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PRODUCTION COST OPERATION OF SOME USED MACHINES DURING THE CONSTRUCTION WORKS IN THE REPUBLIC OF BENIN

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Abstract

The aim of this research is to determine appropriate correction coefficient of production machine to be considered during the construction of pavement in Republic of Benin. Given that reliable construction project should be in accordance with appropriate services and workmanship, this research proposes a method to be followed for the choice of machines according to the nomenclature of all the tasks necessary for the construction of a pavement. Then, a method for determining the actual production of machinery to be used on the job site while listing some factors to consider in determining prices. Based on the maximum theoretical production of the machines used during construction works, this research shows that improving the soil's performance depends on the quality and the machines' performance. Additionally, the results show that, the machines' theoretical productions must be corrected by appropriate factors linked to the conditions under which the works will be executed. Consequently, for a reassuring determination of the machines' operating cost, this research proposes that the machines to be used will work under challenging conditions.

1. Introduction

Reliable construction project should be in accordance with appropriate services and workmanship. Best results must be a key and permanent target for those who are in charge of expenditures of constructed facilities. There are some key factors that compulsory contribute to lower costs such as: material handling, shop installation, inventory. Over decades, new machines and methods have great impact on technologies which reasonably have kicked out of the system of construction companies and associations who are now obsolete [1]. Analysing construction technologies, they have varieties and vague schemes. And the introduction of machines into construction technology at the beginning of the twentieth century keeps most of techniques and materials unchanged. The Table 1 displays details [2].

Table 1. Machine required per task or per workstation [2]

Designation	Necessary machinery
Site installation	Machine carrier, light vehicle, bull, grader, truck crane. truck
Preliminary activities	
Woodcut	Bull, grader
Clearance of right of way	Bull, grader
Demolition of structure	Bull, mechanical or hydraulic excavator
Scouring	Bull
Earthworks and pavement works	
Excavation in loose soil	Bull, loader, grader, dump truck
Embankments from cuttings or Embankments from borrowings	Bull, loader, dump truck, water tank truck, grader, compactor, motor pump
Purging poor quality land and alternative materials	Bull, Chargeuse, Pelle hydraulique, dump truck, loader, compactor, water tank truck
Ditches	Grader, bull
Rock excavation	Bull, compressor + jackhammer, hydraulic shovel + rock breaker
Surface layer	Bull, loader, grader, compactor, dump truck, water tank truck, moto-pompe
Workstation	
Construction of pavements and various works	Cement mixer, truck crane, dump truck, hand compactor, water tank truck, vibrator, motor pump

Opposite of what is previously said about big project, it’s necessary to highlight the progressive changes ~ innovations in traditional materials and practices. Bricklaying for instance maintains the traditional way of putting one on another. Meanwhile masonry has wonderful development of its technology. Masonry uses tipper trucks, mortar mixers, sophisticated scaffolding systems, motorized wheelbarrows, forklift trucks, new epoxy mortars which provide better adhesion between bricks [3]. Masonry, in addition to the above innovations, will likely use robotic bricklaying. Many other technical changes are being carried out on masonry technology even though they are very slow [4].

Knowing the quantity of work, contractors and owners have to be realistic, they must take into account the knowledge of the maximum theoretical production of each machine. This theoretical production is often mentioned in catalogs or technical sheets by machine builders. The theoreticals productions of the machines are provided by catalogs established on the database which do not correspond to the real conditions of the sites [5].

The maximum theoretical production is calculated under the ideal working conditions by the manufacturer [5, 6]. The machine is supposed to work full time (60 min per hour), that is to say that no waiting time for the driver and no delay are taken into account. These manufacturers provide inputs, according to the available power of the machines, the values of their maximum theoretical productions per task on graphs or charts. Consequently, these theoretical productions must be corrected by appropriate factors linked to the conditions under which the work will be carried out.

Several brands of machines exist and these different machines are manufactured according to the standards in force, they have characteristics which allow the user to classify them or to make the comparison. For example, knowledge of the power and the theoretical production of the caterpillar D6 bulldozer allows to find the approximate theoretical production of a Komatsu or Fiat-Allis bulldozer according to its power.

