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Major Factors Affecting Highway Construction Productivities

Yi Jiang
Associate Professor
Department of Building Construction Management
Purdue University
West Lafayette, Indiana 47907, USA
E-mail: jiang2@purdue.edu

Abstract
This paper presents the identified major factors affecting highway construction productivities and their effects on construction production. The analysis indicates that the production rates are statistically different for different construction firms. Generally, the production rates in rural areas are higher than those in urban areas. This should be attributed to the fact that the traffic volumes in urban areas are much higher than those in rural areas. The traffic conditions in urban areas would require different traffic control, limit the number of roadway lanes to be closed for construction, cause traffic congestion and material delivery delays, and put more restrictions on time periods for construction. Adverse climatic conditions negatively affect many highway construction activities. The results exhibit that the production rates increase as the air temperature increases up to 70°F. Then the production rates tend to slowly decrease beyond 70°F. Air temperatures are directly related to the seasons. Thus, the effects of air temperatures on production rates imply that the season is one of the major factors affecting production rates. The study reveals that the production rates are highest in the summer and lowest in the winter.

Keywords
Highway construction, productivity, work zone

1. Introduction

Highway production rates have been studied for different types of projects under various envronments (EI-Rayes & Moselhi, 2001; Lee, et. la., 2000; and Lee, et. la., 2002). The Indiana Department of Transportation (INDOT) utilizes the average production rates of itemized highway and bridge work as a general guide for setting workdays for construction contracts. In this study, highway construction production rates were calculated based on highway construction records in Indiana. The effects of various factors on production rates were quantitatively analyzed to determine their significances. Based on these identified factors, the production rates can be classified into groups with consideration of the major factors. The research results would minimize the subjective or judgmental errors in estimating contract times and improve the accuracy of the estimated contract time. The INDOT Construction Daily Reports were utilized as the primary source of productivity data. The Construction Daily Reports were stored in Microsoft Access files. The data files contain 1,818 highway construction projects between 1995 and 2002 with thousands of records, including project descriptions, construction items, project magnitudes, weather information, and daily quantities of material utilizations. The construction data includes seven full-year data from 1995 to 2001 and partial-year data for 2002. In addition, INDOT annual reports of highway traffic counts and statistics were used to obtain traffic information at construction sites.

2. Factors Affecting Production Rates

2.1 Effects of Construction Firms

Construction firms or contractors differ in many aspects, such as management, labor skills, equipment, construction methods and techniques. Therefore, it was expected that the production rates were different for different construction firms. To examine the effects of construction firms, the production rates of two construction activities from ten construction firms are shown in Figures 1 and 2. The two figures indicate that the production rates vary for different construction firms. By comparing the two figures, it can be seen that a firm's low production rate in one construction activity does not necessarily mean it is also low in another construction activity. For example, the ninth construction firm had a low production rate in "bituminous widening" (Figure 1), but had a relatively high production rate in "class B concrete in structure." This implies that the productivity of a particular construction activity may not represent the overall productivity of a construction firm.

To determine the significance of the differences in production rates of construction firms, t statistical test can be performed. To test if the production rates of any two firms are statistically equal, it is to choose between two alternatives about mean μ_1 and μ_2 of two populations (Neter, Wasserman, & Kutner, 1985):

H_0: $\mu_1 = \mu_2$, and

H_a: $\mu_1 \neq \mu_2$.

The decision rule is:

If $|t^*| \leq t(1-\alpha/2; n_1 + n_2-2)$, conclude H_0; if $|t^*| > t(1-\alpha/2; n_1 + n_2-2)$, conclude H_a.

where:

$\overline{X_1}$ and $\overline{X_2}$ are the means of the samples from population 1 and 2, respectively;
n_1 and n_2 are the samples sizes from populations 1 and 2, respectively;
α is the significant level;

$$t^* = \frac{\overline{X_1} - \overline{X_2}}{S_p\left(\frac{1}{n_1} + \frac{1}{n_2}\right)^{0.5}}$$

S_p is the square root of the pooled variance, which can be calculated as:

$$S_p = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}}$$

where:

S_1^2 and S_2^2 are the variances of the samples from population 1 and 2, respectively.

