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An Assessment of Nominal and Actual Hourly Production of the Construction Equipment Based on Several Earth-Fill Dam Projects in Iran

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Abstract: Optimum planning for heavy construction equipment is a vital task in succeeding the construction projects. In a construction plan one should significantly concentrate on the type, number and schedule of presence of the equipment at the project site. In this paper, we have studied the hourly production of a model of dozer, a wheel-type loader, a crawler-type loader, a grader, a crawler-type excavator, a sheepsfoot roller and a smooth wheel roller, at the site of several earth-fill dams around Iran. Each model was individually considered and the site conditions were taken into account. The nominal hourly production of the equipment was derived according to the data obtained from Caterpillar, Komatsu, and Volvo manufacturers. The actual production was calculated according to the statistical data from various earth-fill dams in Iran. The derived results showed that the actual production of a sheepsfoot roller had the least difference with its nominal production; whilst the loader had the most difference in actual and nominal production (i.e. it had the lowest working efficiency).

Key Words: Construction equipment, Nominal hourly production, Actual hourly production, Earth-fill dam projects.

1. INTRODUCTION

It has been universally accepted that the equipment hourly production is one of the key factors in construction projects. It is also well known that the actual hourly production of the equipment differs from the nominal hourly production provided by the manufacturers. Increasing the actual hourly production has always been an ideal aim in achieving success throughout large scale earthmoving construction projects. Estimating this parameter is a key element in estimating the time and cost required to terminate the construction operations (Oglesby *et al*. 1989 [1]). The accurate estimation of earthmoving hourly production has intrigued many researchers for many years (Alkass and Harris 1988 [2]; Amirkhanian and Baker 1992 [3]; Karshenas and Feng 1992 [4]; Smith 1999 [5]), and yet there is no robust model for prediction of the hourly production of earthmoving activities at the construction site (Seung and Sunil, 2006 [6]). Apparently, each manufacturer provides the users with an ideal hourly production plan, according to the equipment's specifications. It should be taken into account that the actual production at the site is different from the nominal production given by the manufacturer and depends mainly on the condition of the site. Thus, determining the actual production will make considerable help in gaining a more suitable planning for the construction equipment which would, in turn, lead to a more accurate planning throughout the project. Edmonds *et al.* (1994) [7] have taken actual production into account. They viewed the actual production as a percentage of full capacity, which provided a better measurement of the actual hourly production. In their research, the actual production of the equipment has been estimated as approximately 52.5 percent of the nominal production. They used several methods such as the short range analysis, analysis of running time and analysis of running speed. The richness of analysis was said to be reduced when traditional techniques are used. In 2002, Bhurisith and Touran [8] studied the equipment production in a certain period of time, according to the equipment models. In this paper a comparison has been made between nominal hourly production and unit cost results obtained through different years and average rage of change are calculated. Their investigation was based on six equipment models, studied through a fifteen year period. In 2006, Zou [9] studied the effect of site conditions on equipment production using the HSV Color Space Digital Image Processing method. He tried to achieve more realistic results using the mentioned method.

2. OBJECTIVE

The main objective of this paper is to determine the actual production of different construction equipment according to their power. This information could certainly be useful in planning equipment and is a great help to the project management team.

3. METHODOLOGY

3.1. Definitions

- Nominal production: the production given by the manufacturer, which recognizes an ideal production while the equipment is operated on a continuous basis.
- Actual production: the production of the equipment at the site and is, obviously, less than the nominal production. Thus, the more efficient it is estimated, the better result would be obtained from managing the project.

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3.2. Equipment Selection

The choice of equipment in our study is limited to three manufacturers, namely, Caterpillar, Komatsu and Volvo. Caterpillar is believed to control more than 45% of the U.S. construction equipment market and 35% of the world market (Arditi *et al*. 1997 [10]). Since these manufacturers are amongst the most creditable heavy construction equipment suppliers all over the world, the obtained results could be applicable for the whole heavy equipment industry. The equipment studied here, has been chosen according to their application in earth-fill dams. For instance, Volvo loaders are used in most of the dam projects.

3.3. Data Sources

The data for the nominal hourly production was estimated using the performance handbooks and construction charts. The data for the actual production analysis was collected from various earth-fill dams constructed around Iran. The location of the dams being investigated has been shown in Fig. (**1**). Fig. (**2**) presents the distribution of rainfall in the investigated projects. Although the dams are located in areas containing similar soil and climate condition but the annual rainfall has a significant effect on the equipment efficiency. However, concerning the small difference in the annual rainfall (less than 10%), this parameter has been neglected in our calculations. The actual production for seven various types of heavy equipment which played the main role in dam construction, was estimated according to the site conditions.

