Fuel Consumption in Timber Haulage

Radomír Klvač, Josef Kolařík, Marcela Volná, Karel Drápela

Abstract – Nacrtak

The paper presents an assessment of road timber transport by trucks, which included 132 truck-and-trailer units – three types of trucks (Tatra, Mercedes Benz and Iveco) with a selection of trailers in the Czech Republic. The main aim of this work was to establish the effect of hauling distance in the individual types of timber-transport units on the fuel consumption per 100 km and on the specific fuel consumption per one transported cubic metre of timber. Any decrease of fuel consumption per unit of production can enhance environmental profile of secondary transport. Freight transport recorded conspicuous changes in the last ten years, and the analysis presented in this work provides important information useful in the planning and organization of road timber transport. During the study period, obsolete and inadequate truck-and-trailer units were continuously replaced with new units, which resulted in a considerable reduction in fuel consumption per unit of production (0.5 L/m^3 ub).

Keywords: haulage road, timber transport, truck, truck-and-trailer unit, fuel consumption

1. Introduction – *Uvod*

Timber transport from the roadside landing to the customer represents a very demanding phase in the chain of timber supply in terms of energy and cost. It is characterized by several specific factors that influence its implementation and differentiate it from the goods transport by trucks. In general, we can say that it is a one-way haulage, where it is very difficult or even impossible to utilize the timber-transport unit in its return run. The machines are specifically designed and can be used only to a limited extent for the haulage of other goods. Also, they have to drive a larger part of the hauling distance on forest roads. Holzleitner (2009) and Holzleitner et al. (2011) studied the operation of timber-transport units by using the GPS/GIS system and concluded that the share of their travel on forest roads was 14%. The machines often have to drive deep into the forests and have to be adapted accordingly. They have to work in difficult field conditions and therefore they are very frequently affected by them as well as by extreme seasonal weather. This is why the trucks are often equipped with the multiple-wheel drive and heavy-duty engines. These specific technological requirements considerably increase fuel consumption of timber-transport units.

Svenson (2011) mentioned a range of technical factors directly affecting the fuel consumption of timber-transport units and classified them into the following groups: vehicle characteristics, trailer characteristics, road geometry, road surface, goal speed, gear change, driving behavior, weather and road surface conditions.

The above factors of technical and technological character have a considerable influence on the average fuel consumption of timber truck-and-trailer units, which may be double as compared with the common road goods transport by trucks (Devlin 2010).

The number of information systems specialized in goods or bus transportation is high in the Czech Republic but the number of information systems specialized in timber transport is low. Hauling timber from the roadside landing features problems such as heterogeneity of the transported material, difficult utilization of vehicles at their return run, seasonal character of operations, climatic effects – all these resulting in a high rate of »empty« drives. Data processing, transport optimization and necessity of flexible response to unexpected situations put high requirements both on the information system and on timber haulage managers. This is why an information system was designed, which tries to respond to the absence of information systems in the field of timber haulage (Klvač 2006).

From the economic point of view, the share of timber haulage in total timber supply chain costs may reach more than 30% (Favreau 2006). He mentions that transport is the biggest cost item in round wood costs in Canada. In Sweden, Svenson (2011) says that 35% of total transportation costs are related to the fuel consumption of timber trucks. Economic data provided by the contractor of timber-transport units, which were the subject of our study, demonstrated that diesel fuels accounted for the highest share in total costs (30%), followed by depreciation and leasing (20%) and repairs and maintenance (16%). Wages (15%), overhead costs (13%) and other costs (5%) followed. The objective of implementation of the information system was to conduct a basic analysis of individual types of timber-transport units and based on the acquired data to find primary relations affecting transport efficiency and thus to find ways how to reduce the cost of timber haulage.

Any decrease of fuel consumption per unit of production can enhance environmental and economy profile of secondary transport. As the fuel cost makes the largest part of total timber haulage costs, the aim of this work is to analyze the fuel consumption in the individual types of truck-and-trailer units used in timber transport. Any replacement of obsolete and inadequate truck-and-trailer units by new more efficient units can result in a considerable reduction of fuel consumption per unit of production.

2. Material and methods – *Materijal i metode*

A »tailor made« information system was designed in 2003, which can receive orders placed by customers, support the decision-making process of dispatchers by using suitable truck-and-trailer units (TTU), make records of hauling performance, monitor production in progress and summarize data in the form of databases. In 2004, the system was characterized in the form of diagrams so that designers would be capable of meeting customer requirements (Klvač 2006). This information system was designed for larger companies with a greater number of vehicles dislocated on remote workplaces. All workplaces had an access to the system via client and worked with data on multiple levels related to the position in company or business interrelationship. Each position/client type had centrally set rights and responsibilities in the system. A timber transport company implemented the system at the beginning of 2005 and data on each individual transportation case started to be recorded from the end of the same year. The data was summarized for each TTU in monthly intervals for purposes of analytical assessment by the company management. The monthly indicators of TTUs were used in this study.

The structure of the assessed data related to this study was as follows:

- ⇒ Truck-and-trailer unit, inventory number provided for non-commutability of data,
- ⇒ TTU operational centre,
- ⇒ Trailer, inventory number,
- ⇒ Total travel distance, km,
- ⇒ Travel unloaded, km,
- ⇒ Travel loaded, km,
- ⇒ Backhauling, % of kilometers driven loaded,
- ⇒ Volume of transported timber, m^3 ub; softwood and hardwood,
- ⇒ Number of loads per month and per day,
- ⇒ Average size of load, m^3 ub,
- ⇒ Average hauling distance – one way distance, km,
- ⇒ Fuel consumption in liters per month.

Parameters that were calculated based on the above data were as follows:

- ⇒ Average fuel consumption per unit of production, *l*/m^3 ub
- ⇒ Average fuel consumption per 100 km, *l*/100 km

All data were checked at first and records containing gross errors caused by human factor at recording were eliminated. Then the data were imported and organized within the spreadsheet software (Microsoft Excel) and subsequently summarized for individual types of TTUs. In the period 2005 – 2009, considerable changes occurred in the fleet of timber transport units with obsolete TTUs being put out of operation and replaced by new TTUs where necessary. Old and technically unfit Liaz TTUs were taken out of service first. As the amount of data on these TTUs was not representative, the Liaz type of TTU was not statistically evaluated in this study. Types of truck-and-trailer units assessed in this study were Iveco (represented by models ASTRA, MP260 and STRALIS), Tatra (represented by Tatra 815 only), Mercedes Benz (models 3344, 3341, 2644 and 3348). The data were aggregated and analyzed according to truck manufacturers.

