ENERGY EFFICIENCY AS A CRITERION IN THE VEHICLE FLEET MANAGEMENT PROCESS

by

Davor VUJANOVIĆ, Radomir MIJAILOVIĆ, Vladimir MOMČILOVIĆ and Vladimir PAPIĆ

Transport represents an industry sector with intense energy consumption, the road transport sector within is the dominant subsector. The objective of the research presented in this paper is in defining the activities which applied within road freight transport companies contribute to enhancing vehicles' energy efficiency. Vehicle fleet operation management process effects on fuel consumption decrease have been looked into. Operation parameters that influence vehicle fuel consumption were analysed. In this sense, a survey has been realised in order to evaluate the vehicle load factor impact on the specific fuel consumption. Measures for enhancing vehicle's logistics efficiency have been defined. As a tool for those measures' implementation an algorithm for vehicle fleet operation management was developed which represented a basis for a dedicated software package development for vehicle dispatching process decision support. A set of measures has been recommended and their effects in fuel savings were evaluated.

Key words: *energy efficiency, vehicle fleet management, logistics efficiency*

Introduction

A growing attention is given to the environmental protection and energy efficiency throughout the world. This is especially important in road transport where has been observed an important and intensive growth in energy consumption [1]. The reason lies in growing transport demand during the latest three decades. According to [2] there are two main factors governing the transport demand growth. The number of passenger vehicles has tripled in the last 30 years, with an average annual growth of 3 million vehicles. Furthermore, the implementation of *just-in-time* concept in the production chain has lead to transport demand intensification.

Transport's energy efficiency took a leading place among strategic measures to attain sustainable development all over the developed world. The latter has recently become tangible also in the Republic of Serbia [3,4,5,6].

Road vehicles manufacturers have been encouraged, even obliged by different policies and measures to produce more energy efficient vehicles with lower emissions of air pollutants in the last decade. Nevertheless, the intention is to also act upon large vehicle fleets as to become more energy efficient and environmentally aware.

Transport companies (as well as vehicle fleets for own-account) realise carriage of goods often with heterogeneous fleets, with different vehicle cargo load capacities (payloads) and kerb weights. The main problem is how to rationally perform transport activities with the objective of accomplishing all planned transport tasks, i.e. increasing vehicle fleet energy efficiency for the given transport quantity.

The focus of this paper is on identifying measures in the field of vehicle fleet operation management aimed at lowering fuel consumption, with the requirement of accomplishing all planned transport tasks. In view of solving such problem, load factor influence on the fleet's energy efficiency was observed.

The impact of the cargo weight on the fuel consumption was researched, i.e. intensity of fuel consumption increase linked to the cargo weight raise. The test consisted in analysing the impact of the load factor γ on specific fuel consumption q ($l/100\ km$), and especially on specific fuel consumption per transport quantity unit q_t ($l/100\ tkm$).

Those researches of logistics efficiency illustrate the influence of vehicle fleet operation management onto energy efficiency enhancement. The aim is to upgrade the existing and introduce new tools incorporated into fleet management process in order to attain its overall energy efficiency. The developed measures for improving fleet's energy efficiency should also be cost effective.

Finally, the results of the proposed measures implementation on the increase of fleet's energy efficiency within the company with a vehicle fleet will be presented.

1 Fleet's Energy Efficiency

As indicated by [7], the increase of vehicle fleet energy efficiency could be influenced by enhancement of vehicle operational parameters. This can be reached by activities aimed at improving:

- engine efficiency through its construction, i.e. vehicle efficiency by implementation of new technologies,
- driving efficiency (drivers' training and with the assistance of on-board computers),
- route choice efficiency (route choice optimisation based on information about the journey plan and traffic conditions),
- logistics efficiency (optimisation of freight weights and volumes with different vehicle classes or cargo compartment sizes).

In the last 30 years important efforts of engine manufacturers have been made toward improving its energy efficiency. In the report [8] it has been shown the improvement of the engine energy efficiency in road freight vehicles between 1992 and 2002. According to the mentioned report considering international and intercity transport vehicles (articulated and heavy goods vehicles) an improvement of 11% is attained. As for the urban transport vehicles (light goods vehicles, vans and pickup vehicles) this improvement attains 16%. Ruzzenenti and Basosi in their paper [9] reveal a decrease of specific fuel consumption ($l/100\ km$) for freight vehicles between 1970 and 2000 for several developed countries. In the United States the aforementioned decrease attains even 27% for heavy freight vehicles and 12% for light freight vehicles (vans and light pickup vehicles). In Europe, this decrease attains in average 8% for freight vehicles. Similar results regarding freight vehicles' engine energy efficiency have been obtained by analyses of test drives presented in the magazine [10]. Based on the selected sample from manufacturers like Mercedes Benz, Scania and Volvo, the specific fuel consumption in 2009 was 11-13% minor to the consumption from 1989 both for vehicles with similar technical and operational features. Nevertheless, although the investments into these engine improvements do not decrease in time, the effects of those investments are getting less and less important. In the last couple of years only small changes in the engines regarding their energy efficiency aspects have been presented. Therefore, today we need far more important investments to attain very small, sometimes negligible improvements in their energy efficiency. According to [10], specific fuel consumption enhancement for the period from 2000 to 2009 is minor to 4%.

Alternative fuels offer new possibilities to engine constructors in view of energy efficiency improvement [11,12]. The major effects of alternative fuels' introduction are in decreasing transport sector dependence on fossil (non-renewable) fuels and environmental pollution's adverse impact. For example, upon [12] usage of biodiesel importantly decreases CO_2 emission compared to diesel fuelled engines. There are also intense activities on the hybrid drive development, equally with the objective of increasing energy efficiency.

