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Effect of Subsurface Materials on Earthwork Operation Costs of Forest Road

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Abstract

Major cost of forest construction operation is spent to earthwork operations. Therefore, time studies, estimation machine productivity and earthwork operation cost would be necessary to better utilization of current resources. In this research, impact of subsurface materials as key factor in forest road construction operation was investigated in a one kilometer forest road as study area. Subsurface material of the road, constructed by a Hydraulic excavator and a bulldozer, was contained three layers in term of digging: soft (soil), medium and hard (rocky). For this purpose, time of machines work cycle elements included warm up, movement from camp to study area, extracting remained trunk if any, earthwork activity, mealtimes and regular delays were accurately recorded during 15 working days. Furthermore, relevant cut and fill subsurface material was measured precisely. The results of continues time studies showed that mean production rates vary from 34.98 m3/hr in hard layer to 331.63 m^3/hr in soft layer. The results indicated that there was a direct relationship between rock share volume and delay times, therefore technical and personal delays in rocky layers were considerably more than other layers. Proportions of delays were 9% and 16% in soil and rocky layers, respectively. Also, production cost was 0.12 $/$m^3$, 0.27 $/$m^3$ and 1.13 $/$m^3$ in soil, medium, and rocky layers, respectively.

Keywords: Time study, Earthwork operation, Digging, Rock share, Hourly cost

1. Introduction

Forest roads serve as an undeniable tool in forest management from economic and environmental perspectives (Ezzati et al., 2011). However, the construction of forest roads due to the high sensitivity of the economic costs on one hand, and causing damage to nature and permanently changing the natural forest landscapes in the environmental viewpoint on the other hand has been in the center of public attention. Therefore, estimating the implementation time of road construction is of great importance in determining the process of road construction in order to reduce economic and environmental costs (Tan, 1992).

One of the most important factors influencing the operation cost of the project is earthwork, contributing up to 80% of the construction costs in the mountainous areas (Stuckelberger et al., 2006; Gumus et al., 2008; Contrares et al., 2012). Thus, estimating the volume of earthwork operations is necessary for managing the budget and the project as well as reducing the damage caused. In the meantime, machinery contribute a large share in the construction costs of projects (Moeini, 2004). Typically bulldozer machines and due to environmental concerns in recent years the excavator machines have been used for the construction of forest roads because of their considerable capabilities (Parsakho et al., 2009). Machinery production is influenced by many factors including machine characteristics (such as efficiency, weight and power), human resources (skilled driver, factors related to ergonomics), weather conditions, the characteristics of the area of interest (material type, slope) and finally environmental measures (compatibility of earthwork volume in the nature with predicted amount) respected to environmental sensitivities in recent years. The type of subsurface soil materials considerably impacts on the machine production (Abeli, 1993; Stuckelberger et al., 2006). For example, according to the FAO report, the progress of earthwork on the rocky areas can be significantly reduced in road construction projects compared to soil layers (Abeli, 1993). In addition to impacting on machine efficiency, the type of soil ingredients also psychologically influences on human

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workforce. The time management of projects and decreasing the time delay can play a major role in increasing the economic balance because management and hourly cost of machinery have the greatest share of earthwork cost (Orleans Department of Natural Resources of California, 2003). Poor information about subsurface can lead to technical problems and to cost overruns. Many studies have been carried out on the effect of the natural ground slope on the production of road construction machineries.

In a study, Abeli (1993) evaluated the costs and earthworks production of Caterpillar bulldozers (D4D and D6D models) and Ford-County tractors with a soil transport distance of 30 m, and found that production of these machines were 129 m^3, 41 m^3, and 28.1 m^3 per hour and the production costs of these machines were 0.49 \$/m^3, 0.79 \$/m^3 and 0.76 \$/m^3, respectively (Abeli, 1993). Parsakho et al. (2009) studied the economic performance of earthwork operations by Komatsu bulldozer (D60 model) on the slope classes of 30-50% and 50-70%. Their results showed no significant differences between the two slope classes in terms of the length of road path but hourly earthwork volume and volume per meter increased with increasing the slope (Parsakho et al., 2009).