The initial analysis was made with the use of pivoting (contingency) tables and graphs. GraphPad Prism 5 (Motulsky 2007) was used for non-linear regressions. The software enables a very flexible choice of the regression model, it has very good graphical capabilities and provides the possibility to compute and draw confidence intervals of the model. Prism 5 can eliminate outliers with the ROUT method (Motulsky and Brown 2006). This method is based on a new robust non-linear regression combined with outlier rejection. It is an adaptive method that gradually becomes more robust as the method proceeds. Press et al. (1988) based their robust fitting method on the assumption that variation around the curve follows a Lorenzian distribution rather than a Gaussian distribution. The Marquardt non-linear regression algorithm was adapted to accommodate the assumption of a Lorenzian (rather than Gaussian) distribution of residuals. After fitting a curve using robust non-linear regression, a threshold is needed for deciding when a point is far enough from the curve to be declared an outlier. All methodology is described in detail in Motulsky and Brown (2006). The authors state that their method identifies outliers from non-linear curve fits with reasonable power and few false positives (less than 1%).

In all cases, the logarithmic function used for the regression model was in the following form:

$$y = a \times \ln(x) + b \qquad (1)$$

Where:

x explaining (independent) variable,
y explained (dependent) variable,
a, b coefficients.

The respective statistical assessments include a, b coefficients established by the regression analysis, 95% confidence interval (shaded in the graphs), R^2 – determination coefficient, number of analyzed points and number of outliers.

The respective dependencies are presented in summary diagrams in Microsoft Excel, in which only regression curves were plotted.

3. Results – *Rezultati*

The total number of assessed records (i.e. monthly performances of various truck-and-trailer units) was 2 548. The total number of TTUs assessed in the period 2005 – 2009 was 134 and the units were operated at different places in the Czech Republic. In the period 2003 – 2004, we monitored only 21 trucks; this number increased in 2005 to 90. In the following years, the fleet was gradually renewed and some old vehicles were put out of operation. This is why the number of trucks monitored in 2006, 2007 and 2008 was 87, 80 and 71, respectively. In 2009, the process of renewal was completed and the final number of trucks was 51 of which 45 were Mercedes Benz.

In the period under study (Table 1), more than 3.4 million cubic meters of timber were hauled from the roadside landing to the conversion depot, directly to customers or to the siding railway. They were recorded and assessed - softwood accounted for 92% and hardwood for 8% of the total volume. Total diesel consumption of monitored TTUs was 6.8 million liters. The fuel consumption is not broken down to the amount used directly in timber haulage and the amount used indirectly, i.e. driving to the working place or driving to the workshop for repair. The share of »empty kilometers« in the total number of driven kilometers was 47%. Average backhauling of TTUs (loaded vehicles) was 53%. The presented values represent and summarize a total of 136 292 cases of timber transport.

The average hauling distance was changing in the course of years depending on activities of the company operating the trucks. From 2005, the number of timber yards was decreasing and the amount of timber handled at the roadside landing was increasing as well as the timber haulage from the landing directly to the customer. The average hauling distance was

Table 1 Mean values for all monitored TTU types
Tablica 1. *Značajke promatranih kamionskih skupova*

Volume of transported timber, m^3 – *Obujam transportiranoga drva,* m^3	3 418 171	Softwood – *Crnogorica*	3 161 533
		Hardwood – *Bjelogorica*	256 638
Total distance, km – *Ukupno prijeđena udaljenost,* km	11 032 534	Empty kilometers – *Vožnja praznim kamionom,* km	5 172 109
		Kilometers driven loaded – *Vožnja punim kamionom,* km	5 860 425
Fuel consumption, l – *Potrošnja goriva,* l	6 811 604	–	–
Number of cycles – *Broj turnusa*	136 292	–	–
Average fuel consumption, l/m^3 – *Prosječna potrošnja goriva*, l/m^3	2.19	–	–
Average consumption, l/100 km – *Prosječna potrošnja goriva,* l/100 km	67.4	–	–
Average hauling distance*, km – *Prosječna udaljenost turnusa**, km	45.05	–	–

* One way distance – * *U jednom smjeru*

Table 2 Trends of important indicators in all TTU types in the studied period

Tablica 2. *Trendovi i važne karakteristike promatranih kamionskih skupova u vremenu istraživanja*

Year – *Godina*	2005	2006	2007	2008	2009
Average fuel consumption, l/m^3 – *Prosječna potrošnja goriva*, l/m^3	2.32	2.06	1.87	2.67	3.08
Average fuel consumption, l/100 km – *Prosječna potrošnja goriva,* l/100 km	69.51	68.4	70.94	61.22	61.36
Average hauling distance*, km – *Prosječna udaljenost turnusa**, km	39.31	37.6	36.87	65.76	74.21
Average size of load, m^3 – *Prosječni obujam tovara,* m^3	20.59	23.45	25.96	26.13	27.57
Average backhauling**, % – *Prosječna transportna udaljenost punoga kamiona***, %	53	48	48	52	49

* One way distance – * *U jednom smjeru*

** % of kilometers driven loaded – ** *Udio s obzirom na udaljenost turnusa*

Table 3 Outputs and indicators of individual TTU types

Tablica 3. *Tehničke karakteristike promatranih kamionskih skupova*

TTU type – *Model kamionskoga skupa*	IVECO	TATRA	MB*
Average fuel consumption, l/m^3 – *Prosječna potrošnja goriva,* l/m^3	2.26	1.93	2.71
Average fuel consumption, l/100 km – Prosječna potrošnja goriva, l/100 km	66.74	72.25	58.31
Average hauling distance**, km – *Prosječna udaljenost turnusa* **, km	48.97	28.98	76.11
Average loads per day – *Prosječan broj turnusa po danu*	2.96	3.25	2.98
Average size of load, m^3 – *Prosječan obujam tovara*, m^3	25.21	22.84	28.38
Average backhauling*** – *Prosječna transportna udaljenost punoga kamiona* ***	51	46	55
Total, km – *Ukupno*, km	903 845	4 014 736	6 055 543
Volume of hauled timber, m^3 – *Obujam transportiranoga drva,* m^3	285 683	1 701 892	1 408 446

* MB: Mercedes-Benz

** One way distance – **U jednom smjeru

*** % of kilometers driven loaded – *** Udio s obzirom na udaljenost turnusa

increasing towards the end of the study period – see Table 2. The lowest distance was achieved in 2007 due to the Kyrill gale disaster when a substantial part of all TTUs were concentrated to work in affected areas, where the trucks mostly transported timber over short hauling distances, which considerably affected the annual average hauling distance. The average size of load was markedly increasing during the years thanks to changes in the fleet because the newly used TTUs of Mercedes Benz type featured a considerably higher capacity than the other assessed TTU types (Table 3).