Fig. (1). Project locations.

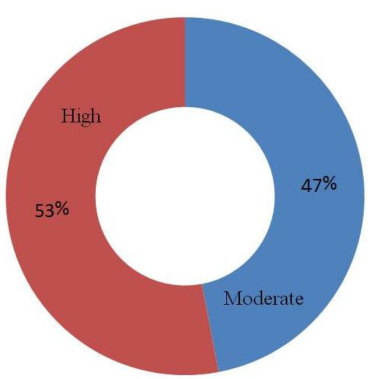

Fig. (2). Distribution of rainfall.

3.4. Production Estimation

The actual construction conditions at various project sites differ according to the climate, the soil type, equipment age and the driver's workmanship. The equipment were divided into four groups based on their ages. Fig. (**3**) presents the distribution of four age groups. As shown in the Fig. (**4**), the majority of the driver (62%) had more than ten years construction working experience.

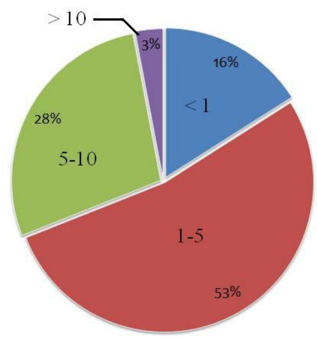

Fig. (3). Distribution of age group of equipment (years).

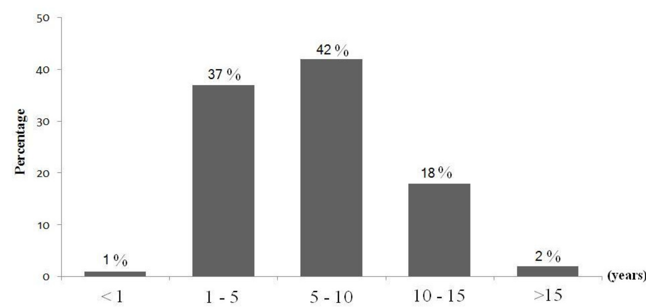

Fig. (4). Distribution of years working experience of drivers.

3.5. Data Analysis

In our study, the actual production of the equipment was derived according to the following Analysis.

3.5.1. Long-Range Analysis

The more the equipment and work conditions are considered, the better result are achieved. Thus, the analysis of the falls in nominal hourly production may contribute to a more effective management of machine efficiency. Long range analysis is a reliable method for this purpose. In this analysis, the actual hourly production of equipment at the site project is obtained and the effective factors causing the shortfall are considered. For example, the running speed and accordingly, running time of the equipment may cause a significant difference between actual and nominal productions. There are several elements preventing full capacity construction. These non-productive time elements include setup time, scheduled maintenance and operation disengagement (e.g. meals and breaks.) At this level, the equipment models were classified according to their power (hp). For example, for a wheel-type loader with a power of 260 hp, 3 various models were studied. The model 972G from Caterpillar, the model WA450-3MC from Komatsu, and the model L150F from Volvo, all having a power of 260 hp were chosen; their nominal hourly production and actual production at the site were estimated.

3.5.2. Ratio Analysis

In order to verify the actual production in accordance to time duration a ratio analysis is also required, so that one should obtain approximately the same ratio for the given hourly production.

$$\frac{2\ \ hour\ \ production}{2} \approx \frac{1\ \ hour\ \ production}{1} \approx \frac{half\ \ hour\ \ production}{1/2}$$

3.5.3. Variance Analysis

Analysis of variance is an effective tool for analyzing pure experimental data (e.g. industrial experiments in which multiple factors may be altered at different times and in different locations). This analysis for a model with limited variable is as follow:

1. The expected value of the collected data is calculated. This value, E(x), is given by:

$$E(x) = (x_1 + x_2 + ... + x_n)/n$$

2. The variance is calculated according to:

$$Var(x) = E[(x - E(x))^2]$$

3. The standard deviation, $\sigma(x)$, is calculated:

$$\sigma(x) = \sqrt{Var(x)}$$

The value analysis carried out on the data is shown in the Table **1**. In the first step, the standard deviation is compared with the expected value as well as comparing the expected value to the initial data, resulting in the omission of four of the values achieved. Thus the expected value is taken as the actual hourly production value.

4. RESULTS

By applying the above mentioned methodology the obtained results are given in the following Tables for various equipment models. The actual production for a grader, a smooth wheel roller, a sheep-foot roller, a dozer, a wheel-type loader, a crawler-type loader, and for a crawler type excavator are given in Tables **2**, **3**, **4**, **5**, **6**, **7** and **8**, respectively.