In another research, Hoseinpour Asli et al. (2015) studied the price and production amount in forest road construction using a combination of excavator and bulldozer machines. Their findings indicate that the production rate was significantly higher in slope class of 50-70% compared to 10-30% and 30-50% while the production amount per meter per hour was the highest in slope class of 30-50% compared to other classes (Hossienpour Asli et al., 2015).

Although many studies have been carried out on the machinery performance in terms of slope and transport distance, there is not any case study based on impact of subsurface materials on the machinery cost and production rate in road construction. This research aimed to evaluate the effect of the hardness of subsurface materials from the perspective of digging on the earthworks productivity and cost, machinery economic performance as well as usual delays in the road construction process. To achieve this objective, instructions and standard development regulations of Planning and Budget Organization have been used.

2. Materials and Methods

2.1. Study Area

In order to study the effects of subsurface materials, this study was carried out in 1 km length of a proposed forest road in Babakoh forest, Gilan province which located on northern part of Iran (Hyrcanian Forests) (Figure 1). Based on geological characteristics, steep area and rocky outcrops, it was predicted that rocks contribute a large part of subsurface materials (Ghajar et al., 2012). Elevation range varies between 450 to 700 m above sea level and slope range in the region is 8-70%. All the trees in the roadway width corridor were cut and removed after logging, while few tree logs left in the area were moved by machinery used for excavation during construction. The average road platform width was 5.5 m while tree clearing width of the road was the average of 15 m which varies between 12 and 18 m depending on slope and soil types of the field conditions. According to data obtained from weather stations, the climate in the area is humid. Excavator and bulldozer machines were used in this project for road construction.

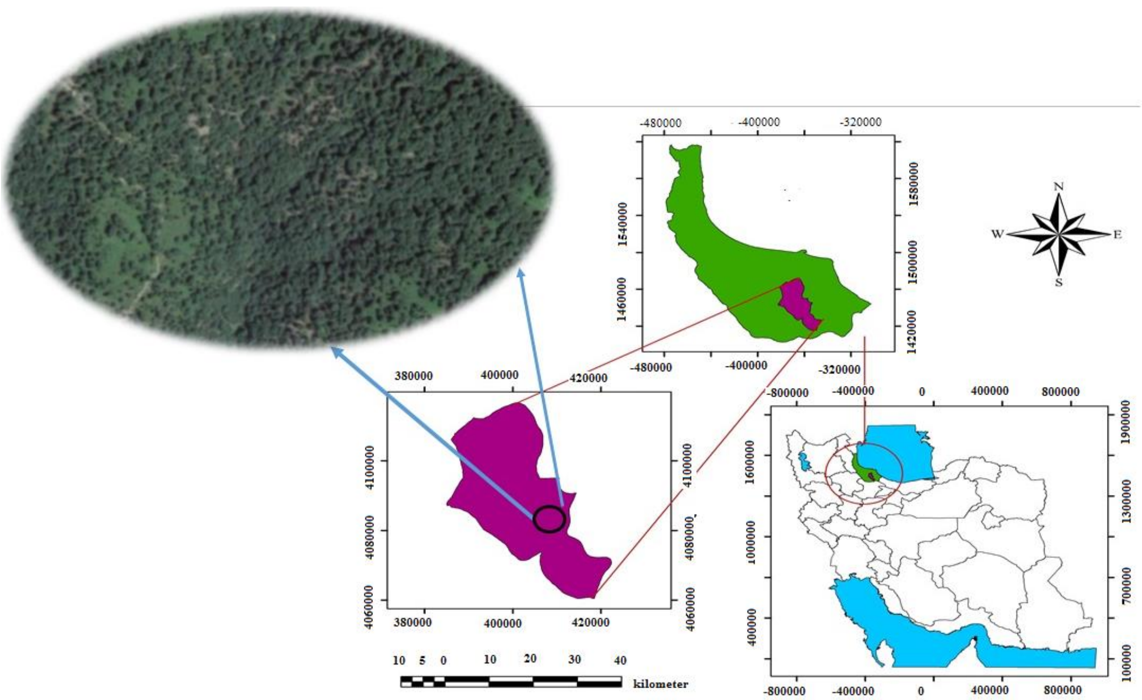

Figure 1. Location of study area in Hyrcanian forest

2.2. Method

In this project, Komatsu bulldozer (D65 Model) and Doosan excavator (DX230solar model) were used as seen in Figure 2, and additional information for both machines is provided in Table 1.