Table 2 shows that the increasing average hauling distance resulted in the increasing average fuel consumption per unit of production and that the fleet renewal brought a gradual decrease in the fuel consumption per 100 km. In 2008 and 2009, when the Mercedes Benz type of TTU started to dominate the fleet, the average fuel consumption per 100 km dropped dramatically by 9%. A detailed survey of indicators and outputs by individual types of timber transport units is presented in Table 3, where the prominent indicator is the load size.

Backhauling considerably affects transport efficiency; average backhauling increased depending on average hauling distance, which was favorably affected by the easier coordination of loads by dispatchers. Over short hauling distances, timber transport from the forest is operated more or less in one-way direction; backhauling is often unrealistic and the trucks are additionally burdened by driving to their workplace and to repair or maintenance workshops. This is why its efficiency is below 50%. With the increasing of the hauling distance, the possibility of finding suitable backhauling increases and the effect of driving to the workplace or repair is minimized (Fig. 1). Extremely low values mostly resulted from loading into wagons (when the vehicle was used for loading wagons) and its number of empty kilometers increased due to frequent drives within the terminal (timber yard). On the other hand, extremely high values resulted from a nearly ideal relation when empty kilo-

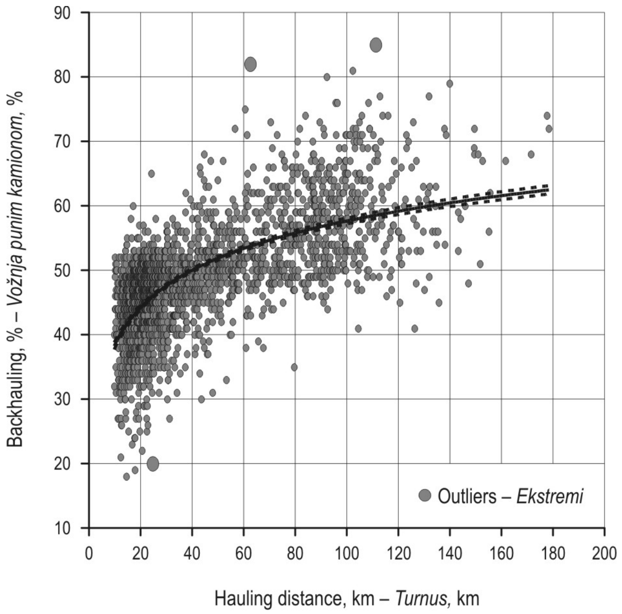

Fig. 1 Dependence of backhauling on hauling distance (all TTU types)
Slika 1. *Udio vožnje punim kamionom po turnusu (svi promatrani modeli kamionskih skupova)*

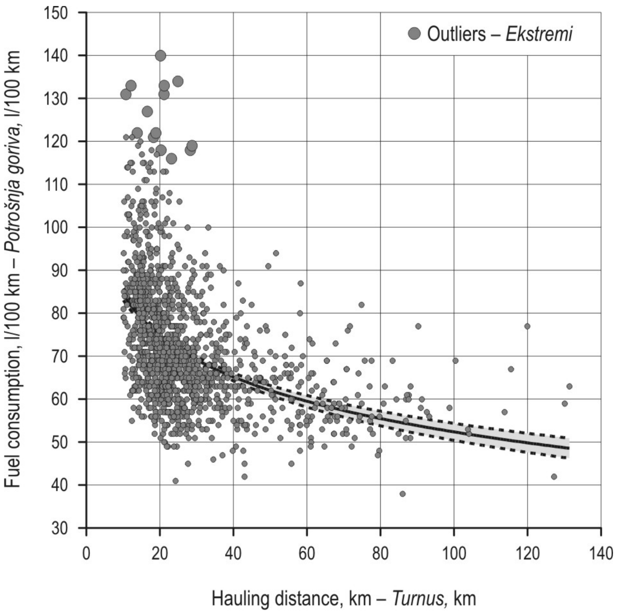

Fig. 3 Relation between fuel consumption per 100 km and hauling distance for the Tatra type of TTU
Slika 3. *Odnos između potrošnje goriva na 100 km i duljine turnusa za kamionski skup Tatra*

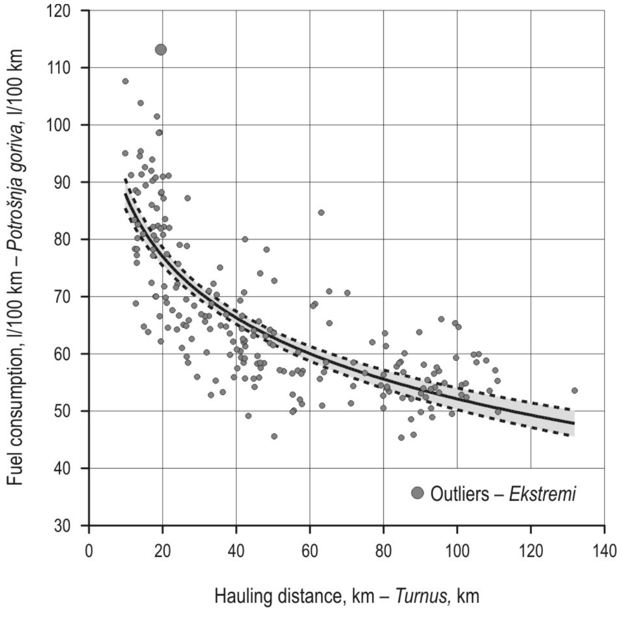

Fig. 2 Relation between fuel consumption per 100 km and hauling distance for the Iveco type of TTU
Slika 2. *Odnos između potrošnje goriva na 100 km i duljine turnusa za kamionski skup Iveco*

