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An assessment of nominal and actual hourly production of crawler-type front shovel in construction project

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Abstract

The hourly production of machinery is generally one of the key factors in construction projects. In a construction plan, one should significantly concentrate on the type, number and schedule of presence of the machinery at the project site. This paper presents the hourly production of a model of a crawler-type front shovel at the site of several earth-fill dams in Iran. The data obtained from Caterpillar, Komatsu, and Hitachi manufacturers derive the nominal hourly production of the machine. The actual hourly production was calculated according to the statistical data from various earth-fill dams around Iran. The derived results showed that the crawler-type front shovel has a considerable difference in actual and nominal hourly production.

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Keywords: Construction Machinery; Crawler-type Front Shovel; Nominal Hourly Production; Actual Hourly Production; Earth-Fill Dam Projects

1. Introduction

Optimum planning for heavy construction machinery is a vital task in succeeding the construction projects. Manufacturers provide an ideal hourly production of their own machinery to users, according to the machinery's specifications. The nominal production provided by manufacturers is obviously different from the actual production of the machinery at the project sites. The actual production depends mainly on the condition of project sites. Estimating the actual hourly production is a key element in estimating the time and cost required to terminate the construction projects (Oglesby *et al*., 2005) and can yield substantial savings in both time and cost. Determining the actual production can make considerable help in gaining a more suitable planning for the fleet of construction machinery which would, in turn, lead to a more accurate planning throughout the project. Accordingly, increasing this parameter has always been an important aim in achieving success throughout large scale construction projects (Nabizadeh Rafsanjani *et al*., 2009).

Construction literatures have proposed some methods used for the accurate estimation of machinery hourly production in earth-moving operations (Alkass and Harris, 1989; Amirkhanian and Baker, 1992; Karshenas and Feng, 1992). However, Maximum actual hourly production is rarely reached (Smith, 1999). Edmonds *et al.* (1994) took actual production of machinery into account and proposed the actual production as a percentage of full capacity by using several methods such as running time and running speed analyses. The actual production of construction machinery, on the basis of their results, has been estimated as 52.5% of the nominal production.

Bhurisith and Touran (2002) studied the production of machinery in certain a fifteen year period, according to the machinery models. Their investigation was based on six machinery models. They calculated average rage of nominal hourly production and unit cost of machinery. However, they did not consider the actual production of machinery.

In 2006, Zou (2006) applied the HSV Color Space Digital Image Processing method to study the effect of site conditions on the actual machinery production. He provided no data of actual hourly production. Recently on the basis of previous researches, Nabizadeh Rafsanjani *et al.* (2009) 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 in Iran. In their research, they used several methods such as the long range analysis and ratio analysis. The actual production of a sheepsfoot roller showed had the least difference with its nominal production; while the loader had the most difference in actual and nominal production.

Apparently, over the past 20 years, literatures have written little information to advance the theoretical basis for actual machinery production estimation and hence estimates of machinery actual production are relatively rare. In this study, some procedures, observations and analyses develop a new actual hourly production estimation of crawler-type front shovel according to its power. Crawler-type front shovels use for hard digging and loading haul units in construction projects. None of the Current approaches for determining actual production of machinery provides accurate data of the crawler-type front shovel. The actual data is certainly useful in planning machinery and is a great help to the project management team.

2. Methodology

2.1. Machinery Selection

In this study, the choice of crawler-type front shovel is limited to three manufacturers, namely, Caterpillar, Komatsu and Hitachi. Models of crawler-type front shovel of Caterpillar, Komatsu and Hitachi dominates in most earth-fill dam projects. Caterpillar is believed to control more than 45% of the U.S. construction machinery market and 35% of the world market (Arditi *et al*., 1997). In the term of engine, the models of the three manufacturers usually used in earthmoving operation of earth-fill dams have the same power. Accordingly, these manufacturers are amongst the most creditable crawler-type front shovel suppliers all over the world and then the obtained results could be applicable for the whole models of crawler-type front shovel.

2.2 Data Sources

Using the performance handbooks, manufacturer catalogues and construction charts estimates the data of the nominal hourly production. The data of the actual production analysis was collected from various earth-fill dams constructed around Iran. The time duration for gathering data was 2 years. Fig. 1 shows locations of the dams. In the locations, 10 earth-fill dames are investigated. In these dames, the actual hourly production for nearly 20 number of crawler-type front shovel are assessed.