Figure 2. Road profile and construction machines A) Doosan excavator, B) hard rock trench, C) Komatsu bulldozer in soft (soil section) layer

Table 1. Purchase prices of the machinery and machine hours per year

	Excavator (Doosan DX230solar)	Bulldozer (Komatsu D65)
Total price of excavator ($)	128571	157142
Scheduled Machine Hours	2500	2500
Productive Machine Hours	1800	1800

Total time study of daily operations, which lasted for 15 discontinuous days, was carried out by a stopwatch with 0.1 second precision using continuous time study method. In any part of the process, in order to enhance the precision, photos were taken from the stopwatch in addition to recording the technical, administrative and personal delays. Scheduled daily time was calculated from sum of the delays and effective work by machines. Delay time that occur within the cycle and greater than 10 seconds were recorded. In order to determine the earthwork volume, cross-sections were measured at 20 m intervals along alignments and 10 m intervals on the curves. For initial classification of subsurface material, slope, geology, and rocky outcrop information were evaluated (Ghajar et al., 2012). Then, cross-sections were plotted before and after completing the operations. The cost of earthwork was calculated based on the basic unit prices of field road, railway and runway of Iran listed for the year of 2016. Time studies were designed based on the International Union of Forest Research Organizations (IUFRO) model. The elements of machine work cycle included warm up, movement from camp to study area, extracting remained trunk if any, earthwork activity (loading the bucket, swinging the loaded bucket, dumping the bucket, and swinging the empty bucket), mealtimes and delays, which were accurately recorded in each section. The starting point of excavation and embankment was recorded and then laser meter and clinometer was used for measuring dimensions in order to determine the excavation volume in each section. It should be noted that in areas with soil layer as subsurface materials, the hauling distance was up to 20 m, while there was no transport in rocky areas.

Average-end-area method was used to extract the earthwork volume in both excavation and embankment (Abeli, 1985; Akay, 2003, Aruga et al., 2007;). Equation 1 was used to compute the earthwork volume in both adjacent excavation and embankment areas.

$$V_{i,i+1} = 0.5(A_i + A_{i+1})L_{i,\,i+1} \tag{1}$$

where, $V_{i,i+1}$ is volume of soil (cut and fill) between the roads section i and the next section $i+1$ per m^3. A_i and A_{i+1} are cross-sectional end road section i and the next section i+1 in terms of square meters, and finally $L_{i,\,i+1}$ is the distance between i and the next section $i+1$ in terms of meter.

Then, by using the daily earthworks and productive daily working time, the earthwork production of Komatsu bulldozer (D65 model) and Doosan excavator (DX230 solar model) was calculated. The sum of hourly fixed cost, operating costs and labor costs were considered for estimating total hourly machine cost in this study (FAO, 1992). Fixed cost was computed by using following equation:

$$Fc = D + I + T \tag{2}$$

where, D is depreciation rate, I is hourly cost charge of interest on investment and T is insurance and tax cost. Hourly depreciation rate was calculated using Equation 3.

$$D = \frac{P - S}{N} \tag{3}$$

where P is the total cost of the initial investment (purchase price), S is Salvage Value and N is the economic life. It should be noted that 10% of the purchase price was commonly considered as salvage value for road construction machines (Jiroušek et al., 2007). Hourly cost of interest on investment was calculated using Equation 4:

$$I = AVA * i \tag{4}$$

In this equation, I is the interest rate of capital which was considered as 12%, AVA is annual value of average investment which was obtained from Equation 5 (Miyata, 1980):

$$AVA = \frac{(P - S)(N + 1)}{2N} + S \tag{5}$$

Insurance, tax and parking costs was calculated by using Equation 6:

$$T = (D + I) * 10\% \tag{6}$$

Since all equipment related to road construction in the station was kept along the road site, the contractor did not pay any fee for parking. Operation costs (variable cost), unlike fixed cost change in proportion to hours of operation or use. The hourly variable cost includes hourly costs of repairing and maintenance, fuel, filter, oil, grease and auto-parts (Miyata, 1980).