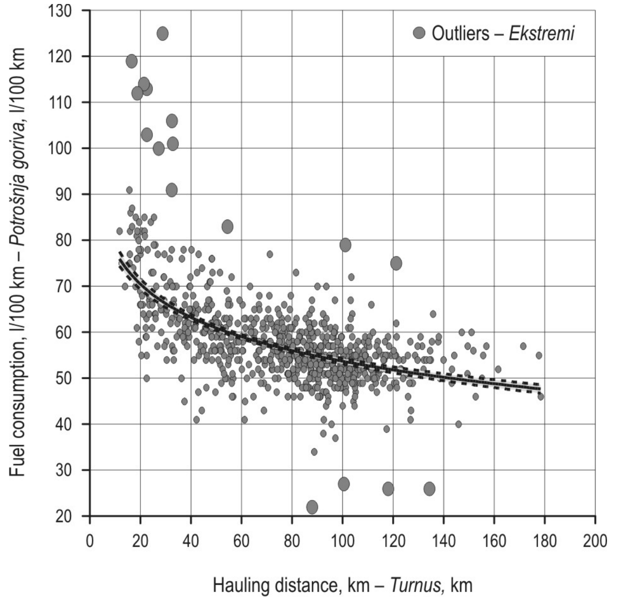

Fig. 4 Relation between fuel consumption per 100 km and hauling distance for the Mercedes-Benz type of TTU
Slika 4. *Odnos između potrošnje goriva na 100 km i duljine turnusa za kamionski skup Mercedes-Benz*

meters represented only driving on forest roads and very short travels for another load. Details of regression analyzes were as follows: Best-fit values $a = 8.352$, $b = 19.19$; Std. Error $a = 0.1920$, $b = 0.6994$; 95% Confidence Intervals $a = 7.976$ to 8.728, $b = 17.82$ to 20.56; R square 0.4500; Outliers (excluded, Q = 1.0 %) 3.

Table 4 Results of regression analyses of the relation of fuel consumption per 100 km and hauling distance

Tablica 4. *Rezultati regresijske analize potrošnje goriva na 100 km i duljine turnusa*

TTU type *Model kamionskoga skupa*	* Regression coefficients of equation * *Regresijski koeficijenti jednadžbe* $y = a \times \ln(x) + b$		Border coefficients, 95% *Granični koeficijenti*, 95 % Confidence Intervals – *Faktor pouzdanosti*		R^2	Range of × value *Raspon × vrijednosti*
	a	*b*	*a*	*b*		
Iveco	–15.47	123.4	–17.14 ; –13.81	117.2; 129.6	0.6102	10 – 132
Tatra	–13.96	116.7	–15.30 ; –12.61	112.3 ; 121.0	0.2390	10 – 131
MB	–10.42	101.7	–11.25 ; –9.576	98.12 ; 105.3	0.4397	12 – 178

* x – hauling distance – *Duljina turnusa*
y – fuel consumption per 100 km – *Potrošnja goriva na 100 km*

Table 5 Results of regression analyses of the relation of fuel consumption per unit of production (m^3) and hauling distance

Tablica 5. *Rezultati regresijske analize potrošnje goriva po jedinici proizvodnje (m^3) i duljine turnusa*

TTU type *Model kamionskoga skupa*	* Regression coefficients of equation * *Regresijski koeficijenti jednadžbe* $y = a \times \ln(x) + b$		Border coefficients, 95% *Granični koeficijenti,* 95 % Confidence Intervals – *Faktor pouzdanosti*		R^2	Range of × value *Raspon × vrijednosti*
	a	*b*	*a*	*b*		
Iveco	0.9842	–1.399	0.8887; 1.080	–1.756 ; –1.043	0.6601	10 – 132
Tatra	1.335	–2.444	1.280; 1.391	–2.624 ; –2.265	0.6311	10 – 131
MB	1.531	–3.749	1.460; 1.601	–4.048 ; –3.450	0.7025	12 – 178

* x – hauling distance – *Duljina turnusa*
y – fuel consumption per unit of production, m^3 – *Potrošnja goriva po jedinici proizvodnje,* m^3

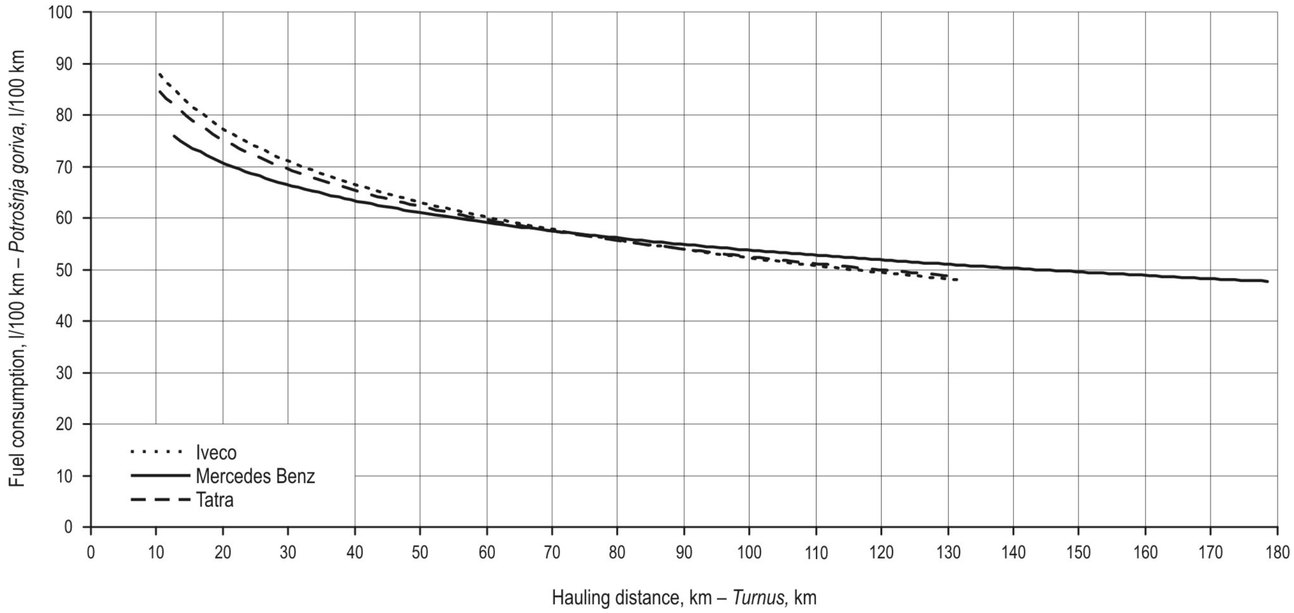

Fig. 5 Relation between fuel consumption per 100 km and hauling distance for all types of TTUs

