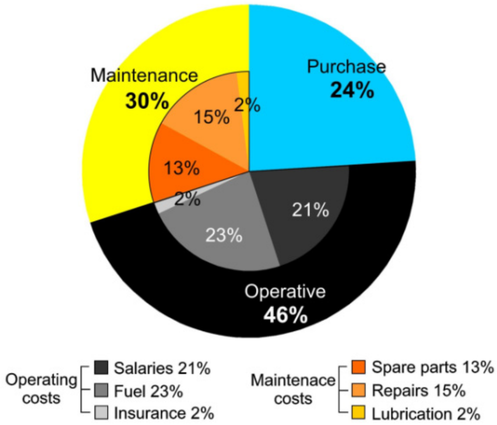

Figure 1. Life cycle costs structure of refuse collection vehicles

2. GPS TRACKING PARAMETERS

By installing additional sensors/encoders on vehicle, the GPS tracking of parameters such as motor fuel consumption (flow meter), change of fuel level in tank (capacitive sensor), cargo mass in transport or loading (weight sensor), available volume of cargo space (volume encoder) [2] and pressure in hydraulic system (pressure transducer) is enabled. The use of more additional sensors/encoders corresponds to vehicles with a superstructure such as RCV, and it depends on the input-output (I/O) capacity of tracking device.

A significant vehicle fleet efficiency indicator is the motor fuel consumption per quantity unit of transported burden, travelled distance and working hour. In the logistics systems of service activities such as the supply chain system or the waste collection system, a significant efficiency parameter is the fuel consumption per unit of transported goods, row material, waste and service, [3].

The city logistics systems, such as the waste collection system, are spatially limited most often by size of a city, city quarter or district which implies the use of vehicles with frequent stops and engine operation without moving. Therefore, the indication of fuel consumption per engine-hour corresponds to these logistics systems. The RCV operates most often in the moving regimes with frequent short breaks due to the waste loading. Driving engine uses also for moving the executive devices on vehicle which requires its work during these moving breaks of vehicle. The operating – exploitation fuel consumption depends on objective (engine type, traffic congestion, topography, weather conditions, etc.) and subjective (vehicle handling, routing) factors. The fuel consumption is an exploitation vehicle parameter which can be variously traced depending on an applied technological solution.

Modern standard measurement of fuel level is performed by transferring signals from the level tank sensor via the controller area network bus (CAN). Accuracy of these standard measuring systems is limited to 90% due to the impossibility of fuel level measurement at the top of tank [4]. A more precise measurement of fuel level in tank, with an error less than 1%, [5], requires the use of capacitive sensor. On the other side, a direct measurement of fuel consumption is based on the measured difference of fuel flow in the intake and return branch. By observing the fuel consumption at time unit and the level state in fuel tank, eventual irregularities (and misuses) in vehicle exploitation can be determined. In the absence of direct measurement with the flow meter, the operating fuel consumption is calculated using the GPS tracking parameters i.e. the distance travelled and engine operating time.