The repairing and maintenance costs were calculated by using Equation 7:

$$MR = D * F \tag{7}$$

where, D is the hourly cost of depreciation and F is a coefficient declared by the manufacturer company and, based on the suggested form by FAO, is equal to 1 for road construction machinery (Sarikhani, 2001). The other operation cost like fuels and replacement parts were obtained from the operator and inquired from the market (Table 2-5).

Table 2. Hourly costs of excavator (Doosan DX230solar) parts in 2016

	Function (year)	Number	Unit Price ($)	Hourly Cost ($)
Pin and teeth	1	4	71.43	0.114
Track shoe	10	80	1000	0.320
Roller	10	9	12.86	0.046

Table 3. Hourly costs of oils and filters of excavator (Doosan DX230solar) in 2016

	Function (hours)	Consumption	Unit Price ($)	Number of replacements per year	Hourly Cost ($)
Engine oil	60	Liters 20	4.29	28	0.960
Hydraulic oil	1500	200	414.29	2	0.331
Oil filter	120	1	12.86	16	0.082
Gasoline filter	350	2	12.86	14	0.072
Water filter	550	1number	17.14	4	0.274

Table 4. Hourly costs of bulldozer (Komatsu D65) parts in 2016

	Function (hours)	Number	Unit Price ($)	Hourly Cost ($)
Pin and Teeth	5	3	234.29	0.562
Track shoe bulldozer	5	80	200.00	1.280
Roller	5	9	185.71	1.337
Underneath blades	3	2	100.00	0.027
Side blades	3	2	560.00	0.149

Table 5. Hourly costs of oils and filters of bulldozer (Komatsu D65) in 2016

	Function (hours)	Consumption	Number of replacements per year	Unit Price ($)	Hourly Cost ($)
Engine oil	80	20 liters	30	37.14	0.891
Gearbox oil	800	200 liters	3	68.57	1.646
Hydraulic oil	1000	120 liters	2	10.00	0.960
Gear and roller waxine	1000	40	2	37.14	1.189
Filters	130	1	20	62.86	0.583
Grease	150	5 kilograms	17	1.14	0.389

Labor costs were derived from the sum of the costs related to operator and workers (Miyata, 1980). Since the residence location of operators and workers was close to their work place and guard camp, we can say that the contractor did not bear any cost for personnel movement. Other costs including fuel, oil and filter costs were obtained using the data provided by the operator and adjusting with market price. In addition to labor costs which are obtained from the costs related to operator and workers, also overhead costs were considered. Machine rate per hour for productive working time was obtained from the sum of fixed costs and variable costs. Also, machine rate per hour for scheduled work was obtained the sum of fixed and variable costs of scheduled hours. The total cost of the machine in productive and scheduled working hours was obtained from the total personnel costs plus machine rate per productive hour and total personnel costs plus a machine rate per scheduled hour. Finally, the production unit cost ($/m^3) was derived from the following equation:

$$Cost = System\ costs\ (\$/hr) / Productivity\ (m^3/hr) \tag{8}$$

Hourly cost of the machine parts and consumption materials for both machines of Doosan excavator (DX230solar model) in 2016 was obtained through inquiries from concerned companies adjusting the dollar price with currency. For classification of the subsurface materials in terms of digging, standardization instructions were used (Money and Hodgson, 1992). Based on hardness and the ability of digging in subsurface materials, these materials were classified in three classes of soft (soil), medium and hard (continuous rocks) layers. To determine which cross-section is placed in each material type, the estimations provided by experts and the classification based on the machinery performance in nature was used.

One-way analysis of variance (ANOVA) was used to determine significantly difference within the classes of subsurface material and production rate of machinery and delay time. Tukey multiple-comparison test (SPSS 16 software) was used in order to determine which groups are different (subsurface layer with different hardness). All statistical tests were done at the 95% confidence level (α=0.05). Also Pearson correlation analysis was used to check the correlation between production rate and subsurface classes.

