VEHICLE FLEET ENERGY EFFICIENCY
Influence on Overall Vehicle Effectiveness

by

Dušan M. RADOSAVLJEVIĆ[a*], Aleksandar V. MANOJLOVIĆ[b], Olivera M. MEDAR[b], and Nebojša J. BOJOVIĆ[b]

[a] College of Applied Technical Sciences Nis, Nis, Serbia
[b] Faculty of Transport and Traffic Engineering, University of Belgrade, Belgrade, Serbia

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This paper presents the research on vehicle fleet energy efficiency impact upon overall vehicle effectiveness. Transport companies and companies with own vehicle fleets tend to enhance their resource effectiveness, and to increase their transport service quality with the objective of attaining a competitive position on the market. Since energy consumed for transport operations is an important transport process resource, a method for assessing transport process effectiveness has been developed with the objective of increasing vehicle fleet effectiveness and its energy efficiency, and the overall vehicle effectiveness human indicator has been defined accordingly. The developed method was then implemented in an actual vehicle fleet and variations of the overall vehicle effectiveness human indicator were researched, as well as specific energy consumptions for respective net transport volumes depending on the following indicators: vehicle payload capacity utilization rate and mileage utilization rate. It is shown that specific energy consumption influences overall vehicle effectiveness depending on both the payload capacity utilization rate and mileage utilization rate.

Key words: *energy efficiency, road transport, overall vehicle effectiveness, vehicle fleet*

Introduction

Throughout the world an important emphasis is presently given to environmental protection and energy efficiency. Transport energy efficiency has gained an important position among strategic measures to attain sustainable development in the European Union [1-5]. The most important objective of the European transport policy is to assist in implementation of a system favorable to economic progress, increasing competitiveness and offering high quality mobility related services with as efficient as possible resource expenditure [6-8].

In the period from 2007 to 2014, the economic crisis led to a decrease of annual transport sector energy consumption by 8%, in the EEA-33 countries. Nevertheless, in 2014 annual transport sector energy consumption was 27% higher compared to the 1990 level. Road transport has the principal share in annual transport sector energy consumption with as much as 74% in the EEA-33 countries. Between 2005 and 2014, final energy consumption in the transport sector decreased by 4.5% in the European Union. Despite the economic crisis' consequences, road transport energy consumption in 2014 was 25% higher than in 1990. Diesel fuel consump-

* Corresponding author, e-mail: dusan.radosavljevic@vtsnis.edu.rs

tion share was rising and amounted to 72% in the total fuel sales in 2014 [9]. Road freight transport in the European Union had a share of 71.3% in total freight transport (in tones-kilometers) in 2014 and a share of 47.8% in the USA in 2013. Moreover, road passenger transport had a share of 82.2% in the EU's total passenger transport (in passenger-kilometers) in 2014 and a share of 86.3% in the USA [10]. To consider the interdependence of the road transport energy efficiency and overall vehicle effectiveness, numerous strategies, studies and reports dealing with road vehicle fleet energy efficiency increase have been analyzed [11-17].

Stringent targets were imposed upon road vehicle manufacturers to make them produce more energy efficient vehicles with lower exhaust gas emissions. On the other hand, the pressure has been put simultaneously on large public fleets, as well as fleets for own account to become more efficient [18]. Sustainable development, among other things, requires development of the transport process effectiveness measurement, *i. e*. overall road vehicles' and drivers' effectiveness, as well as transport service quality.

The focus of this paper is the influence of vehicle fleet energy efficiency upon overall vehicle effectiveness. A methodology for transport process management with the objective of increasing vehicle fleet effectiveness is defined in this paper. In order to solve the formulated problem, the impact of vehicle fleet energy efficiency on the overall vehicle effectiveness was observed. The defined methodology was implemented in an actual vehicle fleet and influence of payload capacity utilization variation on energy efficiency was researched, *i. e*. the specific energy consumption intensity decrease with the increase of vehicle payload capacity utilization rate. Essentially, it was researched how the increase of vehicle payload capacity utilization rate (γ) affects energy efficiency e_v (in MJ/tkm), and especially how γ impacts overall vehicle effectiveness. Such research demonstrates how vehicle fleet capacity utilization influences its energy efficiency, and equally how it influences the overall vehicle effectiveness.