Among technologies not related to engine construction, which influenced energy efficiency of vehicles during the previous 30 years, a major impact was attained from technological advances in vehicle aerodynamics, improvements in rolling resistance, vehicle kerb weight reduction, electronic speed limiters, improved vehicle transmission and superior motor oils [8]. Upon data analyses from the magazine [10], kerb weight reduction of Schmitz Cargobull semi-trailer was approximately 14% among 1994 and 2009, while for Schwarzmüller semi-trailer this reduction amounts roughly 6% in previous 10 years.

On the other hand, in view of the driving efficiency, the driver could importantly influence fuel consumption decrease by an adequate behaviour with the vehicle [13], which also influences certain decrease in vehicle operation and maintenance costs. According to [3] the cost savings from efficient driving might attain up to 20%.

Fuel and CO_2 emissions savings could be influenced by route choice [14,15] based on information of journey planning as well as traffic and technical characteristics of the network. Traffic management measures have an effect on higher traffic flow intensities alongside higher vehicle speeds, which on the other side increase the energy efficiency of vehicles.

Within the logistics efficiency a minimal progress has been achieved worldwide [9,16]. Moreover, in certain developed EU countries, based on research results from 2005 [17], average load factor of lorries either slightly, almost negligibly increase (Germany), stagnates (Denmark) or decreases (United Kingdom and Netherlands) at very low rates (between 30 and 47%), which may be observed on Figure 1. In the paper [18], by analysing experimental data it is concluded that additional freight carried by the vehicle influences certain specific fuel consumption increase q (l/100 km). However, it should be pointed out that this increase was far from proportional to the vehicle gross weight increase. The authors of the paper [18] come to the result that for vans (less than 3.5 tonnes of total permissible weight) with the load factor of 30%, the increase of the specific fuel consumption amounted between 10 and 20% related to the specific fuel consumption of unloaded (empty) vehicle.

Therefore, based on previously mentioned reasons and upon authors' opinion, transport sector's reserves, i.e. potential for a substantial increase in energy efficiency currently lies in increasing vehicles' logistics efficiency. This comprehends usage of the most favourable vehicle in terms of its freight load and cargo compartment capacity in relation to the cargo weight and volume that is to be transported. The objective is to attain the higher possible vehicle load factor value (γ) while dispatching vehicles to transport tasks. This influences specific fuel consumption decrease per freight transport quantity unit (l/100 tkm), i.e. total fuel consumption savings of the vehicle fleet for the planned transport quantity.

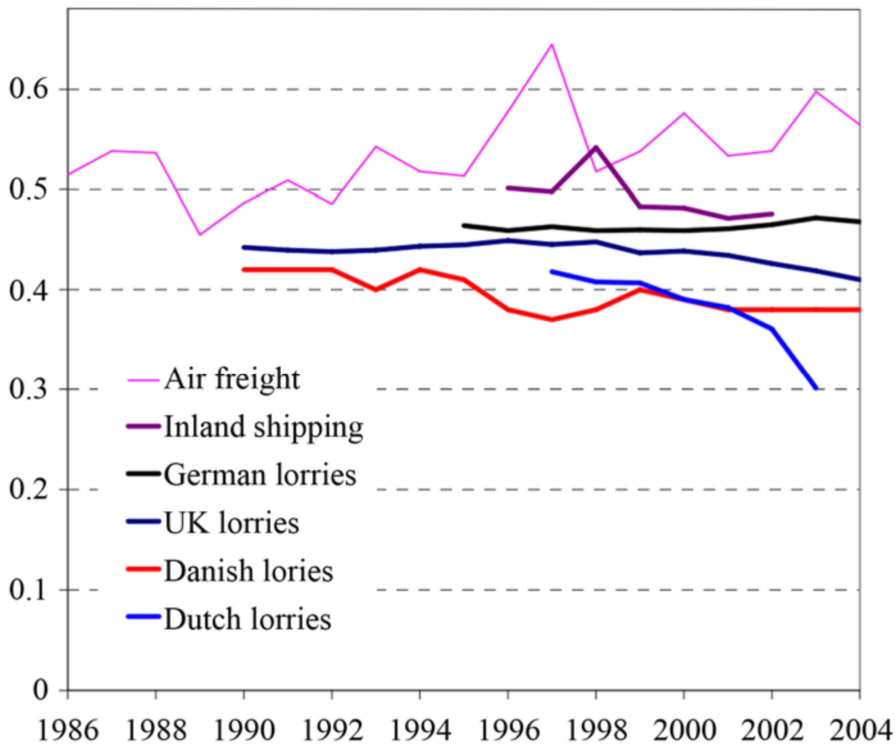

Figure 1: Average load factors for air freight, inland waterways, as well as road freight in selected EU countries [17]

2 Research of Logistics Efficiency

The starting point is the hypothesis that the specific fuel consumption per realised freight transport quantity q_t (l/100 tkm) directly depends from the load factor. In order to substantiate this hypothesis and check it experimentally, we have initiated the research on a selected vehicle set. Realised researches have the objective to determine how load factor influences total fuel consumption for the defined transport quantity.

The measurements of the specific fuel consumption q (l/100 km) on different road freight vehicles and varying load factors have been realised. In this sense, it has been measured the cargo weight impact on the fuel consumption. The measurements took place in April 2009.

2.1 Research Description

The measurements have been realised on the following vehicle classes:

– Articulated vehicles of total permissible weight up to 40 tonnes,
– Light goods vehicles of total permissible weight up to 15 t,
– Vans of total permissible weight up to 3.5 t,
– Small pickup vehicles of total permissible weight up to 2.5 t.