3. Results

Result of time study showed that about 68% of the total time of earthwork operations in a 1 km route belonged to hydraulic excavator machine. Also the average scheduled time was 9.08 hours per day, of which, 7.5 hours per day is allocated to productive time. On average, 1.5 hour per day of the scheduled time was devoted to having lunch and the remaining time belonged to the delays occurred during the operation.

In soft classes in terms of digging, about 9% of the total operation time (0.88 hour/day) belonged to the delays. The administrative delays (tree movement on road width, machine work at the same time) were accounted for the highest percentage, while the technical delays contributed a little time in operations. In the second class in earthworks operation, delays were accounted for 10% (0.98 hours/day) of the total time. In these cross-sections, like the soft class, administrative and technical delays were accounted for the highest and lowest time delays, respectively.

In the rocky layer, working conditions was quite different from the two above-mentioned classes, that high proportion of delays in the total time is visible, and technical delays (such as technical problems of the machine) followed by personal delays (telephone conversation, rest, etc.) increased dramatically in this class which resulted in progressively increase in the machinery costs and consequently increased cost of the operation. These delays totally contribute to 16% of the operation time, accounting for 1.5 hour of the operation time on a daily basis. On the other hand, facing very hard layers causes failure of machine parts and the need for assistive devices such as hydraulic hammers caused a few day delays in carrying out the earthwork operations (Figure 3).

Altogether sample number were 19, 22 and 15 in soft (soil), medium and hard (rocky) layers, respectively. One-way analysis of variance (ANOVA) was used to identify significant differences between layers of subsurface material (three layers) in term of delay times. The result indicated significant deference in each delay times due to subsurface layers at the 95% confidence level ($\alpha = 0.05$) (Table 6).

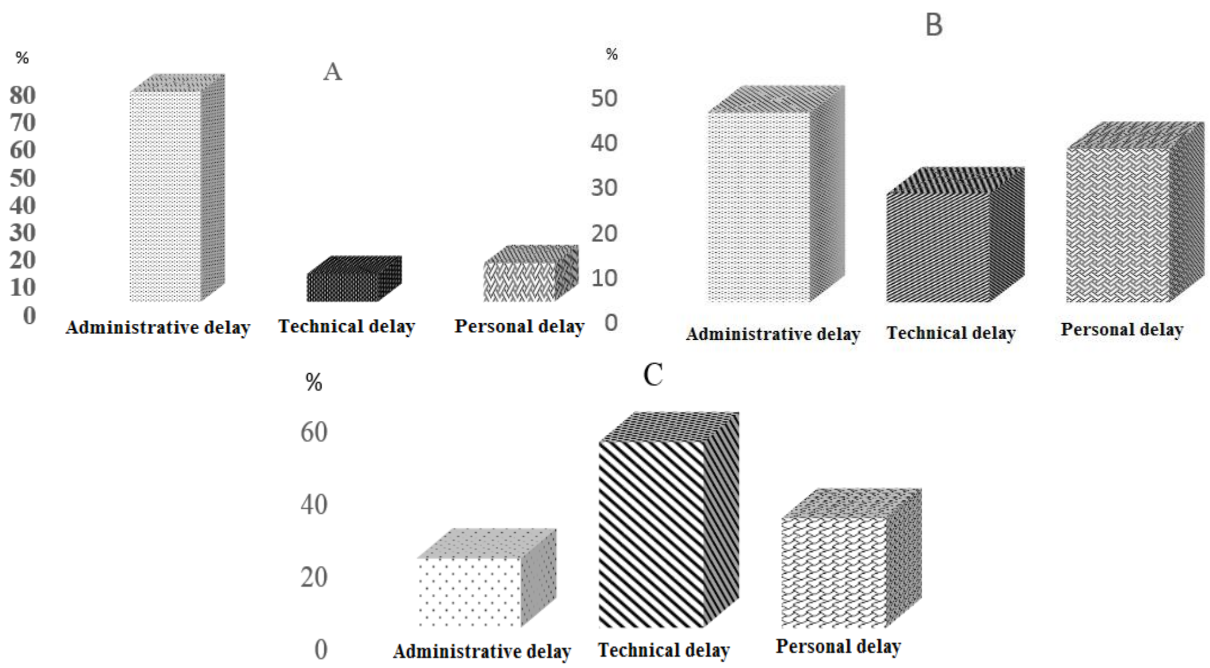

Figure 3. Diagram of working components with the excavator and bulldozer in different layers of subsurface A) share of triple delay time in soft layer B) share of triple delay time in medium layer C) share of triple delay time in hard layer

