The Need for Improvement of the Productivity Understanding in Highway Asphalt Pavements in Brazil

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Abstract

Introduction: The importance of heavy construction, in Brazil, is demonstrated by the latest interest in the topic of infrastructure development, motivated by three factors: the need for infrastructure investments; the sector was opened to private enterprise; and the infrastructure has permanent effects on the income level and in the attraction of foreign investments, with direct results on human development. The interest in the infrastructure development, leads us to the urgent need to improve the quality of road pavements. Therefore, investments, organized in various sectors: research, consulting engineering, construction and quality control, become necessary. **Study objectives:** This work studies the productivity variation in the highway asphalt pavement construction in Brazil and discusses the differences among the opinions of budget manuals. **Methods:** Based on the Model of Factors (this approach entails the prediction based on aspects observation related to a greater or lower expectation of efficiency of equipment in a certain service), the selection of research methods covers the objectives outlined, including literature review, exploratory studies and field surveys. **Conclusions:** Regarding services of asphalt pavement, there are many manuals, however each one deals with the execution steps differently and the productivity indicators presented are extremely variable. Furthermore, it is not possible to know (reading the manual) which factors were considered when the manual indicates a specific value for a certain service. Accordingly, its usage (the manuals) as a tool for budgeting and management is inefficient. The result of budget manuals study is presented and new methodology is proposed.

Keywords: productivity, pavement, highway infrastructure.

1. Introduction

In Brazil, in recent decades, investment in road infrastructure is far below the needs of the country, with a growing dissatisfaction of the productive sector with this level of investment. The IPEA survey, from 2010, showed that of $ 89.8 billion needed for the Brazilian federal

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highways, the Programa de Aceleração do Crescimento – PAC (Program of Acceleration of Growth) only predicts investments equivalent to 13% demand.

1.1 The highway as a response to demand for infrastructure

Providing infrastructure represents major public investments and a long-term planning. It is essential that the functionality is in line with the useful life of the enterprise (Fehrl 2008). Aware of this reality and the social importance and needs of the sector, between 2007 and 2010 several works were completed in Brazil: 1.306 kilometers of roads were doubled, 1.789 kilometers were paved and 3.282 kilometers were granted to private companies, which manage 15.000 kilometers - less than 1% of the paved mesh. There are duplication works on 1.592 kilometers and 3.524 kilometers of pavement in execution, besides signposting and maintenance services hired for more than 50.000 kilometers of network. For the private sector, there is immediate potential to grant, at least, over 12.000 kilometers (Abdib, 2011).

1.2 Available pointers of productivity

For the forecast of the productivity in Brazil the cost data manual use is common. However, it is perceived in practice, that the productivity pointers can have a great variability requiring knowledge of the factors that make them vary.

In the revision / perfection work developed for the Polytechnic School of São Paulo, USP (EPUSP, 2008) of the prognostic costs effected by the Brazilian Federal Government for the airport construction it was found a great variability of relative efficiencies to the pavement service (according to study in construction and consults to specialists, manuals and technical documents). Examples of variability are presented in Figure 1.

Hot Bituminous Concrete (CBUQ)

Tandem Roller (h)		Pneumatic Roller (h)		Asphalt Paver (h)		Labor (h)	
0.0014	0.0050	0.0005	0.0100	0.0010	0.0060	0.0071	0.0490
771%		879%		535%		1874%	

Figure 1 – Change (%) among the yields for the service CBUQ (number of equipment hours to launch a ton of material)

This example, which varies from 535% to 1874%, is a warning about not being able to make reliable decisions based on imprecise indicators.

1.3 Study objectives

This paper proposes studies of productivity variation in the highway asphalt pavement in Brazil and discusses the differences among Brazilian budget manuals. Built on the concept of productivity variable (unprecedented in the subsector of heavy construction) and it uses the approach of Model Factor. This approach entails a prediction based on careful observation of various aspects related to a greater or lesser expectation of labor productivity and the efficiency of equipment in a particular service.

2. Material and methods

The improvement of understanding the productivity of highway asphalt pavement started from the finding that many available methods assume postures that prevent them from making different decisions: those related to budgeting to those associated with production management.