Slika 5. *Odnos između potrošnje goriva na 100 km i duljine turnusa za sve promatrane kamionske skupove*

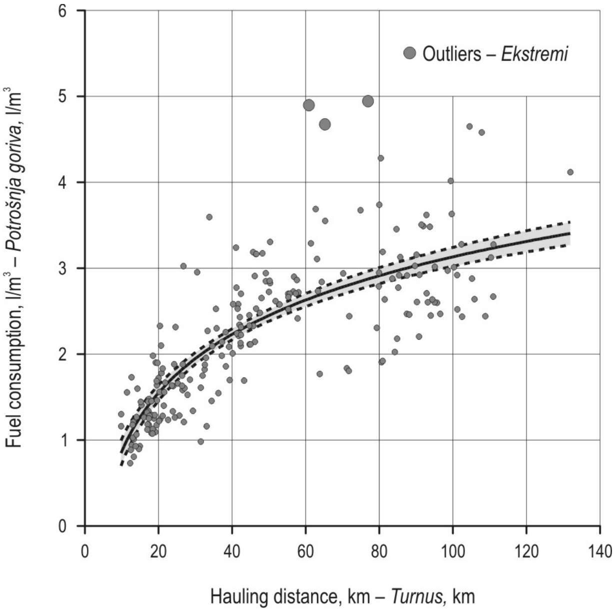

Fig. 6 Relation between fuel consumption per unit of production (m^3) and hauling distance for the Iveco type of TTU

Slika 6. *Odnos između potrošnje goriva po jedinici proizvodnje (m^3) i duljine turnusa za kamionski skup Iveco*

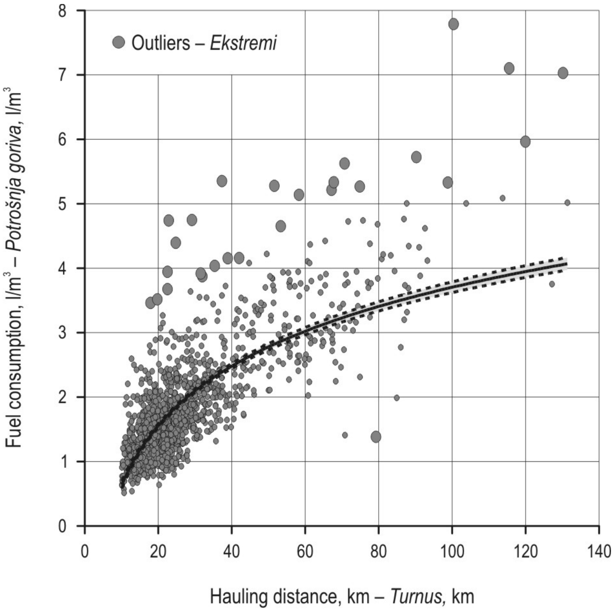

Fig. 7 Relation between fuel consumption per unit of production (m^3) and hauling distance for the Tatra type of TTU

Slika 7. *Odnos između potrošnje goriva po jedinici proizvodnje (m^3) i duljine turnusa za kamionski skup Tatra*

3.1 Average fuel consumption in relation to driven distance including the effect of uploading and unloading and proportion of time spent on forest roads – *Prosječna potrošnja goriva po prijeđenom kilometru uključujući utovar, istovar te udio vožnje šumskom cestom*

Average fuel consumption per 100 km is markedly higher in the older TTU types such as Iveco and Tatra in particular (see Table 3). It is also synergy affected by uploading and unloading times as well as by the hauling distance. If the hauling distance is shorter, the average consumption per 100 km is markedly higher than over longer distances due to the effect of uploading and unloading. During the uploading and unloading, the engine of the truck (energy source) drives the hydraulic crane and the consumption of fuel thus increases without a change in driven kilometers. According to company workers (personal communication), the loading time was different when loading stems or timber shortened to transportation length (max. 35 min.) and when loading stacked assortments up to 8 m (max. 50 min.).

The second effect is the proportion of time spent on forest roads. The shorter journey meant a higher proportion of travel time spent on forest roads. The trucks have a higher fuel consumption on forest roads due to harsh terrain conditions, limited speed (lower gear) and worse road quality that decreases with the increasing hauling distance. None of these

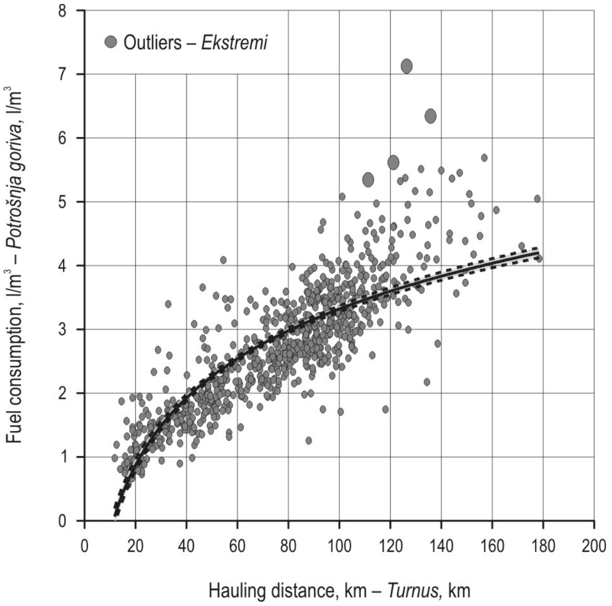

Fig. 8 Relation between fuel consumption per unit of production (m^3) and hauling distance for the Mercedes-Benz type of TTU

Slika 8. *Odnos između potrošnje goriva po jedinici proizvodnje (m^3) i duljine turnusa za kamionski skup Mercedes-Benz*