Based on the t test procedure, the mean production rates were compared among all of the major construction firms with a significant level of 0.05. The test results indicate that the production rates are statistically different for different construction firms. Therefore, construction firms have significant effects on highway production rates.

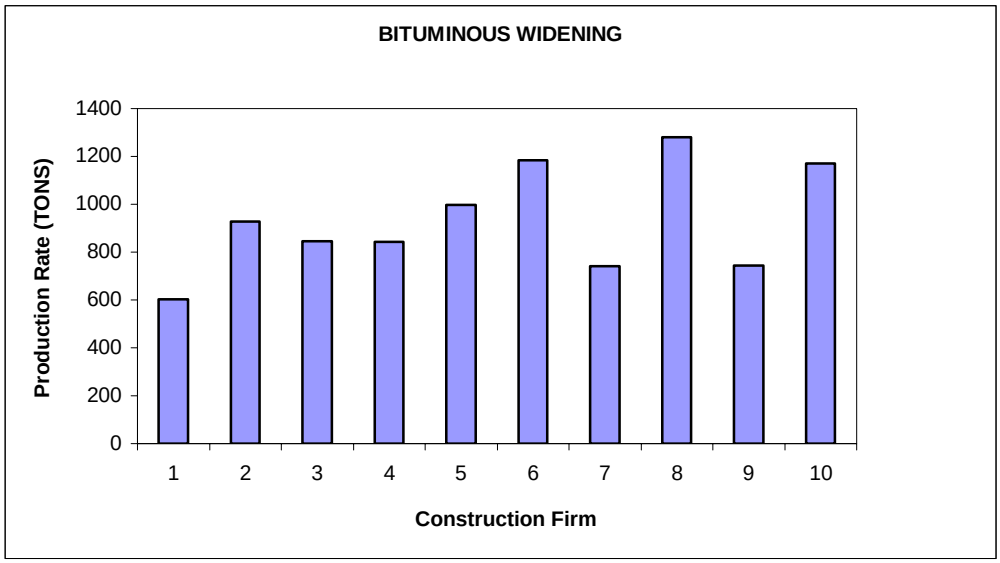

Figure 1: Production Rates of Different Contractors

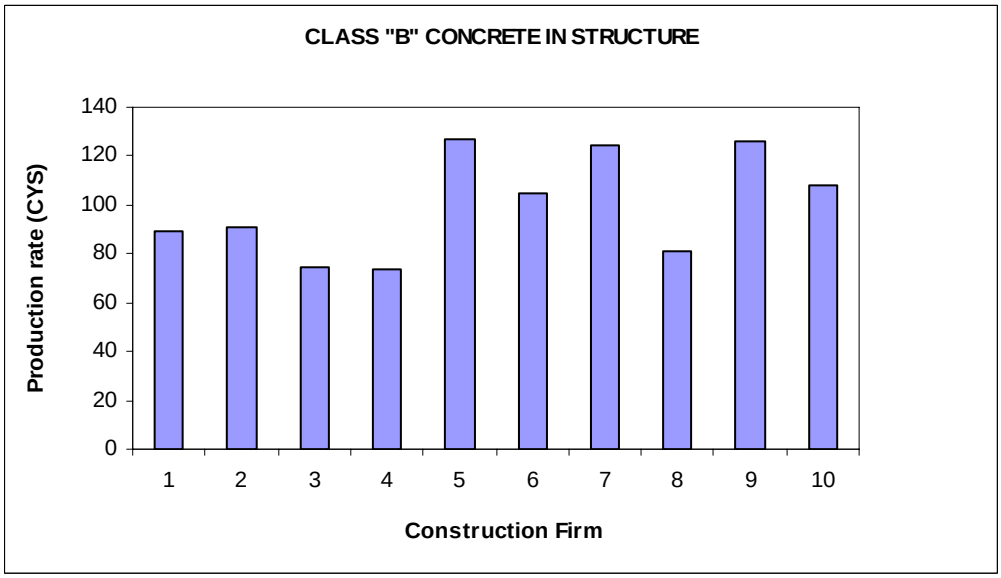

Figure 2: Production Rates of Different Contractors

2.2 Effects of Construction Project Locations

The locations of highway construction projects are classified as urban and rural in INDOT highway construction data base. Whether a highway construction project is located in urban or in rural area may affect material supply, distance of material delivery, cycle time of delivery trucks, traffic condition, and work zone layout. The statistical tests to determine mean production rates at urban and rural locations were performed. Based on the test results, it is concluded that the production rates differ significantly in urban and rural areas. The production rates in urban and rural areas for some major highway construction activities are listed in Table 1. Generally, the production rates in rural areas are higher than those in urban areas. This should be attributed to the fact that the traffic volumes in urban areas are much higher

that those in rural areas. The traffic conditions in urban areas would require different traffic control, limit the number of roadway lanes to be closed for construction, cause traffic congestion and material delivery delays, and put more restrictions on time periods for construction. Table 1 provides a useful source when specific productivity information is needed in terms project locations for construction process management and planning.

Table 1: Production Rates in Urban and Rural Areas

Construction Activity	Locations	
	Urban	Rural
BACKFILL, ROCK	560(TONS)	600(TONS)
BITUMINOUS APPROACHES	200(TONS)	260(TONS)
BITUMINOUS BASE	760(TONS)	900(TONS)
BITUMINOUS BINDER	1,130(TONS)	1,230(TONS)