The aim of this paper is therefore to improve the already existing methodology and develop a new one, the implementation of which, in the transport process, would lead to vehicle fleet energy efficiency increase. Measures developed for vehicle fleet energy efficiency improvement are meant to be equally cost efficient, which will represent one of the future research objectives.

Literature review

Customers expect transport service providers to offer excellent quality, reliable delivery and competitive pricing. In such case, transport service providers are expected to increase resource availability utilization, maximize resource performance rate and increase quality of service rate. Transport process resources are vehicles, drivers, dispatchers, but also energy, infrastructure, capital, *etc*. For measuring transport process performance, a reliable tool based on a set of transport process operation indicators is needed.

A tool that represents the basis for maximizing technical resource's (equipment) effectiveness, by setting and maintaining optimal relation between human and technical resources (equipment), is the total productive maintenance (hereinafter referred to as TPM) [19]. Originally, TPM uses process (resource) effectiveness in order to emphasize the value (importance) of operators and people working in production and maintenance, *i. e*. it uses Overall Equipment Effectiveness (hereinafter referred to as OEE) as a quantitative performance indicator in the production process. The aim is to maintain the optimal state of the equipment so as to prevent unplanned breakdowns, running at reduced speed, failures, quality losses, etc. arising in production or while supplying services. Three ultimate TPM objectives are: zero defects, zero accidents and zero breakdowns [20].

Overall effectiveness indicator related to the transport process (vehicle utilization) based on TPM methodology, OEE indicator, expert knowledge and best practice examples result in the Overall Vehicle Effectiveness (hereinafter referred to as OVE) [21]. Since its definition and first literature appearance [22], OVE has been perfectioned and improved. The OVE indicator identifies five losses inherent to the transport process: driver breaks, excessive load and unload time, fill loss, speed loss and quality delays [21]. The methodology for OVE calculation represents a tool that measures transport process availability, performance and quality using these five losses. OVE methodology implementation represents a simple, complete, applicable and improved approach to measuring transport process effectiveness. The measuring itself of the OVE indicator and actions towards transport process improvement directly ensure enhancement potentials in energy efficiency and environmental protection.

According to OVE calculation methodology, activities in transport process are divided into those with added value for the end customer and those not adding any value [23]. Early OVE calculation methodologies have appointed larger OVE values to less energy efficient routes in cases where deliveries or collections were made to/from a significant number of destinations (points). Such a problem has been identified for multiple drop-offs or collections [23]. OVE, in its original form, does not consider the energy efficiency while making the route selection [21]. In order to solve the mentioned issue, a new component which measures route effectiveness is introduced into the OVE equation. The OVE takes up new shape and is named modified overall vehicle effectiveness (hereinafter referred to as MOVE).

Upon request by companies with own vehicle fleets, another specific indicator of overall transport process effectiveness has been introduced. For such companies with own vehicle fleets it is recommended to calculate the OVE indicator based on the total calendar time [24]. Since vehicle procurement represents a major investment, the importance of vehicle engagement rate becomes crucial. Lower availability utilization rate will cause higher transport process costs. Calculation of OVE indicator based on the total calendar time consequently led to creating total overall vehicle effectiveness (hereinafter referred to as TOVE). The TOVE methodology considers some new losses referring to: vehicle availability time, preventive and corrective maintenance, breakdowns, excessive delays caused by customers, quality of service, *etc*. [24]. In TOVE calculation, transport process effectiveness is expressed through administrative or strategic availability, operational (working) availability, performance, and quality rates. TOVE indicator is obtained by multiplying administrative availability, operational availability, performance, and quality rates [24]. Further research on TOVE implementation was related to the route efficiency improvement [25], and application of the lean analysis based on TOVE calculation in different industries to facilitate company's better understanding of its performance and wasteful activities within its road transport operations [26, 27].

Vehicle fleet energy efficiency represents yet another transport process effectiveness indicator. Road transport energy efficiency indicators are defined by European Parliament's Directives [28, 29]. Energy efficiency represents the level of energy consumed while realizing transport operations. Transport process energy efficiency represents the ratio of transport volume and energy consumption, and is expressed in tone-kilometers per kWh (tkm/kWh). The expression may be inverted as well, resulting in kWh/tkm, which is consistent with the methodology presented hereinafter. Other indicators expressing energy efficiency are: energy intensity (MJ/tkm), fuel efficiency (koe/tkm), emission efficiency (g of CO_2/tkm), as well as CO_2 efficiency (tkm /kg of CO_2). A liter of diesel fuel has a constant energy density (approx. 10.1 kWh/L, 36.3 MJ/L or 0.87 koe/L) and while burnt in an internal combustion engine it produces a constant amount of CO_2 (2.66 kg/L) [28, 29].