In table 1 the main features of the vehicles involved in the measurements are shown. The vehicle condition was satisfying, in other words vehicles were technically faultless, with predefined tires of known dimensions and adequate pressure. During measurements the engines were at the operational temperature. The research was realised in two phases:

– First phase – it has been measured specific fuel consumption for vehicle cruising at constant speed always on the same plane motorway section (without uphill and downhill),

– Second phase – it was measured specific fuel consumption on different longer transport routes, with longitudinal slopes. This phase involves as uniform as well as variable vehicle movements, corresponding to average operation conditions of those vehicles.

In both phases, measurements were performed under similar weather and temperature conditions, without the influence of wind and atmospheric precipitations.

Table 1: Vehicles involved in measurements of the specific fuel consumption *q* (*l*/100 *km*)

Veh. No.	Manufacturer and make of the standard/articulated vehicles	Vehicle class	Production Year	EURO emission standard	Engine power (kW)	Weight of empty standard /articulated vehicle (*kg*)	Mileage (*km*)
1.	Mercedes Actros 1841 + semi-trailer Schmitz Cargobull	Articulated vehicle	2005	EURO 3	301	15 139	312 000
2.	Mercedes Actros 1841 + semi-trailer Schwarzmüller	Articulated vehicle	2005	EURO 3	301	14 160	325 000
3.	Volvo 42T FH16 480 + semi-trailer Berger	Articulated vehicle	2008	EURO 4	353	13 498	128 000
4.	Volvo FLL 42R	Light goods vehicle	2007	EURO 4	177	6 250	134 000
5.	Citroen Jumper 2,2 HDI	Van	2008	EURO 3	74	1 960	57 000
6.	Citroen Jumper 2,2 HDI	Van	2007	EURO 3	74	1 960	142 000
7.	FIAT Doblo Cargo RST 1.9 JTD	Pickup	2008	EURO 3	77	1 330	42 000
8.	FIAT Doblo Cargo RST 1.9 JTD	Pickup	2008	EURO 3	77	1 280	35 000

As to observe the influence of cargo weight on the specific fuel consumption, during the first phase of research it was essential to provide equal or similar operation and traffic conditions for all vehicles participating in the measurements. The chosen road section is located on the motorway E75 (on the corridor X), between Batajnica and Stara Pazova. This motorway section is 6.7 km long without slope and allows maintaining a constant vehicle speed.

The specific fuel consumption measurement was realised by means of the on-board computer [19,20,21]. During the vehicle movement the system displays a momentary (actual) value of the specific fuel consumption (*l*/100 *km*) on approximately 3 seconds delay and also the average fuel consumption in (*l*/100 km) for the selected observation period.

As the measurement has been performed on long-haul freight vehicles of intercity and international road hauliers, their predominant movement is uniform with constant speeds, so-called cruising. In this sense, during the first phase the vehicles were cruising at 85 *km/h*. Such speed was chosen because upon former Serbian road safety legislation the speed limit for freight vehicles was set at 80 *km/h* with a tolerance of +10% (allowing a maximum of 88 *km/h*). At the end of the chosen motorway section the average specific fuel consumption was recorded for the mentioned conditions and actual transported cargo weight. This measurement procedure for the same articulated vehicles or standard goods vehicles was repeated for different cargo weights.

In the second phase of the experiment, the actual specific fuel consumption was measured in authentic operation conditions. For those measurements different transport routes were selected with habitual longitudinal slopes. Prior to departing on transport tasks realisation, vehicles were fully refuelled and weighted, never mind that cargo weight was previously determined. Return journeys involved often different transported cargo weights, including partially loaded routes and also empty runs. After returning to vehicle base, the average value of specific fuel consumption q (*l*/100 *km*) from the on-board computer was collected. In order to check the obtained measurement value the vehicle was fully refuelled while returning to base. The amount of tanked fuel related to the travelled distance gives the specific fuel consumption for the journey in question. For example, articulated vehicle Mercedes Actros 1841 with Schwarzmüller semi-trailer was measured on following transport routes during the second phase (in detail in Table 2):

– A: Knjaževac–Trieste–Civitanola Marche–Parma–Trieste–Šabac with a distance around 3,855 *km*;
– B: Valjevo–Trieste–Casalmoro–Trieste–Valjevo with approximate distance of 2,262 *km*;
– C: Zrenjanin–Trieste–Villapoma–Trieste–Zrenjanin with a distance around 2,359 *km*;
– D: Kovačica–Trieste–Arsego–Udine–Trieste–Kragujevac with approximate distance of 2,421 *km*;
– E: Srpska Crnja–Trieste–Cremona–Perara–Trieste–Bačka Palanka with a distance around 2,427 *km*.

2.2 Results

Performed research in the first phase it has been established the relation between specific fuel consumption q (*l*/100 *km*) and load factor γ in observed vehicle classes. Analysis of the results (Figure 2) highlights that the specific fuel consumption increase is linked to the growth of cargo weight, that is increase of the vehicle load factor, for every analysed vehicle class. However, this increase in cargo weight does not influence a proportional specific fuel consumption raise.

For example if we transport cargo occupying 41% of the freight load capacity by articulated vehicle Mercedes Actros 1841 with Schwarzmüller semi-trailer, its specific fuel consumption increases for 11% in relation to the specific fuel consumption of unloaded articulated vehicle. When the load factor reaches 97%, the specific fuel consumption increases for only 22% regarding the empty run fuel consumption.

Similarly, when the van Citroen Jumper 2.2 HDI carries goods occupying 35% of the freight load capacity, its specific fuel consumption increases for 4% in comparison to the empty vehicle consumption. When the load factor reaches 65%, the specific fuel consumption rises for just 11% in relation to the empty vehicle consumption. Therefore, the increased load factor for the same transport quantity will allow overall fuel consumption savings.