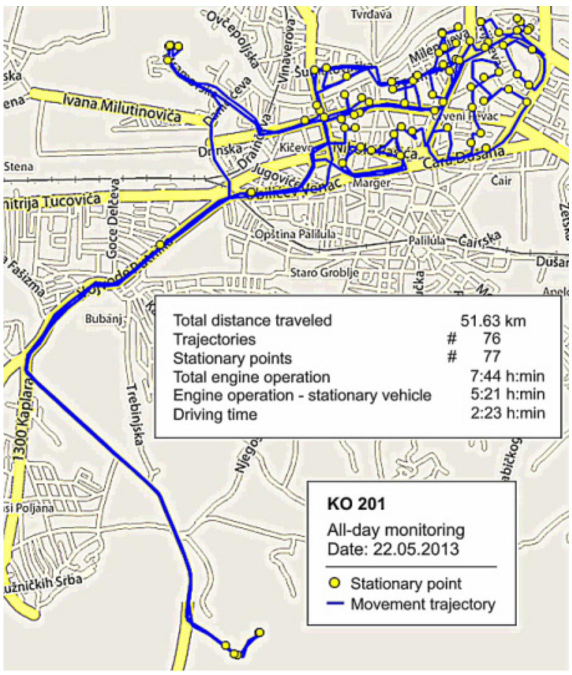

Figure 2. An all-day route of a refuse collection vehicle

The distance travelled is measured by odometer and it is a systemic parameter in GPS that is obtained by comparing the current position and initial - previous position (longitude, latitude and altitude) according to the terms of geo-referential mapping. A route of the refuse collection vehicle KO-201 from the vehicle fleet of the company Mediana-Niš, Fig. 2, was obtained by an all-day GPS tracking using software [6]. The total distance travelled was consisted of 76 elementary trajectories and 77 stationary points. The tracking device Teltonika FM4200 with voltage range of 10÷30 V and max consumption of 250 mA was used in the vehicle tracking process.

The engine operating time (mh – motor hour, engine hour) can be measured using the engine-hour meter (general solution) and GPS (modern solution). The measured engine operating time by software GPS application depends on a global time which is a satellite-measured time and other I/O parameters such as contact, number of crankshaft revolutions and battery voltage. Is the "contact" time identical to the engine operating time? Can it be taken as an accurate engine-hour indicator?

3. USE OF GPS DIAGNOSTICS IN VEHICLE MAINTENANCE – CASE STUDIES

The electric power supply system of vehicle is playing an important role in the GPS monitoring so it is necessary its permanent maintenance. A nonconforming unit of the system (generator, voltage regulator, battery) can cause the irregularities to determine the significant parameters of vehicle tracking. Such significant parameter is the battery voltage, which if takes value lower than default, then can lead to the error of engine operating time as well as fuel consumption calculation.

The three case studies of characteristic conformity states of the electric power supply system in vehicle are shown hereinafter. The following diagrams show the time records of tracking parameters change obtained by the GPS technology. In the next diagrams, Fig. 3-5, two each of measurements are shown together, as the measurement of battery voltage change and the measurement of contact state in a given time range. In the same time, these diagrams are the diagnostic tools to detect the irregularities of electric power supply system in vehicle.

In the first example of GPS diagnostics, Fig. 3, an often case of nonconforming system to charge the battery in vehicle – the impulse charging is shown. The battery has alternative charging and discharging which can be cause by nonconformity of some elements of electric power supply system in vehicle. The occurrence of error in the automatic calculation of engine hours is a consequence of the impulse battery charging if the software has a predefined default value of the limit battery voltage. Then, the voltage higher than the limited (e.g. 26.5 V) implies turned on vehicle motor, while the voltage under the predefined limit indicates turned off engine, Fig. 3 on the below. In the same time, the contact diagram, Fig. 3 above, shows the total engine operating time.