In this chapter the Caterpillar brand was opted for in the search for the theoretical production of machines. This option is due to the fact that the caterpillar brand is the most used in studied areas by companies.

The document entitled “Caterpillar equipment and method edition October 31, 2000” [7] was used and allowed to obtain different road tasks, towards the theoretical production of Caterpillar brand machines.

2. Methodology

2.1. Theoretical production of bulldozers caterpillar by task

2.1.1. Theoretical production for tree felling

The diameter at the base of the trunk and the species of trees to be felled affected the condition of the theoretical production of bulldozers [6]. It should be noted that in the method of evaluating road works, only the felling of trees with a circumference greater than 1.5m (diameter greater than or equal to 50cm) measured at 1m from the ground is remunerated [6]. All other trees below this circumference are classified as shrubs [6]. The felling times of a tree according to the diameter by new bulldozers, the blade perfectly adjusted, working under ideal conditions are listed in Table 2.

Table 2. Time in minutes to fell a tree

Bulldozers Caterpillar	Available power at the wheel	Time (M) in minutes to fell a tree by diameter category (min/tree)		
		M_1 for diameter from 60 to 90cm	M_2 for diameter from 90 to 120cm	M_3 for diameter from 120 to 180cm
D6R	123KW (165HP)	3.4	6.8	Insufficient power for slaughter
D7R	171KW (230HP)	1.7	3.3	10.2
D8R	228KW (305HP)	1.3	2.2	6
D9R	302KW (405HP)	0.4	1. 3	3

KW = Kilowatt, HP = Horsepower, 1KW = 1.341HP = 1.36CV.

The time (T) per hectare takes into account the number (N) of trees per hectare in each diameter category, obtained during the field study as shown in Equation (1) [6].

$$T = \alpha(M_1 \times N_1 + M_2 \times N_2 + M_3 \times N_3), \tag{1}$$

where T is time per hectare in minutes and α is percentage of hardwoods.

According to caterpillar, the percentage of hardwoods encountered in the field affects the total time T as follows:

75 to 100%: add 30% to the total time $(\alpha = 1.3)$,

25 to 75%: unchanged $(\alpha = 1)$,

0 to 25%: subtract 30% from the total time $(\alpha = 0.7)$.

M_1 is the time in minutes per tree in each diameter category; N is the number of trees per hectare, in each diameter category obtained during the field study.

2.1.2. Theoretical production for stripping or clearing work making right of way without cutting down large trees

Theoretical production for these kinds of works largely depends part of the environment [6, 7]. The environmental factors that affect production are: density of vegetation, climbing plants, undergrowth, type of surface soil and so on.

The theoretical production of caterpillar bulldozers according to their power, to the type of vegetation and the ideal working conditions [6, 7] is mentioned in the Table 3. In this Table 3, all shrubs are considered to be vegetation and, the base time per hectare mentioned is established for average vegetation.

Table 3. Time in minutes for stripping work or clearing of right-of-way

Caterpillar bulldozers	Available power at the wheel	Basic time per hectare in minutes	Time in minutes to cover one hectare of land depending on the vegetation		
			Sparse vegetation (Less than 990 shrubs/ha)	Average vegetation (990 to 1480 shrubs/ha)	Dense vegetation (more than 1480 shrubs/ha)
			Corrective coefficient: 0.7	Corrective coefficient: 1	Corrective coefficient: 2
D6R	123KW	85	$85 \times 0.7 \approx 60$	$85 \times 1 = 85$	$85 \times 2 = 170$
D7R	171KW	58	$58 \times 0.7 \approx 41$	$58 \times 1 = 58$	$58 \times 2 = 116$
D8R	228KW	45	$45 \times 0.7 \approx 32$	$45 \times 1 = 45$	$45 \times 2 = 90$
D9R	302KW	39	$39 \times 0.7 \approx 28$	$39 \times 1 = 39$	$39 \times 2 = 78$

Clearance of the right-of-way for roadworks requires also, in this same operation, the evacuation of the products out of the cleared area. In this case, caterpillar recommends increasing by 50% the time mentioned in this Table 3.

