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Expert Shell for On-line Dynamic Control of a Transportation Process

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Abstract*— New technologies reach public utility enterprises with difficulty and are slow in finding their everyday application in less developed cities and municipalities in Serbia, particularly when it comes to the utilities of public interest to urban areas. Certain developmental attempts to introduce new technologies have provided initial results, primarily in increasing the effectiveness and optimization of certain work process costs. These attempts are present in a small number of communities and utility companies. This paper provides an example of an advanced system (expert shell) for controlling the process of solid waste collection and transportation within the fleet management system of a public utility company. Characteristic control methods, which are based on tracking the selected parameters in real-time and post-processing of the realized vehicle routes, are shown in the paper. Part of the original software algorithm to support the monitoring of the system and the analysis of the obtained results is also shown. The paper indicates the importance of using modern GPS technology in improving similar systems of city logistics. The original measured and calculated vehicle tracking parameters were used in the paper.

***Index Terms*— Expert approach, fleet management, GPS application, signal processing, telecommunications.**

I. INTRODUCTION

A waste management system generally includes four main processes of waste handling: storage, collection and transportation, processing and disposal [1]. The process of waste collection and transportation is particularly interesting here because its main cost carriers are transportation objects –refuse collection vehicles (hereinafter: RCV) [2]. Dispatch centers of waste management companies in Serbia mainly organize the work of their vehicles in a conventional manner using radio or mobile connection, tachograph and operational field control. In urban traffic conditions of a large city, the organization of vehicle use is a serious logistic task with the main objective being the reduction of operating costs. Experiences in organizing waste collection and transportation indicate significant costs and not so high quality of service provision. Therefore, greater needs to use modern technologies such as the Global Positioning System (GPS), the Geographical Information System (GIS) and the Radio Frequency Identification (RFID) are obvious. Modernization of a local waste management system requires the synergy of modern technological tools and logistics experiences with their own specificities.

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This is achieved through the development of an expert system (expert shell) for control and preparation of the process of waste collection and transportation which is based on telecommunications and signal processing.

The possibility for the application of GPS technology is nowadays intensively investigated in various scientific fields. A larger number of GPS patent applications are incorporated into practice. One can mention the application of GPS technology in civil engineering, to measure the vibration of engineering structures, such as a longer bridge under the influence of a dynamic load, [3], or to determine the dynamic responses of tall buildings (above 150 m) under the influence of wind, [4,5]. Some studies suggest a possibility for application of an integrated GPS and GIS technology in the research field of special waste flows, e.g. construction waste flows, [6]. The current studies [7, 8, 9] have found solutions for route optimization in the process of municipal solid waste collection and transportation using the GIS modeling techniques. The researchers, in the field of logistics engineering and material handling, have showed the ability of combined RFID and GPS technology to increase automation of the tracking process of moving objects such as a vehicle and cargo, e.g. container in terminal, [10, 11].

II. A CONCEPT FOR VEHICLE TRACKING

The quality of a GPS vehicle tracking system depends on the type and the number of tracking parameters. The basic parameters for tracking indicate the individual influences of monitored vehicles to the transport process effectiveness (and efficiency). Some of the important types of basic influences are: the change of pressure in the hydraulic oil installation, the battery voltage in the vehicle, the state of hydraulic switch (open/close), the number of crankshaft revolutions per unit of time, the coolant temperature in the engine, the travelled distance, the total fuel consumption, the vehicle velocity, the state of engine contact (on/off) and the vertical position of the vehicle (altitude).

The basic types of GPS parameters in the tracking system of RCV are represented by the measuring records of output signals from sensors which measure selected sizes – the process parameters in the function of time. The number of parameters depends on the technological development level of the vehicle and monitoring system. Higher quality systems imply the inclusion of a larger number of different sensors or transducers. The GPS device FM-4200 (see the website: http://www.teltonika.lt) was selected in the voltage range of 10-30 V and installed in the RCVs from the vehicle fleet of the Public Utility Company “Mediana“ - Niš. The device was selected because of its own properties as well as four digital inputs (Fig. 1, DIN 1…4) and outputs (OUT 1…4) and four analogue inputs (AIN 1…4), which enabled the development of a monitoring system in the future. Tracking of the total

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loaded mass, i.e. the weight of waste during the movement of the vehicle in real time as well as the individual masses (weights) of waste from bins and containers, are very important in the process of waste collection and transportation. It is also important to assess the availability of the remaining volume in the depot of the truck [12]. The expert answers to these questions require the involvement of an oil pressure transducer in the hydraulic installation, weight sensor and volume sensor (actually, the sensor of inclination angle of the pressure plate cylinder). Other sensors can also be installed depending on the number of required parameters as well as input-output ports on the GPS device. Fig. 1 shows the electrical schematic of the pressure transducer connection in detail and the simplified schematic of other current sensor connections with the GPS transmitter.