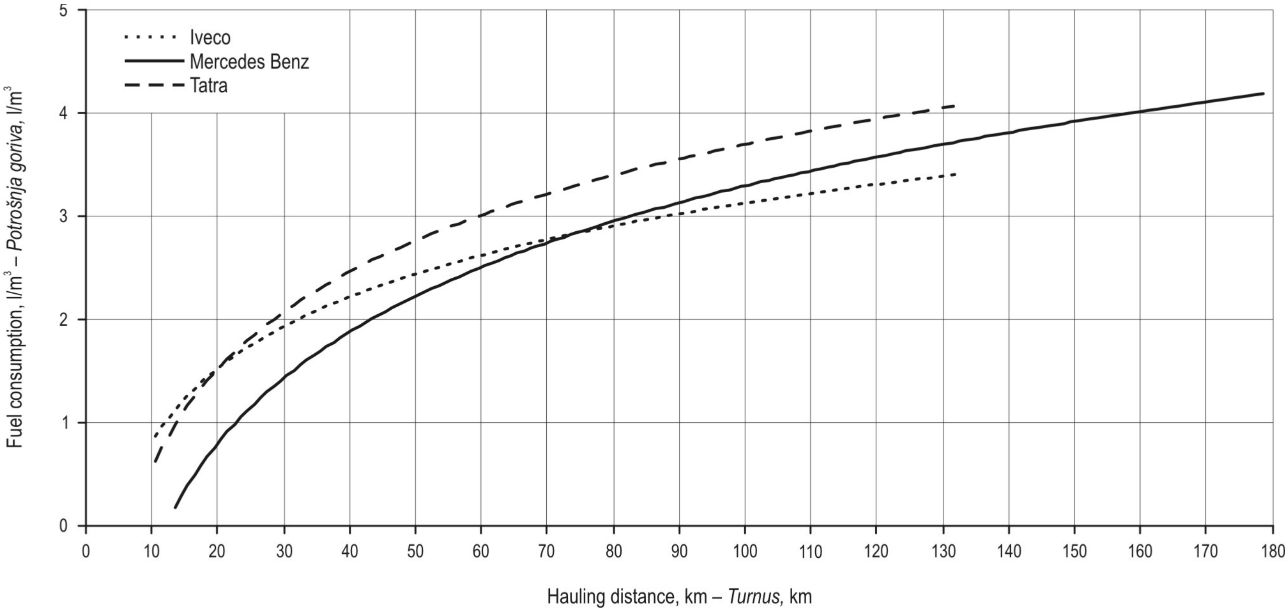

Fig. 9 Relation between fuel consumption per unit of production (m^3) and hauling distance for all types of TTUs

Slika 9. *Odnos između potrošnje goriva po jedinici proizvodnje (m^3) i duljine turnusa za sve promatrane kamionske skupove*

two aspects can be eliminated to determine the influence of each separately. In other words, as the two aspects are inseparable part of timber haulage, the assessment was made including the impact of them both.

Both effects also correspond to the average number of daily delivered loads with respect to hauling distance i.e.: 4 deliveries at 10.7 km average hauling distance, 3 at 38 km and 2 at 200 km, respectively.

Regression equations of fuel consumption for the respective TTUs are presented in Figs. 2 – 4 including discerned outliers and including confidence interval of 95% reliability. The regression equations are plotted in a comprehensive graph (Fig. 5) for the comparison of individual TTU types. The regression curves are drawn in the interval of hauling distances in which TTU types were operating. The results of regression analyses for individual types of timber transport units are presented in Table 4.

3.2 Average fuel consumption per unit of production (hauled cubic meter) – *Prosječna potrošnja goriva po jedinici proizvodnje (prevezeni kubni metar)*

In this case, too, the respective types of truck-and-trailer units were assessed separately (Figs. 6 – 8). The average fuel consumption per unit of production (m^3) was conspicuously different in the individual TTU types, the reason for the difference being mainly the effect of hauling distance and the size of TTU load. The greater the hauling distance, the higher was the fuel consumption per unit of production; at the same time, the greater the vehicle capacity, the lower was the average fuel consumption. The two factors act in synergy and there are other impacts to be expected, too, such as seasonal character of the work, effect of the operator, etc. Results of regression analyses for individual types of timber transport units are presented in Table 5.

The comprehensive diagram in Fig. 9 shows regression equations for the respective types of timber transport units. The regression curves are plotted only within the hauling distance interval in which the values used in the regression analysis occurred. Tatra type trucks showed unambiguously the highest fuel consumption per unit of production.

4. Discussion and conclusion – *Rasprava sa zaključcima*

The above graphs (Figs. 2 – 5) show the dependence of fuel consumption per 100 km on average hauling distance of the individual TTU types. The average hauling distance ranged from 10 – 180 km. Older Iveco and Tatra trucks in particular had a considerably higher fuel consumption per 100 km, which supposedly resulted from the fact that their hauling distances were relatively short (38 km) and loading and unloading was more frequent. Thus, due to more frequent loading and unloading, the fuel consumption increased although it did not show in the travel distance. The average fuel consumption per 100 km of Mercedes-Benz TTUs was markedly lower, because the hauling distances were apparently higher. Another aspect affecting the fuel consumption together with this factor was the proportion of driving on forest roads, which decreases with the increasing hauling distance i.e. loading is limited within one working day. Fig. 5 shows that the fuel consumption per 100 km decreases with the increasing hauling distance. The third very important factor is the engine category. Mercedes Benz Trucks were Euro 3 and Euro 5 class, which should guarantee lower fuel consumption. However, this is not as visible as expected and further detailed analysis of Mercedes Benz truck is necessary. Other impacts, such as the seasonal character of work, locality (road quality, relations), human factor in loading/unloading, equipment operators, drivers, etc. could not be identified but their influence can be anticipated at least to some extent. The authors consider that the volume of data is representative for estimating the mean values of fuel consumption.

Svenson (2011) informs that in Sweden the average fuel consumption per 100 km is 58 liters but does not mention the hauling distance, which could be corresponding to 65 km according to the results of our study. Although the value is highly speculative, it might be realistic for such a vast country as Sweden even if it is by 40% higher than the average hauling distance of 45 km established in this study. It is however fully comparable with values recorded in 2008 and 2009, when the timber transport company that provided the data focused on longer hauling distances. Similar conditions as in the Czech Republic can be expected in Austria, where Holzleitner (2009) claims the average hauling distance of 51 km, which is in line with the values detected in this study.

Fuel consumption can be reduced in different ways. Considerate driving may considerably reduce the fuel consumption. By a program that can monitor the driving regime, the Tom Tom Corporation can identify inappropriate driving manners and demonstrate a more economical regime (personal communication Tom Tom). Lofroth and Lindholm (2005) mention further possibilities of fuel economy, e.g. that haulage trucks can reduce their fuel consumption by 5 – 10% simply by fitting a wind deflector and by removing all unnecessary items such as signboards, extra air horns, extra lamps and other unnecessary accessories.