BITUMINOUS BINDER WITH FIBERS	1,670(TONS)	2,000(TONS)
BITUMINOUS PATCHING	60(TONS)	80(TONS)
BITUMINOUS SURFACE	1,000(TONS)	1,120(TONS)
BITUMINOUS WEDGE AND LEVEL	510(TONS)	610(TONS)
BITUMINOUS WIDENING	910(TONS)	960(TONS)
BORROW	890(CYS)	1,100(CYS)
BRIDGE DECK OVERLAY	340(SYS)	370(SYS)
COMPACTED AGGREGATE FOR BASE	270(TONS)	420(TONS)
COMPACTED AGGREGATE FOR SHOULDER	420(TONS)	540(TONS)

2.3 Effects of Weather Conditions

Adverse climatic conditions negatively affect many highway construction activities. Some highway construction operations can not be performed under certain weather conditions. For example, both HMA and Portland cement concrete pavements should not be placed when the air temperature is below a certain level. Also, soil stabilization with lime should not be operated under windy conditions. Moreover, highway construction production rates will not be the same under different weather conditions. Weather conditions may be represented by individual or combined indices, including air temperature, relative humidity, wind velocity, barometric pressure, and precipitation. In this study, only the air temperature information was available from the INDOT construction daily reports. Therefore, only the effects of air temperatures were analyzed. It was found that the highest production rates occurred at air temperature between 70 and 80^{o}F. As temperature increased to 95^{o}F, most of the production rates decreased in comparison with those at 70 or 80^{o}F. Apparently, this is attributed to the comfortable level of construction workers because most people would feel most comfortable at around 70^{o}F. The statistical analysis indicated that the differences in production rates were significant at a significant level of 0.05 with respect to air temperatures. Figure 3 is plotted with selected two production activities to illustrate the changes of production rates with air temperatures. The two curves exhibit that the production rates increase as the air temperature increases up to 70^{o}F. Then the production rates tend to slowly decrease beyond 70^{o}F.