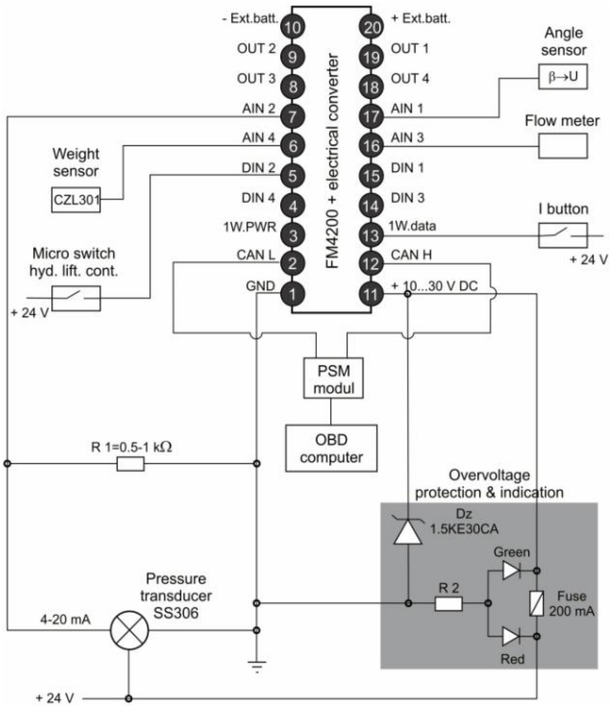

Fig. 1. The electrical schematic of the connection between the FM-4200 transmitter and all current sensors

Fig. 2 shows the conceptual schematic of the monitoring system in a sample of new generation RCV with On-Board Technology (vehicle fleet, PUC "Mediana" - Niš). Analogue signals from sensors and transducers are converted into digital and sent to a mobile service provider together with the satellite signal of the current GPS position via the GSM/GPRS transmitter with an integrated GPS receiver in a vehicle. The mobile provider communicates with the GPS device in the vehicle and WEB server using bidirectional internet traffic. The WEB server provides necessary information about the vehicle (position, parameters, etc.) to the dispatch center. The dispatch center conducts the management and reengineering of the transportation process using a feedback loop. Certain information is provided to the driver on the display in the vehicle cabin using a GPS device or directly on a mobile phone using voice or SMS. This fleet management system is supported by software MobTrack:24, version 2.6.0.7 [13], and Telenor GSM/GPRS telecommunication protocol.

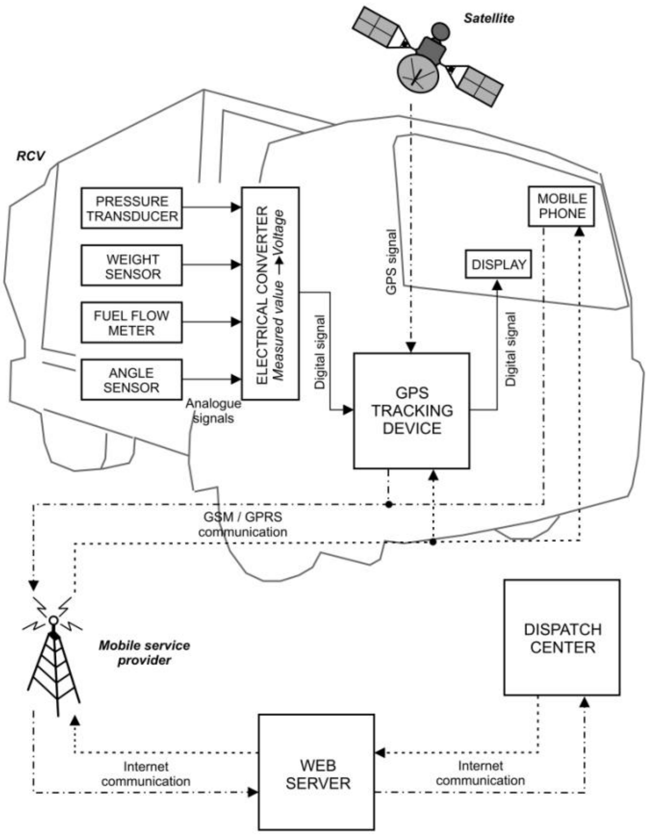

Fig. 2. The conceptual schematic of the current monitoring system

The basic functions of the MobTrack:24 application are: the display position of objects on an integrated map; the continuous collection of data on time intervals, position and velocity of objects; the generation and display of vehicles routes and individual distances; data collection, storage and analysis of additional tracking parameters; the generation of graphical and textual reports on the objects and tracking parameters. The MobTrack:24 application uses two criteria in the data collection process, which are the spatial and temporal one. The spatial criterion prescribes the minimum distance between two consecutive positions that causes a new data packet to be sent to the server. The temporal criterion prescribes an interval of time between a previously sent and current data packet. The order for the application of criteria is exactly spatial-temporal. The data obtained using the sensors in a monitored object (vehicle) are called events. In order to be identified as events, the data are stored in the device and then processed if they satisfy the above two criteria. Depending on the processing time, the data (events) are divided into active and passive. Besides the hardware internet connection, the software application MobTrack:24 requires one of the following software systems to be installed: OS MS Windows 2000 SP3, OS MS Windows XP SP2, OS MS Windows Vista, as well as MS Internet Explorer 7 (or newer).

An extremely important element of monitoring which influences the accuracy of basic GPS parameters is the number of visible satellites, Fig. 3. Therefore, it is necessary that at least four satellites always are visible to the GPS receiver (!). In Fig. 3, one can see the decline in the number of visible satellites from a GPS receiver in a vehicle to "zero" (?), at the moment between 15:30 and 16:00 hours on

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19/08/2013, for unknown reasons. This event led to the interruption of data flow on the observed vehicle position.