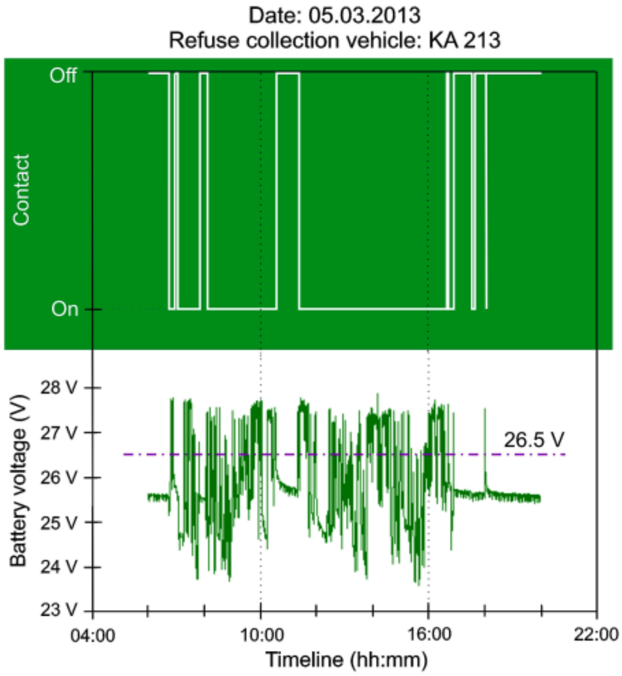

Figure 3. A problem of impulse battery charging

This is a good example that two different parameters, the engine contact and battery voltage, can give a significant difference of engine hour values which influences to the calculation of normed fuel consumption. If the analyst dispatcher relies on the total engine operation time of 3 hours, obtained from diagram in Fig. 3 on the below, it will not have a realistic insight to vehicle performance as well as the fuel consumption which will be then significantly higher per unit of time. On the other side, if the contact data is taken, Fig. 3 above, one can see that the operating time of vehicle amounted 8 hours. However, even this data is not completely objective because it may contain the contact time without starting the engine. Nevertheless, the contact time criterion has a much greater precision to calculate the engine operating time in relation to the battery voltage criterion, in this example.

The following example indicated the absence of battery charging during all operating time of vehicle, Fig. 4. Prior the morning starting of engine, the battery unit voltage had a satisfactory value slightly higher than the nominal U_n = 24 V. This data indicated the system conformity. However, the engine starting was not successfully and it required the use of auxiliary methods which caused the expressed impulse battery discharge (area of largest discharge at start up, Fig. 4 on the below).

By observing Fig. 4, one can see that the battery charging system had nonconformity, at all operating time of the vehicle, which caused the voltage drop in the battery (discharging) even to the value of 10 V, in the area of largest operational discharge. During that time, the contact diagram from Fig. 4 showed the engine operation at voltages lower than the limit. With the reliability aspect, it had a higher probability for the complete battery discharge. If the next measurement will indicate the voltage lower than 12.4 V, which is the limit voltage of lead batteries, then the battery will not be a good further to use.

In the case study from Fig. 4, the preventive maintenance of electrical installation in vehicle was not good, so the unnecessary costs occurred as the consequence of bad decisions in the maintenance. Using the limit voltage method (mentioned voltage of 26.5 V), also according to the voltage diagram from Fig. 4 on the below, here we would not have got the operating engine hours contrary to the contact diagram where we can determine the operating time around 5 hours. The "contact method" was a more reliable method than the "battery voltage method" and in this case.

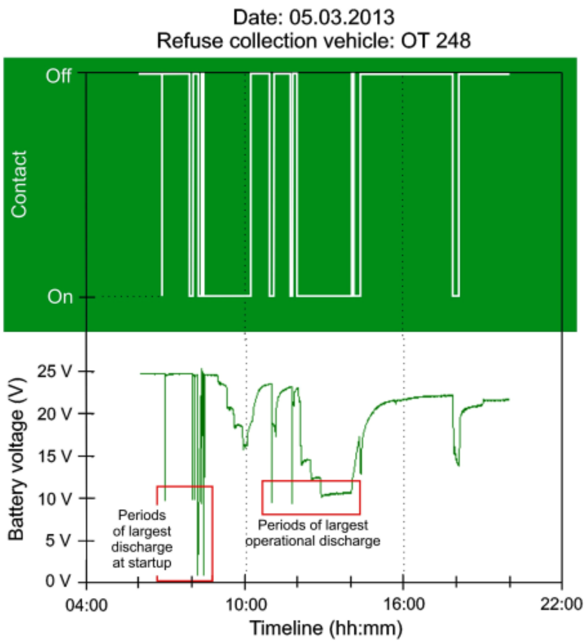

Figure 4. A problem of continuous battery discharge

The superposition of battery charging time and contact on time is clearly seen in Fig. 5 ("voltage" on the below, "contact" above). It speaks that the contact on time is identical to the operating engine time. The electric power supply is stable with small oscillations in the highest voltage area (close to 28.2 V). The battery voltage declines gradually, but it does not exceed below the nominal value i.e. $U_{\min} = 25.44 > U_n = 24$ V in the idle engine time (contact = off).