Thus, the following steps were developed: a) expert opinion survey; b) use of theoretical and empirical methods; c) review the different executive phases of each type of service; d) present the indicators of these services through ranges of values (representing the variable productivity), e) and allies to the tracks are the guiding factors for the decision on what value to adopt. Therefore, based on ranges of values (productivity variable), and abnormalities of the factors that affect the productivity of paving, data obtained from eight sources studied (five books and two case constructions), and grounded in bibliographical studies, presents the following is the proposal to improve the understanding of productivity. This proposal aims to apply the concepts of variable productivity in Asphalt Paving of Highways.

The following criteria were used to choose the Brazilians manuals adopted in this work: technical recognition; degree of detail as the description of the cases examined, avoided use of manuals with the same sources of information.

The manuals used in this study are derived from the following sources:

a) National Department of Transport Infrastructure – DNIT (Brasil, 2007);

b) Company of Public Works of the State of Rio de Janeiro – EMOP (EMOP, 1999);

c) Municipal and Urban Infrastructure Works – SIURB (Sao Paulo, 2010);

d) Composition Table Prices Budgets – TCPO (TCPO, 2008);

e) Department of Civil Engineering at the Polytechnic School of the University of São Paulo (EPUSP, 2008).

The results of data collection processing and the posterior analysis are originated from the system presented in Figure 2.

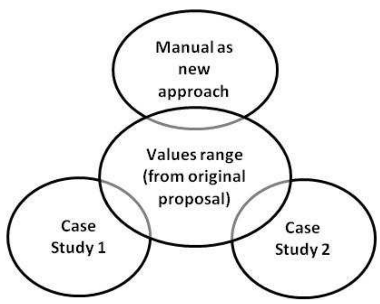

Figure 2 – Range of values: build system

3. Divergence between the Brazilian budget manuals

Amongst the services related to the highway asphalt pavement construction, aiming at illustrating the application of the productivity improvement, the service of the Hot Bituminous Concrete (CBUQ) will be presented as follows.

In the study effected in some cost data manuals the variety of equipment teams met a great difference and the same enters the productivity adopted for service. The variations found were: a) Asphalt Paver was 643%; b) Pneumatic Tire Compactor was 1042%, c) and Tandem Vibratory Roller was 918%. Table 1 illustrates this situation.

Table 1 – Hot bituminous concrete machined (ton/h)

Discrimination	DNIT	EMOP	SIURB	EPUSP
Asphalt Paver	90.7	14.1	13.1	37.0
Pneumatic Tire Compactor	126.1	14.1	13.1	12.1
Tandem Vibratory Roller	129.5	14.1		31.9
Farm Tractor	303.4			

4. New approach for productivity prediction (theory)

The method of prediction of productivity of asphalt paving services, proposed here, is divided into five parts, as the matters described below:

a) Unitary Production Ratio;

b) Unitary Production;

c) Model of factors;

d) Use of Quartile;

e) Details of equipment hours.

According to Souza (1996), although in most cases, the definitions on how to measure productivity represent a ratio between inputs and outputs of the process you want to evaluate, there may be variations in its scope, it is measured as inputs and outputs and the establishment of the ratio between inputs and outputs, among others. From the physical point of view, productivity could be defined as the efficiency (and, to the extent possible, the effectiveness) in the transformation effort by workers or equipment on construction products (the work or its parts), see Figure 3.

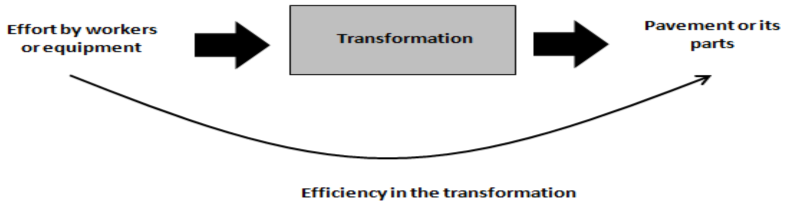

Figure 3 – Definition of productivity

4.1 Unitary Production Ratio

The accepted definition of productivity shown in Figure 3, Souza (2006) suggests adopting the indicator called unitary production ratio (RUP) as a measure of productivity by linking the human effort, measured in hours x men (Hh) or equipment x time (Eqh), with the amount of work performed, *Equation* (1). It is emphasized that, according to the setting made, a high value indicates productivity worse than a low value.

$$RUP = \frac{Hh}{Amount\ of\ service} \qquad \textbf{(1)}$$

4.2 Unitary Production

The unitary production (PU) translates the amount of service produced for the equipment (or workers) at the moment available for the service. He is the inverse one of the RUP, *Equation* (2).

$$Unitary\ \ \mathrm{Pr}oduction = \frac{1}{RUP} = \frac{\text{Amout of Serviçe}}{H_{available\ to\ the\ service}} \qquad \textbf{(2)}$$

4.3 Model of factors

According to Souza (2006), the unitary production (PU) of equipment and labor may vary according to age rather large amplitude. Figure 4 justifies the assertion that demonstrates that the production unit for the asphalt pavers ranges from 400 m^2/h to 800 m^2/h. The wide variation in the unitary production for the construction work force leads to the following conclusion: we cannot make good decisions without the knowledge of such ranges and the reasons why they change.