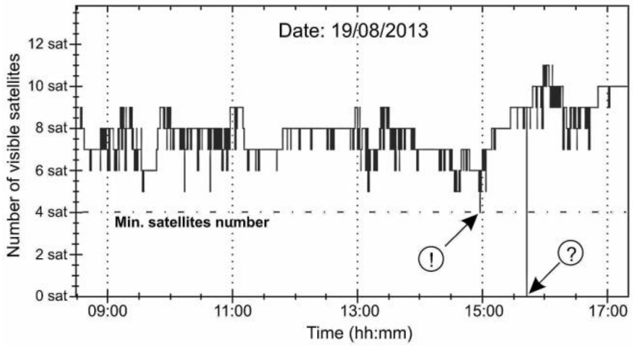

Fig. 3. The satellite visibility of a GPS receiver in a vehicle

The positioning of objects is theoretically based on the calculation of three unknowns: *x*, *y* and *z* (global coordinates), and the travel time of the radio signal. To calculate the distance *d*, one uses:

$$d = V \cdot t \tag{1}$$

where $V = 290{\cdot}10^3$ km·s^{-1} is the propagation velocity of the radio wave and *t* (s) is the travel time of the radio signal from the satellite to the GPS receiver, [14, 15, 16].

III. THE STRUCTURE OF THE EXPERT SYSTEM AND SOFTWARE SUPPORT

A developed expert system, at the basic level of decomposition, contains three entities: expert group, dispatch center and vehicle (driver), as well as four subsystems: expert solution making, use of knowledge base, process preparation and process control, Fig. 4. Using multidisciplinary engineering and experiential knowledge, as well as the feedback on control, the expert group performs the engineering and reengineering of expert solutions in order to improve the work process. Apart from the technical and statistical information of waste flows, vehicles and fuel consumption norms, the expert knowledge base includes the logistics experiences from many years of performing duties, such as: observations of drivers and supervisors, data on service users, information about schedule and characteristics of the Point of Interest (POI), route shapes, etc. The dispatch center performs vehicle monitoring in the control system and makes the operating decisions to correct the work plans on the basis of feedback. The preparation of a work process is based on clear plans and operating instructions and it results in the work order. The control system operates on the comparison of default data and feedback from the work process. The dispatch center and the expert group simultaneously receive data from the process control through feedback.

The expert system in Fig. 4 is supported by the original software that can enable the advanced management of fuel consumption, the realization of routing tasks and the management of corrective and preventive vehicle maintenance [17]. The software provides many forms of planning and reports such as: the schedule of vehicles, the work order of a vehicle, the order for the requisition of fuel, the plan of norming fuel consumption depending on the type of vehicle and work task, the GPS report (including work time, the number of engine hours, spent fuel, mileage, the number of working cycles, the number of emptied waste containers, etc.). The process preparation and decision-making are supported by modern SQL programming in the Oracle database [18]. The process control of the RCV operation is supported by the current GPS technology, software and hardware.

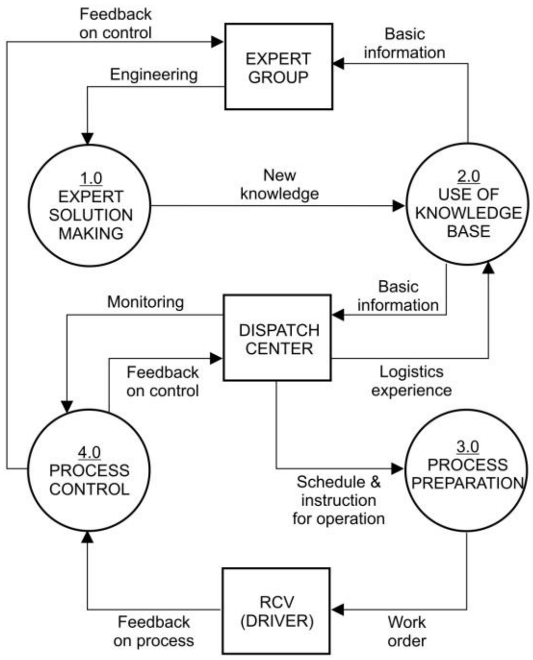

Fig. 4. The data flow diagram of a waste collection system

The analysts of logistics dispatch center can generate a large number of reports and plans by using the basic types of GPS parameters and the developed expert base. Specially written algorithms are used for this purpose. One of these is used to calculate fuel consumption. A very important software report is the report on fuel consumption per driver (Fig. 5, PIN – driver) in a period of time (e.g. monthly, as shown in Fig. 5). The model of fuel consumption analysis is designed to perform the parallel computation of normed fuel consumption according to the two data series of engine hours, obtained by the GPS tracking system and the tachograph device. The percentage fuel overspending is software determined for the both of data series i.e. the tachometric (CF_1) and GPS (CF_2) data, in relation to the normed values (nor_tah, nor_GPS). Furthermore, the lowest value (CF_3) of two obtained percentage values of the difference of fuel consumption is adopted using this software algorithm. Thus, the drivers with the negative computed differences had less than anticipated fuel consumptions (✓). On the other hand, the drivers with the positive differences experienced fuel overspending. In the case of unacceptable consumption e.g. the difference $D > 10\%$ (✕), the corrective measures were applied. The difference, marked as “?”, was located in the tolerance field of exceeding.