Table 6. One-way ANOVA for delay time in subsurface classes

		Sum of Squares	df	Mean Square	F	sig
Administrative delay	Between Groups	45470.677	2	22735.338	749.974	.000
	Within Groups	1606.686	53	30.315		
	Total	47077.362	55			
Technical delay	Between Groups	487746.087	2	243873.043	1.625E3	.000
	Within Groups	7953.748	53	150.071		
	Total	495699.835	55			
Personal delay	Between Groups	155682.970	2	77841.485	965.543	.000
	Within Groups	4272.828	53	80.69		
	Total	159955.798	55			

Results of the one-way ANOVA for earthwork production value in the various classes of subsurface showed highly significant differences (*p = 0.05*) between the production in different classes at confidence level of 95% (Table 9). Tukey's multiple-comparison test revealed significant difference among three layers of subsurface due to earthwork production. The value was 34.98 m^3 per hour in the hard layer, while the production value in soft layer was 9 times and 2 times higher than the hard and medium layer, respectively. According to the analyses, the daily volume of earthworks in soft layer was up to 10 times higher than the rocky one (Table 10).

The production cost is obtained from hourly production of the machines and the hourly cost of the system. The earthwork production costs of Doosan excavator track (DX230solar model) in scheduled working hours were 0.096 $/m^3, 0.22 $/m^3 and 0.90$/m^3 and in productive work hours were 0.11 $/m^3, 0.26 $/m^3 and 1.08 $/m^3 for soft, medium and hard layers, respectively. These values for Komatsu bulldozer (D65 model) were 0.09 $/m^3, 0.21 $/m^3 and 0.88 $/m^3 for scheduled working hours and 0.12 $/m^3, 0.28 $/m^3 and 1.18 $/m^3 per hours for productive work in the above-mentioned classes, respectively. Pearson correlation coefficients were carried out to show the relationship between earthwork production and rock share in subsurface. The result indicated that production rate is significantly (negative relationship) correlated (Pearson correlation coefficient = 0.484, df = 55, p = 0.00) with subsurface soil type.

Table 9. One-way ANOVA for machines productions (m^3/hr) in subsurface classes

		Sum of Squares	df	Mean Square	F	sig
Machines productions	Between Groups	741232.370	2	370616.185	387.948	.000
	Within Groups	50632.184	53	955.324		
	Total	791864.554	55			

Table 10. Production cost of earthwork machines for various layers

	Working days	Daily earthworks volume (m^3)	Value of productions (m/hr)	Value of productions (m^3/hr)	Production cost in Scheduled time ($/$m^3$)	Production cost in Productive time ($/$m^3$)
Soft layer	2	3250	40.50a	331.63a	.09	0.12
Medium layer	6	1416.66	16.31b	144.55b	0.21	0.27
Hard layer	7	342.87	7.1c	34.98c	0.89	1.13

-Mean within the table followed by the same script are not significantly as determined by Tukeys test at 5% level

4. Discussion

Selecting the machinery type is a function of slope and geological properties and environmental conditions of the region. In our study area, due to rocky subsurface materials and steep slopes, excavator machine has played the highest contribution of earthwork operations. Based on a field survey, the efficiency of excavator machine is much higher than bulldozer because of its higher maneuverability and the multi-functionality perations such as root out, crushing the rocks, its excavation and embankment ability. But it should be noted that as an assistive machine, bulldozer can be efficient and economic tool along with excavator because it can perform longitudinal leveling operations better in soil layer with lower slope.