Methodology

A vehicle fleet effectiveness indicator named OVE Human has been introduced and presented in this paper. OVE Human represents a mathematical expression involving vehicles, drivers, and energy as vehicle fleet resources influencing transport process effectiveness. Increased effectiveness of vehicles and drivers and energy savings increase the OVE Human value as well, while equally improving transport process performance.

OVE Human may be applied to all forms of transport process regardless of their purpose. The aim is to intensively implement the OVE Human indicator in order to improve transport process effectiveness and its energy efficiency. The aforementioned indicator has been expanded compared to OVE [21] and adapted to the existing market conditions. Transport process effectiveness evaluation depends on the available resource utilization rates. The calculation is based on determining availability utilization rates of vehicles and drivers, their performances, quality of supplied service and quality of realized transport service. The OVE Human indicator is influenced by:

– availability utilization rates (α) of vehicles (α_v) and drivers (α_d),
– performances (β) of vehicles (β_v) and drivers (β_d), and
– transport process quality (c) in view of quality of supplied services to customers (c_s), vehicle fleet energy efficiency (c_v) and quality of services rendered (c_d).

The OVE Human indicator formulation is shown in (1) and its value is contained in the interval between 0 and 1 (0 ≤ OVE Human ≤ 1) and expressed in percentage ranging from 0 to 100%.

$$OVE\ Human = \alpha\beta c \tag{1}$$

Consequently, OVE Human represents the product of availability utilization rate α, performance β, and transport process quality c.

Availability utilization rate (α) corresponds to the product of vehicle availability utilization (α_v) and driver availability utilization (α_d) rates.

Vehicle availability utilization rate depends on vehicle roadworthiness and administrative conditions that vehicles should comply with. The entirety of vehicles in the fleet is denoted by A_i and is named the total number of vehicles in inventory. It is sum of the number of operational (roadworthy) vehicles, *i. e.* ready for operation (A_s), and the number of defective vehicles, *i. e.* unready for operation (A_n). Upon operational function, roadworthy vehicles (A_s) are then further subdivided according to ($A_s = A_r + A_d$) into vehicles in operation (A_r) and vehicles ready for operation but not engaged in operation (A_d). Every vehicle in the inventory during the considered period D_i (total number of calendar days) is in operational state in view of roadworthiness and administrative condition compliance, *i. e.* ready for operation during D_s (number of) days, or in (defective) non-operational state, *i. e.* unready for operation during D_n days. The same D_i period is composed of ($D_i = D_r + D_d + D_n$), where the vehicle is roadworthy during D_s days, and due to operational utilization it may be in operation for D_r days or else in operational state but not engaged in (and available for) operation for D_d days.

Vehicle availability utilization rate (α_v) is an indicator representing utilization rate of operational vehicles (ready for operation). This indicator (2) reveals the ability of organizational structures to engage operational vehicles (roadworthy and complying with administrative conditions).

$$\alpha_v = \frac{A_r D_r}{A_i D_i - A_n D_n} = \frac{\sum_1^n ADr_i}{\sum_1^n ADi_i - \sum_1^n ADn_i}, \quad i = 1,..,k,..,n \text{ vehicles} \tag{2}$$

Driver availability depends on the number of days for: annual leave, sick leave, disciplinary measures, penalization for traffic offences (resulting in driving prohibition measures), but also driver training and testing. Available drivers may be allocated to transport tasks – performing working activities, allocated as backup – on active duty, unallocated due to lack of work, poor organization, *etc*., and attending training, knowledge refresher/upgrade courses, best practices, *etc*.

Unavailable drivers (unready for operation) are either on annual leave, sick leave, disciplinary measures, penalized for traffic offences or even no-show/late for work.

Driver availability utilization (α_d) reflected by the ratio of total number of days when a driver is driving (is engaged in operation) to total number of days when the driver is available for operation, is shown in (3).