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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	X
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	X
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	X
2642	SASA CEKIC	129.68	126.93	133.11	2.17	- 2.58	- 2.58	✓

Fig. 5. A monthly report on fuel consumption

The fuel consumption analysis is the integral program module of the expert shell for the control of the waste collection and transportation process. The original program algorithm of the model was generated in the standard database management software [18]. Part of the module algorithm to determine the percentage fuel overspending using the function CF_1 and CF_2, and the lowest percentage value of them using the function CF_3, is shown below.

```
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
```

IV. THE TYPES OF EXPERT METHODS

The expert combinations – methods which contribute to the decision making in the fleet management system were established using the knowledge and experience of engineers and logisticians as well as the experimentally measured GPS tracking parameters. There are more expert methods but the comparison of two or three experimentally obtained tracking parameters is implemented most frequently. All of the expert combinations are the functions of time and they are represented by diagrams.

The quality of battery charging was checked by the expert combination B-C during the engine operation when “contact” = “on”, Fig. 6. The battery charging, represented by curve *B*, should be even (working voltage ≈ 28 V) during a turned on contact (engine operation), such as it is shown in Fig. 6, which indicates the correctness of the electric supply system in the vehicle. The contact line *C* also indicates a proper behavior of a driver who always turns off the contact (*C* = “off”) if he/she plans a longer retention of his/her vehicle in the place – the nonfunctional retention. The diagnostics of the electric supply system in the vehicle can also be successfully performed using the B-C control method [19]. However, this solution to determine the number of engine hours is not entirely accurate.

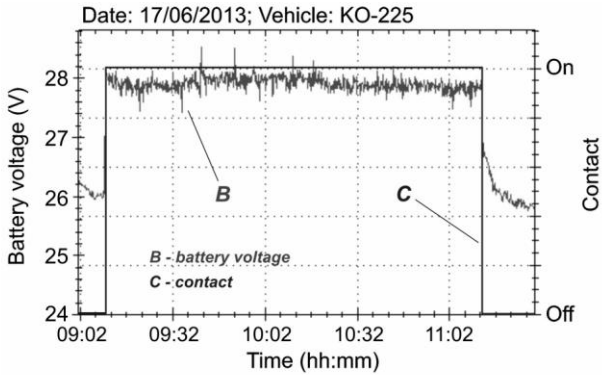

Fig. 6. Control method B-C

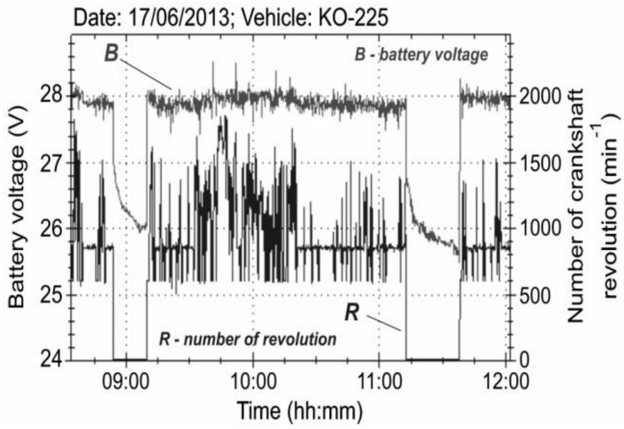

Fig. 7. Control method B-R

The correctness (or incorrectness) of the electric supply system, i.e. battery charging system, was determined by the expert combination B-R, Fig. 7. The number of crankshaft revolutions (curve *R*) clearly indicates the engine operation periods, while the battery voltage curve *B* shows the simultaneous battery charging. Observing the diagram in Fig.7, one can conclude that the balanced changes of the number of crankshaft revolutions influence the occurrence of small voltage amplitudes. This control method enables a more accurate measurement of engine hours using the direct readings on the timeline. The method is more hardware-demanding than the previous one because it requires the use of an electronic transducer for reading the number of crankshaft revolutions. Older vehicles require the subsequent installation of a transducer system and connection with the GPS device.

The A-T combination of GPS parameters, Fig. 8, indicates a higher increase in engine temperature (coolant temperature) by almost 10^{O}C at the increase in altitude of more than 50 m in the shorter periods of time (see the rounded details in Fig. 8). The information about temperature indicates the possibility of engine overheating. The temperature sensor is a standard solution in the engine cooling system.

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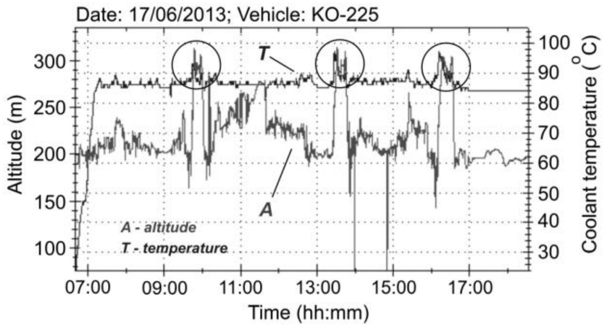

Fig. 8. Control method A-T

If the current altitude A is simultaneously observed with the total fuel consumption F then the partial fuel consumptions can be calculated for the corresponding climbs. The diagram in Fig. 9 shows the highest, almost continuously achieved height of an individual route distance which amounts to $\Delta A_{max} = 135$ m, as well as the climbing time $\Delta T = 6.25$ min and the corresponding elemental fuel consumption $\Delta F_{\Delta A\text{-max}} = 2$ liters. The response of the sensor of the current volume change will be sent to each 5 liters of spent fuel. This method uses the data on the altitude obtained by the satellite, as well as the total fuel consumption obtained by the flow-meter in the vehicle.

