https://doi.org/10.17221/133/2017-JFS

Estimating the economic life of forest machinery using the cumulative cost model and cost minimization model in Iranian Caspian forests

Mohammad HEJAZIAN[1]*, *Majid LOTFALIAN*[1], *Soleiman MOHAMMADI LIMAEI*[2]

[1]*Department of Forestry, Faculty of Natural Resources, Sari Agricultural and Natural Resources University, Sari, Iran*

[2]*Department of Forestry, Faculty of Natural Resources, University of Guilan, Sowmeh Sara, Iran*

**Corresponding author: m.hejazian@stu.sanru.ac.ir*

Abstract

Hejazian M., Lotfalian M., Mohammadi Limaei S. (2018): Estimating the economic life of forest machinery using the cumulative cost model and cost minimization model in Iranian Caspian forests. J. For. Sci., 64: 216–223.

This study was conducted in order to estimate the economic life of two models of rubber-tired skidders, namely Timberjack 450C and HSM 904, in Iranian Caspian forests. The total annual costs and average cumulative cost of skidders were calculated by life-cycle costing analysis. The economic life of the machines was estimated by both the cumulative cost model and cost minimization model. The results indicated that the economic life of Timberjack 450C and HSM 904 is 7,700 h (at the end of the 11th year) and 15,300 h (at the end of the 17th year), respectively, using the cost minimization model. Furthermore, the results indicated that the economic life of Timberjack 450C and HSM 904 is 9,100 h (at the end of the 13th year) and 11,900 h (at the end of the 21st year), respectively, using the cumulative cost model. The cumulative cost model estimated the economic life of skidders longer than the cost minimization model.

Keywords: skidder; Timberjack 450C; HSM 904; life-cycle costing; machine life; replacement

The correct and economical use of machinery is one of the most important aims of the forest machinery management. Both the purchase and utilization of the machinery involve huge investments in forest logging. Equipment will eventually wear out, so the need for reliable and dependable operations should compel forestry contractors to follow the proper equipment replacement strategies (Cantú, LeBel 2010). In the replacement strategies, the primary function of contractors is to replace the right equipment at the right time and with the lowest overall cost (Fan et al. 2011). The replacement is performed by the different goals when one of the most important goals is the economic goal: reducing costs and increasing revenues. In fact, based on the desire to minimize costs, as soon as a machine reaches a certain age, it can be more cost-effective to replace it with a new machine. Hence, how and when the equipment is replaced can mean a difference of thousands of dollars in the annual costs. Furthermore, the return of investment is maximized when replacement occurs at the optimal economic life of the equipment (Mellal et al. 2013; Fallahnezhad et al. 2014; Hernández Gress et al. 2014; Zvipore et al. 2015).

Generally, the optimum replacement life can be mathematically defined in three different ways: physical life, profit life and economic life as follows (Gransberg, O'Connor 2015):

(i) Physical life: the physical life of equipment is identified as the service life. This time period ends when the equipment can no longer be operated

(Hunt, Wilson 2016). The physical life of an asset will always be greater than the economic life of an asset because the asset first fails economically and then it becomes physically useless;

(ii) Profit life: the profit life is the time period where the equipment generates a profit (Gransberg et al. 2006);

(iii) Economic life: it is defined as the age that minimizes the average ownership and operating costs (Mitchell et al. 2010; Fan et al. 2011; Rahimdel et al. 2013; Zvipore et al. 2015). The replacement age for a machine that is placed on the economic life arrives before the fundamental breakdowns resulted in worn-out and technological disabling.

Life-cycle costing (LCC). LCC analysis is used as one component of the equipment fleet management process. LCC is a concept originally developed by the U.S. Department of Defense in the early 1960s to increase the effectiveness of government procurement (Barringer, Weber 1996). It allows the fleet manager to make the equipment repair, replacement, and retention decisions on the basis of the equipment's economic life. Life-cycle costs have two components: ownership and operating costs. Ownership and operational costs are calculated using the recorded data and some costing methods such as the FAO method. Also operating costs are predictable in the future years using a mathematical model. An accurate prediction model is critical to the different decisions on the equipment management, such as allocation, repair, replacement and retirement because equipment maintenance costs constitute a major fraction of the total life cycle cost of a piece of equipment (Yip et al. 2014).