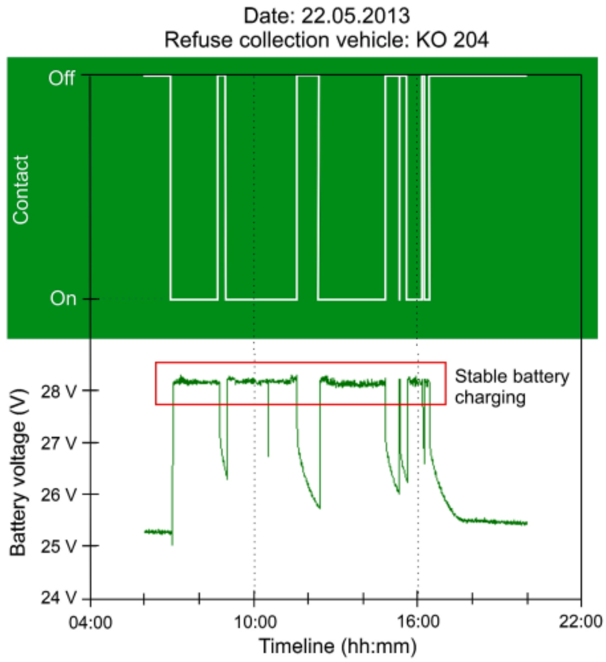

Figure 5. An example of good battery charging system

It can be concluded, from Fig. 5, that the battery structure is quality and allows the predicted range of limit voltages, which means that the battery "keeps" voltage. Therefore, this diagram indicates the complete conformity of system for electric power generation and energy storage in the vehicle. Data about vehicle tracking parameters, obtained using such example, are reliable and they can be unambiguously used to calculate the normed fuel consumption.

4. A MODEL FOR FUEL CONSUMPTION ANALYSIS

Using Eq. (1) to (3), the calculation and comparison of effective and normed fuel consumption, for a selected driver d, can be theoretically described as:

$$D^d = F^d - N^d \,, \tag{1}$$

$$F^d = \sum_{k=1}^{t} \sum_{j=1}^{r} \sum_{i=1}^{p} F_{ijk}^d \,, \tag{2}$$

$$N^d = \sum_{k=1}^{t} \sum_{j=1}^{r} \sum_{i=1}^{p} n_{ij} E_{ijk}^d \,, \tag{3}$$

where D is the difference between the realized F and normed N fuel consumption in litres per month; i, j and k are the subscripts that denote respectively the number of vehicles in work "i", the number of working areas - tasks "j", the number of a vehicle working days per month "*k*"; *n* is the norm of fuel consumption in l/h per vehicle "*i*" and working area "*j*" and *E* is the vehicle operating (effective) time that is obtained using GPS or tachometer record in hours (h).

Here, it should be distinguished from each other the total vehicle working time *W*, which contains the breaks of engine operation, and the vehicle effective time *E* when is the driving motor turned on and the vehicle consumes fuel. The calculated difference *D*, Eq. (1), determines the fuel consumption area i.e. the permissible and non-permissible consumption. If is $D \leq 0$, then the fuel consumption is an acceptable consumption. If the difference is within the interval $0 < D \leq 0.1N$, then the overspending of fuel is within the tolerance limits. However, if is $D > 0.1N$, then the overspending is an unacceptable consumption.

A key parameter in the fuel consumption analysis of RCV is the number of engine hours. A large influence on the accuracy of this parameter obtained by GPS technology has the conformity of electric system in vehicle which is considered in the case studies from Fig. 3-5. Since this conformity state is changeable, the model for fuel consumption analysis [7] is designed to perform the parallel computation of normed fuel consumption according to the two data groups of engine hours, obtained by the GPS tracking system and tachometer device. Fig. 6 (table) shows a part of the program report for cumulative fuel consumption per driver (matbr) in an observed period, e.g. monthly. The percentage fuel overspending is software determined for both data groups of engine hours e.g. the tachometric (CF_1) and GPS (CF_2) data, in relation to the normed values (nor_tah, nor_GPS). Of the two obtained percentage values of fuel consumption difference, the lower value (CF_3) is adopted using software [8]. Thus, the drivers with the negative computed differences had the lower fuel consumptions (✓) than the anticipated one, and they with the positive differences, overspending. In the cases of unacceptable consumption e.g. the difference D>10% (✕), the corrective measures were applied while the difference, marked as "?", was located in the tolerance field of exceeding.