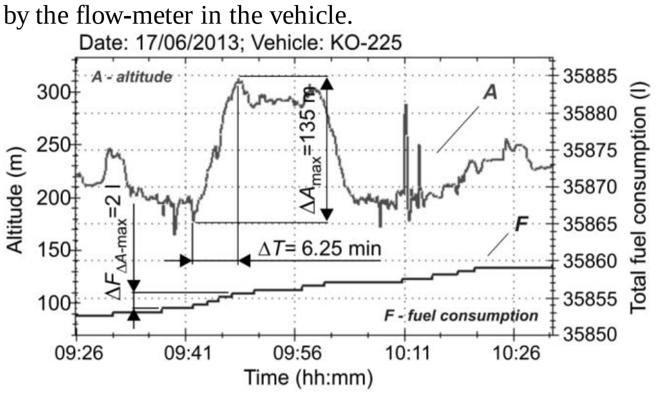

Fig. 9. Control method A-F

Following the H-P combination of parameters is especially suitable to the waste collection and transportation management process because it enables the control of working effectiveness without an insight into the driver's reports. This is achieved by post-processing the set of measured tracking parameters such as: the trajectory of vehicle, the pressure in the hydraulic installation and the change of the switch state of the hydraulic valve. The active executive hydraulics of the lifting mechanism (Fig. 10, H = "open") enables the unloading of waste containers into the RCV. After the completion of waste unloading, the executive (H = "close") and propulsion (P = 0) hydraulics are turned off in order to move the vehicle. The voltage equivalent of switched off hydraulic power amounts to $U_0 = 0$ V. Often in practice, the forced non-functional fluid circulation in the hydraulic system is enabled during the elemental displacement of the vehicle. This fluid circulation is characterized by pressure p_{wl} and voltage equivalent $U_{wl} \approx 3.5$ V which are dependent on sensor and GPS modem features. Hence, the darker area on the diagram in Fig. 10 represents the non-loaded zone of the hydraulic drive. Summing the peaks of the curve of hydraulic pressure equivalent P in the range of one H open-period yields the number of lifted containers per location (or "island"). Also, summing all peaks P (in Fig. 10, total of 8 peaks) yields the total number of unloaded containers per daylong work cycle.

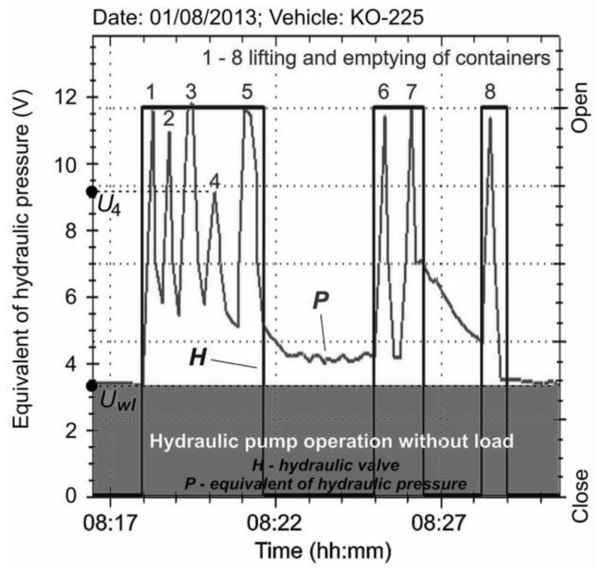

Fig. 10. Control method H-P

The conversion of the voltage value into the mass value is performed using Eq. (2) in which M_i (i = 1, 2, ..., n) is the measured waste mass in kilograms to the i^{th} container, K_j is the constant value of own mass to an empty container in kilograms (Eq. (3)), K_U is the conversion coefficient of voltage into the mass in kg·V^{-1}, U_i is the voltage equivalent of hydraulic pressure due to the current load that is read in V and U_{wl} is the voltage equivalent of hydraulic pressure in the installation without load, also in V.

$$M_i = K_U\left(U_i - U_{wl}\right) - K_j \tag{2}$$

$$K_j \begin{cases} K_{\mathrm{I}} - steel \\ K_{\mathrm{II}} - plastics \end{cases} \tag{3}$$

The total mass of loaded waste M_C can be calculated in kilograms per work cycle, Eq. (4), by summing the elemental masses M_i which are determined by the peaks of curve P on the ordinate of the diagram in Fig. 10.

$$M_1 + M_2 + \cdots + M_i + \cdots + M_n = \sum_{i=1}^{n} M_i = M_C \tag{4}$$

The H-P control method uses the electrical impulse of the hydraulic "on/off" switch and oil pressure sensor in the hydraulic installation. The oil pressure, as an analogue value, is converted into the voltage value. Using the data from the expert base, the constant values of waste containers K_{I} and K_{II} are obtained in relation to the type of container and position on the field. This mass-constant is software subtracted from the measured mass, Eq. (2), so the diagram also shows the net values of loaded waste beside voltage. The measuring system contains the pressure transducer SS306 (manufacturer Sendo, China) mounted in the hydraulic pipeline behind the control valve of the hydraulic cylinder to lift the waste containers. The measurement procedure includes the calibration of the measured hydraulic pressure values – voltages and their conversion into the corresponding mass values with an error of ±5 kg. A wider investigation of the measurement of the loaded waste mass in motion also

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included the contact type sensor CZL-301 (other manufacturer) in the parallel measurement of weight in the range of 100-5000 kg. This sensor did not satisfy the long-term dynamic measurement conditions in the real RCV system due to the damage of contact surface on the sensor body.