Those savings are especially noticeable while analysing the relations between specific fuel consumption per realised freight transport quantity q_t (*l*/100 *tkm*) to the vehicle load factor (Figure 3). On the following figure it can be seen how specific fuel consumption decreases with higher load factors for all vehicle classes. If for example for the articulated vehicle Mercedes Actros 1841 and Schwarzmüller semi-trailer loaded with 80 kg cargo, when the load factor is $\gamma = 0.003$ the specific fuel consumption per tonne-kilometre is extremely high and amounts 330 *l*/100 *tkm*. If the same articulated

vehicle is loaded so that the load factor becomes γ = 0.408, the specific fuel consumption per *tkm* will decrease and becomes 2.77 *l*/100 *tkm*. The lowest specific consumption values per *tkm* are for the highest load factors. So, for the case when cargo weights 25,080 kg, i.e. when vehicle load factor is γ = 0.97, the specific fuel consumption per *tkm* is now only 1.28 *l*/ 100 *tkm*.
The deviation in repeated measurements for same vehicles and same cargo weights is under 1% which will not depreciate shown functional relations.

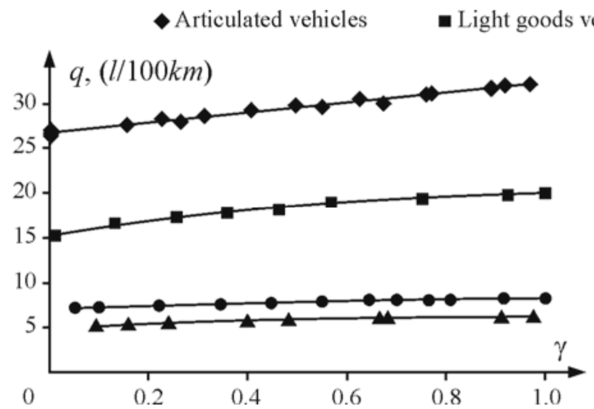

Figure 2: Relation of the specific fuel consumption *q* (*l*/100 *km*) to vehicle load factor

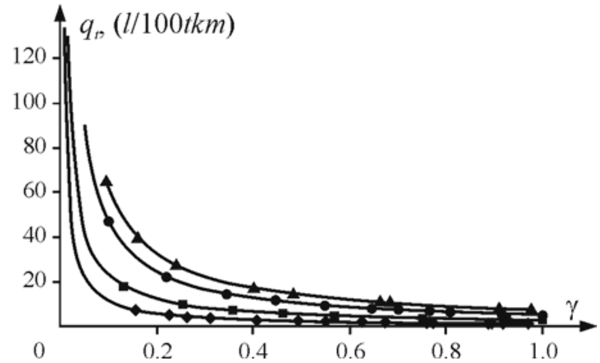

Figure 3: Relation of the specific fuel consumption per realised freight transport quantity q_t (*l*/100 *tkm*) to vehicle load factor

In the second phase of the research the obtained values of the specific fuel consumption *q* (*l*/100 *km*) represented actual consumptions on authentic transport routes and operation conditions. By this fact, the load factor impact on the specific fuel consumption was additionally confirmed. In Table 2 are shown the results of measurements on the articulated vehicle Mercedes Actros 1841 with Schwarzmüller semi-trailer, besides the results of the research from the first phase performed on the same vehicle. For the rest of the vehicles, similar results were obtained with negligible deviations.
Even in the second phase of the research, the specific fuel consumption *q* (*l*/100 *km*) grows with the cargo weight increase, within each single vehicle class. Equally, in this research phase the same hypothesis that with higher load factors the specific fuel consumption per transport quantity q_t (*l*/100 *tkm*) decreases will firmly stay in power. This will result in an overall decrease in fuel consumption for the given transport quantity.
As by the papers [22,23] the relation of the specific fuel consumption (*l*/100 *km*) and specific CO_2 emission (*g/km*) is linear, the influence of a higher load factor due to this fact will become more important. Therefore, the improved load factor will also influence total CO_2 emission decrease for the given transport quantity.

Table 2: Specific fuel consumption measurement results on the example of the articulated vehicle Mercedes Actros 1841 with Schwarzmüller semi-trailer

<table>
<tr><th></th><th colspan="4">First phase</th><th colspan="5">Second phase</th></tr>
<tr><td>Transport route</td><td>E75</td><td>E75</td><td>E75</td><td>E75</td><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td></tr>
<tr><td>Route length (km)</td><td>6.7</td><td>6.7</td><td>6.7</td><td>6.7</td><td>3855</td><td>2262</td><td>2359</td><td>2421</td><td>2427</td></tr>
<tr><td rowspan="2">Cargo weight (kg)</td><td rowspan="2">80</td><td rowspan="2">10540</td><td rowspan="2">23080</td><td rowspan="2">25080</td><td>7300</td><td>10750</td><td>23600</td><td>24150</td><td>24450</td></tr>
<tr><td>11400</td><td>9800</td><td>15350</td><td>23200</td><td>24300</td></tr>
<tr><td rowspan="2">Vehicle load factor γ</td><td rowspan="2">0.003</td><td rowspan="2">0.408</td><td rowspan="2">0.893</td><td rowspan="2">0.971</td><td>0.294</td><td>0.432</td><td>0.949</td><td>0.971</td><td>0.984</td></tr>
<tr><td>0.459</td><td>0.394</td><td>0.617</td><td>0.933</td><td>0.977</td></tr>
<tr><td>Specific fuel consumption q (l/100 km)</td><td>26.4</td><td>29.2</td><td>31.6</td><td>32.2</td><td>29.1</td><td>29.6</td><td>31.5</td><td>31.8</td><td>32.1</td></tr>
<tr><td>Specific fuel consumption per realised freight transport quantity q_t (l/100 tkm)</td><td>330</td><td>2.77</td><td>1.37</td><td>1.28</td><td>3.11</td><td>2.88</td><td>1.62</td><td>1.34</td><td>1.32</td></tr>
</table>

Based on shown results the initial hypothesis that higher load factor will influence improved vehicle fleet energy efficiency was substantiated. Hence, this statement will be implemented into the algorithm for vehicle fleet management, which is shown in the following chapter, among measures for energy efficiency enhancement.