Average fuel consumption per unit of production (m^3) is first of all affected by the hauling distance and by the load size – the two factors acting in synergy. The higher is the vehicle capacity, the lower is the average consumption per unit of production, and the greater is the hauling distance, the higher is the fuel consumption per unit of production. Further to the above, the Tatra TTUs would have the lowest fuel consumption per unit of production if the average values of TTU types from global assessment were compared without a more detailed analysis (see Table 3). Nevertheless, this view of the problem would be rather naïve, because these are the average values for the entire 5-year monitoring period and they are related to anaverage hauling distance calculated for the whole period of the study. Therefore, it is necessary to compare the average fuel consumption based on data presented in Fig. 9. The Tatra truck-and-trailer unit has the highest average fuel consumption per unit of production in relation to the hauling distance, the likely reason being the average size of load but also the construction of the machine, which is designed for difficult, inaccessible terrains and is fitted with older engine types.

By contrast, the Mercedes-Benz TTUs exhibited the highest average fuel consumption per unit of production (approx. 3 liters per cubic meter) in the global assessment (Table 3), which resulted from the long hauling distance in the monitored period. However, it can be concluded from Fig. 9 that the Mercedes-Benz TTUs are more economical in terms of fuel consumption per unit of production with the load size playing once again the most important role. The load size in the Mercedes-Benz TTUs was approximately 5 m^3 greater than in the Tatra TTUs. Further to the above, it can be concluded that the timber transport units cannot be evaluated only according to summarized data (Table 3) but that more detailed analyses, such as in Figs. 6 – 8, are absolutely necessary.

The issue of relations between the individual indicators is very complex and it would be certainly useful to conduct a detailed survey within the respective types of trucks e.g. in relation to hauling distance, loading capacity, trailer type or region in which the TTU operated. All activities connected with the detailed characterization of these relations are focused on fuel economy. This direction is also obvious from the activities of FP Innovation, where the so-called StarTrack was designed aimed at reducing machine weight and providing maximum loading capacity. The specifications placed on the research truck considered the local operating conditions and included the following requirements: heavy-duty aluminum rims, smaller fuel tank (but the right size for one shift), aluminum cab protector, central tire inflation (CTI), on-board weighing, in-cab auxiliary heater, on-board computer, single tractor frame rail, lightweight multi product semi-trailer and road maintenance management system. All these innovations resulted in the following improvements:

- ⇒ The Star Truck had a higher payload by 9.8% and consumed only 1% more fuel,
- ⇒ The Star Truck transported 8.6% more products per liter of fuel,
- ⇒ The Star Truck fuel cost per ton was by 8% lower than in the control truck,
- ⇒ Tire wear was by 40% lower in the Star Truck due to CTI. (Anon. 2012)

The reduced fuel consumption per unit of production aims at mitigating the environmental pollution caused by emissions of greenhouse gases (GHGs). Fuel consumption by trucks is one of the largest contributors of these emissions. Komor (1995) informs that in the U.S.A., trucks account for over 80% of the freight energy use and 19% of US oil consumption. Plans to improve the technical efficiency through new technologies, careful driving and optimal driving conditions can increase the efficiency by 50 to 70%. Bandivadekar et al. (2008) believe that the increase in the consumption of oil for transport in the U.S.A. is a challenging environmental problem that needs to be addressed in terms of reducing fuel consumption based on drivers' behavior rather than concentrating on the improvement of vehicle performance through new propulsion technologies and new fuels in the shorter term. Other methods leading to reduced fuel consumption are decision support systems and use of telemetry in combination with GPS/GIS. An example may be the study published by Devlin et al. (2007).

The amount of timber extracted in the Czech Republic per year is about 15 million m^3. Adequate fleet changes, improved optimization and technical modifications may be used to reduce fuel consumption per unit of production by 0.5 – 1.0 liter. This would bring a reduction of fuel consumption in timber haulage by 0.75 – 1.5 million liters of oil in the Czech Republic. Devlin (2010) claims that each liter of oil burnt in the truck-and-trailer unit is responsible for 2.67 kg of carbon dioxide emitted into the atmosphere. Based on the emission factors established by Lewis (1997), we can state that each liter of oil is responsible for additional 0.25 kg CO_2 emitted during the production and distribution. Thus, saving 1.5 million liters of oil equivalent would result in a reduction of CO_2 emissions into the atmosphere of 4.4 million tons. The unambiguous conclusion is that optimization and use of adequate TTU types in timber transport from the roadside landing can significantly contribute to the mitigation of the negative impact of forest machinery on the environment.

Acknowledgement

The paper was prepared within the framework of research projects of the Ministry of Education of the Czech Republic nos. MSM 6215648902 and OC10041, Mendel University internal project IGA and of the COST Action FP0902. The authors also wish to express their thanks to contractors for providing the possibility of data collection.

5. References – *Literatura*

Anon., 2012: FP Inovation. Timber Transport Research – FERIC's Star Truck Project. Logging-on newsletter. Available on http://www.loggingon.net/timber-transport-research-ferics-star-truck-project_news_op_view_id_43

Bandivadekar, A., Cheah, L., Evans, C., Groode, T., Heywood, J., Kasseris, E., Kromer, M., Weiss, M., 2008: Reducing the fuel use and greenhouse gas emissions of the US vehicle fleet. Energy Policy 36(7): 2754–2760.

Devlin, G., 2010: Fuel consumption of timber haulage versus general haulage. Harvesting/Transportation No. 22. COFORD, 6 p.

Devlin, J. G., McDonnell, K., Ward, S., 2007: Timber haulage routing in Ireland: an analysis using GIS and GPS. Journal of Transport Geography 16(1): 63–72.

Favreau, J., 2006: Six key elements to reduce forest transportation cost. FERIC. Available on http://www.forac.ulaval.ca/fileadmin/docs/EcoleEte/2006/Favreau.pdf

Holzleitner, F., 2009: Analyzing road transport of roundwood with a commercial fleet manager. In: Prknová H (ed) Formec 2009. Kostelec nad Černými lesy: Czech University of Life Sciences Prague, p. 173–181. ISBN 978-80-213-1939-4.

Holzleitner, F., Kanzian, Ch., Stampfer, K., 2011: Analyzing time and fuel consumption in road transport of round wood with an onboard fleet manager. Eur J Forest Res 130(2): 293–301.