Replacement analysis. Replacement analysis is a tool with which equipment owners time the equipment replacement decision. Some owners replace the old machine by an intuitive method that perhaps is the most well-known approach to making replacement decisions due to its simplicity and reliance on individual judgment. This method mainly depends on a professional judgment or an apparent feeling of correctness to make replacement decisions that is not a scientific approach (Douglas 1978).

Cost minimization model (CMM) and cumulative cost model (CCM) can be considered as the two most important scientific methods in replacement analysis (Roohani, Masoudi 2014).

According to the CMM, the economic life is the cumulative operating hours in which the annual cost reaches the minimum amount and then starts to increase. In other words, the minimum point of the annual cost curve is considered as the economic life of the machine (Khoubbakht et al. 2010). According to the CCM, the optimal time to replace a machine is that year where the average cumulative cost is minimized. The average cumulative cost can be calculated using Eq. 1:

$$A_{cc} = \frac{C_{op} + C_{ow}}{C_{oh}} \tag{1}$$

where:

A_{cc} – average cumulative cost,
C_{op} – cumulative operating cost,
C_{ow} – cumulative ownership cost,
C_{oh} – cumulative operating hours.

All machine replacement models found in literature are formulated from the economic analyses. They were originally based on cost estimations to forecast cumulative hourly costs (Cantú, LeBel 2010). Bonhomme and LeBel (2003) carried out a financial analysis of 20 forestry contractors based on cost data. Their results show that forestry contractors who replace machines more often have low repair, maintenance, fuel, and lubricant costs, but at the same time high capital costs. Khoubbakht et al. (2010) conducted a study in Iran to determine the economic life of the MF285 tractor. The economic life of the tractor, 18,316 h was predicted. Roohani and Masoudi (2014) indicated that the economic life of the tractor using the CCM and CMM model is 29,025 and 27,778 h, respectively.

Various machines have been purchased by forestry companies in Caspian forests which often retire at the end of their physical life. Generally, Timberjack 450C and HSM 904 are the most commonly used skidders in this area. Despite recorded costs and the existence of data on the cost of skidders, there has not been a study on the economic life of machines based on scientific methods. In the present study, we aimed to estimate the economic life of these skidders in Caspian forests and compare the estimated life using the CMM and CCM approaches. Moreover, this study presents the best time to replace and solve the equipment replacement optimization problem of contactors by the economic life model and examining the total cost of these machines.

MATERIAL AND METHODS

Site of study. This study was carried out in Caspian forests in the north of Iran. Caspian forests are located between the Caspian Sea and the Alborz Mountain Range. A ground-based skidding system using wheeled skidders appeared in the early

1970s and nowadays it is still the most widely used method (Mohammadi Limaei, Naghdi 2009). Required data were obtained from Nekachoub and Mazandaran Pulp and Paper Industries (MWPI) that are regarded as the two biggest forestry contractors in the north of Iran. Nekachoub used Timberjack 450C (Timberjack, Canada) (Fig. 1a) and MWPI used HSM 904 (HSM, Germany) (Fig. 1b) to transport the timber to the landings (Table 1).