Figure 4 – Range of variation of the production unit: Asphalt Pavers (m^2 / h)

It has arrived, then, to another important question: why does the unitary production of the equipment and the labor vary? Conceptually, the model of factors would have an answer to the question. In an attempt to classify the factors potentially altering the unitary production presented in the various parts of the production process, it is said that the unitary production can be influenced in the presence of the normal manner by factors linked to the content and related to factors having the service context under consideration. In addition, the unitary production can be changed when anomalies occur. They are usually factors related to the content on the characteristics of the "product" running and "processed resources" such as materials and components. The context factors normally associated with "processing resources" such as labor and equipment and the "boundary conditions", such as temperature and usual attitude of the unions. Abnormalities would be "offsets" exacerbated by the regular features of the content and context cited.

4.4 Use of quartiles

The maximum and minimum values represent the extremities of the range, representing, obviously, situations have limited the available database; the medium value represents the central region of the data set, that is, it represents the central value of the data set.

Completing this reasoning, for the determination of the high and low values, the concept of Quartile will be used. Alternatively to the presentation of the maximum and minimum raised values, the processing of the data will be concentrated in the First and the Third Quartile as the extreme of the variation range to be argued. Ramos (2003) recommends this methodology (the application of quartiles) as a tool of statistical control. In the civil construction it is indicated by some authors such as: Souza (1998); Albuquerque *et al.* (2007); Duarte and Lamounier (2007).

4.5 Details of equipment hours

It is a common situation having a product and during some periods of time not having work to allocate it, becoming idle in the company. Within the period in which the equipment is available for service is the time it is effectively working, in other words, the power is on. This leads to the definition of "working hours". To develop this work it will be used these two moments of the incidence of equipment hours, the hours available for service ($H_{service}$.) and hours in operation ($H_{operation}$). Deducting from the “available hours for the service” the “hours in operation” one has the “unproductive hours” (H_{improd}). Figure 5 presents an example of application of these definitions.

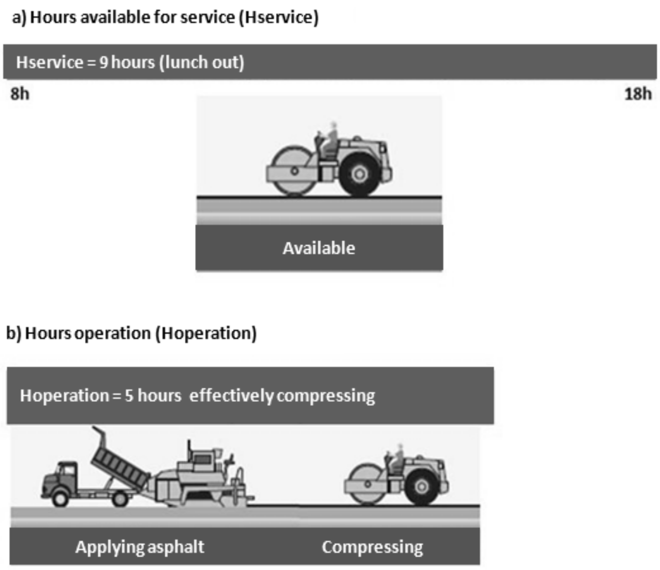

Figure 5 – Different moments in the highway asphalt pavement construction

5. Application example of the methodology proposal

Studied the subject (literature, five manuals and two case studies). A proposed approach to the compositions was performed. The indicators of the manuals were adequate according to this proposal. Tracks contemplating productivity variable (1st quartile, median, 3rd quartile), referring to manuals and case studies were developed. Based on all the learning acquired abnormalities were identified and the factors that make the productivity of these tracks vary. This study was presented to experts who opined on indicators and scored abnormalities and factors. The result of this research led to the improvement of the understanding of productivity in services asphalt paving.