3 Measures to Enhance the Vehicle Fleet Energy Efficiency

From the literature analysis, performed researches, as well as authors' hands-on experience, the approach for decreasing the fuel consumption was through logistics efficiency. This will equally lead to CO_2 emission savings. In this purpose, measures that will improve the vehicle operation process are recommended:

- unlinking related: vehicle – driver – route,
- improving vehicle load factor based on transport demand and routes – better utilization of available freight load capacity of the vehicle,
- improving vehicle fleet structure upon following renewals based on transport demand analysis.

As usual in transport companies and vehicle fleets, certain pairs of vehicles and drivers are always dedicated to certain transport routes. This policy, on one side, has an advantage that driver(s) quickly and accurately get to know the route and might optimize the travel time and avoid unnecessary delays, but on the other hand often has as consequence low load factor due to unmatched vehicle capacity and cargo volumes for all transport tasks on the same route. This will influence high specific fuel consumption per tonne-kilometre (*l*/100 *tkm*), which increases vehicle fleet overall fuel consumption. Besides, the adverse case is also when an adequate vehicle cannot be used for an actual task due to the temporary absence of a related driver. Then, if a vehicle that can be used is not the best choice it will induce higher fuel consumption. For that reason, a logical conclusion is that in the dispatching process the link between vehicles, drivers and routes should be broken or at least to have the lowest priority.

The dispatchers can influence fuel savings if during the vehicle allocation to specific work tasks increase the priority of the criterion: higher load factor. As favourable indicators that will lead to respect of the "weight" efficiency criterion are adopted:

$$\gamma = \frac{\text{cargo weight (kg)}}{\text{vehicle payload (kg)}} \tag{1}$$

$$\eta = \frac{\text{cargo weight (kg)}}{\text{vehicle kerb weight (kg)}} \tag{2}$$

The objective of vehicle allocation to transport tasks is that for a certain task a vehicle that should be chosen should be such that obtains higher values of indicators γ and η, because it will decrease the overall fuel consumption for the defined transport quantity. In that sense, the dispatchers are to be stimulated while allocating vehicles to certain transport tasks to respect the maximisation of mentioned criteria, for the chosen vehicles to be the "best fit" for the cargo transported in view of its weight and volume.

Based on the knowledge of transported cargo characteristics, an empirical distribution of freight can be performed regarding its weight. This is especially important while purchasing vehicles (at fleet renewal) to better fit vehicles to transported cargo weights and volumes. The fleet structure will gradually adapt to transport demand and more important fuel savings will be attained for the defined transport quantity.

3.1 Algorithm for Vehicle Fleet Operation Management

With the objective of implementation of energy efficiency measures, an algorithm for vehicle fleet operation management has been developed. It is composed out of two segments: the current (*on-line*) management and the strategic (*off-line*) management (Figure 4).

The *on-line* segment is dealing with the vehicle dispatching process. Upon appearance of transport requests the cargo attributes are input: weight, volume and commodity type, approximate start of the journey and end of journey dates and times, as well as the itinerary (transport route). The cargo is then classified by destinations and commodity types. Based on the vehicle fleet availability and cargo weights and volumes, a vehicle is allocated to each transport task or group of tasks. Upon vehicle allocation the primary criterion is the "weight" efficiency, i.e. the best possible load factor of available vehicles. The objective is to maximise indicators γ and η.

As a result realised transport data are obtained, which could influence possible changes in fleet structure. Such data on vehicle load factor represent a dispatching efficiency assessment and make a good action database of possible dispatchers' decisions for future vehicle allocation.

In the second, *off-line* segment, a simulation of a transport process is performed based on the built transport model. The objective is to better harmonise the fleet size and structure to the transport demand with the condition of the highest possible vehicle load factors. One fleet size and structure variant is generated and the process of transport requests' initiation is defined. The distributions of cargo weights, volumes and commodity types, as well as transport routes, distances, transport duration, preventive and corrective maintenance durations are determined based on haulier historical data. For each transport request a cargo weight and volume is generated. While allocating vehicles to transport tasks the highest load factor criterion is respected, expressed by γ and η indicators. Upon return of the vehicle to the base, it goes to the daily inspection and then to parking. If in some moment, based on mileage, the vehicle should undertake preventive maintenance, it should enter the maintenance as soon as possible. In case of vehicle failures or breakdowns, corrective maintenance takes place. After leaving the maintenance facility, the vehicle heads to the parking lot where it waits for the next transport task.