V. EXPERT SOLUTIONS IN PRACTICE – CASE STUDY

Trajectories (Fig. 11, dark line) and standing points (Fig. 11, little light circles) can be spatially generated on the basis of a moving object (vehicle) positions and the previous setting of initial values for the lowest limited velocity and idle time. In addition to these default GPS tracking elements, predefined elements, such as the points of interest (POI), are used. It is very useful to group certain points in the POI collection which indicates no moving objects (e.g. waste containers). In the case of individual objects, the little dark circle is used for marking. However, if there are more objects in the place, then the light asterisk is used, Fig. 11. By positioning the cursor on any of the asterisks or little circles the pop up notification appears to show the basic information about the current object and position. The architecture of POI collection includes the global spatial coordinates, number of objects within the POI, type and material of object (e.g. waste container or bin, steel or plastic material).

From Fig. 11 one can reach several important conclusions on the work process effectiveness. Thus, the detail 1 indicates the real situation when the vehicle was stopped in the remote location (light circle) of the POI (dark circle) and the loading was enabled by manually moving the stationary object – a container toward the vehicle. On that occasion, the crew made a vehicle movement saving at the expense of manual labor. The detail 2 shows that the vehicle was not stopped (no light circle) next to the POI with a larger number of stationary objects (asterisk = more containers in one place), meaning that the service was not provided. In detail 3, one can see that there are no dark circles next to the light. This is to say that the vehicle conducted a combined discharge of bins and containers on that day at the same time, so it stopped within detail 3 to empty the stationary objects (bins) which were not covered by the predefined POI collection. By using the expert POI database and the hydraulic pressure change parameter in the installation for lifting and discharging the waste containers, quality conclusions on the execution of waste collection plan may be adopted.

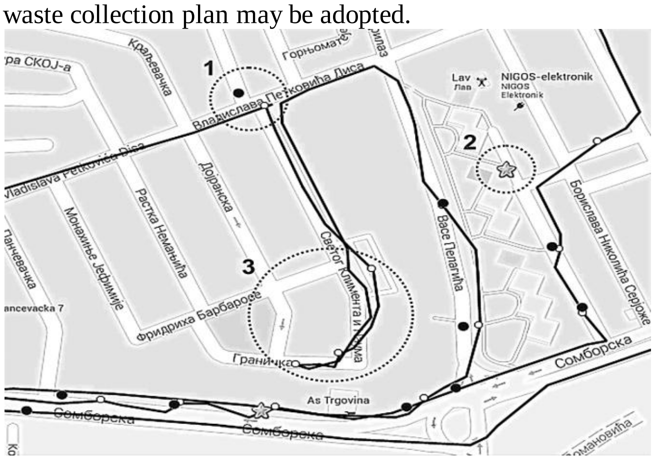

Fig. 11. The trajectory of vehicle KO-225 obtained by using the GPS tracking system on 14/08/2013

A check of the work task "collection and transportation of municipal solid waste", performed by simulation on the selected set of parameters, is shown in Fig.12. One can see that the container from place – "eco-island" p_1 was moved to place p_2. By positioning the cursor on point p_1 and p_2 in the H-P diagram, the corresponding points of trajectory were shown on the map on the right. One can conclude that during a turned off hydraulics $H = 0$, the pressure converted into voltage/weight did not fall on an expected value but it retained the value $P \approx 7$ V (corresponds to the mass of 135 kg) which was the value of an empty steel container (point p_2). Without an insight into the driver's report, one can conclude that the lifting of one object in place p_1 and its transportation, in the grip of the lifter, to location p_2 were performed.

Therefore, by using the H-P control method, no insight into the driver's report, the dispatch center analyst can check the effectiveness of the work order. By positioning the cursor on the two points of curve P (light circles) in Fig. 13 above, the waste loading places (standing points) were displayed on the map. These places are located in close proximity to some of the predefined POI (Fig. 13, dark point – eco-island). The number of peaks of curve P within one H-open period must correspond to the inventory number of containers in each position of POI. However, this was not the case in the example in Fig. 13 because the number of peaks – lifting of containers was one less than required, as defined by the characteristic of island #1212. This difference indicates two possible omissions, i.e. the incomplete implementation of the work task/order or a change of actual POI characteristics (e.g. reducing the number of objects by moving some of them from one location to another).