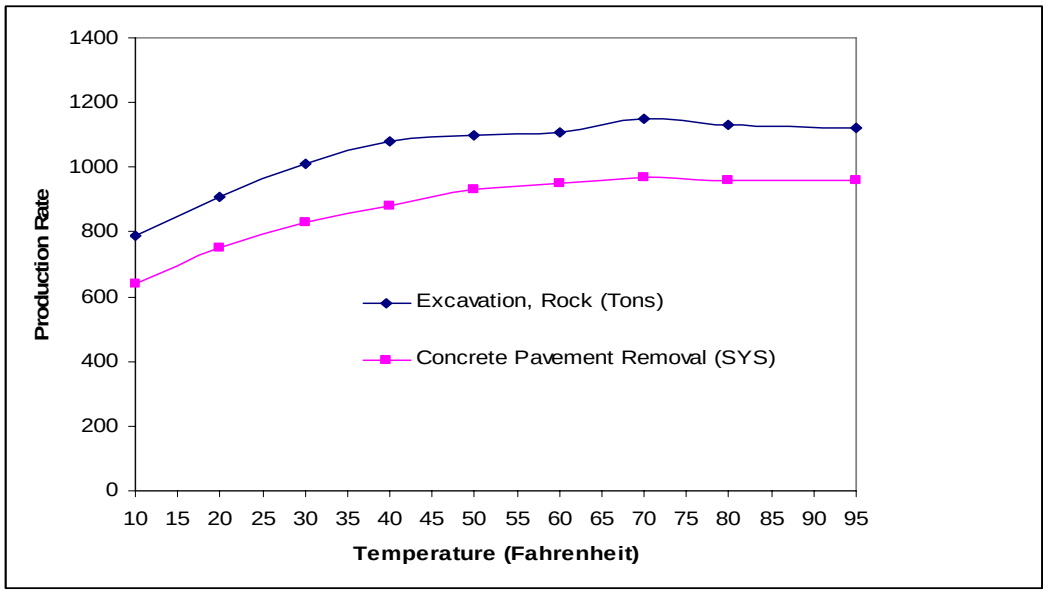

Figure 3: Production Rates at Different Air Temperatures

In addition to production rates, weather conditions also affect construction durations because of the number of non-working days. The relationship between mean temperature and number of non-working days can be seen from Figure 4. As the figure clearly indicates, low mean temperatures result in more non-working days. That is, temperature has great effects on the number of non-working days and thus on construction durations. It should be pointed out that precipitation and wind condition also have effects on construction activities, which are not included in this study because of lack of data.

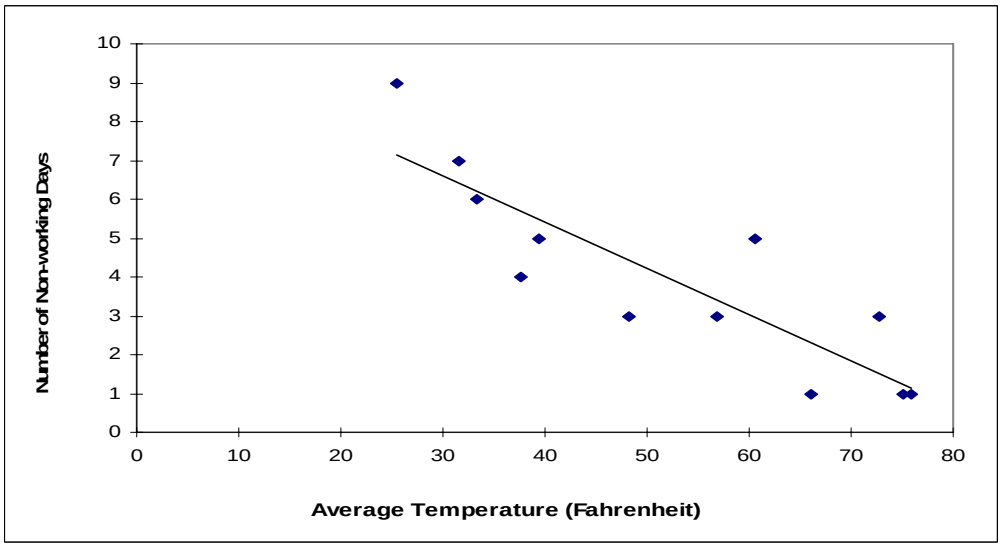

Figure 4: Relationship between Average Temperature and Non-working Days

2.4 Effects of Seasons

Air temperatures are directly related to the seasons. Thus, the effects of air temperatures on production rates imply that the season is apparently one of the major factors affecting production rates. Table 2 summarizes the mean production rates of various highway construction activities in the four seasons. This table reveals that the production rates are highest in the summer and lowest in the winter. As expected, the seasonal production rates indicate that the summer and fall seasons are more suitable for highway constructions than the other two seasons.