According to the LCC analysis, costs of skidders were calculated using Eq. 2. Ownership costs included initial costs, depreciation, insurance, taxes, parking, and investment cost (Peurifoy, Schexnayder 2002; Gransberg, O'Connor 2015). Operating costs included the repair and maintenance, tire, fuel, labour, and any other consumable equipment cost (Gransberg et al. 2006; Gransberg, O'Connor 2015):

Fig. 1. Image of Timberjack 450C (Timberjack, Canada) (a), HSM 904 (HSM, Germany) (b) which were selected for the study

$$\mathrm{LCC}_{\mathrm{fm}} = C_{\mathrm{D}} + C_{\mathrm{I}} + C_{\mathrm{In}} + C_{\mathrm{Tx}} + C_{\mathrm{p}} + C_{\mathrm{M,\,R}} + C_{\mathrm{Tr}} + C_{\mathrm{Lu}} + C_{\mathrm{F}} + C_{\mathrm{lb}} \quad (2)$$

where:

$\mathrm{LCC}_{\mathrm{fm}}$ – life cycle cost of forest machine,
C_{D}, C_{I}, C_{In}, C_{Tx}, C_{p} – ownership costs,
C_{D} – depreciation cost,
C_{I} – interest cost,
C_{In} – insurance cost,
C_{Tx} – tax,
C_{p} – parking cost,
$C_{\mathrm{M,\,R}}$, C_{Tr}, C_{Lu}, C_{F}, C_{lb} – operating costs,
$C_{\mathrm{M,\,R}}$ – maintenance and repair costs,
C_{Tr} – tire cost,
C_{Lu} – lubricant cost,
C_{F} – fuel cost,
C_{lb} – labour cost.

A declining balance method was used to calculate depreciation for the skidders. This method belongs to more sophisticated techniques which recognize the changing rate of value loss over time. This technique results in greater depreciation in the early years of the asset life and smaller depreciation in the later years of the asset life. Eqs 3–5 express these relationships:

$$D_n = \mathrm{RV}_{n-1} - \mathrm{RV}_n \quad (3)$$

$$\mathrm{RV}_n = P \times (1 - r)^n \quad (4)$$

$$\mathrm{RV}_{n+1} = P \times (1 - r)^{n+1} \quad (5)$$

where:

D_n – depreciation for n year,
RV_{n-1} – remaining value for n – 1 year,
RV_n – remaining value for n year,
P – initial purchase,
r – ratio of depreciation.

Interest or investment cost represented the annual cost of capital invested in a machine. In other words, it is equal to the rate of return on investment. It is a function of real interest rate and remaining value of the machine. In this study, the real interest rate was calculated at 10% (based on the Central Bank of the Islamic Republic of Iran da-

Table. 1. Specifications of Timberjack 450C (Timberjack, Canada) and HSM 904 skidders (HSM, Germany)

Machine	Age (yr)	Power (hp)	Weight (kg)	Height (m)	Width (m)	Purchase price (EUR)	Productivity ($m^3 \cdot h^{-1}$)
Timberjack 450C	18	177	10,270	3	2.84	120,000	10.8
HSM 904	15	170	9,000	2.93	2.4	187,000	9.9

tabase). Investment interest was calculated using Eq. 6 (Khoubbakht et al. 2008) as follows:

$$I_n = \mathrm{RV}_n \times I_\mathrm{r} \quad (6)$$

where:
I_n – interest on investment in n^{th} year,
RV_n – remaining value of machine in n^{th} year,
I_r – real interest rate.

Equipment owners often have one or more insurance policies to cover the cost of any loss due to fire, theft, or other damage. Insurance costs data were collected from insurance companies. Nekachoub and MWPI are exempted from tax by the government and they do not pay for parking as there are free parking spaces. Therefore, these kinds of costs are ignored at this study.

Maintenance and repair included everything from simple maintenance items to the periodic overhaul of engine, transmission, clutch, brakes, and other major equipment components (Akay, Session 2004). The repair cost is dependent on the use of equipment, operating conditions and maintenance standards (Bayzid et al. 2016). The hourly maintenance and repair costs of skidders were estimated as 50% of hourly depreciation. Tire costs were estimated using the tire life and 4,000 h was considered (FAO 1992).

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 (Ackerman et al. 2015). To calculate the fuel cost per hour, the total fuel cost is divided by the operating hours of the machine.