The actual production given in the above Tables is based on an efficiency factor of 100%. In the Tables below [**9-12**] some different working conditions were considered. The Tables are organized using performance handbooks and standard construction equipment books given in the references [1, 7, 11-14]. Depending on the project conditions, it is reasonable to apply these coefficients, in order to achieve more realistic results. Namely, the actual production of a dozer with an engine horsepower of 150hp, a bucket capacity of 2 cubic meters, haul distance of 15 meters with +10 ground slope, working in medium conditions containing blaster rock is as following:

150 (m^3/hr) × 0.75 × 0.5 × 0.86 = 48 (m^3/hr)

5. CONCLUSION

This paper has explored the actual hourly production of seven different pieces of earthmoving equipment of earth-fill dam projects in Iran by using a three-stage statistical analysis. The actual hourly production of the equipment can effectively contribute to the management of the construction projects. A sheepsfoot roller shows the lowest efficiency with an actual to nominal hourly production ratio of 0.32 whilst the wheel loader shows the highest efficiency with a ratio of 0.6. A loader shows the lowest shortfall, with a constant actual to nominal hourly production ratio of 0.6 for various engine horse powers, whereas the highest range of variation of 0.5 is observed for a dozer.

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Table 1. Actual Hourly Production Data A Wheel-Type Loader with A Power of 260 hp

(*a*) first analysis

Actual Hourly Production Data										E(x)	Var(x)	$\sigma(x)$
257	264	286	235	267	276	281	277	279	268	267.55	276.23	16.62
245	287	285	276	231	263	243	279	280	272			

(*b*) second analysis

Actual Hourly Production Data										E(x)	Var(x)	$\sigma(x)$
257	264	286	[redacted]	267	281	276	287	279	268	274.81	73.44	8.57
[redacted]	277	285	276	[redacted]	263	[redacted]	279	280	272			

Table 2. Grader Hourly Production

Engine Horsepower (hp)	Blade Length (m)	Blade Height (m)	Nominal Work Hourly Production (m^3/hr)	Actual Work Hourly Production (m^3/hr)
125	3.66	0.61	355	241
135	3.66	0.61	383	301
150	3.96	0.70	427	301
180	3.66	0.61	512	337
200	4.27	0.686	569	361
275	4.88	0.79	1145	663

Table 3. Smooth Wheel Roller Hourly Production

Engine Horsepower (hp)	Operational Weight	Gradeability	Working Conditions	Nominal Work Hourly Production (m^3/hr)	Actual Work Hourly Production (m^3/hr)
77	4000~4500	49%	4 Cycles, Layer thickness of 150 mm	180	85
102	6000~6500	30%	4 Cycles, Layer thickness of 150 mm	230	100
102	6500~6800	50%	4 Cycles, Layer thickness of 150 mm	250	100
155	10000~10500	33%	4 Cycles, Layer thickness of 150 mm	300	115
155	10500~11000	45%	4 Cycles, Layer thickness of 150 mm	310	145
155	10500~11000	45%	4 Cycles, Layer thickness of 200 mm	330	155

Table 4. Sheep-Foot Roller Hourly Production

Engine Horsepower (hp)	Operational Weight	Grade Ability	Working Conditions	Nominal Work Hourly Production (m^3/hr)	Actual Work Hourly Production (m^3/hr)
77	4000~4500	49%	4 Cycles, Layer thickness of 150 mm	180	70
102	6300~6800	50%	4 Cycles, Layer thickness of 150 mm	250	80
134	12000~12500	47%	4 Cycles, Layer thickness of 150 mm	320	110
155	18000~19000	47%	4 Cycles, Layer thickness of 200 mm	330	145

Table 5. Dozer Hourly Production

Engine Horsepower (hp)	Bucket Capacity (m^3)	Working Condition	Haul Distance	Nominal Work Hourly Production (m^3/hr)	Actual Work Hourly Production (m^3/hr)
105	2	Common Earth, 0° Slope	15	250	150
			30	150	80
			75	70	35
124	2.21~2.66	Common Earth, 0° Slope	15	330	180
			30	210	100
			45	150	70
130	2.7	Common Earth, 0° Slope	15	375	220
			30	245	125
			75	110	60
165	3.5~3.89	Common Earth, 0° Slope	15	500	260
			30	320	145
			45	220	107
225	5.2~8.34	Common Earth, 0° Slope	15	680	400
			30	425	255
			45	350	160
285	10.98	Common Earth, 0° Slope	15	1200	720
			45	540	297
			135	180	100
302	8.8	Common Earth, 0° Slope	15	1000	850
			30	630	470
			75	280	195
370	14.4	Common Earth, 0° Slope	15	1400	1100
			45	700	420
			150	250	80
410	15.1	Common Earth, 0° Slope	15	1480	1150
			30	910	650
			75	440	250
525	18.5~20.9	Common Earth, 0° Slope	15	1820	1300
			30	1150	730
			45	950	485
770	25.6~32.4	Common Earth, 0° Slope	30	1830	1300
			45	1430	1100
			135	500	300
1050	45	Common Earth, 0° Slope	30	2300	1500
			75	1080	563
			135	640	355