Total number of days when the driver is available for operation is obtained when weekends (Saturdays and Sundays), annual leave days, public holidays, non-working days and legislated paid leave for slave day are subtracted from the total annual number of days.

$$\alpha_d = \frac{\text{total number of days engaged in operation}}{\text{total number of days available for operation}} \tag{3}$$

Performance (β) represents the product of vehicle performance (β_v) and driver performance (β_d).

Vehicle performance (β_v) depends on the transport volume and represents a ratio of net transport volume to gross transport volume, transport volume being expressed in tone-kilometers [tkm] (4).

$$\beta_v = \frac{U_N}{U_G} = \frac{QL}{q(AK_t + AK_p)} = \frac{\sum_1^{\lambda}(q_\lambda K_{t\lambda})}{q(\sum_1^n AK_{t_i} + \sum_1^n AK_{p_i})} \tag{4}$$

Net transport volume in freight transport (U_N) represents the product of total transported freight weight (Q) and loaded vehicle itinerary length (mileage) (L), and is expressed in tone-kilometers [tkm]. K_t represents loaded vehicle mileage on a single journey. Net transport volume in passenger transport represents the product of the number of carried passengers (N) and average journey length (L), and is expressed in passenger-kilometers [pkm].

Gross transport volume in freight transport (U_G) corresponds to the product of supplied vehicle capacity (q) and loaded vehicle journey length (mileage) and of so-called empty runnings ($AK_t + AK_p$), and is expressed in tone-kilometers [tkm]. Meanwhile, gross transport volume in passenger transport corresponds to the product of the supplied vehicle capacity (number of seats) and length of vehicle itinerary on the route (L), and is expressed in seat-kilometers [skm].

Driver performance depends on the time utilization that a driver spends at his/her workplace. Driver performance, representing the ratio of driving hours (AH_w) to hours on duty (AH_r), is shown in (5).

$$\beta_d = \frac{AH_w}{AH_r} = \frac{\sum_1^n AH_{w_i}}{\sum_1^n AH_{r_i}} \tag{5}$$

Driving hours (AH_w) correspond to total driving time that drivers spend in moving motor vehicles. This time includes empty running times from the vehicle base location to the first loading point, from the unloading place to a subsequent loading place, and from the last unloading place to the vehicle base, and driving times with freight between loading and unloading places. Vehicle driving hours include the sum of driving times of all drivers.

Vehicle hours on duty (AH_r) represent working time of the driver from the beginning of work (arriving at the workplace) until the end of work (leaving the workplace). This time involves vehicle and driver preparation times, driving times, loading /unloading times, service waiting times (for loading, unloading, waiting at border crossings, *etc*.), times for freight securing, or else assistance to passengers in passenger transport. This time also includes preparation of driver work gears, additional transport related documents (tachograph sheets, drive log, freight documents, *etc*.), vehicle handover and visual inspection, handover of financial assets from sold tickets and remaining tickets, *etc*.

Transport process quality (c) is represented by three parameters. The first is related to the quality of services rendered to customers (ki_s), the second to vehicle fleet energy efficiency (c_v), and the third to quality of realized drivers' work from the aspect of their compliance with regulations and internal procedures (violations) (c_d).

The quality of services supplied to customers (c_s), corresponding to the ratio of the number of transport services (journeys) with freight without deficiencies (faults) to the total number of transport services with freight, is given in (6).

$$c_s = \frac{N - N_{\text{off}} - N_{\text{delay}} - N_{\text{damage}} - N_{\text{fault}}}{N} \tag{6}$$

The number of loaded journeys with deficiencies is determined based on the number of service user (customer) complaints and claims (sender or receiver of goods) and represents the sum of the number of non-served users (customers) – N_{off}, number of delays for (late showing to) loading/unloading – N_{delay}, number of damaged deliveries – N_{damage} and number of faulty deliveries – N_{fault}.

The quality parameter (c_v) related to attaining the envisioned vehicle fleet energy efficiency, calculated as a ratio of anticipated unit energy consumption for gross transport volume (e_{plan}) to realized unit energy consumption for realized net transport volume (e_{net}), in MJ per tonne-kilometer (MJ/tkm), is shown in (7).

$$c_v = \frac{e_{\text{plan}}}{e_{\text{net}}} \tag{7}$$

Total energy consumed for realized net transport volume is obtained from the total fuel used for the realization of transport services (journeys), *i. e*. total vehicle fleet mileage. Unit energy consumption for realized net transport volume is a quotient of total consumed energy in (MJ) and accomplished net transport volume in (tkm). Unit energy consumption for gross transport volume corresponds to the ratio of anticipated energy to be consumed in (MJ) if maximum transport volume would be accomplished to the gross transport volume in (tkm).