Table 2: Production Rates in Different Seasons

Construction Activity	Unit	Season			
		Spring	Summer	Fall	Winter
COMPACTED AGGREGATE FOR SHOULDER	TON	450	540	510	390
CONCRETE PATCHING	SYS	120	140	120	90
CONCRETE PAVEMENT	SYS	2710	3200	2990	2270
CONCRETE SIDEWALK	SYS	1010	1180	1120	860
CONTRACTION JOINT	LFT	280	310	300	230
CRACKS, TRANSVERSE, ROUT CLEAN AND SEAL	LFT	8710	9910	9540	7300
CURB AND GUTTER	LFT	310	360	340	260
CURB AND GUTTER, COMBINED	LFT	320	340	340	270
CURB, INTEGRAL, C, CONCRETE	LFT	190	220	210	160
CURB RAMP, CONCRETE	SYS	23	26	25	19
EMBANKMENT	CYS	2240	2570	2460	1890
EXCAVATION, COMMON SMALL AREAS	CYS	490	570	540	420
GUARDRAIL	LFT	490	570	540	420
GUARDRAIL, CHANNEL	LFT	230	260	240	190
GUARDRAIL, RESET	LFT	340	410	400	300

2.4 Effects of Type of Highway

The type of highway is an important factor of construction production because it is considered to set contract time so that the impact of highway construction on motorists' safety, traffic delay, and business operations can be controlled. Construction projects on highways with higher traffic volumes are often required to have shorter contract times to minimize traffic interruptions caused by construction activities. Based on the INDOT construction data, the analysis showed that construction durations were indeed different for different types of highways. Figure 5 presents an example of the effects of types of highways on construction durations. The actual construction durations of bridge replacement projects are shown in the figure with respect to total construction costs for three types of highways. The bridge replacement projects on county roads had consistent longer construction durations than US Routes and State Roads for given total construction costs. The differences clearly reflect the importance of the types of roads in determining contract times because of different levels traffic volumes on the roads. Consequently, the specified contract times influence the actual construction durations because the contractors would utilize their resources to increase production according to the contract times.