The time value of money is the idea that money available at the present time is worth more than the same amount in the future due to its potential earning capacity. The provided money can earn interest, any amount of money is worth more the sooner it is received. We took into account the time value of money using Eq. 7 (Oskounejad 2015):

$$\mathrm{FV} = \mathrm{OA}\left(1 + \mathrm{IR}\right)^{n_\mathrm{p}} \quad (7)$$

where:
FV – future value,
OA – original amount,
IR – interest rate,
n_p – number of period.

Generally, annual operation hours of skidders for Nekachoub and MWPI are 700 h.

In order to determine the best model for predicting the operating costs for future years, several linear and nonlinear mathematical models were used. The models can be described by Eqs 8 (linear), 9 (logarithmic), 10 (exponential), and 11 (power) as follows:

$$Y = a + bx \quad (8)$$

where:
Y – dependent variable (cumulative operating cost),
a, b – parameter values that will be estimated by regression analysis,
x – independent variable (cumulative operating hours).

$$Y = a\ln x + b \quad (9)$$

$$Y = \exp\left(a + bx\right) \quad (10)$$

$$Y = ax^b \quad (11)$$

SPSS (Version 17, 2008) as a statistical package was used for the statistical analysis of data. The best model procedure was selected by identifying the highest R^2 value for predicting the skidder operating cost.

RESULTS AND DISCUSSION

Tables 2 and 3 illustrate the operating hours and the calculated costs for Timberjack 450C and HSM 904, respectively. The data shown in these tables were used to analyse and determine the operating cost model.

First of all, depreciation cost tended to be great but it declines over time. Likewise, the interest cost is high initially but it gradually diminishes. In contrast, the operating cost could be low or zero when a machine is still under warranty, eventually it increases as parts wear out and maintenance repairs rise. The first year's costs of the machines were high because of the very real marketplace depreciation obtained from the estimated value method.

As shown in Figs 2a and b, the total cost of Timberjack declines from the 1st year and then reaches the lowest amount in the 11th year after rising. Based on the CMM, the 11th year is the replacement time of Timberjack and the cumulative operating hours are 7,700 h. The total cost of HSM continues to decline and the contractor can keep it as shown in Tables 2 and 3 by K (keep) and R (replace).

Table 2. Calculated costs for Timberjack 450C (Timberjack, Canada)

Age (yr)	Operating hours	Cost (EUR)				
		depreciation	interest	ownership	operating	total
1	700	7,200	12,000	19,200	2,660	21,860[K]
2	700	6,768	11,280	18,048	2,730	20,778[K]
3	700	6,362	10,603	16,965	3,134	20,099[K]
4	700	5,980	9,967	15,947	3,405	19,353[K]
5	700	5,621	9,369	14,990	3,738	18,728[K]
6	700	5,284	8,806	14,090	3,907	17,998[K]
7	700	4,967	8,278	13,246	4,388	17,633[K]
8	700	4,669	7,782	12,451	5,040	17,491[K]
9	700	4,389	7,315	11,704	5,621	17,325[K]
10	700	4,126	6,876	11,002	6,062	17,064[K]
11	700	3,878	6,463	10,341	6,594	16,935[R]
12	700	3,645	6,076	9,721	7,301	17,022[R]
13	700	3,426	5,711	9,138	8,736	17,874[R]
14	700	3,221	5,368	8,589	10,738	19,327[R]
15	700	3,028	5,046	8,074	12,964	21,038[R]

decision: K – keep the current machine, R – replace by a new machine

Table 3. Calculated costs for HSM 904 (HSM, Germany)