Among the various services related to the construction of asphalt pavements for highways, aiming to exemplify the application of the proposed method, the hot bituminous concrete machined (CBUQ) is presented below.

In terms of the different parts of the service of CBUQ part of the scope the values shown below: cleaning; the release (discharge, spreading, leveling and pre-compression) and compaction of mix asphalt.

The ranges of unit output of the equipment shown below were made with the following considerations:

- to show ranges of values for the production unit including the equipment and his operator (Table 2).

- those bands are related to the factors which lead to an expectation better or worse than the value of the output indicator unit. In another word, a greater closeness of the extreme right or left, respectively, of the band (Table 3).

Table 2 – Hot bituminous concrete machined - cover or binder - esp. 5 cm

a) Step: spreading and leveling asphalt coating (trucks supplying the asphalt paver and this spreads the material layer and leveling)						
Equipment	Unitary Production ($m^2/H_{service}$)			$H_{operation}$		
	1º Quartile	Median	3º Quartile	1º Quartile	Median	3º Quartile
Asphalt Paver	400	600	800	70%	80%	90%
b) Step: Compression layer						
b1) pre-compacting and finishing (the tandem vibratory roller compaction starts making the accommodation of the original material. After compaction itself. the pneumatic tire compactor. tandem returns and finishes the layer)						
Equipment	Unitary Production ($m^2/H_{service}$)			$H_{operation}$		
	1º Quartile	Median	3º Quartile	1º Quartile	Median	3º Quartile
Tandem Vibratory Roller	400	650	820	70%	80%	90%
b2) compaction of the layer (after pre-compression. performed by the tandem vibatory roller. the pneumatic tire compactor compresses the tire itself)						
Equipment	Unitary Production ($m^2/H_{service}$)			$H_{operation}$		
	1º Quartile	Median	3º Quartile	1º Quartile	Median	3º Quartile
Pneumatic Tire Compactor	400	550	715	70%	80%	90%
c) Stage: support						
c1) water for smooth rollers (a water truck is available to provide water for the smooth rollers)						
Equipment	Unitary Production ($m^2/H_{service}$)			$H_{operation}$		
	1º Quartile	Median	3º Quartile	1º Quartile	Median	3º Quartile
Water truck	400	500	650	10%	15%	20%

Table 3 – Factors and abnormalities: hot bituminous concrete machined - cover or binder

Approaches the 1st Quartile	Approaches the 3rd Quartile
Unstable weather conditions	Stable weather conditions
Low effective capacity of the plant (fewer hours working)	High effective capacity of the plant (largest amount of hours in operation)
Operator untrained	Trained operator
Poor continuity and sequence of operations	Good continuity and sequence of operations
Preliminary tasks to be performed (e.g. lead paint)	Preliminary ready tasks (e.g. lead paint)
Low quality of mass produced at the plant	High quality mass produced at the plant
Equipment in poor condition and calibrated	Equipment in good condition and calibrated
Improvisation prevails	Plan activities in advance

6. Conclusions

Studies in the economic area indicate that the development of infrastructure is essential in determining the level of income "per capita" of a country. Providing this infrastructure represents a major public investment and long-term planning.

In recent decades in Brazil investment in highway infrastructure is far below the needs of the country. It is, therefore, that the highway pavement is a technology area with development potential and needs sorted investments in various sectors.

This paper proposes studies of productivity variation in the highway asphalt pavement in Brazil and discusses the differences among budget manuals. In the first moment, the Hot Bituminous Concrete (CBUQ) was presented as an example of service, and variations between 643% and 1042% were found.

Concluding, for the services of highway asphalt pavement there are, in Brazil, many budgeting manuals, but the indicators are sometimes presented as the theoretical basis without empirical proof, extremely variable and, the factors that do vary are not perceived. This imprecision makes it difficult to trust decisions, affecting the budget processes and production management.

To solve this problem the prediction method of asphalt paving productivity was propose. The model was developed based on the concept of variable productivity (productivity indicators presented through ranges of values) that in addition to unprecedented heavy construction subsector in Brazil, the approach uses the Model Factor (demonstrates the guiding factors for the decision on which embrace value).

Improving the understanding of productivity in performing asphalt paving of roads, proposed here, can mitigate the failures presented in the Brazilian budgeting manuals and thus help to bring the technological highway to new level of productivity and efficiency.

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