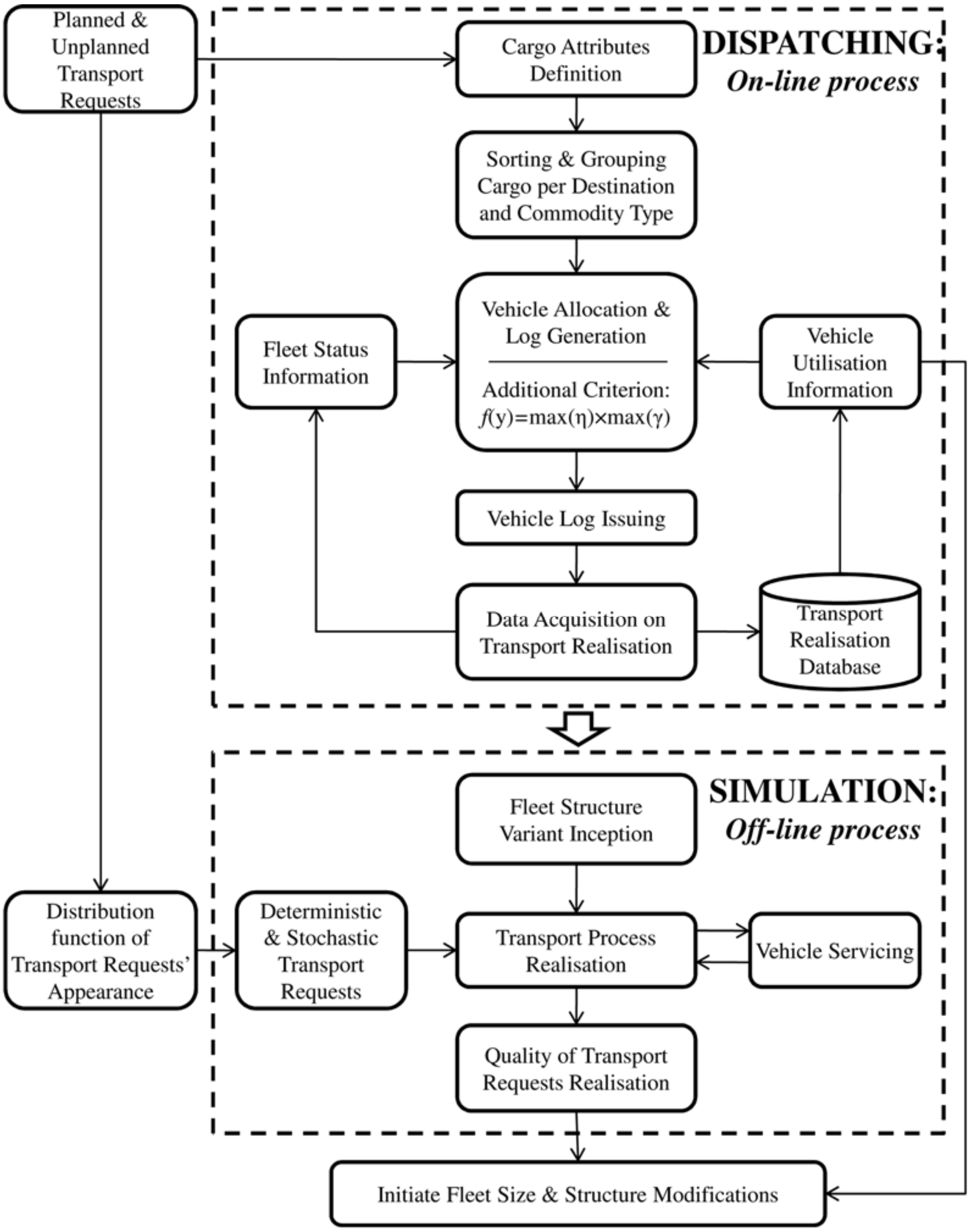

Figure 4: Algorithm of vehicle fleet operation management aimed at increasing vehicle operation efficiency

The result of the simulation of one fleet variant (structure and size) is obtaining a quality assessment of the transport request realisation and values of indicators γ and η. By the next generation of actual fleet variants we research for the most favourable solution: such fleet size and structure that will allow good values of γ and η indicators. This solution is suggested to the management in subsequent considerations of fleet renewal and fleet size and structure modifications.

The objective of the algorithm implementation is to improve the vehicle operation management: better vehicle utilisation, fleet structure and size adjustment to transport demand. Those enhancements should improve the fleet's energy efficiency.

3.2 Software Package for Dispatching Process Management Support

As to perform more efficiently the current (*on-line*) fleet operation management process upon presented algorithm, the authors have developed a dedicated software package as a support for vehicle dispatching process. The mentioned software was developed in programming language Delphi 7.0.
The purpose of the software is: efficient vehicle allocation to transport tasks from the aspect of maximising vehicle load factors while monitoring planned transport tasks realisation, analysing effected transport quantities of vehicles in view of indicators γ and η, in the chosen observation period. Software offers, by tables and graphical presentations, an outline of vehicle activities for daily vehicle logs. It also offers possibility of manual input of data into issued daily vehicle logs. Upon newly submitted transport requests it ensures the selection of the most favourable among available vehicles.
The software graphically illustrates the load factors: ratio of cargo weight and vehicle payload upon loading and unloading locations. Collected information on realised load factors and transported cargo characteristics represent a fair basis for improving vehicle fleet structure and size and for adapting it to transport demand, i.e. a quality foundation for the transport simulation model.
The implementation of this software actively influences defined activities that lead to the increase of vehicles' logistics efficiency. The result of this software usage is an increase in fleet's energy efficiency through improved load factors.

4 Implementation of Measures for Vehicle Energy Efficiency Increase in an Actual Company with a Vehicle Fleet – a Case Study

A company "Delmax" Ltd., where the research was performed, is a sale and distribution company dealing with passenger vehicles' spare parts. The distribution of spare parts is realised on a daily basis on predefined routes. The company owns a vehicle fleet. The objective of the company is to deliver the goods to the clients within the indicated timeframe.
The realised research in the company was aimed at transport process rationalisation. It was also necessary to improve vehicle fleet energy efficiency.
In March 2009 a survey of the transport process in the previously mentioned company. Cargo weights and volumes were recorded for all realised transport tasks, as well as travelled mileages (distances), load factors, fuel consumptions, etc. Vehicle fleet was composed of 14 vehicles. Vans were making 64% of the fleet, light goods vehicles 29%, and small pickup vehicles 7%. The average age of the fleet was 4.5 years.
Major vehicle fleet operation indicators for March 2009 are shown in Table 3. Average daily vehicle engagement consisted in 11 vehicles, accounting for 78% of the fleet. Fuel consumption per vehicle was 713 litres per month. The vehicle load factor was only 23.3%. Very similar indicators were obtained in April of the same year, even though the company was under examination of authors' team.