Age (yr)	Operating hours	Cost (EUR)				
		depreciation	interest	ownership	operating	total
1	700	16,830	18,700	35,530	3,948	39,478[K]
2	700	15,315	17,017	32,332	4,138	36,471[K]
3	700	13,937	15,485	29,422	4,273	33,696[K]
4	700	12,683	14,092	26,774	4,545	31,319[K]
5	700	11,541	12,824	24,365	5,040	29,405[K]
6	700	10,502	11,669	22,172	5,209	27,381[K]
7	700	9,557	10,619	20,176	6,013	26,189[K]
8	700	8,697	9,663	18,361	6,174	24,535[K]
9	700	7,914	8,794	16,708	6,433	23,141[K]
10	700	7,202	8,002	15,204	6,874	22,078[K]
11	700	6,554	7,282	13,836	7,084	20,920[K]
12	700	5,964	6,626	12,591	7,301	19,892[K]
13	700	5,427	6,030	11,458	7,434	18,892[K]
14	700	4,939	5,487	10,426	7,483	17,909[K]
15	700	4,494	4,993	9,488	7,560	17,048[K]

decision: K – keep the current machine

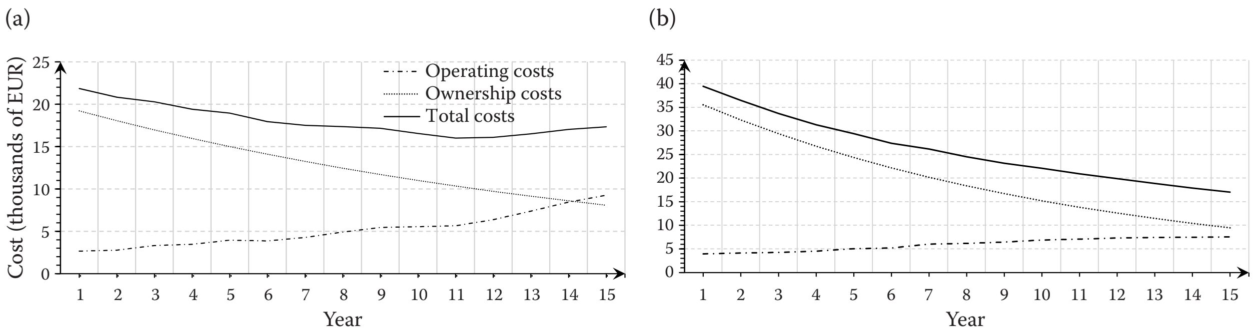

Fig. 2. Operating, ownership and total costs of Timberjack 450C (Timberjack, Canada) (a), HSM 904 (HSM, Germany) (b)

Table. 4. Cumulative operating hours, the ownership, total cost and average cumulative cost per year for Timberjack 450C (Timberjack, Canada) and HSM 904 (HSM, Germany)

Age (yr)	Cumulative operating hours	Cumulative cost (EUR)			Average cumulative cost (EUR·h^{-1})
		ownership	operating	total	
Timberjack 450C					
1	700	19,200	2,660	21,860	31.23^K
2	1,400	37,248	5,390	42,638	30.46^K
3	2,100	54,213	8,519	62,732	29.87^K
4	2,800	70,160	11,921	82,081	29.32^K
5	3,500	85,150	15,652	100,802	28.81^K
6	4,200	99,241	19,558	118,799	28.29^K
7	4,900	112,487	23,940	136,427	27.85^K
8	5,600	124,937	28,980	153,917	27.49^K
9	6,300	136,641	34,601	171,242	27.18^K
10	7,000	147,643	40,663	188,306	26.90^K
11	7,700	157,984	47,257	205,241	26.66^K
12	8,400	167,705	54,558	222,263	26.46^R
13	9,100	176,843	63,294	240,137	26.39^R
14	9,800	185,432	74,032	259,464	26.48^R
15	10,500	193,506	86,996	280,502	26.72^R
HSM 904					
1	700	35,530	3,948	39,478	56.40^K
2	1,400	67,862	8,085	75,947	54.25^K
3	2,100	97,284	123,655	109,639	52.21^K
4	2,800	124,059	168,989	140,957	50.34^K
5	3,500	148,423	21,938	170,361	48.68^K
6	4,200	170,595	27,146	197,741	47.08^K
7	4,900	190,772	33,159	223,931	45.70^K
8	5,600	209,132	39,333	248,465	44.37^K
9	6,300	225,840	45,766	271,606	43.11^K
10	7,000	241,044	52,640	293,684	41.96^K
11	7,700	254,880	59,724	314,604	40.86^K
12	8,400	267,471	67,025	334,496	39.82^K
13	9,100	278,929	74,459	353,388	38.83^K
14	9,800	289,355	81,942	371,297	37.89^K
15	10,500	298,843	89,502	388,345	36.99^K