Klvac, R., 2006: Draft of Information system for timber haulage. In Charvát K (ed) Information Systems in Agriculture and Forestry. Praha: ČZU Praha, p. 1-8. ISBN 80-213-1494-X.

Komor, P., 1995: Reducing energy use in US freight transport. Transport Policy 2 (2): 119–128.

Lofroth, C., Lindholm, E. L., 2005: Reduced fuel consumption on roundwood haulage rigs. Skogforsk. Resultat no. 23.

Motulsky, H. J., 2007: GraphPad Prism Version 5.0. Regression Guide. GraphPad Software. Inc.. San Diego. 294 p.

Motulsky, H. J ., Brown, R. E., 2006: Detecting outliers when fitting data with nonlinear regression – a new method based on robust nonlinear regression and the false discovery rate. BMC bioinformatics. Available on http://www.ncbi.nlm.nih.gov/pubmed/16526949.

Press, W. H., Teukolsky, S. A., Vettering, W. T., Flannery, B. P., 1988: Numerical Recipes in C. The Art of Scientific Computing. New York. Cambridge University Press.

Svenson, G., 2011: The impact of road characteristics on fuel consumption for timber trucks. In Ackerman P, Ham H, Gleasure E (eds) Proceedings of 4th Forest Engineering Conference: Innovation in Forest Engineering – Adapting to Structural Change. Stellenbosch University, p. 172. ISBN 978-0-7972-1284-8.

Sažetak

Potrošnja goriva pri prijevozu drvnih sortimenata

U ovom je radu istraživana pristupačnost drvnih sortimenata prijevozu kamionskim skupovima, a istraživala su se 132 kamionska skupa i tri modela kamiona (Tatra, Mercedese Benz i Iveco) s različitim vrstama kamionskih prikolica.

Svako smanjenje potrošnje goriva po jedinici proizvodnje može povećati okolišni i ekonomski profil sekundarnoga prijevoza. S obzirom na to da na gorivo otpada najveći dio troškova koji nastaju pri prijevozu drvnih sortimenata, cilj je ovoga rada bio analizirati potrošnju goriva promatranih kamionskih skupova korištenih za prijevoz. Svaka zamjena zastarjeloga i neučinkovitoga kamionskoga skupa novim učinkovitijim kamionskim skupom može rezultirati značajnim smanjenjem potrošnje goriva po jedinici proizvodnje.

Glavni je cilj ovoga rada bio ustanoviti na koji način prijevozna udaljenost (duljina jednoga turnusa) kod promatranih kamionskih skupova utječe na potrošnju goriva na 100 km te na specifičnu potrošnju goriva po prevezenom kubnom metru drva.

Dizajniran je informacijski sustav koji može primati narudžbe od naručitelja i koji pruža potporu dispečerima pri donošenju odluka da bi se odabrao najpogodniji kamionski skup. Sustav također bilježi podatke o pojedinom turnusu, zbraja ih te ih pohranjuje u baze podataka.

Početna je obrada podataka napravljena usporedbom velikoga broja tablica i grafikona. Za nelinearnu regresiju koristili smo se programom GradhPad Prism 5. Taj program omogućuje vrlo fleksibilan izbor regresijskoga modela, ima vrlo dobre grafičke mogućnosti i moguće je ubaciti i ucrtati intervale pouzdanosti pojedinih modela. Navedeni program eliminira ekstreme metodom »ROUT«.

U vrijeme istraživanja više od 3,4 milijuna kubnih metara drva prevezeno je od pomoćnoga stovarišta do glavnoga stovarišta, krajnjega korisnika ili do željezničke pruge. U ukupnom obujmu prevezenoga drva udio je crnogorice bio 92, a bjelogorice 8 %. Ukupan utrošak goriva za promatrane kamionske skupove iznosio je 6,8 milijuna litara.

Na potrošnju goriva po jedinici proizvodnje (m^3) najviše utječu duljina turnusa i obujam tovara. Ta dva čimbenika djeluju u sinergiji. Što je veći obujam tovarnoga prostora kamionskoga skupa, manja je prosječna potrošnja goriva po jedinici proizvodnje, dok s druge strane, što je veća udaljenost pojedinoga turnusa, veća je i prosječna potrošnja goriva po jedinici proizvodnje.

Zastarjeli i neadekvatni kamionski skupovi tijekom istraživanoga razdoblja stalno su zamjenjivani novim i učinkovitijim, zbog čega je primijećeno značajno smanjenje prosječne potrošnje goriva (0,5 l/m^3) po jedinici proizvodnje.

Smanjenje potrošnje goriva po jedinici proizvodnje u konačnici znači smanjenje emisije stakleničkih plinova te ublažavanje štetnoga utjecaja na okoliš. Sagorijavanjem jedne litre goriva u motoru kamionskoga skupa u atmosferu se ispušta 2,67 kg ugljičnoga dioksida te bi se smanjenjem potrošnje goriva za 1,5 milijuna litara smanjila i emisija ugljičnoga dioksida u atmosferi za 4,4 milijuna tona. Nedvosmisleni je zaključak ovoga rada da se pri odabiru kamionskih skupova za prijevoz drvnih sortimenata, tj. njihovom optimizacijom, može značajno pridoni-

jeti ublažavanju negativnih utjecaja šumskih strojeva na okoliš. Cestovni je promet u posljednjih deset godina zabilježio velike promjene, a analiza predstavljena u ovom radu daje važne informacije korisne u planiranju i organizaciji cestovnoga prijevoza drvnih sortimenata.

Ključne riječi: šumska cesta, prijevoz drvnih sortimenata, kamionski skup, potrošnja goriva

Received (*Primljeno*): February 18, 2013
Accepted (*Prihvaćeno*): August 06, 2013

Authors' address – *Adresa autorâ*:

Assoc. prof. Radomír Klvač, PhD.*
e-mail: klvac@mendelu.cz
Mr. Josef Kolařík
e-mail: j.kolarik@email.cz
Mrs. Marcela Volná
e-mail: 12796@node.mendelu.cz
Assoc. prof. Karel Drápela, PhD.
e-mail: karel.drapela@mendelu.cz
Mendel University in Brno
Faculty of Forestry and Wood Technology
Department of Forest and Forest Products Technology
Zemedelska 3
613 00 Brno
CZECH REPUBLIC

* Corresponding author – *Glavni autor*