Compliance with regulations and internal procedures in driver's everyday operation, denoted by parameter c_d, calculated as a quotient of number of journeys without infringements and total number of journeys ($A_{Z\lambda}$), is shown in (8):

$$c_d = \frac{A_{Z\lambda} - N_{Vin} - N_{Vre}}{A_{Z\lambda}} \tag{8}$$

Based on the evidence of internal control the number of internal procedure violations Nv_{in} is determined. These violations refer to breaching internal procedures, technological procedures, internal acts, *etc*. Number of violations related to traffic and transport regulations Nv_{re} is established by infringement records issued by enforcement bodies during roadside checks or at transport undertaking facilities.

Finally, OVE Human indicator formulation (1) can be presented as in (9):

$$OVE\ Human = \alpha_v \alpha_d \beta_v \beta_d c_s c_v c_d \tag{9}$$

The purpose of the developed methodology is to discover improvement potentials in the transport process, as well as measuring the effects of implemented improvement measures in the transport process. Thus, values of defined indicators are calculated, closely monitored, analyzed and compared to anticipated values (objectives). Calculated values allow transport managers to observe resource utilization rates and quality levels in transport process realization. Subsequently, appropriate decisions are made with the objective of increasing vehicle capacity utilization in certain time periods. Better capacity utilization will eventually lead to increasing the energy efficiency for the realized transport volumes.

Implementation of the proposed methodology in a road transport company

The proposed methodology was implemented in one transport company from Serbia, engaged in long-haul freight transport. Its vehicle fleet operation data from 2015 were analyzed. The company operates freight transport services all across Europe, but mostly in Central and Western Europe. The vehicle fleet is composed of 94 truck and semitrailer combinations. The trucks are equipped with EURO V, EEV and EURO VI emission standard engines accompanied by tarpaulin platform semitrailers, intended for general commercial freight transport. Payload capacity of each vehicle combination is 24 tones. Annual number of working days is 252. There are 98 drivers employed with the considered company and they were engaged on average 218 days a year. The vehicle fleet operation indicators for 2015 are shown in tab. 1. Indicators were calculated based on data collected from the following sources: transport documents, route plans, driver's time and activity records, existing Automatic Vehicle Location System, service plans for the fleet, work orders for service, *etc*.

In the considered period, payload capacity utilization rate (γ) is 0.69, mileage utilization rate (ω) is 0.78, while the average energy consumed per net tkm (e_{ntkm}) totals to 0.799 MJ/tkm.

Based on vehicle fleet operation indicators from (1)-(9), the values of vehicle and driver availability utilization rates, performance rates, quality of supplied services to customers, vehicle fleet energy efficiency and regulation and internal procedure compliance level in operation, as well as OVE Human, are calculated and presented in tab. 2.

Energy consumed per net tonne-kilometer is influenced by both payload capacity utilization and vehicle mileage utilization rates. In order to determine the degree of influence of the energy efficiency upon OVE Human indicator, its variation depending on the payload capacity utilization rate (γ), vehicle mileage utilization rate (ω) and unit energy consumption per net tonne-kilometer (enet) is considered (tab. 3, fig. 1). The calculation is made according to (1)-(9), for values γ from 0.4 to 1 and for values of ω between 0.75 and 1. Values for enet are taken from the company's database, and they differ depending on the γ values.

By increasing payload capacity utilization rate for constant values of vehicle mileage utilization, energy consumption per net tonne-kilometer is decreasing, and OVE Human indicator value is rising. Similarly, by increasing the vehicle mileage utilization rate for constant values of payload capacity utilization, energy consumption per net tonne-kilometer decreases, and OVE Human indicator value increases.