decision: K – keep the current machine, R – replace by a new machine

The cumulative operating and ownership costs and the cumulative costs (total cost) and the average cumulative costs of the skidders are shown in Table 4. The average cumulative costs of Timberjack drop to the lowest value in the 13th year and then begin to rise as depicted in Fig. 3a. According to the CCM method, the economic life of Timberjack 450C is 13 years and the operating hours would be 9,100 h. The average cumulative costs of HSM 904 are declining and have not reached the lowest value yet. Therefore, the total costs and the average cumulative costs of HSM 904 were predict-

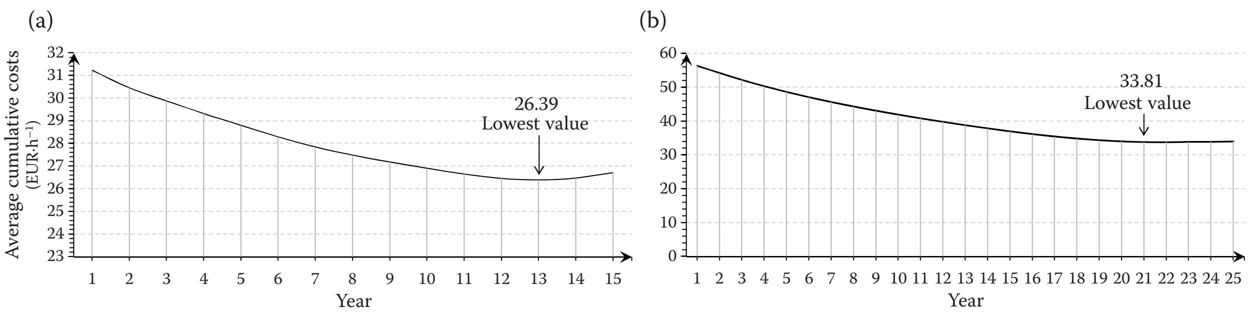

Fig. 3. Average cumulative costs of Timberjack 450C (Timberjack, Canada) (a), HSM 904 (HSM, Germany) (b)

ed for the future to estimate when they reach the lowest value.

The operating cost for HSM 904 skidder was predicted by a power model that was selected from among different models. Table 5 shows the relationship between the cumulative operating cost and the cumulative operating hours based on exponential, linear, logarithmic and power regression models for HSM 904. It was observed that the highest value of the correlation coefficient between the presented models was related to the power model with R^2 = 0.89.

Using the power model, cumulative operational costs were calculated for the next 10 years, for example x = 14,000 (Eq. 12):

$$Y = 731.21(14,000)^{0.5918} \cong 207,836\ (\text{EUR}) \quad (12)$$

In addition, the ownership costs and total costs were calculated. According to the CMM, the end of the 17th year or operating hours of 15,300 h are the time to replace with the new one because the total cost reached the lowest value.

The average cumulative cost graph for HSM 904 is shown in Fig. 3b. The graph shows that according to the CCM model, the economic life of this machine will end after 21 years or 14,700 operating hours.