Table 3: Operation indicators of the "Delmax" Ltd. company vehicle fleet before (March 2009) and after measures' implementation (May 2009 and March 2010)

Observation period	March 2009	May 2009	March 2010
Total freight transport quantity (*tkm*)	52,309	52,903	52,805
Fuel consumption (*l*)	9,981	9,975	9,158
Specific fuel consumption q (*l*/100 *km*)	11.47	11.32	10.44
Specific fuel consumption per realised freight transport quantity q_t (*l*/100 *tkm*)	19.08	18.86	17.34
Vehicle load factor γ	0.233	0.248	0.274

In May 2009 the implementation of a new set of measures was initiated. In the first phase, the links between drivers, vehicles and routes were broken and the vehicles were allocated to transport tasks based on vehicle load factor maximisation. By means of the algorithm the objective was to increase the values of indicators γ and η. Vehicles that were more adequate to transport requests were used instead of habitual previous allocations. The dispatching software implementation assisted the personnel of the company to obtain and analyse those indicators.

Fuel savings of 1.2% were attained (Table 3). The load factor was improved for 6.4% and in figures was amounting 0.248.

In the second phase, during the following months, the activities were concentrated to vehicle fleet structure and size improvement in view of submitted transport requests. By using the dispatching software the transported cargo weights and volumes were determined. On Figure 5 is shown the empirical distribution of transported cargo weights during May 2009. It was determined that in the observed month there was 194 loaded journeys with cargo weight up to 1,000 kg, which represented 68.6% from the total number of journeys. In June that number was 189, which is 68.2% out of 277 transport journeys. Similar results were obtained for the subsequent months.

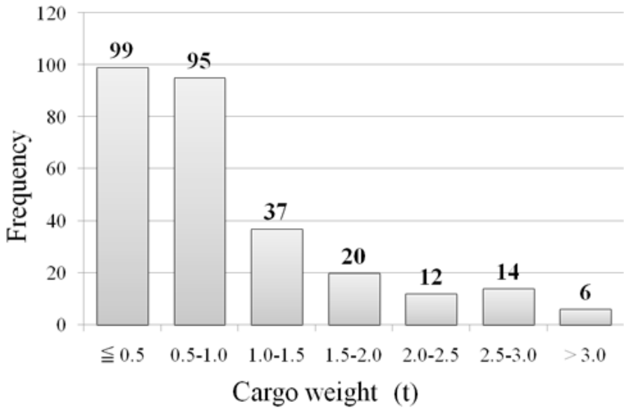

Figure 5: Empirical distribution of transported cargo weights in May 2009

On Figure 6 it is illustrated the share of cargo weights upon existing vehicle classes in the observed vehicle fleet. During May 2009 a 59% of realised transport journeys were carrying cargo that could be satisfied by small pickup vehicles of 850 kg of freight load capacity. The cargo weight between 850 kg and 1,540 kg that could be transported by vans represented a 23% of all journeys. The least share of 18% of journeys had cargo weights over 1,540 kg that should be transported exclusively by light goods vehicles.

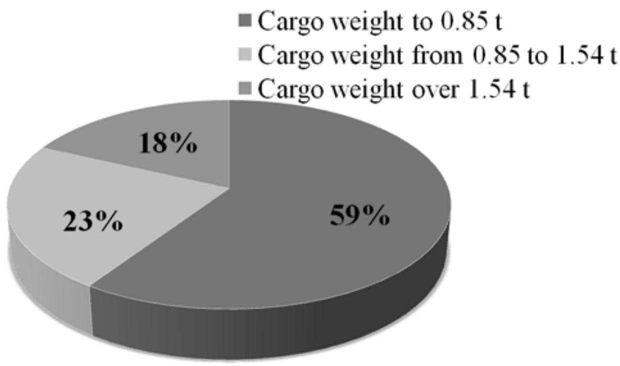

Figure 6: Shares of transported cargo weights in May 2009

It has been realised a simulation of the vehicle fleet operation upon a model suiting the observed company. A vehicle fleet structure proposal capable of realising all imminent transport requests with high probability of realisation and higher vehicle load factor is obtained.

The analysis of transported cargo weight and volumes and the realised simulation of vehicle fleet operation have served to fleet managers as a tool for the decision making upon vehicle purchase policy. As the intention was to highlight the importance of the load factor the vehicle fleet renewal policy opted for more energy efficient and adapted vehicles.

In the second half of 2009 it took place a partial fleet renewal. Some of the light goods vehicles and vans were sold while the pickup vehicles were purchased instead. The effected replacements did not compromise the transport demand realisation.

By implementation of mentioned measures in a second phase, in March 2010, fuel consumption savings were attained at around 9.1% (Table 3). The load factor was further improved for 17.6% by implementation of smaller vehicles and amounted 0.274.

Conclusions

In this paper it has been presented the importance of the vehicle fleet operation management process on the vehicle fleet energy efficiency.

It has been shown that vehicle energy efficiency can be importantly improved my logistics efficiency measures, i.e. by higher vehicle load factor.

By means of realised research, the impact of vehicle load factor on fuel consumption has been quantified. A measurement of the specific fuel consumption took place on road freight vehicles for different cargo weights and volumes. The results have confirmed that the specific fuel consumption increases with the cargo weight, related to the load factor increase, although this relation is not proportional.

Measures of logistics efficiency aimed at rationalising the transport process fuel consumption have been recommended. A set of adequate indicators for the “weight” efficiency criterion in the vehicle allocation to transport requests have been set out. An algorithm for vehicle fleet management with the objective of improved vehicle operation efficiency has been developed. The algorithm represents a tool for more efficient implementation of recommended measures. It is based on both *on-line* and *off-line* fleet management segments, where the *on-line* segment consists in a vehicle dispatching support system, and *off-line* on modelling and simulation support for intelligent fleet renewal.