Table 6. Wheel-Type Loader Hourly Production

Engine Horsepower (hp)	Bucket Capacity (m^3)	Working Condition	Nominal Work Hourly Production (m^3/hr)	Actual Work Hourly Production (m^3/hr)
85	1.2~1.4 General Purpose	Loose soil, Average Cycle Time 0.45 min	160	100
110	1.7 General Purpose	Loose soil, Average Cycle Time 0.45 min	225	135
130	2.1 General Purpose	Loose soil, Average Cycle Time 0.45 min	260	150
163	2.5 General Purpose	Loose soil, Average Cycle Time 0.45 min	300	175
187	3.1 General Purpose	Loose soil, Average Cycle Time 0.45 min	350	215
217	3.1~ 3.7 General Purpose	Loose soil, Average Cycle Time 0.45 min	380	225
260	4.2 General Purpose	Loose soil, Average Cycle Time 0.45 min	450	275
315	5 General Purpose	Loose soil, Average Cycle Time 0.45 min	500	290
375	6 General Purpose	Loose soil, Average Cycle Time 0.45 min	630	350
415	5.7 Excavating Bucket	Loose soil, Average Cycle Time 0.50 min	680	410
640	9.2 General Purpose	Loose soil, Average Cycle Time 0.50 min	960	585
789	10.5 Excavating Bucket	Loose soil, Average Cycle Time 0.50 min	1210	735
828	13 Excavating Bucket	Loose soil, Average Cycle Time 0.50 min	1320	795

Table 7. Crawler-Type Loader Hourly Production

Engine Horsepower (hp)	Bucket Capacity (m^3)	Working Condition	Nominal Work Hourly Production (m^3/hr)	Actual Work Hourly Production (m^3/hr)
67	0.8 General Purpose	Uniform Aggregate, Bucket fill Factor 0.95 Haul Distance 10 m	60	40
67	0.8 General Purpose	Uniform Aggregate, Bucket fill Factor 0.95 Haul Distance 20 m	39	22
78	1 General Purpose	Uniform Aggregate, Bucket fill Factor 0.95 Haul Distance 10 m	86	45
78	1 General Purpose	Uniform Aggregate, Bucket fill Factor 0.95 Haul Distance 20 m	54	30
110	1.15 General Purpose	Uniform Aggregate, Bucket fill Factor 0.95 Haul Distance 10 m	186	101
110	1.15 General Purpose	Uniform Aggregate, Bucket fill Factor 0.95 Haul Distance 20 m	156	98
150	2 General Purpose	Uniform Aggregate, Bucket fill Factor 0.95 Haul Distance 10 m	247	152
150	2 General Purpose	Uniform Aggregate, Bucket fill Factor 0.95 Haul Distance 20 m	205	115
210	2.8 General Purpose	Uniform Aggregate, Bucket fill Factor 0.95 Haul Distance 10 m	347	217
210	2.8 General Purpose	Uniform Aggregate, Bucket fill Factor 0.95 Haul Distance 20 m	285	173