The depreciation cost and investment interest are regarded as a function of the salvage value. As the machine usage increased, the machine's salvage value was reduced, so the depreciation cost and investment interest as well as the total cost of ownership would decrease over time. The ownership costs annually decreased and there was no direct relationship between this type of costs and the usage rate during the machine life. The operating cost increased annually because the repair costs were low early in the life of the machine, but they increased rapidly as the machine accumulated more hours of operation. In the present study, the CCM method estimated the economic life of the skidders longer than the CMM method, which was in line with the results of Roohani and Masoudi (2014). The results produced by both methods indicated that the economic life of Timberjack 450C is over whereas the contractor tends to continue using it. So, for this machine the CCM method was more in line with contractor's expectation. Moreover, the estimated economic life of Timberjack 450C was longer than the useful life reported by FAO (10 years or 10,000 h). It is shown that there was a difference between the economic life of Timberjack and its true and operational function. The main reason can be due to the cheap spare parts and repairman wages in Iran. The contractor can overhaul the skidders by paying a small amount of money. Furthermore, Nekachoub does not pay the fine for the wood transport delay due to the machine downtime and can spend much time to repair the skidder. They tend to use the machine until the end of physical life when the equipment can no longer be operated. According to the CCM and CMM method, the economic life of HSM 904 would end two years and six years later, respectively. In this case like Timberjack, the CCM method estimated the economic life longer than the CMM. It means that according to the economic principles the contractor can use it for the next six years. Moreover, with respect to the longer economic life, HSM 904 would be better choice for the forestry contractors in Iran. A power model was suggested as the final form of the operating cost model for HSM 904 that corresponded with the models developed by Karimi et al. (2012) and Roohani and Masoudi (2014). The power model gave better cost prediction with higher confidence and less variation than the other models because of easiness in calculations and the high correlation coefficients.

Table 5. Models for estimating the operating costs of HSM 904 (HSM, Germany)

Model	Equation	*F*-value	R^2
Exponential	$Y = 1,252.2e^{0.154x}$	160.57**	0.65
Linear	$Y = 606.89x + 372.19$	1,355.163**	0.68
Logarithmic	$Y = 3,329.5\ln(x) - 965.37$	63.318**	0.74
Power	$Y = 73.121x^{0.5918}$	3,897.9**	0.89

Y – cumulative operating cost, *x* – cumulative operating hours, **significant at the 0.05 level

CONCLUSIONS

The results of this study indicated that the replacement decisions were based on an intuitive method in the north of Iran. In other words, they were based on a professional judgment or an apparent feeling of correctness. It is not considered as a scientific method and forestry contractors should conduct operations with using methods such as CMM and CCM that could help them to manage the machine replacement efficiently. In addition, investigation of alternatives to select a new machine can be regarded as an important point in replacement decision making. In other words, other studies should be conducted to assess new productions in global markets to introduce new machines adopted by local environmental and economic conditions.

References

Ackerman P., Belbo H., Eliasson L., de Jong A., Lazdins A., Lyons J. (2014): The COST model for calculation of forest operations costs. International Journal of Forest Engineering, 25: 75–81.

Akay A.E., Sessions J. (2004): Identifying the factors influencing the cost of mechanized harvesting equipment. Journal of Engineering Sciences, 7: 65–72.

Barringer H.P., Weber D.P. (1996): Life cycle cost tutorial. In: Proceeding of the 5th International Conference on Process Plant Reliability, Houston, Oct 2–4, 1996: 1–58.

Bayzid S.M., Mohamed Y., Al-Hussein M. (2016): Prediction of maintenance cost for road construction equipment: A case study. Canadian Journal of Civil Engineering, 43: 480–492.

Bonhomme B., LeBel L. (2003): Harvesting contractors in Northern Quebec: A financial and technical performance evaluation. In: Council on Forest Engineering (COFE) Conference Proceedings: "Forest Operations among Competing Forest Uses", Bar Harbor, Sept 7–10, 2003: 673–676.

Cantú R.P., LeBel L. (2010): How adequate are equipment replacement models for logging contractors? In: Mitchell D., Gallagher T. (eds): Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future, Auburn, June 6–9, 2010: 1–15.