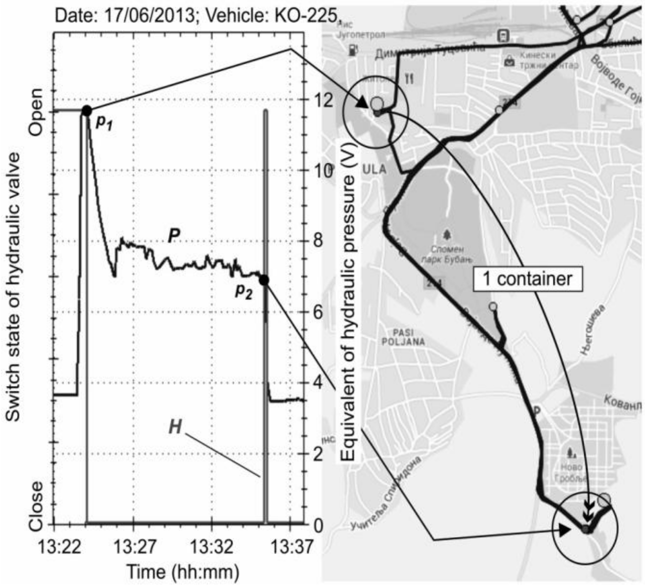

Fig. 12. Use of the H-P control method

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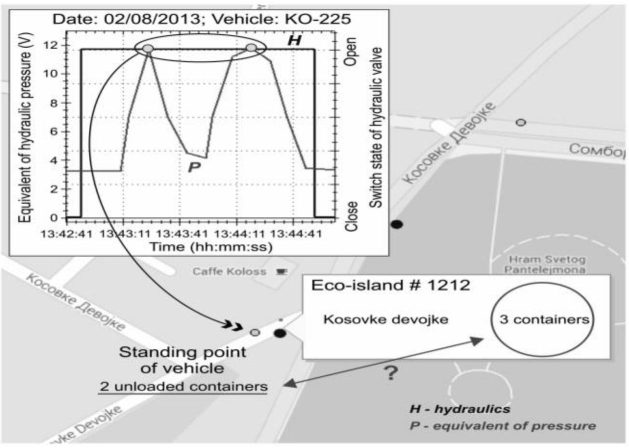

Fig. 13. An example of the incomplete execution of the work task

Summing the voltages of impulse events (peaks of curve *P* in Fig. 13), the total voltage equivalent of mass was obtained. By parallel weighing the vehicle on a weighbridge, the value of the limit equivalent of mass was determined. This limit equivalent was 720 V to the overloaded vehicle (sample) KO-225 with the carrying capacity of 5.5 t. By using the H-P method, the dispatch center can determine the occurrence of vehicle overload and order the suspension of work as a preventive action. The notification of work interruption is done by a remote signal – alarm.

More precisely, the dynamical measurement of loaded waste mass in RCV can be performed by converting the voltage equivalent into mass for each loading. Therefore, it is necessary to know the individual masses of objects – containers. A significant part of the POI collection is the object characteristics list which contains the information about the individual masses. Masses of objects – containers may vary depending on the type of material and shape as well as the level of correctness. The experimentally determined voltage equivalent for mass of the empty steel container of volume V = 1.1 m^3 and standard dimensions and material (EN840) amounts to ~ 7 V.

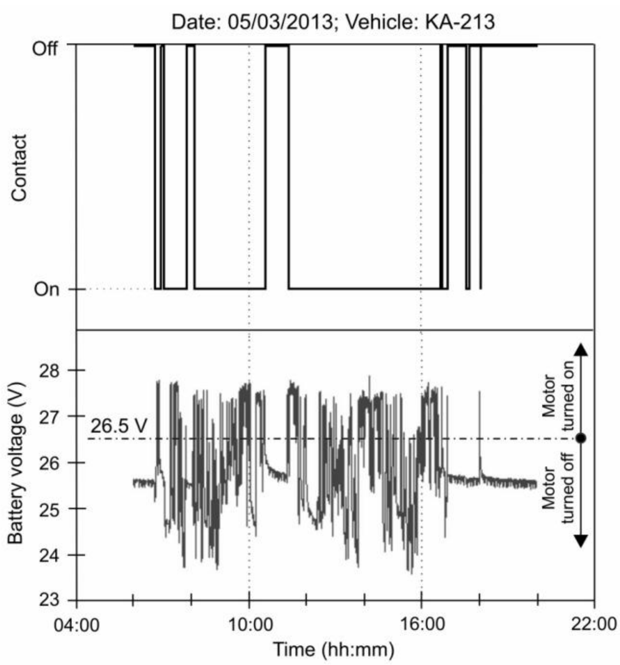

Fig. 14. An example of the impulse battery charging

Some of the expert methods are very good diagnostic tools and contribute to better maintenance of vehicles. The B-C method is very suitable for the diagnosis of the electric power supply system in a vehicle which normally plays a significant role in proper functioning of GPS technology. Namely, a malfunction of one of the elements of the electric power supply system can cause irregularities in determining the significant parameters of vehicle tracking such as the engine operating time. Fig. 14 shows a frequent case of malfunction of the system for charging the battery in a vehicle – the impulse charging. The diagram is obtained by parallel simultaneous record of the two GPS parameters, the motor contact and the battery voltage, for the selected RCV named KA-213. The diagram shows that the alternate charging and discharging of the battery leads to an error in the automatic calculation of engine hours. The selected GPS software uses a default size of the limited battery voltage (Fig. 14, 26.5 V) which separates the turn on and turn off motor periods in the analysis.

The example in Fig. 14 shows that two different parameters, the engine contact and battery voltage, can give a significant difference of engine hour values which influences the calculation of the normed fuel consumption. If the analyst in the dispatch center relies on the total engine operation time of 3 hours, obtained from diagram in Fig. 14 below ("motor turned on"), he/she will not have a realistic insight into the vehicle performance as well as the fuel consumption, which will then be significantly higher per unit of time. On the other hand, if the contact data is taken, Fig. 14 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.