Table 8. Crawler-Type Excavator Hourly Production

Engine Horsepower (hp)	Bucket Capacity (m^3)	Working Conditions	Maximum Loading Height (m)	Maximum Digging Depth (m)	Nominal Work Hourly Production (m^3/hr)	Actual Work Hourly Production (m^3/hr)
54	0.24 (0.14-0.34)	Loose Soil, Dumping Near Excavation Site Rotation Angle 30° Bucket Fill Factor 100%	4.66	4.11	66	23
54	0.24 (0.14-0.34)	Medium Soil, Dumping Near Excavation Site Rotation Angle 60° to 90° Bucket Fill Factor 85%	4.66	4.11	43	17
54	0.24 (0.14-0.34)	Dense Soil, Dumping Near Excavation Site Rotation Angle more than 120° Bucket Fill Factor 60%	4.66	4.11	25	11
79	0.42 (0.22-0.63)	Loose Soil, Dumping Near Excavation Site Rotation Angle 30° Bucket Fill Factor 100%	6.6	5.44	113	35
79	0.42 (0.22-0.63)	Medium Soil, Dumping Near Excavation Site Rotation Angle 60° to 90° Bucket Fill Factor 85%	6.6	5.44	74	23
79	0.42 (0.22-0.63)	Dense Soil, Dumping Near Excavation Site Rotation Angle more than 120° Bucket Fill Factor 60%	6.6	5.44	43	20
118	0.88 (0.67-1.1)	Loose Soil, Dumping Near Excavation Site Rotation Angle 30° Bucket Fill Factor 100%	6.69	6.71	211	65
118	0.88 (0.67-1.1)	Medium Soil, Dumping Near Excavation Site Rotation Angle 60° to 90° Bucket Fill Factor 85%	6.69	6.71	134	50
118	0.88 (0.67-1.1)	Dense Soil, Dumping Near Excavation Site Rotation Angle more than 120° Bucket Fill Factor 60%	6.69	6.71	77	33
148	1.01 (0.58-1.44)	Loose Soil, Dumping Near Excavation Site Rotation Angle 30° Bucket Fill Factor 100%	6.78	7.41	227	110
148	1.01 (0.58-1.44)	Medium Soil, Dumping Near Excavation Site Rotation Angle 60° to 90° Bucket Fill Factor 85%	6.78	7.41	150	82
148	1.01 (0.58-1.44)	Dense Soil, Dumping Near Excavation Site Rotation Angle more than 120° Bucket Fill Factor 60%	6.78	7.41	77	45

Table 8 contd….

Engine Horsepower (hp)	Bucket Capacity (m^3)	Working Conditions	Maximum Loading Height (m)	Maximum Digging Depth (m)	Nominal Work Hourly Production (m^3/hr)	Actual Work Hourly Production (m^3/hr)
206	1.29 (0.76-1.82)	Loose Soil, Dumping Near Excavation Site Rotation Angle 30° Bucket Fill Factor 100%	7.27	8.33	273	88
206	1.29 (0.76-1.82)	Medium Soil, Dumping Near Excavation Site Rotation Angle 60° to 90° Bucket Fill Factor 85%	7.27	8.33	175	60
206	1.29 (0.76-1.82)	Dense Soil, Dumping Near Excavation Site Rotation Angle more than 120° Bucket Fill Factor 60%	7.27	8.33	99	40
276	1.75 (1.15-2.35)	Loose Soil, Dumping Near Excavation Site Rotation Angle 30° Bucket Fill Factor 100%	8.05	9.24	331	105
276	1.75 (1.15-2.35)	Medium Soil, Dumping Near Excavation Site Rotation Angle 60° to 90° Bucket Fill Factor 85%	8.05	9.24	220	85
276	1.75 (1.15-2.35)	Dense Soil, Dumping Near Excavation Site Rotation Angle more than 120° Bucket Fill Factor 60%	8.05	9.24	119	53
375	2.45 (1.85-3)	Loose Soil, Dumping Near Excavation Site Rotation Angle 30° Bucket Fill Factor 100%	8.36	8.8	438	147
375	2.45 (1.85-3)	Medium Soil, Dumping Near Excavation Site Rotation Angle 60° to 90° Bucket Fill Factor 85%	8.36	8.8	280	113
375	2.45 (1.85-3)	Dense Soil, Dumping Near Excavation Site Rotation Angle more than 120° Bucket Fill Factor 60%	8.36	8.8	150	603

Table 9. Correction Factor for Working Conditions of All Equipment Types

Working Condition	Factor
Good (50min per hour)	0.83
Medium (45min per hour)	0.75
Weak (40min per hour)	0.67
Very weak (35min per hour)	0.58

Table 10. Material Correction Factor for A Dozer

Type of Material	Factor
Loose soil	0.9-1.1
Soil containig rubble stone, fine rock aggregate	0.7-0.9
Cohesive clay, Hard ground	0.6-0.7
Blaster rock, Large rock slab	0.4-0.6

Table 11. Ground Slope Correction Factor for A Dozer

Ground Slope	Factor
15	0.77
10	0.86
5	0.94
0	1.00
-5	1.08
-10	1.14
-15	1.20

Table 12. Bucket Fill Factor for A Loader

Type of Material	Bucket Fill Factor
Moist loam	1.00
Moist mixed loam	0.95
Uniform aggregate	0.95
3mm-9mm	0.90
12mm-20mm	0.85
24 and over	0.80
Bluster rock	0.70

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