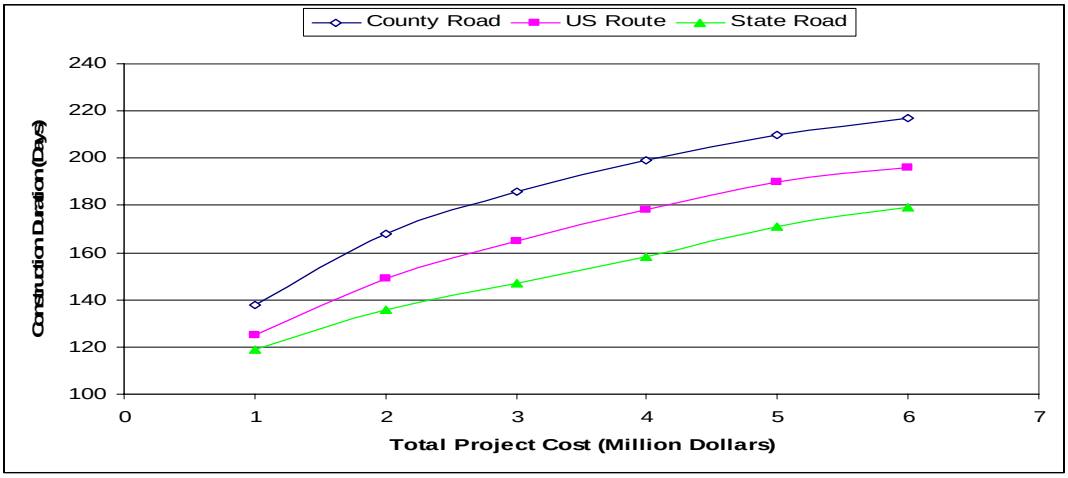

Figure 5: Types of Roads and Construction Durations of Bridge Replacements

2.5 Trend of Production Rates

Although the change in highway construction is relatively slow, the construction industry has been inevitably influenced by the improvements in technology, materials, and management. Therefore, the efficiency of highway construction is expected to increase with time. In order to examine the trend of highway construction productivity, the mean production rates of major highway construction activities for a period of consecutive seven years were compared statistically (between 1995 and 2001). Figure 6 is plotted with the mean production rates of three selected highway construction activities for the seven years. The figure illustrates that production rates followed a gradually increasing trend. This proves that highway construction efficiency has been gradually and stably improving. It is therefore necessary to update the highway construction production rates periodically.

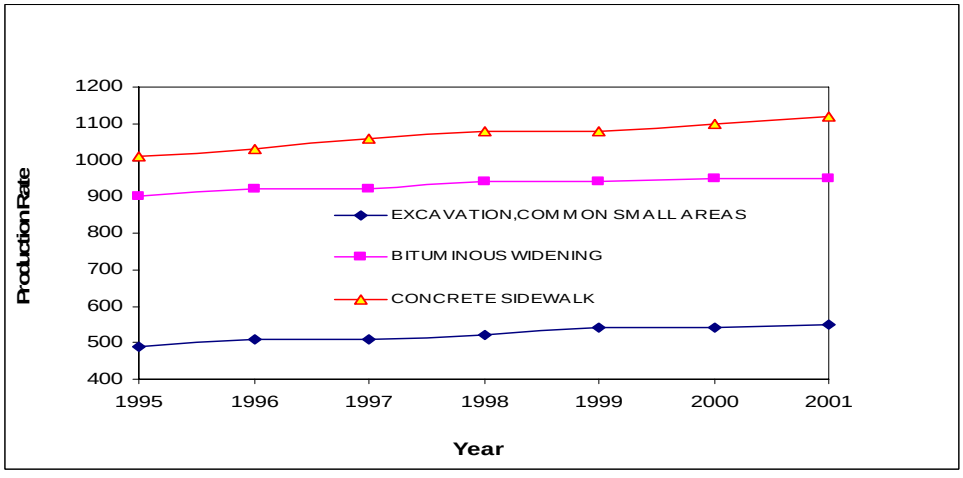

Figure 6: Production Rate Change Trend

3. Conclusions

Production rates of highway construction are affected by many factors. Under different conditions, production rates may vary considerably because of the effects of these factors. Construction firms or contractors differ in many aspects, such as management, labor skills, equipment, construction methods and techniques. The analysis indicates that the production rates are statistically different for different construction firms. Therefore, construction firms have significant effects on highway production rates. The locations of highway construction projects are classified as urban and rural in INDOT highway construction data base. Whether a highway construction project is located in urban or in rural area may affect material supply, distance of material delivery, cycle time of delivery trucks, traffic condition, and work zone layout. Generally, the production rates in rural areas are higher than those in urban areas. This should be attributed to the fact that the traffic volumes in urban areas are much higher than those in rural areas. The traffic conditions in urban areas would require different traffic control, limit the number of roadway lanes to be closed for construction, cause traffic congestion and material delivery delays, and put more restrictions on time periods for construction. Adverse climatic conditions negatively affect many highway construction activities. The results exhibit that the production rates increase as the air temperature increases up to 70^{o}F. Then the production rates tend to slowly decrease beyond 70^{o}F. Air temperatures are directly related to the seasons. Thus, the effects of air temperatures on production rates imply that the season is one of the major factors affecting production rates. The study reveals that the production rates are highest in the summer and lowest in the winter.

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