The results of this study showed that the subsurface soil type plays a significant role in the earthwork operation cost in road construction, so that the time of earthwork operations in one of the rocky section was 70 times higher than the soil section with the same length. The mean of earthwork production in soft layer was 331.63 m^3/h and it was 34.98 m^3/h in hard layer. This finding show that the main factor affects the excavation cost was the ground classes. Although the other parameter like slope condition in rocky area can affect the production rate of machinery, the impact of the slope is not tangible as stated by the previous studies as well. For example, Hoseinpour Asli et al. (2015) found that production amounts of hydraulic excavator and bulldozer in the slope classes of 10-30, 30-50 and 50-70 percent were 71.23 m^3/hr, 61.49 m^3/hr, and 87.18 m^3/hr and 13.31 m^3/hr, 20.87 m^3/hr and 12.28 m^3/hr, respectively.

Also, results showed that the material type has a direct impact on the amount of delay time. For example, in rocky hard section, personal delays were much higher than the profiles with clay materials. The reason can be attributed to the psychological activities and ergonomics. Because of the slow progress in hard layers, the machine operator becomes mentally and physically bored and therefore spends more time to personal delays, such as smoking and drinking tea. However, technical delays in rocky profiles was much higher than others areas where conditions are more favorable in terms of digging. Abeli (1993) also found a direct relationship between the decrease in the three delays, especially unnecessary delays, with monitoring and favorable working conditions in the road construction. So that in favorable working conditions, the machinery production will increase significantly. However, the technical problems were directly related to the soil subsurface type, as the technical delays in the hard layers were several times higher compared to soil layers. In fact, it suggests that hard materials such as rocks caused technical problems and disorder in the earthwork operations in the project, and stock (scrapped) machinery caused unfavorable conditions which resulted in long-term interruption in the operation process because of technical problems. One of the factors causing serious technical problems during excavation operations can be attributed to the high productive lifetime of machinery in Iran, though it may somewhat reduce the capital cost, it will increase the total system cost because of increased technical defects, problems during operations, and causing the long-term interruptions (such as delays in rock drilling in this study). Administrative delay in soft layer compare to other delays was slightly higher. The reason for this can be interpreted due to constant administrative delay in all classes, while other delays are inconstant. Many related problems can be avoided by improving the quality of machinery and skilled personnel. Another point is the high contribution of personal delays in the rocky classes which caused long delays in the daily work. In this regard, better monitoring and applying assistive forces can greatly reduce the time of personal delays. Parsakho et al. (2009) reported that the delay times contribute 25% of the total time and assessment of earthwork production on different slopes showed that the volume of earthwork operations and consequently production (m^3) was the highest in slope class of 50-70% due to the high vertical distance of the slope with project line (Parsakho et al., 2009).

The results show that earthwork production rate is direct correlated with subsurface soil type, this can be attributed to exponential increase in the three related delays in addition to the hard working conditions. The role of bedrock and soil mechanical properties in the earthwork production by machinery have been demonstrated (Abeli, 1985). Earthwork production of excavator machine on a terrain with silt-textured soil and a slope of 55% was 86 m^3 per hour while on an area with clay-textured soil and a slope of 50% was 123 m^3 (Cabezas, 1994). There is usually difference between the quantity (volume) and quality (type of subsurface material) of the estimated excavation before the construction and the actual excavation after road construction. To minimize the differences, advanced calculation techniques implementing computer-based methods can be employed.

5. Conclusions

Time and cost planning of forest road construction project is critical task in forest management. The aim of this research was time study, measuring cost and productivity of excavator machines and delay times due to subsurface material in term of digging that classified in three layers included soft, medium and hard. The results indicate that in addition to the earthwork volume, subsoil type has a great influence on the progress of earthwork operation, the delay is also increased by increasing the rock share. Due to high impact of subsurface material in excavation we can say a reliable estimation of rock share in subsurface before road design lead to easier road path whit lower cost. One of the important issues that must be considered during road design is dimensions and size of rock share in subsurface, since it was not possible to stop the machines and accurately calculate the soil type during the operation we approximately estimated the rock dimensions. Thus, it can be suggested that remote sensing methods should be used to obtain remotely sensed data in future research.

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