*Fifth International Conference on Construction in the 21st Century (CITC-V)*
*"Collaboration and Integration in Engineering, Management and Technology"*
*May 20-22, 2009, Istanbul, Turkey*

# An Assessment of Nominal and Actual Productivity 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 productivity of a model of dozer, a wheel-type loader, a crawler-type loader, a grader, 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).

## Keywords
Construction Equipment, Nominal Productivity, Actual Productivity, Earth-fill Dam Projects

## 1. Introduction

It has been universally accepted that the equipment productivity is one of the key factors in construction projects. It is also well known that the actual productivity of the equipment differs from the nominal productivity provided by the manufacturers. Increasing the actual productivity 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).

The accurate estimation of earthmoving productivity has intrigued many researchers for many years (Alkass and Harris, 1988; Amirkhanian and Baker, 1992; Karshenas and Feng, 1992; Smith, 1999), and yet there is no robust model for prediction of the productivity of earthmoving activities at the construction site (Seung and Sunil, 2006). 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, 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 productivity. 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. Bhurisith and Touran (2002), 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 productivity 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. Zou, 2006, 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.

### 3.2 Equipment Selection

The choice of equipment in our study is limited to three manufacturers, namely, Caterpillar, Komatsu and Volvo. 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 actual production for six various types of heavy equipment which played the main role in dam construction, was estimated according to the site conditions.

### 3.4 Production Estimation

The actual construction conditions at various project sites differ according to the climate, the soil type and the driver's workmanship. In our study, the actual production of the equipment was derived according to the following methodology.

#### 3.4.1 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 productivity 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 productivity 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. 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.

$$\frac{2\ \text{hour production}}{2} = \frac{1\ \text{hour production}}{1} = \frac{\text{half hour production}}{1/2}$$

#### 3.4.2 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, Var(x), is calculated according to:

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

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

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

## 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 and a crawler-type loader are given in Tables 1, 2, 3, 4, 5 and 6, respectively.

**Table 1: Grader Productivity**

| Engine Horsepower (hp) | Blade Length (m) | Blade Height (m) | Nominal Work Hour Productivity ($m^3$/hr) | Actual Work Hour Productivity ($m^3$/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 2: Smooth Wheel Roller Productivity**

| Engine Horsepower (hp) | Operational Weight | Grade ability | Working Conditions | Nominal Work Hour Productivity ($m^3$/hr) | Actual Work Hour Productivity ($m^3$/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 3: Sheep's Foot Roller Productivity**

| Engine Horsepower (hp) | Operational Weight | Grade ability | Working Conditions | Nominal Work Hour Productivity ($m^3$/hr) | Actual Work Hour Productivity ($m^3$/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 4: Dozer Productivity**

| Engine Horsepower (hp) | Bucket Capacity ($m^3$) | Working Condition | Haul Distance | Nominal Work Hour Productivity ($m^3$/hr) | Actual Work Hour Productivity ($m^3$/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 | 5 |
| 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 5: Wheel-type Loader Productivity**

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

**Table 6: Crawler-type Loader Productivity**

| Engine Horsepower (hp) | Bucket Capacity ($m^3$) | Working Condition | Nominal work Hour Productivity ($m^3$/hr) | Actual work Hour Productivity ($m^3$/hr) |
|---|---|---|---|---|
| 67 | 0.8 | Uniform Aggregate, Bucket fill Factor 0.95, Haul Distance 10 m | 60 | 40 |
| 67 | 0.8 | Uniform Aggregate, Bucket fill Factor 0.95, Haul Distance 20 m | 39 | 22 |
| 78 | 1 | Uniform Aggregate, Bucket fill Factor 0.95, Haul Distance 10 m | 86 | 45 |
| 78 | 1 | Uniform Aggregate, Bucket fill Factor 0.95, Haul Distance 20 m | 54 | 30 |
| 110 | 1.15 | Uniform Aggregate, Bucket fill Factor 0.95, Haul Distance 10 m | 186 | 1015 |
| 110 | 1.15 | Uniform Aggregate, Bucket fill Factor 0.95, Haul Distance 20 m | 156 | 98 |
| 150 | 2 | Uniform Aggregate, Bucket fill Factor 0.95, Haul Distance 10 m | 247 | 152 |
| 150 | 2 | Uniform Aggregate, Bucket fill Factor 0.95, Haul Distance 20 m | 205 | 115 |
| 210 | 2.8 | Uniform Aggregate, Bucket fill Factor 0.95, Haul Distance 10 m | 347 | 217 |
| 210 | 2.8 | Uniform Aggregate, Bucket fill Factor 0.95, Haul Distance 20 m | 285 | 173 |

The actual production given in the above tables is based on an efficiency factor of 100%. In the tables below some different working conditions were considered. The tables are organized using performance handbooks and standard construction equipment books given in the references. 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:

$$150\ (m^3/hr) \times 0.75 \times 0.5 \times 0.86 = 48\ (m^3/hr)$$

**Table 7: 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 8: 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 9: 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 |

**Table 10: 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 |

## 5. Discussion

Seung and Sunil, (2006), studied the construction equipment using artificial neural networks. There investigations were based specifically on Dozers. There results were given according to the maximum daily (working day) production. A deficiency that could be noted in their studies is the absence of an average of the hourly production of the equipment.

Table 1 shows that the actual production of this type of equipment is approximately 65% of the nominal production. It can also be seen that for the models with an engine horsepower of 135 to 150 hp, the actual production is equal to 301 $m^3$/hr. This indicates that we may employ the 135 hp model instead of the 150 hp model. In table 2, the actual production is approximately 43% of the nominal production. Table 3 shows an actual production of approximately 32% in comparison with the nominal production, expect for the model with 155 horsepower which is about 45%. In table 4 a diversity in the obtained results is seen. The equipment efficiency ranges from 32% (for the 370 hp model) to 85% (for the 302 hp). Tables 5 and 6, show an actual production of approximately 60% to the nominal production. Edmonds *et al*., 1994, have reported the constant value of 0.525 as the ratio of actual production to nominal production. Whereas our results given in this study range from 0.32 to 0.85 and we believe that they are more realistic.

## 6. Conclusion

This paper has explored the actual productivity of seven different pieces of earthmoving equipment of earth-fill dam projects in Iran by using a statistical analysis. The actual productivity of the equipment can effectively contribute to the management of the construction projects. A sheep's foot roller shows the lowest efficiency with an actual to nominal productivity 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 productivity 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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