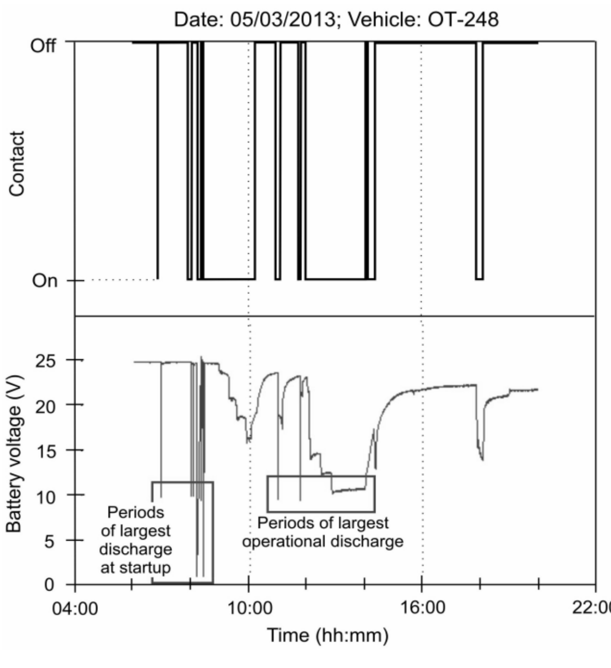

Fig. 15. An example of permanent battery discharging

Using the B-C method and observing Fig. 15, one can see that the battery charging system malfunctioned during the

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entire 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. At the same time, the contact diagram showed activity of the engine ("contact" = "on") at lower voltages than the limited one. From the reliability aspect, there is a high probability that the battery is completely discharged and not for further use if the next measurement indicates the voltage lower than the limited one of 12.4 V for a lead acid battery. According to the voltage diagram in Fig. 15 below and using the limited voltage of 26.5V, the number of operating engine hours was not determined contrary to the contact diagram by which the operating time of around 5 hours was determined. The "contact method" was a more reliable method than the "battery voltage method" in this case as well.

The superposition of battery charging time and contact on time is clearly seen in Fig. 16. The diagrams show 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 the nominal value i.e. $U_{\min} = 25.44 > U_n = 24$ V in the idle engine time ("contact" = "off"). By looking at Fig. 16, one can conclude that the battery structure is of good quality and that it allows the predicted range of limit voltages, which means that the battery "keeps" voltage. Therefore, this diagram indicates the complete correctness of the system for electric power generation and energy storage in the vehicle. The data on the vehicle tracking parameters, obtained by using such an example, are reliable and they can be unambiguously used to calculate the normed fuel consumption.

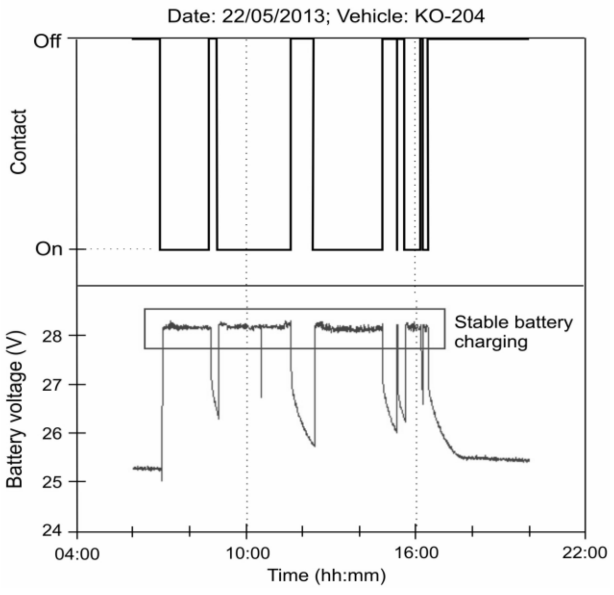

Fig. 16. A good example of the correct battery charging system

VI. CONCLUSION

1)Further development of the expert shell is possible by expanding the GPS monitoring system using new sensors or encoders. A quality GPS receiver of higher capacity, i.e. with a larger number of input-output ports, allows expansion. In terms of the expansion, the pressure, volume and weight sensors are especially interesting because they enable development of the dynamical tracking of collected waste quantity into the depot of a truck i.e. RCV. New sensors enable the expert group to create a larger number of process control methods.

2)Presence of the POI collections of stationary objects is highly desirable on maps because it allows the monitoring of work task implementation. Thereby, in addition to tracking the position of a moving object (vehicle), the dispatch center also gets an insight into the implementation or delay of individual service. The creation of POI collection requires a precise positioning of each POI, i.e. object, on the field and defining of all necessary POI characteristics in applied GPS software. The observed system of solid waste management can be expanded with a new POI collection that includes smaller waste storage objects (bins). Updating the database of all POI collections should be conducted on regular basis because a change in the state of some POI, such as the relocation of object or the replacement of one type of object with another, is possible over a longer period.

3)RFID technology could allow the development of precise mass identification of each empty object (container, bin) in the monitoring system by installing the RFID transponder (tag, plate), as an information carrier, on (in) the object and placing the RFID reader on the vehicle superstructure. This mass will always be subtracted from the measured mass at each individual loading of waste – emptying container.

4)GPS technology, in the maintainer's hands, is a very good tool for detecting faults on a vehicle (diagnostic tool). Using GPS software graphics, malfunction of the electric power supply system in a vehicle can be detected and decisions of corrective and preventive maintenance can be made in a timely manner. This technology can also contribute to a better observation of some irregularities in exploitation and even misuse, such as the fuel overspending or overload of a vehicle.

5)The developed logistic model for the fuel consumption analysis is suitable to be used in the city logistics systems which employ the same vehicles to perform a larger number of different work tasks. This model corresponds to the municipal systems which perform waste collection on a relatively small territory with big population (city, municipality, district, city quarter). The model is developed for use in the logistics-dispatch center of a public utility company. The model provides the software support for the planning and analysis of vehicle use 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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