

## Time consumption and productivity analysis of timber trucking using two kinds of trucks in northern Iran

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**ABSTRACT:** Increasing productivity and reducing cost in long-distance transportation have become increasingly important in the logistics of forest harvesting operations. This paper presents the research results of the performance of loading with Volvo 4500 BM and timber trucking using two types of common trucks in the Nav watershed in Iran. Both trucks can carry logs shorter than 7.8 m in length. The study used a time study based on empirical data for loads collected from one procurement district in the Nav watershed. The models included the following explanatory factors: driving distance, number of logs, and load volume. The time consumption and productivity of loading and timber trucking depends on several variables such as volume and number of logs per cycle. To evaluate the current transportation system in the Nav watershed, the empirical time study was conducted. Since transportation includes several phases and since many factors affect the work performance, significant variation in the total transportation time was observed. This makes planning and cost accounting more difficult. The models developed in the study are a promising way to support route planning and optimization, and cost and profitability calculation for trucking entrepreneurs and the forest industry. The average productivity of log transportation was 2.84 and 3.4 m<sup>3</sup>·effective h<sup>-1</sup> for the dump truck and chassis truck, respectively. The average hauling unit cost was 18 and 15 USD·m<sup>-3</sup> in the dump truck and chassis truck, respectively.

**Keywords:** Hyrcanian forest; Iran; secondary transportation; productivity; cost

The landing element interfaces with truck loading because of this interrelationship, loading should always be considered when building log decks. Landing should be levelled, well drained, and large enough to accommodate, if necessary, skidder activity, truck loading, log storage and sorting. The actual size of landing depends upon the size and number of skidding units, size of loader and the number and size of trucks being used in a particular operation. Side slopes should be limited to 10% (CONWAY 1978). The commonly used equipment for loading in Iran is a wheeled loader. For efficient operation the number of trucks must be balanced with the loader capacity to avoid delay waiting to load. If possible, roadside decks should be built on both sides of the road, this of course depends on the terrain and the road width. Such a decking procedure allows the loader to load from either side of the truck. One important consideration is timing. Wood should be decked ahead of loading if possible (CONWAY 1978).

Secondary transportation provides the link between the landing site and the mill. Given the rapidly increasing costs of transportation in the forestry sector, there is a growing need to explore all the components involved (LJUBIC 1982). In order to investigate and optimize operation costs, a systematic study of forestry transportation is vital (LJUBIC 1985). The size of the vehicle carrying out the road transportation depends on the dimension of the timber, road condition, traffic regulation, and the availability of the machinery and capital to purchase or rent the equipment (EERONHEIMO 1988). The main emphasis in the long-distance transportation in Iran is on truck transport. Other kinds of transportation, such as bundle floating, barge transport and railway transport, are not practiced in Iran because of inappropriate conditions and insufficient facilities. Trucks used in logging vary widely in size and load-carrying capabilities. Choosing a truck with different capacities depends on different variables such as topography, climate,

size of operation, haul distance, volumes available, and the product to be hauled. Additionally, local highway regulations restrict the gross vehicle weight, length, width, and height of loaded log trucks travelling on public roads (CONWAY 1979). However, timber trucking takes the biggest share of total harvesting cost (MOUSAVI 2009), but only few studies are available. For example, KARAGIANNIS et al. (2012) studied timber trucking in Greece in both broadleaved and conifer trees from 1980 to 2012. According to the results, the number of two-axle trucks that dominated in the 1980s was reduced rapidly, mostly to the benefit of larger three-axle and four-axle trucks. Mean load per vehicle type differs between conifer and broadleaved species from 7.1% up to 23.9%. Transportation of stacked wood in overloaded conditions could entail serious problems for public safety and the condition of the road network, which needs more attention.

LAITILA and VAATAINEN (2012) evaluated the competitiveness of various supply systems of small diameter wood harvested from young stands for fuel. Trees were harvested for the cost comparison either as multi-stem delimbed shortwood or whole trees, and the harvesting was based on bundle-harvesting using the Fixteri II bundle harvester. According to the results of the study, harvesting of multi-stem delimbed shortwood is a promising way to simplify operations and to reduce transportation and chipping costs. In the case of whole-tree bundling, savings in transportation and chipping costs did not offset the high felling and compaction costs, and the bundling system was the least competitive alternative.

In the Hyrcanian forests, the average truck volume for hauling logs is about 10–15 m<sup>3</sup> in the western part of the forests while in the eastern part it is 10–20 m<sup>3</sup> where truck with trailer is used for hauling in the tree length method (NAGHDI 2005).

The basic factors affecting timber transport include the size of the operation, the geographic location of the forest and the mill and the distance between them, the assortment of timber for which the mill is designed, as well as the availability of suitable transportation (CONWAY 1979; EERONHEIMO 1988). In any instance, the logs in the forest should be moved to the storage place at the right time, otherwise the quality of wood decreases because of fungal or insect attacks. Therefore the planning of long-distance transportation should be done carefully.

Time study is one of the most common practices of work measurement. It is used worldwide, in most types of production to determine the input of time

in the production process (BJÖRHEDEN 1991). Time study is used to determine the input – element of productivity, to study factors affecting productivity, to develop work methods by eliminating ineffective time, etc. (HARSTELA 1991). Time study can also be used for assessment of different harvesting methods and finding the most profitable methods. The time consumption will be studied for various reasons. The most common tasks are to investigate the main factors affecting work productivity and to establish a base for the calculation of cost and salaries or payments (NURMINEN et al. 2006). Time study methods are used by public forest agencies, for timber sale appraisal, and by companies which employ the operation research staff or consultants (STENZEL 1985).

Cost calculation for different work phases is one of the most important parts of evaluation of work efficiency. It is used for paying piece rate and also to know the number of workers needed for a special activity. With combination of time study for the calculation of productivity and cost, unit cost will be calculated. It helps managers for rational management and increasing operational efficiency. Information on the productivity, cost and application of harvesting equipment and system is a key component in the evaluation of management plans for the rehabilitation and utilization of the Hyrcanian forests (SOBHANI 1991). The study covers a more detail of performing timber trucking at two different truck platforms while using the same machine for both of them. The specific objective of the study is: (1) evaluation of timber trucking performance using two different trucks and finding out the best approach to increase efficiency and organization of timber trucking activities by comparing the types of trucks, (2) prediction of required time for loading and timber transportation in the trucks, (3) creation of productivity and time consumption models of long-distance transportation for both of the trucks.

## MATERIAL AND METHODS

### Study area

The project area is located between 37°61' and 37°20' north latitude, and between 48°39' and 48°44' east longitude. According to the action plan, the total standing volume of all species of approximately 400 m<sup>3</sup>.ha<sup>-1</sup> (trees > 5 cm DBH) in undisturbed forests is typical of a certain area. Normally, the average height of taller trees is 20 to 40 m, while some individuals may reach a height

Table 1. Main work phases that make up total transportation time

Work phase	Definition
Driving without a load	begins when the truck leaves the mill storage area after unloading and ends when the truck stops at a log deck to receive a new load
Log deck activities	begins when the truck stops at a log deck and the loading with a front-end loader starts and ends when a full load is prepared and the truck is ready to leave the landing
Driving with a full load	begins when the trucks leaves the deck area and ends when the truck stops at the yard. Preparations, maneuvering the truck and miscellaneous activities during driving are also included
Unloading	begins when the truck arrives at a mill yards and ends when the truck leaves without a load
Delays	delays were divided into personal delay (e.g. social break), technical delay (e.g. repair and maintenance), and operation delay (e.g. no spare part is available)

of 45 m or more. Commercial species tend to be represented fairly well. The surface area of the Nav watershed is 3700.87 ha. Most of the area is dominated by *Fagus orientalis* (56.3 %). Common hornbeam (*Carpinus betulus*) constitutes 14.6%, Caucasian alder (*Alnus subcordata*) 7.3%, Norway maple (*Acer platanoides*) 6.3%, and other species account for 15.6% (Action Plan 2000). The total standing volume of all species is about 400 m<sup>3</sup>·ha<sup>-1</sup> (trees > 5 cm DBH) in an undisturbed forest (Action Plan 2000).

### Data collection

The study covered the regular working hours of drivers and we defined a transportation time that was divided into the main work phases shown in Table 2. Loads were mostly single source loads where hauled from a single log deck in the summer season. In this study, a log deck was defined based on the wood procurement company practice, in

which a pile or several piles in close vicinity at a single site were considered to be a single deck. During the time study, work phases were further divided into time elements that were recorded using a stopwatch. The time analyst observed the transportation work while sitting in the truck cabin. Driving distances were measured using the truck odometer, to the nearest 100 m. Roads were divided into three categories: (1) forest roads, (2) paved asphalt steep roads, (3) low slope asphalt roads. Volumes were measured using the log volume formula.

During the follow-up study, each work shift during the study periods was analysed by asking drivers to independently complete a form on which they recorded start and times for the main work phases to the nearest 1 minute, and the odometer reading at the beginning and at the end of driving phases (NURMINEN, HEINONEN 2007). They also recorded information about the number of logs and volume of each load. To minimize errors and maximize consistency in the data collection, each driver was taught how to fill in the forms. Drivers were

Table 2. Summary of detailed machine cost calculation parameters

Cost factor	Cost	Cost factor	Cost
Purchase price (USD)	97,000	Interest annually (USD)	13,270
Salvage value (USD)	38,800	Deprecation annually (USD)	11,640
Economic life (yr)	5	Tax and insurance annually (USD)	2,490
Tire life (h)	2,000	Total fixed cost (USD·PMH <sup>-1</sup> )	16.6
Tire price (USD)	270	Maintenance and repair, (USD·PMH <sup>-1</sup> )	6.34
Number of tires	10	Fuel and lubricant cost (USD·PMH <sup>-1</sup> )	14.5
Repair factor (f)	0.9	Fuel and lubricant cost for chassis trucks (USD·h <sup>-1</sup> )	17
SMH annually (h)	1,650	Tire cost (USD·h <sup>-1</sup> )	4
PMH annually (h)	2,200	Total variable cost (USD·h <sup>-1</sup> )	24.9
Utilization (%) $U_t = (PMH \times 100 / SMH)$	75	Total labour cost (USD·h <sup>-1</sup> )	9.6
		Total cost (system cost) (USD·h <sup>-1</sup> )	51.1
		Total cost (system cost) for chassis trucks (USD·h <sup>-1</sup> )	53.6

SMH – scheduled machine hour, PMH – productive machine hour

Table 3. Average driving speeds and proportions of time spent driving on each class of road based on the time study data

Driving	Dependent variable	Paved asphalt roads				Forest roads	All roads	
		low slope		hilly roads				
Without a load	DT	62.6	35	36.5	26	24.7	39	41.1
	CT	58.9	32	34.49	31	24.6	37	39.4
With a full load	DT	56.54	35	25.6	26	20.86	38	34.3
	CT	54.1	33	23.7	31	19.8	36	32.5

DT – dump truck, CT – chassis truck

also reviewed to ensure that they were performing this task correctly. This method was previously reported by NURMINEN and HEINONEN (2007). A total of 6 trucks and drivers were included in the study. The trucks were chosen to permit the comprehensive observation of transportation environment (e.g. driving distance, log products, and mill yards) for the whole district. For each cycle, the following data were collected: time consumption; size of logs loaded (length and diameter) and number of logs per cycle. The data were used to calculate consumed time and productivity, and ultimately costs per cubic meter. Volume per load was calculated by multiplying the average cross-sectional area of the stem by the stem length (Fig.1).

### Data Analysis

Because data from the time study and follow-up study were complementary, the two sets of data were combined, and are henceforth referred to as the combined data (NURMINEN, HEINONEN 2007). The time consumption was modelled separately for each main work phase, and the expected total transportation time was computed as the sum of the expected work phase times. Furthermore, the independent sample *t*-test was employed in the mean comparison to test the null hypothesis ( $H_0 = \mu_1 = \mu_2, P < 0.05$ ).

Total transportation times were divided into the main work phases for both trucks. The mean driving distance, travel speed, and properties of travel on each of the three road classes were also specified. The distances of travel without loads and with a load were compared between two trucks using the independent sample *t*-test. Each work phase which could not make any equation with any variable is calculated as a mean value. A curve estimation method is used for finding the most fitted model between independent variables and dependent variables.

### Machine, operator and working methods

Front-end loaders are mostly used for loading in Iran because neither trucks nor skidders are equipped for loading. The front-end loader is just a possibility for loading. The loader operator and truck driver had several-year experience in the job. The front-end loader model was Volvo 4500 BM and the trucks were Benz 2624 dump truck and Benz 2628 chassis truck. The front-end loader is mostly used in the unloading of chassis trucks because the truck is not equipped for unloading. In the dump truck, the truck driver performs the unloading by dumping the logs. The age of trucks was 5 years but they were still in productive condition.

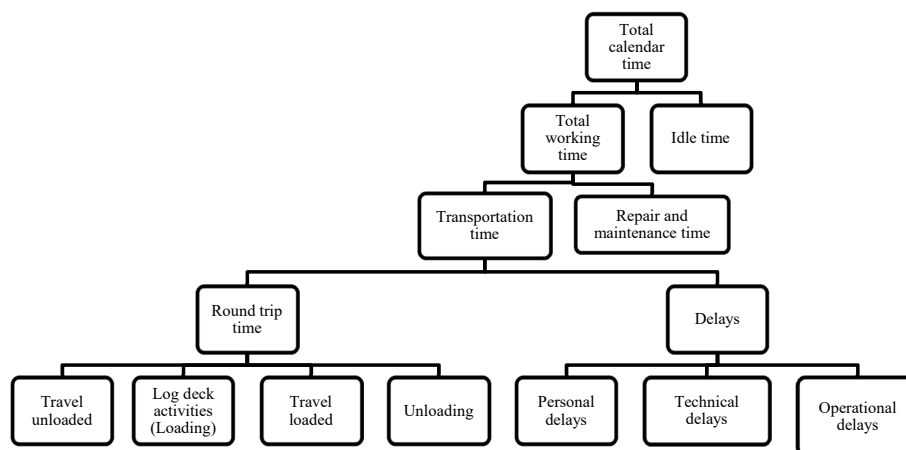


Fig. 1. Division of time in the timber truck operation

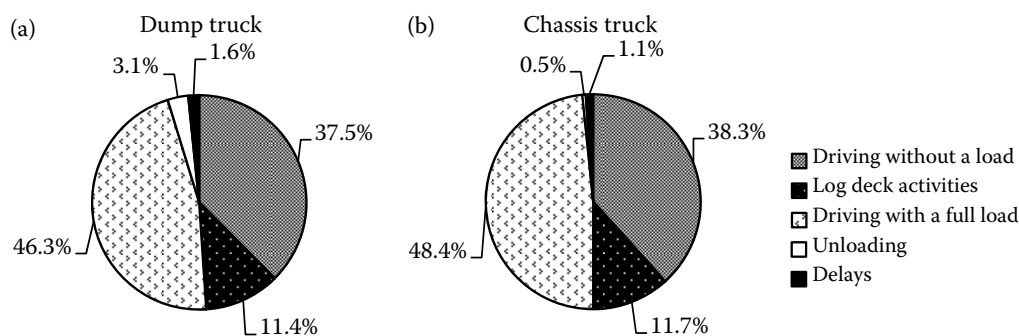


Fig. 2. Division of transportation time during the study for (a) dump trucks and (b) chassis trucks

### Cost calculation

The machine costs are calculated when the machine is being used. In order to calculate the cost, it is needed to know how many hours it is working and how many hours it is planned (scheduled) to work. Personal costs included all costs related to worker, fringe benefits and some bonuses and rewards. The salvage value for trucks was 40% of the purchase price (HEDIN 1980, NAGHDI 2005). Fuel cost is calculated according to the formula (Eq. 1) and oil and grease is 20% of the fuel cost for trucks (SUNDBERG 1998).

$$FLC = HP \times X \times CL \quad (1)$$

where:

$HP$  – engine power (Watt),

$X$  – 0.18 for diesel and 0.25 for gasoline,

$CL$  – fuel price (l:USD<sup>-1</sup>).

## RESULTS

### Time consumption and productivity

#### Distribution of time consumption

Average, minimum and maximum proportions of the work phase times were calculated for two types of trucks in Iran. Delay time was calculated separately (Fig. 2a). Productivity was calculated with delay time and without delay time (Fig. 2b).

Driving distances did not differ significantly between two types of trucks. The proportion of total driving time spent averaged 85–88% for trips using two trucks. On paved asphalt roads average travel speeds when driving with or without a load did not differ however; the proportion of travel time spent on forest road classes (unpaved gravel roads and forest roads) was larger when driving with and without a load in comparison with paved roads. A travel speed in the hilly section of roads was significantly lower than on paved roads with and without a load.

Average driving speed increased with increasing driving distance for both types of trucks (Fig. 3). Only travelling on forest roads is considered in the figure. On paved asphalt roads the speed did not change very much and it was almost fixed for both types of trucks when moving with a load or without a load.

#### Total time consumption and productivity

The total time consumption model of a delay-free work cycle was defined by adding up the time consumption for work phases

$$t_{\text{tot}} = t_1 + t_2 + t_3 + t_4 \quad (2)$$

where:

$t_{\text{tot}}$  – total effective time consumption for timber trucking (min:payload<sup>-1</sup>),

$t_1$  – time consumption for driving without a load (min:payload<sup>-1</sup>),

$t_2$  – time consumption for log deck activities (min:payload<sup>-1</sup>),

$t_3$  – time consumption for driving with a load (min:payload<sup>-1</sup>),

$t_4$  – time consumption for unloading (min:payload<sup>-1</sup>).

Total effective time consumption was converted into delay-free productivity and gross effective productivity

$$p_e = \frac{60x}{t_{\text{tot}}} \quad (3)$$

$$p_{\text{ge}} = \frac{p_e}{t_{\text{tot}} + t_{\text{delay}}} \quad (4)$$

where:

$p_e$  – productivity (m<sup>3</sup>:effective h<sup>-1</sup>),

$t_{\text{tot}}$  – total effective time consumption (min:cycle<sup>-1</sup>),

$x$  – volume (m<sup>3</sup>),

$p_{\text{ge}}$  – productivity, m<sup>3</sup>:gross effective h<sup>-1</sup> (including < 15 min delays).

Table 4. Description statistics of different work phases

Work phase model	Parameter (min)	Mean	Min	Max	SD	N
		(min-cycle <sup>-1</sup> )				
<b>Driving without a load</b>						
DT	$t_1$	91.23	57.7	129	22.5	31
CT		99.9	63.7	128	22.9	31
<b>Log deck activities</b>						
DT	$t_2$	27.8	15.8	36.13	5.37	31
CT		30.4	20.4	42.4	5.4	31
<b>Driving with a full load</b>						
DT	$t_3$	115.3	79.3	157	23.5	31
CT		123.3	89.5	159	21.09	31
<b>Unloading</b>						
DT	$t_4$	1.22	1.7	0.88	0.2	31
CT		8.3	1	12.4	3.77	31

DT – dump truck, CT – chassis truck,  $t$  – time consumption for work phase (min-cycle<sup>-1</sup>), SD – standard deviation

Table 4 shows description statistics of different work phases for both types of trucks. The average time consumption of travel loaded was higher than that of travel unloaded for both types of trucks. Statistical characteristics of regression analysis based models are presented in Table 5. All models were statistically significant.

The total time consumption and productivity of timber trucking for both types of trucks are presented in Table 6. The average time consumption of timber trucking in the chassis truck was higher by 11.5% than in the dump truck. The average productivity of timber trucking using the dump truck was roughly 20% lower than in the chassis truck. The productiv-

ity of timber trucking is greatly influenced by the transportation distance for both methods.

Figs 4 and 5 show error box plots and confidence interval for the time consumption and productivity of hauling by two different types of trucks. According to the results, time consumption ( $P = 0.011$ ) and productivity ( $P = 0.018$ ) of timber trucking showed significant differences between the two methods

**Production cost of hauling**

The production cost of hauling work phases using two different trucks is presented in Table 7. A difference between the minimum and maximum cost of hauling is considerable. As mentioned earlier,

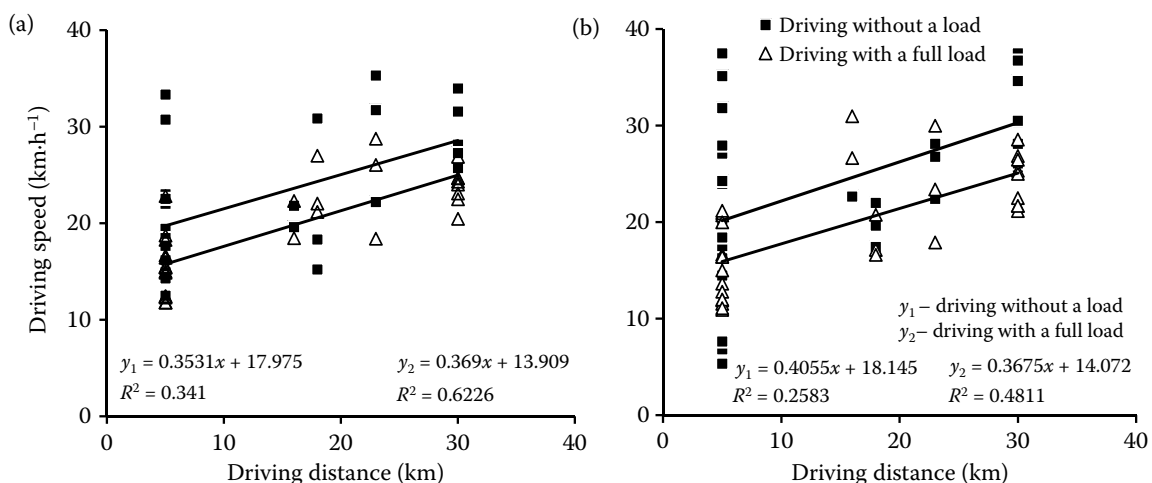


Fig. 3. Average driving speed as a function of driving distance based on the combined data from the time study and the follow-up study: (a) dump truck, (b) chassis truck

Table 5. Statistical characteristics of regression analysis based models (time consumption for work phase min.payload<sup>-1</sup>) ( $n = 31$ )

Model	Dependent variable	$R^2$	F-test		Term	Constant/ coefficient	Estimated SE	t-test	
			F	P				t	P
Travel unloaded (CT)	$t_1$	0.95	331.7	< 0.001	constant	-38.75	7.232	-5.359	< 0.001
					$x_{hd}$	1.995	0.110	18.2	< 0.001
Travel unloaded (DT)	$t_1$	0.92	354.6	< 0.001	constant	-37.9	6.99	-5.4	0.038
					$x_{hd}$	1.98	0.105	18.8	< 0.001
Loading (log deck activities) (CT)	$t_2$	0.5	34.1	< 0.001	constant	-391.04	311.97	-1.253	0.219
					$x_{nv}$	18.128	3.104	5.840	< 0.001
Loading (log deck activities) (DT)	$t_2$	0.3	16.79	< 0.001	constant	-1350.0	725.64	-1.861	0.070
					$x_{nv}$	194.19	47.390	4.098	< 0.001
Driving with a full load (CT)	$t_3$	0.88	231.6	< 0.001	constant	-17.39	9.2	-1.88	0.069
					$x_{hd}$	2.037	0.139	14.6	< 0.001
Driving with a full load (DT)	$t_3$	0.88	231.6	< 0.001	constant	-19.7	9.07	-2.171	0.038
					$x_{hd}$	2.07	0.136	15.21	< 0.001
Overall (CT)	$t_{oc}$	0.85	88.2	< 0.001	constant	-60.338	33.91	-1.779	0.086
					$x_{hd}$	4.117	0.341	12.074	0.001
					$x_v$	3.61	1.052	3.43	0.002
Overall (DT)	$t_{od}$	0.9	407.4	< 0.001	constant	-15.39	12.69	-1.212	0.235
					$x_{hd}$	3.85	0.191	20.1	< 0.001
					constant	5.083	0.515	9.86	4.029
Productivity (CT)	$p_{ec}$	0.95	304.9	< 0.001	$x_{hd}$	-0.059	0.005	-11.43	0.070
					$x_v$	0.153	0.016	9.5	0.120
					constant	3.705	0.254	3.85	4.22
Productivity (DT)	$p_{ed}$	0.96	349	< 0.001	$x_{hd}$	-0.045	0.002	-0.050	-0.04
					$x_v$	0.190	0.014	0.161	0.219
					constant				

CT – chassis truck, DT – dump truck,  $t$  – time consumption for work phase (min.cycle<sup>-1</sup>),  $p_{ec}$  – productivity for chassis truck,  $p_{ed}$  – productivity for dump truck,  $x_{nv}$  – interaction of number of log and volume,  $x_v$  – volume,  $x_{hd}$  – hauling distance

unit cost is derived from dividing the cost per hour by productivity per hour. The main factors affecting hauling productivity are hauling distance and vol-

ume hauled per cycle. The average delay-free unit cost of hauling was 18 USD.m<sup>-3</sup> and 15 USD.m<sup>-3</sup> in the dump truck and chassis truck, respectively.

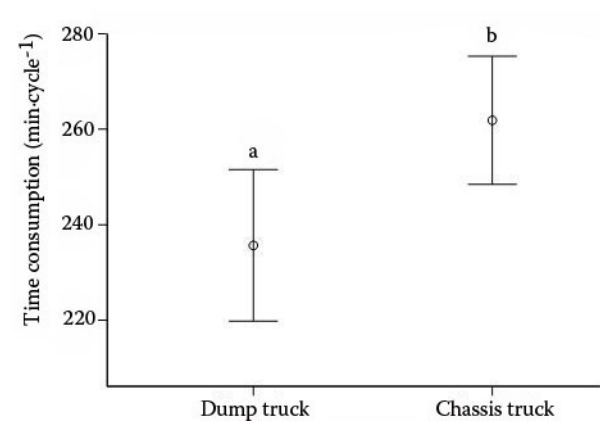


Fig. 4. Error box plot of mean time consumption for finding the differences between mean of two trucks

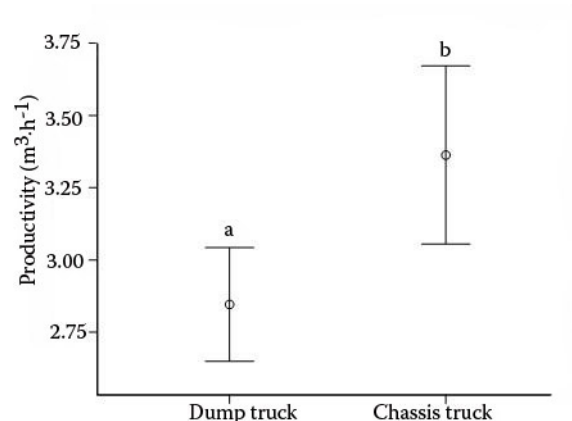


Fig. 5. Error box plot of mean productivity for finding the differences between means of two trucks

Table 6. Productivity of timber trucking in two different types of trucks

	Dump truck		Chassis truck	
	effective time	gross effective time	effective time	gross effective time
Avg. hauling time (min-payload <sup>-1</sup> )	235	238	262	266
Min. hauling time (min-payload <sup>-1</sup> )	174	174	199	204
Max. hauling time (min-payload <sup>-1</sup> )	302	302	313	303
Avg. hauled volume (m <sup>3</sup> )	10.8	10.8	14.2	14.2
Min. hauled volume (m <sup>3</sup> )	9.3	9.3	9.3	9.3
Max. hauled volume (m <sup>3</sup> )	12.8	12.8	16.7	16.7
Avg. productivity (m <sup>3</sup> ·h <sup>-1</sup> )	2.84	2.8	3.4	3.3
Min. productivity (m <sup>3</sup> ·h <sup>-1</sup> )	1.94	1.94	1.9	1.9
Max. productivity (m <sup>3</sup> ·h <sup>-1</sup> )	3.49	3.41	4.7	4.6

Table 7. Unit cost of hauling

Unit cost (USD·m <sup>3</sup> )	Dump truck	Chassis truck
Avg. unit cost	18	15.3
Min. unit cost	14.6	10.8
Max. unit cost	26.3	26.9

## DISCUSSION

Due to the limited number of study stands, operations and work cycles, the results are applicable to the same working conditions, showing trends and estimates for the work performance in the forest. The models for effective time presented in this paper are valid and accurate in analysing the factors effecting the time consumption for work phases. The variation caused by human factors was levelled by studying professional operators who used the same working technique and were familiar with the studied forest machine (NURMINEN et al. 2006). Since the operators were observed for rather a short time period, there is however a risk that their performance was affected by the situation, even if they were asked to work as normally as possible. The easiest way to control the influence of workers on results is to choose average workers as the subjects. This is an important although inadequate means of improving the generalisability of the results of the study.

The transportation environment described in the present paper including the structure of the road network, driving distance, conditions at the log deck and mill yards and the log products being hauled can be considered typical of logistics of the Iranian harvesting system. The number of drivers and trucks, the length of the study periods and the amount of timber that was hauled pro-

vided enough data to meet the study objectives. However, this data did not permit the analysis of activities throughout this year. A traditional approach to time studies of forestry work divided the time consumption of machines into effective time which includes no delays and gross effective time which includes delays shorter than 15 min (NURMINEN, HEINONEN 2007). Accordingly, the hourly costs of operations have typically been computed and introduced per gross effective hour. However, the concept of gross effective time depends on an artificial limit of 15 min for delays which need not fit the realities of timber trucking (NURMINEN, HEINONEN 2007), even though the transportation time and the drivers' working hours are the most relevant parameters from the aspect of planning. Not only distance, but also the distribution of roads, including forest roads and public roads, as well as their gradient are important factors in the time consumption of long-distance transportation. On public roads, in normal conditions, the speed of the truck can exceed 60 km·h<sup>-1</sup>, while on forest roads the truck speed never exceeds 30 km·h<sup>-1</sup>. On public roads the truck speed depends on such factors as the road surface conditions and steepness of the road. In the study, approximately 39% of the total time consumption of hauling is spent on forest roads, 26% on steep public roads, and 35% on public roads with a low-grade slope. On steep public roads, the truck speed was low, which resulted in



increasing the roundtrip time. The average speed of an unloaded truck was around 40 km·h<sup>-1</sup> while the average speed of a truck with a load was 34 km·h<sup>-1</sup>. Speeds were found to be independent of the slope grade for the slope less than 11% and strongly influenced by slopes steeper than 11% (JACKSON 1986).

In work studies of timber trucking both time studies and follow-up studies have been used. Since in this case detailed work on a larger scale with no emphasizing of data was examined, the combination of time and follow-up studies proved to be an efficient way of collecting data (NURMINEN, HEINONEN 2007)

In the time study, short time elements could be registered accurately using a detailed form, whereas in the follow-up study the form had to be designed for ease of use. The drivers were provided with detailed instructions for completing the forms and were monitored during the study period (NURMINEN, HEINONEN 2007). Because the work phases were defined unambiguously, the data collected using these forms were comparable to the more detailed time study data and could be combined with these data for analysis (NURMINEN, HEINONEN 2007).

Methodologically, the study was a comparative study (comparing two trucks in the same working conditions) with less attention paid to a correlation study. A common problem in comparative analysis, the existence of irrelevant and disturbing factors – noise (BERGSTRAND 1991), was levelled out as a result of studying equally skilful drivers and working under similar conditions.

Two techniques were applied to create the models: work phase time consumption models, and overall time consumption models. Both techniques appeared to fit well with the observations and are reliable to predict the time consumption and productivity, as previously found by NURMINEN et al. (2006). The advantage of the work phase based model was, above all, the possibility to observe the harvesting work in greater detail, to decrease the variation of time consumption as well as to reduce the number of influencing factors. A work element is often influenced by few factors, while the total time is influenced by more factors. If the division into work elements is detailed enough, the work element might be affected only by a single factor or correspond to the average time. In the overall time consumption model, the affecting factors might influence the work elements but in different directions, thus the effect on the total time consumption is minimized. In the overall time consumption model, with applying the average value for the model, the average time consumption of the work

phase can be calculated. In order to study the effect of a single factor on the time consumption, only the value of the factor is changed while the other factor is fixed to the average values. The overall time consumption model gives the same results as the work phase model in a simpler form (GONZÁLES 2005).

The hauling work phase was modelled for both methods. The analysis showed that it depends on the payload volume, hauling distance, and truck speed. Independent variables of volume, number of logs, distance, interaction between number of logs and volume were regressed against hauling time and driving time (unloaded and loaded) separately. Hauling distance was the most influential factor on the time consumption of driving unloaded while hauling distance and volume were the most influencing factors regarding the time consumption of driving loaded. In the overall time consumption and productivity model, hauling distance, truck speed, and volume hauled were the most important factors.