Table 1. Considered company's vehicle fleet indicators, 2015

Total number of vehicles in inventory [#]	A_i	94	Average loaded journey length, [km]	$K_{st\lambda}$	712.72
Average number of vehicles in operation [#]	A_r	84.48	Average daily mileage, [km]	K_{sd}	387.30
Total number of calendar days, [#]	D_i	34,310	Maximum anticipated freight weight for transport per total number of loaded journeys, [t]	Q_{max}	216,576
Number of days of vehicles being defective (unoperational), [#]	D_n	1,020	Payload capacity utilization rate, [–]	γ	0.69
Number of days of vehicles being operational but not engaged, [#]	D_{snp}	358	Total transported freight weight, [t]	Q	149,437
Number of days in operation, [#]	D_r	21,290	Maximum transport volume, [tkm]	U_{max}	197,894,400
Number of days of vehicles being operational (roadworthy), [#]	D_s	33,290	Gross transport volume, [tkm]	U_{gross}	154,357,632
Vehicle fleet roadworthiness rate, [–]	α_t	0.9703	Net transport volume, [tkm]	U_{net}	106,506,766
Vehicle availability utilization rate, [–]	α_v	0.6395	Average operation speed, [km h^{-1}]	V_e	45.20
Vehicle fleet availability utilization rate, [–]	α_f	0.6205	Average traffic speed, [km h^{-1}]	V_s	50.75
Total time on duty, [h]	AH_r	182,426	Number of non-served customers, [#]	N_{off}	18
Time utilization rate within 24 hours, [–]	ρ	0.3570	Number of delivery delays, [#]	N_{delay}	359
Average vehicle operation time, [h]	H_{rs}	8.57	Number of damaged deliveries, [#]	N_{damage}	188
Total driving time, [h]	AH_{ws}	162,477	Number of faulty deliveries ,[#]	N_{fault}	59
Working time utilization rate, [–]	δ	0.89	Average fuel consumption of loaded vehicle, [L km^{-1}]	FC_l	0.30
Average daily driving time, [h]	H_{ws}	7.63	Average fuel consumption of empty vehicle, [L km^{-1}]	FC_e	0.24
Total mileage, [km]	AK	8,245,600	Average fuel consumption, [L km^{-1}]	FC_a	0.29
Total loaded mileage, [km]	AK_t	6,431,568	Total fuel consumed of loaded vehicle, [l]	TFC_l	1,929,470
Total dead mileage, [km]	AK_n	659,648	Total fuel consumed of empty vehicle, [l]	TFC_e	435,368
Total empty runinngs, [km]	AK_p	1,154,384	Total fuel consumed, [l]	TFC	2,364,838
Mileage utilization rate, [–]	ω	0.78	Total energy consumed, [MJ]	E_t	85,134,171
Dead mileage rate, [–]	ω_n	0.08	Average energy consumed per km, [MJ km^{-1}]	e_{km}	10.325
Empty runinngs rate, [–]	ω_e	0.14	Average energy consumed per net tonne-km, [MJ km^{-1}]	e_{ntkm}	0.799
Annual average vehicle mileage, [km]	AK_v	87,719	Average energy consumed per gross tonne-km, [MJ km^{-1}]	e_{btkm}	0.552
Total number of loaded journeys, [#]	$A_{z\lambda}$	9,024	Number of driver violations (internal control), [#]	Nv_{in}	224
Average number of loaded journeys per vehicle, [#]	$A_{z\lambda v}$	96	Number of driver violations (external control), [#]	Nv_{re}	297

Table 2. Calculated values of resource availability utilization, performances, transport process quality and OVE Human, 2015

Vehicle availability utilization rate	α_v [–]	0.6395
Driver availability utilization rate	α_d [–]	0.9965
Vehicle performance rate	β_v [–]	0.5382
Driver performance rate	β_d [–]	0.8480
Quality of supplied services to customers	c_s [–]	0.9309
Vehicle fleet energy efficiency	c_v [–]	0.4504
Regulation and internal procedure compliance level in operation	c_d [–]	0.9423
OVE Human [–]		0.1149

Table 3. Variation of unit fuel consumption per net transport volume and OVE Human values in relation to *γ* and *ω*