Fig.1. Project Locations (Stars show the provinces in which dams are located)

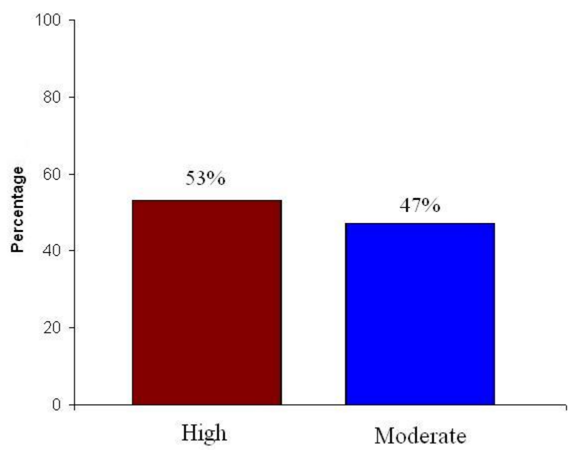


Fig. 2. Distribution of rainfall

The dams locate in mountainous areas containing similar soil and climate condition. The annual rainfall has a significant effect on the machine efficiency.

Fig. 2 presents the distribution of rainfall in the investigated projects. The investigated mountainous areas have the maximum daily rainfall of 35 mm. However, concerning the small difference in the annual rainfall (less than 7%), this small difference has been neglected in calculations.

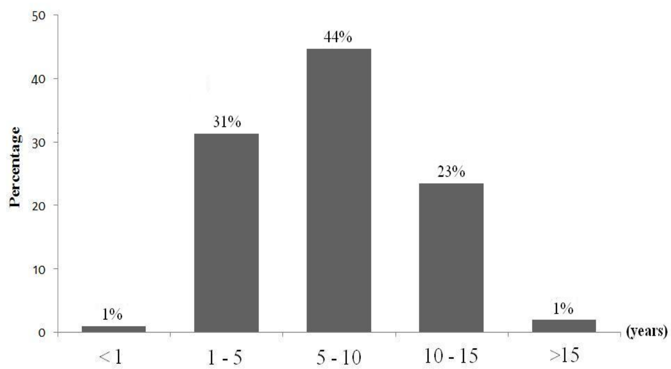


Fig. 3. Distribution of years working experience of drivers

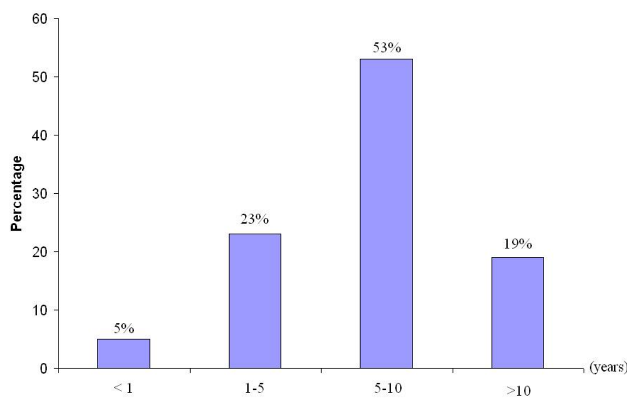


Fig. 4. Distribution of age group of crawler-type front shovel models (years)

The actual production for crawler-type front shovel was estimated according to the site conditions. The construction conditions of various project sites differ according to the climate, the soil type, driver's workmanship and the machinery age. The majority of the driver (68%) had more than five years of construction working experience (Fig. 3).

The crawler-type front shovel models were also divided into four groups based on their ages. Fig. 4 presents the distribution of four age groups. Furthermore, the working hours of crawler-type front shovel models was about 10 hours (8 am 6 pm). Accordingly, none of crawler-type front shovel worked in night.

2.3 Data Analysis

This study derives the actual hourly production of a crawler-type front shovel according to the following analyses:

2.3.1 *Long-Range Analysis*

The more machinery and work conditions are considered, the better results are achieved. The analysis of the falls in actual hourly production may contribute to more effective information of machinery efficiency.

Long range analysis is a reliable method for this purpose. This analysis obtains the actual hourly production of crawler-type front shovel at the different project sites and considers the effective factors causing the shortfall. For example, the running speed and accordingly, running time of the machinery causes a significant difference between nominal and actual productions.

Several elements prevent full capacity of machinery. These non-productive time elements include setup time, scheduled maintenance, and operation disengagement (e.g. breaks and meals.)

In the long-range analysis, crawler-type front shovel models were classified according to their power (hp). To achieve this goal, the engine power of various models of Caterpillar, Komatsu, and Hitachi was assessed. Their engine power on the basis of horsepower (hp) was divided to four categories; 250, 280, 350 and 390.

In a case, the model 245B of Caterpillar, the model PC400 of Komatsu and the model EX550 of Hitachi, all usually used in earth-fill dam projects have a power nearly 350 hp. Therefore, the crawler-type front shovel with engine of 350 hp was chosen as a category. Accordingly, for each category, the actual hourly production at the sites was estimated.

2.3.2 *Ratio Analysis*

A ratio analysis (Eq. 1) is also implemented to verify the obtained actual hourly production in accordance to time duration.