Douglas J. (1978): Equipment costs by current methods. Journal of Construction Division ASCE, 104: 191–225.

Fallahnezhad M.S., Sajjadieh M.S., Abdollahi P. (2014): An integrative decision rule to minimize cost of acceptance sampling plan in machine replacement problem. International Journal of Engineering, Transactions A: Basics, 27: 1099–1106.

Fan W., Machemehl R., Kortum K. (2011): Equipment replacement optimization. Solution methodology, statistical data analysis, and cost forecasting. Transportation Research Record: Journal of the Transportation Research Board, 2220: 88–98.

FAO (1992): Cost Control in Forest Harvesting and Road Construction. Forestry Paper No. 99. Rome, Food and Agriculture Organization of the United Nations: 106.

Gransberg D.D., O' Connor E.P. (2015): Major Equipment Life-cycle Cost Analysis. St. Paul, Minnesota Department of Transportation Research Services & Library: 66.

Gransberg D.D., Popescu C.M., Ryan R.C. (2006): Construction Equipment Management for Engineers, Estimators, and Owners. 1rd Ed. Boca Raton, Taylor & Francis Group: 552.

Hernández Gress E.S., Pérez Lechuga G., Hernández Gress N. (2014): Sensitivity analysis of the replacement problem. Intelligent Control and Automation, 5: 46–59.

Hunt D., Wilson D. (2016): Farm Power and Machinery Management. 11th Ed. Long Grove, Waveland Press, Inc.: 360.

Karimi S., Mesri Gundoshmian T., Khadem Alhossein N. (2012): Determination and analysis of economic lifetime for agricultural tractors in the West Azerbaijan province. Journal of Sustainable Agriculture and Production Science, 22: 87–98. (in Persian)

Khoubbakht G., Ahmadi H., Akram A., Karimi M. (2010): Determination of optimum life for MF285 tractor based on repair and maintenance costs: A case study in center region of Iran. Journal of Agricultural Technology, 6: 673–686.

Mellal M.A., Adjerid S., Benazzouz D., Berrazouane S., Williams E.J. (2013): Optimal policy for the replacement of industrial systems subject to technological obsolescence – using genetic algorithm. Acta Polytechnica Hungarica, 10: 197–208.

Mitchell Z., Hildreth J., Vorster M. (2010): Using the cumulative cost model to forecast equipment repair costs: Two different methodologies. Journal of Construction Engineering and Management, 137: 817–822.

Mohammadi Limaei S., Naghdi R. (2009): Optimal forest road density based on skidding and road construction costs in Iranian Caspian forests. Caspian Journal of Environmental Sciences, 7: 79–86.

Oskounejad M. (2015): Engineering Economy: Economic Evaluation of Industrial Projects. Tehran, Amirkabir University of Technology Press: 210. (in Persian)

Peurifoy R.L., Schexnayder C.J. (2002): Construction Planning, Equipment, and Methods. 11th Ed. New York, McGraw-Hill Publishing Company: 669.

Rahimdel M.J., Hosienie S.H., Ataei M., Khalokakaei R. (2013): The reliability and maintainability analysis of pneumatic system of rotary drilling machines. Journal of the Institution of Engineers (India): Series D, 94: 105–111.

Roohani A., Masoudi H. (2014): Economic life prediction of two-wheel drive tractor using cumulative cost model compared with cost minimization model. Journal of Agricultural Engineering, 36: 59–68. (in Persian)

Yip H.L., Fan H., Chiang Y.H. (2014): Predicting the maintenance cost of construction equipment: Comparison between general regression neural network and Box-Jenkins time series models. Automation in Construction, 38: 30–38.

Zvipore D.C., Nyamugure P., Maposa D., Lesaoana M. (2015): Application of the equipment replacement dynamic programming model in conveyor belt replacement: Case study of a gold mining company. Mediterranean Journal of Social Sciences, 6: 605–612.

Received for publication September 23, 2017
Accepted after corrections May 15, 2018