	γ = 0.4		γ = 0.5		γ = 0.6		γ = 0.7		γ = 0.8		γ = 0.9		γ = 1	
	e_{ntkm}	OVE Human	e_{ntkm}	OVE Human	e_{ntkm}	OVE Human	e_{ntkm}	OVE Human	e_{ntkm}	OVE Human	e_{ntkm}	OVE Human	e_{ntkm}	OVE Human
ω = 0,75	1.20	0.043	1.02	0.063	0.90	0.085	0.81	0.110	0.75	0.137	0.70	0.165	0.68	0.198
ω = 0,80	1.13	0.049	0.96	0.071	0.85	0.096	0.77	0.124	0.71	0.153	0.67	0.184	0.65	0.220
ω = 0,85	1.06	0.055	0.91	0.080	0.81	0.108	0.73	0.138	0.68	0.171	0.64	0.205	0.62	0.244
ω = 0,90	1.00	0.061	0.86	0.089	0.77	0.120	0.70	0.154	0.65	0.189	0.61	0.226	0.60	0.269
ω = 0,95	0.95	0.068	0.82	0.099	0.73	0.133	0.67	0.169	0.62	0.208	0.59	0.248	0.57	0.294
ω = 1	0.90	0.076	0.78	0.109	0.70	0.146	0.64	0.186	0.60	0.228	0.57	0.271	0.56	0.320

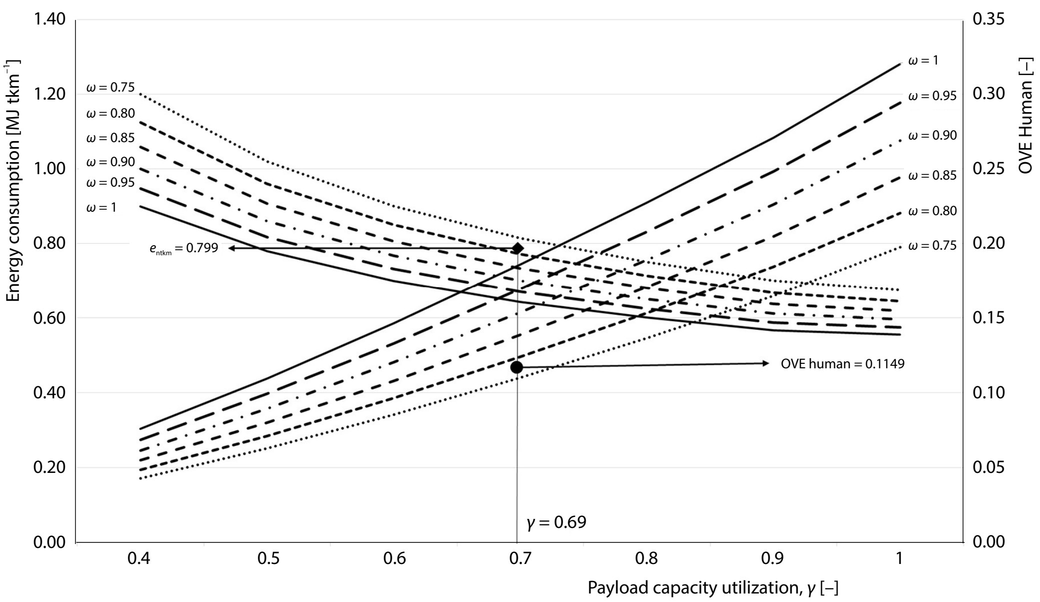

Figure 1. Variation of unit fuel consumption per net transport volume and OVE Human values in relation to *γ* and *ω*

In the considered vehicle fleet, in the hypothetical case where payload capacity utilization rate is maximized ($\gamma = 1$), for the same vehicle mileage utilization rate for equal vehicle fleet mileage, e_{ntkm} would decrease by 17.77%, *i. e.* it would amount to 0.657 MJ/tkm, meanwhile, the OVE Human indicator would increase by 76.41% and amount to 0.2027. On the hypothesis that the vehicle mileage utilization is complete ($\omega = 1$), e_{ntkm} would decrease by 18.40%, *i. e.* it would be equal to 0.652 MJ/tkm, and OVE Human indicator would increase by 57.09% and amount to 0.1805.

If the payload capacity utilization rate increases from 0.4 to 1, the energy consumption per tonne-kilometer will decrease in the range from 38% (from 0.90-0.56 MJ/tkm, for $\omega = 1$) to 43% (from 1.20-0.68 MJ/tkm, for $\omega = 0.75$), while OVE Human indicator will increase by more than four times, from 0.043-0.198 for $\omega = 0.75$ and from 0.075-0.320 for $\omega = 1$.