Suggested measures, along with the algorithm and the software package were implemented in "Delmax" Ltd. company with a vehicle fleet. For a year, attained annual fuel savings were at 9.1%. However, the load factor has significantly improved for 17.6%, which makes the load factor value at 27.4% of available cargo capacity.

Future researches in the observed company are intended for seeking the measures to decrease empty return journeys, which would additionally improve vehicle's logistics efficiency.

Acknowledgement

The research presented in this paper has been realised in the framework of the technological project named "Vehicle Fleet Management System Aimed at Lowering CO_2 Emissions" financed by the Ministry of Science and Technological Development of the Republic of Serbia.

References

[1] Zachariadis T. and Kouvaritakis N. (2003), Long-term outlook of energy use and CO2 emissions from transport in central and eastern Europe, *Energy Policy, 31(2003)*, pp.759–773

[2] EC (2001), White Paper, European transport policy for 2010: time to decide, COM(2001) 370 final, Brussels, Belgium

[3] Momčilović V. (2005), Vehicle Fleet Energy Efficiency Enhancement, M.Sc. thesis, University of Belgrade – Faculty of Transport and Traffic Engineering, Belgrade (original in Serbian)

[4] Oka S., Sedmak A., and Đurović-Petrović M. (2006) Energy efficiency in Serbia – Research and development activity, *Thermal Science: 10(2006),*2, pp.5-32

[5] Stefanović G.M., Trajanović M.D., Duić N.Z. and Ferk M.M. (2008), Pollution data tracking in the western Balkan countries: A state-of-the-art review, *Thermal Science, 12(2008),*4, pp.105-112

[6] Vuchic V.R. (2008), Transport systems and policies for sustainable cities, *Thermal Science, 12(2008)*,4, pp.7-17

[7] DETR. (2002) Energy Efficiency Best Practice Programme: Fuel Management Guide, Department of Environment, Transport and Regions, (DETR), London, UK

[8] Federal Railroad Administration (2009), Comparative Evaluation of Rail and Truck Fuel Efficiency on Competitive Corridors, Final Report, Washington

[9] Ruzzenenti, F. and Basosi, R. (2009), Evaluation of the energy efficiency evolution in the European road freight transport sector, *Energy Policy, 37(2009)*, pp.4079–4085

[10] Lastauto omnibus, http://www.lastauto.de/

[11] Stojiljković, D. (2009), Alternative fuels for the internal combustion engines in the 21st century, University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia

[12] Singaram L. (2009), Biodiesel: An eco-friendly alternate fuel for the future – a review, *Thermal Science, 13(2009)*,3, pp.185-199

[13] DfT (2003), The Safe and Fuel Efficient Driving (SAFED) Standard, Reference: GPG 2100, AEA Technology plc, 329 Harwell, Didcot, Oxfordshire, University of Huddersfield and FuelMaster Logisitcs Ltd, United Kingdom

[14] Jović, J.J. and Đorić, V.D. (2009), Application of transport demand modeling in pollution estimation of a street network, *Thermal Science, 13(2009)*,3, pp.229-243

[15] Han, S. (2003), Dynamic traffic modelling and dynamic stochastic user equilibrium assignment for general road networks, *Transportation Research Part B, 37(2003)*, pp.225–249
[16] Kamakat, F. and Schipper, L. (2009), Trends in truck freight energy use and carbon emissions in selected OECD countries from 1973 to 2005, *Energy Policy, 37(2009),* pp.3743–3751
[17] European Environment Agency (EEA) (2007), Indicator Fact Sheet: TERM 2005 30 Load factors in freight transport, 2nd Draft, http://themes.eea.europa.eu/Sectors_and_activities/transport/indicators/TERM30%2C2005.09
[18] Joumard, R., Andre, M., Vidon, R., and Tassel, P. (2003), Characterizing real unit emissions for light duty goods vehicles, *Atmospheric Environment, 37(2003)*, pp.5217–5225
[19] Noland, R.B., Ochieng, W.Y., Quddus, M.A., North, R.J., and Polak, J.W. (2004), The vehicle emissions and performance monitoring system: Analysis of tailpipe emissions and vehicle performance, *Transportation Planning and Technology, 27(2004)*,6, pp.431-447
[20] Tong, H.Y., Hung, W.T., and Cheung, C.S. (2000), On-road motor vehicle emissions and fuel consumption in urban driving conditions, *Journal of Air and Waste Management Association, 50(2000)*, pp.543-554
[21] Vojtisek-Lom, M. and Allsop, J.E. (2001), Development of heavy-duty diesel portable, on-board mass exhaust emissions monitoring system with NOx, CO2 and qualitative PM capabilities, SAE Technical Paper 2001-01-2641; Society of Automotive Engineers, Warrendale PA, USA
[22] Momčilović V., Vujanović D., Mijailović R., and Papić V. (2009), Exploring the options to decrease CO2 emissions within the vehicle fleet operation process, *Tehnika – saobraćaj, 56(2009),*5, pp.1-9 (original in Serbian)
[23] Olsthoorn X. (2003), Implications of globalization for CO_2 emissions from transport, *Transportation Planning and Technology, 26(2003),*1, pp.105–133

Authors' Affiliation:

D. Vujanović (**corresponding author**)
University of Belgrade, Faculty of Transport and Traffic Engineering
Vojvode Stepe 305, 11000 Belgrade, Serbia
e-mail: d.vujanovic@sf.bg.ac.rs
R. Mijailović
University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia
V. Momčilović
University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia
V. Papić
University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia