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Efficiency and Cost Analysis of Forestry Machinery Usage in Hyrcanian Forests of Iran

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Abstract: The operating hourly cost of the machine is a suitable factor to analyze the cost fluctuation certain machinery in a changing environment and to find of economically feasible work concepts for the studied machine system. This paper, which is based on studies carried out in northern forests of IR-Iran, analyzed and compared costs of four skidding and excavation machines used in timber harvesting and preparing forest roads. Cost calculations were based on the methods used by FAO. Results indicated that the production cost of excavation machines for crawler bulldozer Komatsu D60 and crawler hydraulic excavator Komatsu PC220 was 0.130 € m^{-3} and 0.164 € m^{-3} respectively. Also, production cost of skidding machines for wheeled skidder Timberjak 450°C and HSM 904 was 1.320 € m^{-3} and 2.940 € m^{-3} respectively; where the terrain and forest conditions of Iran are moderate, the crawler bulldozer and wheeled Timberjack must be preferred to other equipments, because hydraulic excavator and HSM are too expensive. To conclude, this study reveals that information on the productivity, cost and applications of skidding and excavation machines and systems is a key component in the evaluation of management plans.

Key words: Production cost・Skidding machine・Excavation machine・FAO method・Hyrcanian Forests

INTRODUCTION

The machine options for sensitive sites should satisfy the economic feasibility, have a social acceptance and deal with environmentally sound equipment employed [1]. Based on the forest machine operability in given site conditions, the machine operating cost and productivity will be the two main factors in the appropriate selection of machine [2, 3].

The method and equipment used in road construction is an important economic and design factor in road location and subsequent design [4]. Hydraulic excavators in forest roads excavation has been the major step towards environmentally sound road construction practices [5, 6]. In some of the valuable stands, marshy, hilly and stoniness terrain of the northern forests of Iran, using excavators not only replaced bulldozers but also improved the quality of roads while reducing environmental impacts [7, 8]. However, approximately 80% of forest roads are still constructed by bulldozer. One major factor preventing the more usage of excavators is their low productivity. Bulldozers are an efficient and economical piece of equipment for road construction where roads can be full benched and excavated material can be side cast and wasted [9]. The most common piece of equipment in forest road construction is the bulldozer equipped with straight or U-type blades. These are probably the most economical pieces of equipment when material has to be moved a short distance [10].

The research relating to cost assessment of the logging systems being used goes back to 1930's, but in northern forests of Iran it has started two decades ago. Due to the higher initial cost of harvesting machines, larger diameters and crowns of hardwoods and the relatively steep terrain in Caspian forests of Iran, manual felling with a chainsaw and mechanized ground-based skidding with wheeled skidder are still the most commonly used system in this region [11]. Wheeled skidding skidders appeared in northern forests of Iran in the early 1970's and are now widely used. The Timberjack 450°C skidder (with the power of 177 HP and the weight was 10257 kg.) and HSM 904, which have been imported from

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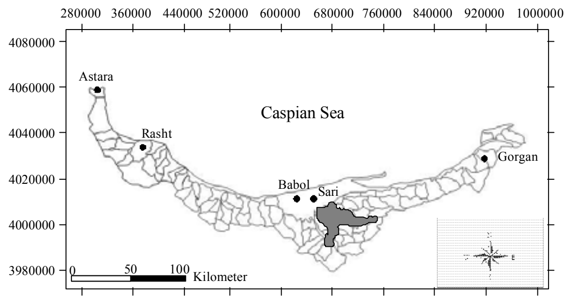

Fig. 1: Geographical position of watersheds in northern forests of IR-Iran

Canada and Germany respectively are used for a ground-based skidding system in order to extract logs from the stump area to a roadside landing [12].

Forestry machines cost calculation and the analysis should take into consideration the effectiveness, the flexibility, and the ease to use for the end-user. The objective of this study was to analyze and to compare costs of four skidding and excavation machines used in timber skidding and preparing a secondary forest road in northern forests of IR-Iran.

MATERIALS AND METHODES

This study was carried out in northern forests of IR-Iran. This area which is named as Hyrcanian vegetation zone is a green belt stretching over the northern slopes of Alborz mountain ranges and covers the southern coasts of the Caspian Sea. This area stretches from Astara in the northwest to Gorgan region in the northeast of Iran. Based on the latest data from the Iranian forests and rangelands organization, northern forests of Iran is approximately 800 km long and has a total area of 1.85 million ha (Fig. 1). Rainfall ranges from 760 to 2000 mm yr^{-1}, with the heaviest precipitation in the summer and fall. Temperature is moderate, ranging from a few degrees below 0°C in December, January and February to +25°C during the summer. The most important soil types in the Hyrcanian zone are the brown soils, alluvial soils, Rendzina soils, Colluvial soils and Rankers soils [4, 5, 13].

The basic principle when analyzing the machine operation and system is to compute the operational costs based on the labor and machine used. The costs involve the costs of running a machine over its expected useful life. The main concern in the machine costs is based on the calculated fixed and variable costs [14]. The fixed costs are incurred through ownership of the machine and are independent from the annual working time (Equation 1) [15, 16].

$$Fc=D+I+T \quad (1)$$

Where, *Fc* is the fixed cost, *D* is the annual depreciation cost, *I* is the investment cost, *T* is the Insurance, taxes and garage cost. The objective of the depreciation charge is to recognize the decline of value of the machine as it is working at a specific task (Equation 2) [15,17].

$$D = \frac{P_0 - P_s}{\text{Life}} \quad (2)$$

Where, P_0 is the purchase cost, P_s is the salvage cost, *Life* is the economic life of machines (hour). Interest can be calculated by multiply the interest rate times by the average annual investment (Equation 3 and 4) [14, 15].

$$A = \frac{(P_0 - P_s)(N+1)}{2N} + P_s \quad (3)$$

$$I = A \times i \quad (4)$$

Where, *A* is the average annual investment, *N* is the economic life of machine (year), *i* is the annual interest rate. The variable costs are incurred when the machine is being used and depend on it (Equation 5) [15].

$$Fv = MR + f + FOG + TW + Q \quad (5)$$

Where, *Fv* is the running cost, *MR* is maintenance and repair cost, *f* is hourly cost of fuel, *FOG* is filter, oil and grease cost, *TW* is hourly cost of tire wear, *Q* is cost of pieces wear [15].

Maintenance and repair category includes everything from simple maintenance to the periodic overhaul of engine, transmission, clutch, brakes and other major equipment components, for which wear primarily occurs on a basis proportional to use. Operator use equipment, the severity of the working conditions, maintenance and repair policies, and the basic equipment design and quality affect maintenance and repair cost (Equation 6) [15].

$$MR = D \times F \quad (6)$$

Where, *F* is the machines coefficient. The fuel consumption rate for a piece of equipment depends on the engine size, load factor, the condition of the equipment, operator's habit, environmental conditions and the basic design of equipment (Equation 7) [15, 17].

$$f = \lambda \times w \times L \quad (7)$$

Where, λ is the fuel factor, w is the horsepower, L is the fuel cost lit^{-1}. Due to shorter life of tires, those are considered an operating cost. Tire cost is affected by the operator's habits, vehicle speed, surface conditions and wheel position (Equation 8) [14, 15].

$$TW = \frac{T_{cf} \times C_{tc}}{T_{lf} \times T_{wf} \times M_{tl}} \quad (8)$$

Where, T_{cf} is the tire cost factor, C_{tc} is the current tire cost, T_{lf} is the tire life factor, T_{wf} is the tire wear factor, M_{tl} is the maximum tire life.

The hourly costs of crawler bulldozer Komatsu D60, crawler hydraulic excavator Komatsu PC220, wheeled skidder Timberjack 450°C and HSM 904 were calculated according to FAO method [15]. Fuel and lube costs were computed based on hourly consumption rate and local prices. Salvage values of machines were obtained from the owners (Equation 9 and 10).

$$C = Fc + Fv \quad (9)$$

$$PC = \frac{C}{P} \quad (10)$$

Where, C is the total cost, PC is the production cost and P is the production rate. Main components of excavation machines are shown in Fig. 2. Felling and grubbing costs were calculated according to costs lists of Iran ministry of road and transportation.

RESULTS

Table 1 shows the labor costing in felling and grubbing operations. The hourly cost of hydraulic tank for crawler bulldozer Komatsu D60 was more than the other forestry machines (Table 2, Fig. 3), whereas the hourly costs of crankcase, gear box and FOG for crawler hydraulic excavator Komatsu PC220 was more than other machines (Table 3 and 4, Fig. 4). Calculation of hourly piece wear cost for crawler bulldozer Komatsu D60 and crawler excavator Komatsu PC220 are presented in Table 2 and 3.

Results of this study indicated that the production cost of excavation machines for crawler bulldozer Komatsu D60 and crawler hydraulic excavator Komatsu PC220 were 0.130 € m^{-3} and 0.164 € m^{-3}, respectively.

Table 1: Labor costing in Euro (€) based on 2008 prices

Trees Diameter Class (cm)	Felling Cost (€)	Grubbing Cost (€)
4.8 - 9.6	0.26	0.46
9.6 - 19.1	0.45	1.26
19.1 - 28.7	0.71	2.09

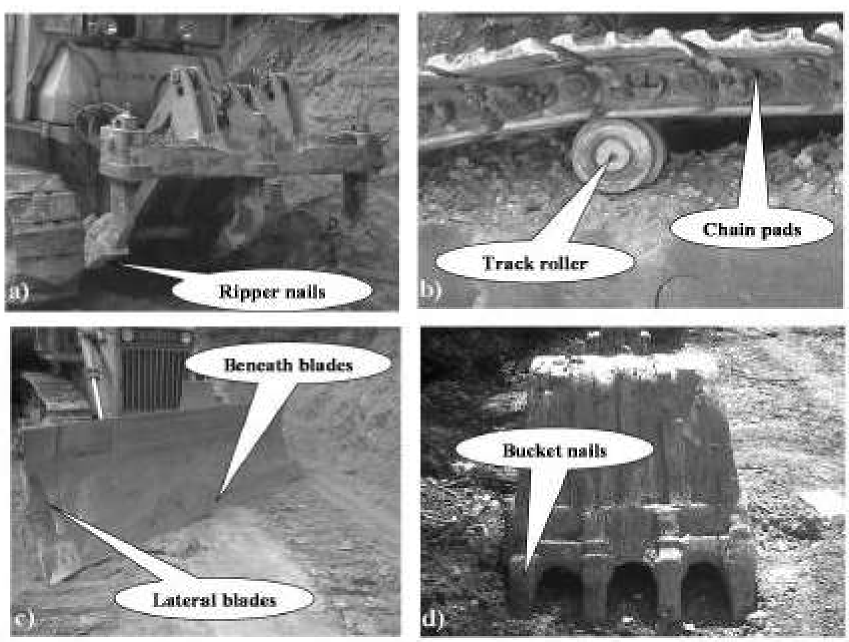

Fig. 2: Different types of the pieces of Komatsu hydraulic excavator and bulldozer

Table 2: Calculation of hourly FOG and piece wear costs for crawler Bulldozer Komatsu D60

Oil and filter	Crankcase	Gear box	Hydraulic tank	Oil of gear and rollers	Oil filter filter	Gas oil	Water filter	Grease
Usage (h)	80	1000	1000	1000	160	160	500	200
Capacity	25 Lit	8 Lit	285 Lit	5 Lit	1 no*	2 no	1 no	5 Kg
Fee (€)	0.786	0.786	0.572	0.643	5.003	1.429	6.433	0.858
Yearly substitute	30	2	2	2	15	15	5	48
Hourly cost (€)	0.246	0.005	0.136	0.003	0.031	0.018	0.013	0.023

Hourly piece wears cost

Type of piece	Pin and ripper nails	Chain pad	Track roller	Beneath blades	Lateral blades
Usage (year)	5	5	5	3	3
Number	3	80	9	2	2
Fee (€)	32.881	35.740	178.699	107.219	57.184
Hourly cost (€)	0.008	0.238	0.134	0.030	0.016

*no: Number

Table 3: Calculation of hourly FOG and piece wears costs for crawler Excavator Komatsu PC220

Oil and filter	Crankcase	Gear box	Hydraulic tank	Oil of gear and rollers	Water filter	Gas oil	Grease
Usage (h)	100	500	500	1000	100	100	200
Capacity	42 Lit	100 Lit	70 Lit	40 Lit	1 no	1 no	5 Kg
Fee (€)	0.786	0.786	0.572	0.643	5.003	3.574	0.858
Yearly substitute	25	5	5	2	25	25	13
Hourly cost (€)	0.344	0.164	0.083	0.021	0.052	0.037	0.023

Hourly piece wears cost

Type of piece	Pin and bucket nails	Chain pads	Track roller
Usage (year)	1	10	10
Number	4	80	9
Fee (€)	17.870	35.740	178.699
Hourly cost (€)	0.030	0.119	0.067

Table 4: Calculation of hourly FOG cost for wheeled Skidder Timberjack 450°C and HSM 904

Oil and filter	Crankcase	Gear box	Hydraulic tank	Tiers	Air filter filter	Hydraulic filter	Oil filter	Gear box	Differ ential
Capacity	18 Lit	19 Lit	150 Lit	2.5 Lit	2 no	2 no	1 no	1 no	9 no
Fee (€)	0.715	1.787	0.286	0.786	15.011	1.251	17.155	10.007	0.786
Cost (€ h^{-1})	0.016	0.023	0.054	0.002	0.037	0.003	0.021	0.012	0.009

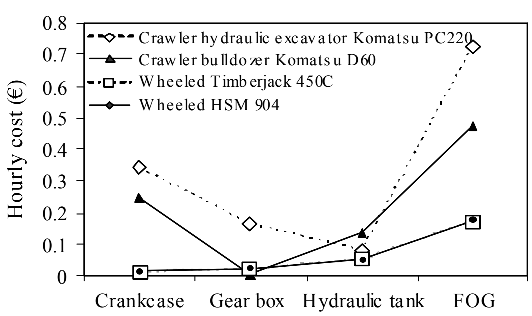

Fig. 3: Comparison of forestry machinery FOG cost in northern forests of IR-Iran

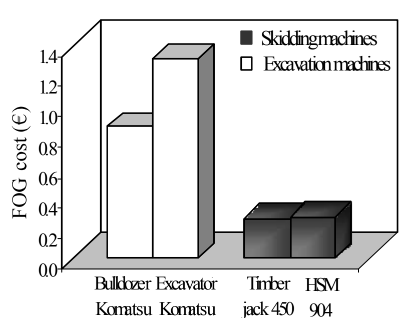

Fig. 4: Comparison of forestry machinery FOG cost in northern forests of IR-Iran

Table 5: Machine and system costing in Euro (€) based on 2008 prices

Type of Machine	Crawler Bulldozer Komatsu D60	Crawler Excavator Komatsu PC220	Wheeled Skidder Timberjack 450°C	HSM 904
General information				
Delivered price (€)	121515.368	121515.368	51699.261	187000
Depreciation period (yr)	20	20	20	20
Annual usage (h)	2400	2400	800	800
Salvage value (10%)	12151.537	12151.537	5169.926	18700
Average annual investment	69567.548	69567.548	30.535	92.313
Machine fixed cost				
Depreciation cost (€ h^{-1})	2.278	2.278	2.910	8.792
Interest: 5% AAI (€ h^{-1})	1.739	1.739	1.527	4.616
Insurance & taxes (€ h^{-1})	1.334	0.364	0.813	0.813
Machine running cost				
Maintenance & Repair (€ h^{-1})	2.278	2.278	2.617	7.912
Fuel cost (€ h^{-1})	0.229	0.229	0.343	0.343
Oil and lubricants (€ h^{-1})	0.613	0.389	0.297	0.297
Personnel (€ h^{-1})	10.507	2.144	6.203	6.616
Transportation cost (€ h^{-1})	1.287	1.287	0.978	0.978
Total cost				
Hourly machine cost (€)	20.804	11.074	17.845	31.347
Mean production (m^3 h^{-1})	160.13	67.530	13.517	10.663
Production cost (€ m^{-3})	0.130	0.164	1.320	2.940

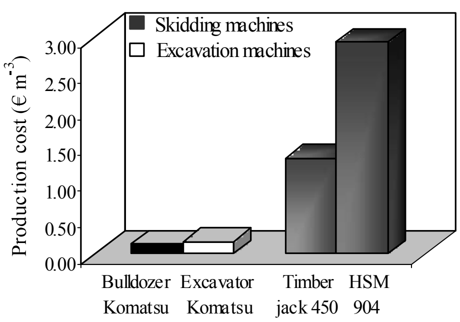

Fig. 5: Comparison of forestry machinery production cost in northern forests of IR-Iran

Also, production cost of skidding machines for wheeled skidder Timberjak 450°C and HSM 904 were 1.320 € m^{-3} and 2.940 € m^{-3}, respectively (Table 5).

Finally, where the terrain and forest conditions in north of Iran is moderate, the crawler bulldozer and wheeled Timberjack must be preferred to other equipments, because hydraulic excavator and HSM 904 are more expensive than the crawler bulldozer and wheeled Timberjack (Fig. 5).

DISCUSSION

The forest machine industry is relatively young if compared to several other industrial sectors. For example, the car industry is more than 100 years old, whereas the first forest machines were built in the 1950s [18, 19]. Nowadays, the development of forest machinery requires a high level of expertise in power transmissions, control technologies, computer sciences, material sciences, machine dynamics, multimedia, etc [20, 21].

In relation to economic studies of other excavation machines, the costs found in this study was lower than those found in Tanzania and Canada. Because depreciation period (approximately 20 years) and annual usage of forestry machines in IR-Iran is more that developed countries. Cost analysis in Tanzania showed that the mean production cost for the D6, D4 and county tractor were 0.712 € m^{-3}, 1.150 € m^{-3} and 1.110 € m^{-3} respectively [17]. In Canada the earthwork costs were 0.672 € m^{-3}, 0.642 € m^{-3} and 1.387 € m^{-3} for D8 Caterpillar bulldozer, 235 hydraulic backhoe and hydraulic shovel respectively [22].

In this study the average skidding costs for wheeled skidder Timberjak 450°C and HSM 904 was 1.320 € m^{-3} and 2.940 € m^{-3} respectively. Behjou *et al*. [12] assessed the production cost of wheeled skidder Timberjack 450°C in Caspian forests of Iran. Selection cutting was performed on a 66-hectare tract with an average slope of 30%. Study was carried out in a steep and difficult terrain. Trees were logged downhill to the landing. Results showed that the gross and net production rate was 20.51 and 22.93 m^3 h^{-1}, respectively. Also, the average production cost considering the gross and net production rate was 9.213 € m^{-3} and 9.081€ m^{-3}, respectively, whereas in Naghdi *et al*. [13] studies the maximum production cost of skidder Timberjack 450°C was calculated 2.36 € m^{-3} which was in agreement with our results. It seems that Behjou *et al*. [12] selected the depreciation period which is considered in developed countries. Also, in 2005, the average logging costs of logging machine contractors (cutting and forwarding) in Finland was 8.53 € m^{-3} [23].

According to Väätäinen *et al*. [16] on average, the relocation cost of forest machines in Finland was about 6 to 10% of the total logging (cutting and forwarding) costs. In the case of a logging contractor with one low-bed truck and one harvester-forwarder system, the machine relocation cost was 0.80 € m^{-3} (Based on 35000 m^3 of annual harvesting), whereas in the case of a contractor with one truck and two harvester-forwarder systems the cost of machine relocation was 0.52 € m^{-3} (Based on 70000 m^3 of annual harvesting). Results showed that the skidding cost (€ m^{-3}) increases linearly with increasing skidding or winching distances. Also, the skidding cost linearly decreases with increasing load volume per travel turn [13].

CONCLUSION

This study concluded that where the terrain and forest conditions of Iran are moderate, the crawler bulldozer Komatsu D60 and wheeled Timberjack 450°C must be preferred to other machines, because crawler hydraulic excavator Komatsu PC220 and HSM 904 are too expensive (Fig. 5). Primary transportation is an upper time, expensive and hard labour. In Iran skidding operations is frequently performed by wheeled Timberjack 450°C that has devoted 60% of utilization expenses. Loading volume for Timberjack 450°C and in ground skidding is almost 3m^3. Pay attention to skidder 450°C power, it is possible to downward skidding with higher volumes. Thus, the hourly costs of machine may be reduced.

Measuring productivity of forest equipment is an important aspect for an industry consumed with increasing efficiency and lowering operating costs [24]. Most of this data is obtainable but usually the result of complex research projects that are cost prohibitive at the contractor level. Often knowledge only exists by contractor “seat of the pants” experience. The need for accurate information on machine productivity is imperative to improve project economics for forestry managers and forest contractors.

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