Conclusions

In this paper, the influence of energy efficiency on the overall vehicle effectiveness has been demonstrated. Transport process effectiveness depends on effective utilization of transport company resources. A methodology for calculating the OVE Human indicator based on determining vehicle and driver availability utilization, vehicle and driver performances, quality of supplied transport services, vehicle fleet energy efficiency and quality of realized transport services has been proposed.

The presented methodology for OVE Human indicator calculation has been implemented in a transport company engaged in long-haul (international) freight transport. In the considered vehicle fleet, if the payload capacity is totally utilized ($\gamma = 1$), for the same vehicle mileage utilization rate for identical vehicle fleet mileage, e_{ntkm} decreases by 17.77%, while OVE Human indicator increases by 76.41% to become 0.2027. On the other hand, if the vehicle mileage is utterly maximized ($\omega = 1$), e_{ntkm} decreases by 18.40%, and OVE Human indicator increases by 57.09%, to become 0.1805.

Based on presented implementation results in the considered transport company, it is concluded that the method for OVE Human indicator calculation is convenient for transport process effectiveness evaluation. By increasing energy efficiency, *i. e.* lowering fuel consumption in regard to net transport volumes, transport process effectiveness is improved as well as OVE Human indicator value. Future research should be oriented toward establishing a methodology for actions minimizing faults that are considered critical for the overall transport process effectiveness and energy efficiency, as well as application of Intelligent Transport Systems and Automatic Vehicle Location System as support for daily fleet management.

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Nomenclature

A_i – total number of vehicles in inventory, [vehicles]
A_s – number of roadworthy vehicles, [vehicles]
A_n – number of defective vehicles, [vehicles]
A_r – number of vehicles in operation, [vehicles]
A_d – number of vehicles ready for operation but not engaged in operation, [vehicles]
AH_W – driving time, [h]

AH_r – working hours, [h]
AK_t – loaded freight vehicle mileage, [km]
AK_p – empty freight vehicle mileage, [km]
$A_{Z\lambda}$ – total number of loaded journeys, [journeys]
c – transport process quality, [–]
c_s – quality of services supplied to customers, [–]
c_v – vehicle fleet energy efficiency, [–]
c_d – quality of realized services in driver's everyday operation, [–]
D_i – total number of calendar days, [days]
D_s – number of days of vehicles being operational (roadworthy), [days]
D_n – number of days of vehicles being defective (unoperational), [days]
D_d – number of days of vehicles being operational but not engaged in operation, [days]
e_{ntkm} – energy consumed per net transport volume, [MJ/tkm]
e_{gtkm} – energy consumed per gross transport volume, [MJ/tkm]
Kt_λ – loaded freight vehicle mileage on a single journey, [km]
L – distance (mileage) between loading and unloading points, [km]
N – number of customers, [customers]
N_{off} – number of non-served customers, [customers]
N_{delay} – number of delivery delays, [customers]
N_{damage} – number of damaged deliveries, [customers]
N_{fault} – number of faulty deliveries, [customers]
N_{Vre} – number of violations (infringements) related to traffic and transport regulations, [violations]
N_{Vin} – number of internal procedures violations, [violations]
Q – total transported freight weight, [t]
q – vehicle payload, [t]
q_λ – transported freight weight on a single journeys, [t]
U_n – net (realized) freight transport volume, [tkm]
U_b – gross (supplied) freight transport volume, [tkm]
U_m – maximum freight transport volume, [tkm]
$\sum_1^n ADi_i$ – total vehicle fleet days, [days]
$\sum_1^n ADr_i$ – defective (nonoperational) vehicle fleet days, [days]
$\sum_1^n ADn_i$ – working vehicle fleet days, [days]

Greek symbols

α – availability utilization rate [–]
α_v – vehicle availability utilization rate [–]
α_d – driver availability utilization rate [–]
β – performance rate [–]
β_v – vehicle performance rate [–]
β_d – driver performance rate, [–]
γ – payload capacity utilization, [–]

Acronyms

MOVE – modified overall vehicle effectiveness, [–]
OEE – overall equipment effectiveness, [–]
OVE – overall vehicle effectiveness, [–]
TOVE – total overall vehicle effectiveness, [–]
TPM – total productive maintenance, [–]
TVSM – transport value stream map, [–]

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