In the ratio analysis, one should obtain approximately the same ratio for the given hourly production. The obtained data do not satisfy the ratio analysis could be wrong and therefore must be ignored for the rest of data analysis.

$$\frac{3\,hour production}{3} \approx \frac{2\,hour production}{2} \approx \frac{half\,hour production}{1/2} \approx 1\,hour production \quad (1)$$

2.3.3 *Variance Analysis*

Variance analysis is a useful and effective tool for analyzing pure experimental data. The process of variance analysis for a model with limited variable is as follows:
The expected value, E(x), of the collected data is calculated (Eq. 2):

$$E(x) = (x_1 + x_2 + ... + x_n) / n \quad (2)$$

The variance is given by Eq. 3:

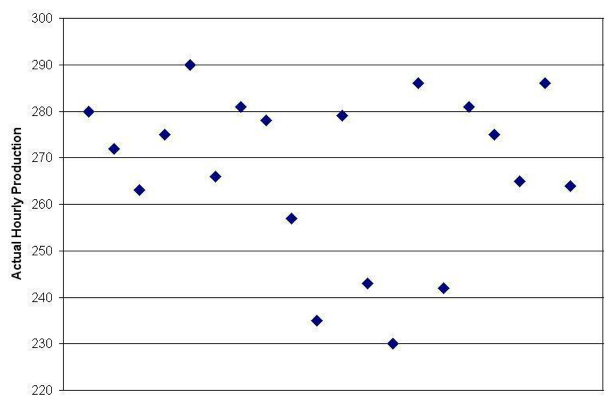
$$Var(x) = E[(x - E(x))^2] \quad (3)$$

The standard deviation, σ (x) is calculated according to Eq. 4:

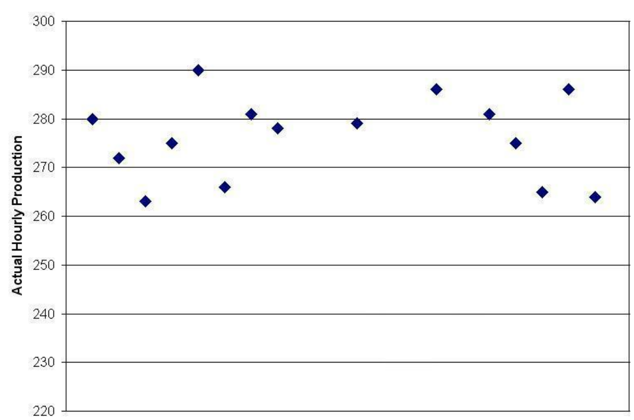
$$\sigma(x) = \sqrt{Var(x)} \quad (4)$$

Table 1
Actual production data a crawler-type front shovel with a power of 390 hp

	Data of Actual Hourly Production										*E(x)*	*Var(x)*	$\sigma(x)$
First Analysis	280	272	263	275	290	266	281	278	257	235	267.40	297.54	17.25
	279	243	230	286	242	281	275	265	286	264			
Second Analysis	280	272	263	275	290	266	281	278	-	-	276.06	68.46	8.27
	279	-	-	286		281	275	265	286	264			



(*a*) first analysis



(*b*) second analysis

Fig. 5. Distribution of actual production data of crawler-type front shovel

The variance analysis can helps to achieve more realistic data. In a case of the crawler-type front shovel with a power of 390 hp, the variance analysis carries out on the data shown in the Table 1.

In the first analysis, 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 five of the values achieved (second analysis).

Conclusively, the expected value resulted of the second variance analysis is the actual production value of crawler-type front shovel. Fig. 5 presents the distribution of data in first (Fig. 5-a) and second (Fig. 5-b) variance analyses.

3. Results

Applying the above mentioned methodology and analysis results the actual hourly production of a crawler-type front shovel (Table 2). The actual hourly production given in the Table 2 is based on an efficiency factor of 100%. Table 3 and 4 provide some different working conditions.

The Table 3 and 4 are organized using literatures, performance handbooks and standard construction equipment books given in the references (Douglas, 1975; StuartWood, 1977; Caterpillar Performance Handbook 2004; Gransberg et al., 2006; Peurifoy et al., 2006; Nabizadeh Rafsanjani et al., 2009).

Depending on the project conditions, it is reasonable to apply these coefficients, in order to achieve more realistic results.

For example, a crawler-type front shovel with an engine horsepower of 390 hp having a bottom dump bucket capacity of 4.0 cm works in a site. The working condition of site is weak. The soil condition of the site is loose containing aggregate with size of nearly 30mm and the machine dumps the soil near excavation site. In these conditions, the actual hourly production of machine is Eq. 5:

$$276\ (m^3\ h) \times 0.583 \times 0.800 = 128.726\ (m^3\ h) \qquad (5)$$

The result shows that the actual hourly production has an impressive difference with nominal production given by manufacturers (800 m^3 h). Ignoring the difference leads to difficult challenges in the management of projects.