The effect of hauling distance, truck speed, and volume hauled on the time consumption of hauling in this study has been proved. The influence of truck driver's skills, motor power, tire inflation, road condition was previously reported by LJUBIC (1984, 1985), which can be considered in order to improve productivity in this section. The other factors that may influence the productivity and costs of forestry transportation are topography, steepness, climate, and size of operation, volumes available and manufacturing year of the truck.

From the aspect of modelling and statistical analysis the study provided sufficient relevant data. Regression models proved to fit the data well and reliably estimated the time consumption for individual work phases. The residuals of the regression models were symmetrical and were normally distributed and the coefficients of determination were high. Overall, the variation in the time consumption of log deck activities and unloading was not great and all variations in time consumption were related to driving loaded and unloaded. As a result, the overall model for transportation time worked less well than we hoped. Additional research to refine the sub-models with the poorest performance may improve the estimation of total transportation time, but it is also possible that the inherent variability in operating conditions in the forest will make it impossible to produce a model with highly accurate prediction.

The ranges of total transportation time for dump truck and chassis truck with and without load are presented for a driving distance of 55–80 km for

transportation of saw logs and for a load volume of 10–15 m<sup>3</sup>. In both cases, the variation in travel time between the lowest and highest estimate was roughly 48% in chassis trucks and 73% in dump trucks.

The variation in time consumption must be taken into account when for example planning routes and schedules for trucks using optimization procedures. In addition, trucking entrepreneurs should understand this variation and incorporate it in their cost accounting and their pricing of shipment (NURMINEN, HEINONEN 2007). The data from the present study clearly indicate that the mean values do not always reflect the whole truth.

From the stand point of transportation times, the load volume is not a particularly significant factor since the roundtrip times did not differ significantly between two types of trucks. Loading times are the main part of the log deck activities; however, they accounted for only about 11% of the total transportation time. However, load volume and log quality have a large financial effect on the transportation issue.

Since the division of total transportation time among work phases is greatly affected by driving distances and by the distribution of load and route types, the proportion shown in Fig. 2 cannot be generalized at a national scale.

The proportion of delays in the total transportation time was smaller than reported by NAGHDI (1996), who reported values around 8% under similar conditions. The differences may result from improvement in cost optimization and training of workers involved in the work phase.

The time consumption for different driving phases generally depends on the speed limits and other relevant legislation, the proportion of the different road classes and the condition of the roads. These phases also include fixed or auxiliary activities such as manoeuvring the truck, service and repair and waiting at the log deck, all of which increase the variation in the time consumption.

The data also enabled to perform a detailed analysis of unloading activities for both trucks. Unloading accounted for a roughly small share of total transportation time (less than 3%). However, the differences between two methods were considerable. In the chassis truck unloading and loading phases are under two drivers' work performance. However, delays during the unloading phase especially in the chassis truck which needs a loader for unloading may disturb the schedules of subsequent trips and can cause financial losses to entrepreneurs.

NAGHDI (2005) studied productivity of hauling in the cut-to-length method and tree length method. Productivity of hauling in his study was

6.1 m<sup>3</sup>·effective h<sup>-1</sup> in the tree length method and 3.3 m<sup>3</sup>·effective h<sup>-1</sup> in the cut-to-length method. The productivity of hauling in this study was 2.8 and 3.4 m<sup>3</sup>·effective h<sup>-1</sup> in the dump truck and chassis truck, which is very similar to the productivity of hauling in the cut-to-length method reported by NAGHDI (2005).

The productivity of two types of trucks was tested by the Kolmogorov-Smirnov test for normality. Since the data were not normal, the Mann-Whitney *U*-test was applied in order to find any difference between the two trucks. The results showed that there were statistically significant differences between production rates of the two trucks ( $P = 0.039$ ).

In hauling, the machine costs accounted for 81% of the total hourly costs (system cost), while labour costs made up 19% of the share. Unit costs of hauling calculated by NAGHDI (2005) were 4.2 and 2.5 USD·m<sup>-3</sup> in the cut-to-length and tree length method, respectively. In this study, the unit cost of hauling was 18 USD·m<sup>-3</sup> in the dump truck and 15 USD·m<sup>-3</sup> in the chassis truck. The main reason for the difference was a change in the value of trucks, diesel oil price, operating cost and different forest structure and routes.

As a conclusion, the models and results provided in this study could, in general, help forest managers to better understand the influencing factors on the productivity and cost of hauling using two types of trucks, to improve the allocation of logistics cost among timber lots and log products and to improve decisions related to processing of trees into a range of products. It can be used for reorganizing and planning of forest work in order to meet both the customer and company needs (MOUSAVI 2009).

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