matbr (PIN - driver)		utr_gor (l)	nor_tah (l)	nor_GPS (l)	CF_1 (%)	CF_2 (%)	CF_3 (%)	
729	SASA PROKIC	165.56	108.23	134.41	52.97	23.18	23.18	✕
781	DRAGAN STEVIC	195.15	145.93	183.62	33.73	6.28	6.28	?
1500	MILIJA RADENKOVIC	217.40	175.94	172.63	23.56	25.93	23.56	✕
1978	MILISA ZIKIC	140.20	141.40	144.95	- 0.85	- 3.28	- 3.28	✓
2076	ZORAN IVANOVIC	148.34	121.00	134.13	22.60	10.59	10.59	✕
2642	SASA CEKIC	129.68	126.93	133.11	2.17	- 2.58	- 2.58	✓

Figure 6. The program report for monthly cumulative fuel consumption

The fuel consumption analysis is an integral program module to control the vehicle exploitation process in the communal system. The original program code of model was generated in software for standard database management [8]. A part of a module algorithm to determine the percentage fuel overspending using the function CF_1 and CF_2, and the choice of lower percentage value using the function CF_3 is shown as follows:

```
select m.sifoj,r.matbr,
nvl(sum(r.utr_gor),0) GOR,
nvl(sum(TO_NUMBER(i.GOR_TAH)),0)  nor_tah,
nvl(sum(TO_NUMBER(i.MC_NERADI)),0) nor_GPS


from matrad m,rad_vozila r, izvrsenost i
where m.matbr=r.matbr and r.matbr=i.matbr and
r.konto=i.konto and r.datum=i.datum
and r.datum>=:od and r.datum<=:do
group by m.sifoj,r.matbr
order by m.sifoj,r.matbr
```

```
function CF_1Formula return Number is
begin
    return ((:gor-:nor_tah)/:nor_tah)*100;
end;

function CF_2Formula return Number is
begin
    return ((:gor-:nor_GPS)/:nor_GPS)*100;
end;

function CF_3Formula return Number is
begin
    if :CF_1>=:CF_2 then
        return :CF_2;
elsif :CF_1<:CF_2 then
        return :CF_1;
        end if;
end;
```

5. CONCLUSION

GPS technology contributes to better cost control of vehicles – cost reduction. Hence, the monitoring tools should be directed to the precise determination of significant tracking parameters. The accuracy of tracking parameters depends on initial setup of predefined sizes. For obtaining a satisfactory accuracy of vehicle operation indicator (engine-hour), the electronic measured data of number of crankshaft revolutions should be used there where it is technologically possible. If it is not possible (for vehicles of older generation), then the cross checking method should be used for more (at least two) of the output GPS parameters (contact, battery voltage, etc.).

A tracking system of vehicles provides a required accuracy of tracking parameters under the condition of eliminated nonconformities of items which imply imperfections of system such as the electric and electronic systems in vehicle, most frequent. This can be achieved by permanent preventive maintenance, especially of the system for charging the vehicle battery as well as the system to protect the GPS tracking device against the impulse voltage overload.

The used GPS technology represents a very good diagnostic tool in the maintainer's hands for detecting the irregularities and nonconformities in vehicles. Using graphical reports – diagrams the nonconformities of electric supply system in vehicle can be detected after which timely the corrective and preventive maintenance decisions can be made.

When choosing a GPS technology, it should pay attention to several important factors. The tracking devices with more input-output ports enable the development of monitoring system. By putting in place new sensors/encoders, the system upgrading is enabled. Also, it is necessary to employ a quality and precise software that allows a comfortable work and a large number of reports. If the dispatch centre of logistics services uses such technology, then the advanced training of employees for working with the technology (software, hardware) should be continuously performed.

The developed logistics model of fuel consumption analysis is a suitable model for application in the city logistics systems which use same vehicles to perform a larger number of different work orders. This model corresponds to the communal systems which perform waste collection on a relative small territory with large population (city, municipality, district, city quarter). The model is developed for use in the logistics-dispatch centre of communal enterprise. The model enables a software support to schedule and analyse the exploitation of vehicles as well as the reporting in all process phases of waste collection (reports: availability of vehicles, implementation of work orders, fuel requisition, GPS tracking parameters, etc.).

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