4. Discussion

Machinery production is one of the key factors in the concept of optimum planning for construction project. Concerning site condition, the actual production differs from the nominal production given by manufacturers. The major factors causing this difference are climate conditions, earthmoving operations, driver's workmanship, machinery age, and construction time according to various seasons. This study uses a three-stage statistical analysis to obtain the actual hourly production of a model of crawler-type front shovel used throughout earth-fill dams being constructed in Iran. The method used involves three steps: long-range analysis, ratio analysis and variance analysis. Table 2 shows that the actual production of this machine is approximately 37% of the nominal production. This considerable difference is one of the controversial issues in managing of construction projects.

Edmonds et al. (1994) have reported the constant value of 0.525 as the ratio of actual production to nominal production of all machinery in earthmoving operations. Seung and Sunil (2006) studied the construction machinery using artificial neural networks. Their investigations were based specifically on Dozers. There results were given according to the maximum daily

Table 2
Crawler-type front shovel hourly production

Engine Horsepower (hp)	Bucket Capacity (m^3)	Working Condition	Maximum Loading Height (m)	Maximum Digging Depth (m)	Nominal Work Hourly Production (m^3/hr)	Actual Work Hourly Production (m^3/hr)
250	2.4 (Front Dump)	Loose Soil, Dumping Near Excavation Site Rotation Angle 45° Bucket Fill Factor 100%	6.8	2.6	470	150
250	2.4 (Front Dump)	Medium Soil, Dumping in Hauling Equipment Rotation Angle 45° to 90° Bucket Fill Factor 100%	6.8	2.6	368	135
250	2.4 (Front Dump)	Dense Soil, Dumping in Hauling Equipment Rotation Angle more than 90° Bucket Fill Factor 100%	6.8	2.6	283	107
280	2.4 (Bottom Dump)	Loose Soil, Dumping Near Excavation Site Rotation Angle 45° Bucket Fill Factor 100%	7.1	2.7	570	195
280	2.4 (Bottom Dump)	Medium Soil, Dumping in Hauling Equipment Rotation Angle 45° to 90° Bucket Fill Factor 100%	7.1	2.7	468	163
280	2.4 (Bottom Dump)	Dense Soil, Dumping in Hauling Equipment Rotation Angle more than 90° Bucket Fill Factor 100%	7.1	2.7	331	138
350	4.0 (Front Dump)	Loose Soil, Dumping Near Excavation Site Rotation Angle 45° Bucket Fill Factor 100%	7.3	2.8	750	253
350	4.0 (Front Dump)	Medium Soil, Dumping in Hauling Equipment Rotation Angle 45° to 90° Bucket Fill Factor 100%	7.3	2.8	608	222
350	4.0 (Front Dump)	Dense Soil, Dumping in Hauling Equipment	7.3	2.8	468	187

(working day) production. A deficiency that could be noted in their studies is the absence of an average of the hourly production of the machinery.

Nabizadeh Rafsanjani et al. (2009) proposed actual hourly production of seven different pieces of earthmoving equipment used in earth-fill dam project, separately. Their results show that sheepsfoot rollers have the lowest efficiency with an actual to nominal hourly production ratio of 0.32 whilst the wheel loader has 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. However, the crawler-type front shovel was not assessed in their study. Conclusively, a crawler-type front shovel did not clearly assessed in the literature. Indeed, no work provides the actual production of this machine.

On the basis of real construction projects, this study explored separate factors of actual hourly production for a crawler-type front shovel according to its power (hp). The obtained results are realistic. These results can contribute greatly to project management teams in order to schedule the construction machinery more effectively as well as decreasing project risk.

Nevertheless, although this study provides real data of a model of machinery, the data analysis approach is difficult and time-consuming to implement in construction projects. The future research approaches in the field of machinery production can be programmed as a systematic procedure. The systematic approaches can provide more accurate data of machinery production and assess more situations of machinery in construction projects.

5. Conclusion

Estimating the actual production of machinery plays an important role in succeeding of construction projects. This study explored the actual hourly production of a model of crawler-type front shovel of earth-fill dam projects in Iran. A statistical analysis verified the real data of machinery gathered from dam projects. The statistical analysis consists of three stages: long-range analysis, ratio analysis, and variance analysis. The data were classified according to the engine power of machinery. A crawler-type front shovel shows a lowest efficiency with an actual to nominal production ratio of 0.37. Climate conditions, earthmoving operations, machinery age, driver's workmanship, and construction time according to various seasons are the main reasons of shortfall in hourly production. Considering this high range of shortfall is certainly useful in planning of machinery in project sites.

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