From the elements in this Table 3, the theoretical hourly production of a given Bulldozer will be deducted according to the type of vegetation. Thus, for the clearance of the right-of-way within the framework of road works (time to be increased by 50%), a caterpillar D6R bulldozer in medium vegetation will do a time $T = 1.5 \times 85$min/ha = 128min/ha. This, gives a theoretical hourly production equal to 60min/T = 60/128ha = 0.47ha. Under the same conditions, the theoretical hourly production of a caterpillar D7R is equal to 0.68ha. It follows that a bad appreciation of the vegetation in the area to treat, will have enormous consequences on the execution of the work.

In order to reduce the risk of errors, a preliminary study is necessary to recognize the type of vegetation (dense, medium or sparse) as shown by [5]. For this purpose, it will be necessary to traverse the zone concerned to determine the surface covered by each type of vegetation and to carry out at least three quantitative surveys of shrubs in each zone. These counts are made by taking two points spaced 100m apart. The vegetation is counted and measured along the line connecting these two points over a width of approximately 5m from each side. This gives the quantity of shrubs on 1/10ha. This simple method has its shortcomings. However, if the sampling is carefully done, these shortcomings are minimized and the result much more realistic.

2.1.3. Theoretical production for earthworks

Most materials are moved with bulldozers. However, theoretical production depends on the following characteristics: the power of the machine; the type and the capacity of the blade; the duration of the cycle; and the density of the material to be moved [8, 9]. Thus, Equation (2) is used to calculate the theoretical production.

$$P_T = B_C \times N_C, \tag{2}$$

where P_T is the theoretical production $(\mathrm{m}^3/\mathrm{h})$; B_C is the blade capacity; N_C is the number of cycles per hour.

For the type of blade, it is important to specify that the blade here is the dozer placed in front of the bulldozer, to allow the delivery of materials. The lower part of this blade is in contact with the soil during work. These lower parts are fixed with bolts, metal plates which are also called wear blades or sharp edges. The cant cylinders mounted today on the dozer's arms increase the productivity and versatility of these bulldozers. Thus, along the pivot axis of the blade, following the operation of tilt cylinders, a bulldozer can also be a tiltdozer or a tipdozer. It takes the name of angledozer when the blade can be oriented obliquely to the direction of travel. Depending on the type of bulldozer and its variants, several blades or dozers were manufactured. The Tables 4 and 5 show the working speed of some caterpillar bulldozers [6]. These working speeds make it possible to calculate the theoretical production per linear meter, or kilometer of the creation of ditches by dividing them, by the number of passes of blades or rippers. Taking into account all the technical data, the calculation formula and the theoretical production, the production for earthworks has been established and shown in Table 6. The results in this table relate to the earthworks of the abundant dry earth with a dry volumic mass of $1300 kg/m^3$. When it comes to clay, gravel or other, it will be necessary to multiply the results of this table by the correction coefficient 1300/w. w being the density of the material to be earthed such as show in Table 7.

Table 4. Working speed of some caterpillar bulldozers

Caterpillar bulldozers	D6R	D7R	D7G	D8R	D9R	D10R
First speed (To go)	3.9km/h	3.7km/h	3.7km/h	3.5km/h	4km/h	4km/h
Second speed (on the return)	8.7km/h	8.3km/h	7.9km/h	8.1km/h	8.4km/h	8.9km/h

Table 5. Number of cycles per hour according to the average cycle time per distance

Distance	15m	30m	50m	60m	100m	120m	150m
Number of cycles	100	60	35	30	16	14	12

Table 6. Theoretical production of bulldozers for earthworks according to the type of blade

Caterpillar bulldozers	Available power at the wheel	Blade type	Blade capacity (m^3)	Production in m^3/h of abundant material with density $1300 kg/m^3$, depending on the delivery distance in meters						
				15m	30m	50m	60m	100m	120m	150m
D6R	123KW (165HP)	U	–	–	–	–	–	–	–	–
		SU	5.62	562	337	196	168	90	78	67
		S	3.70	370	222	129	111	59	51	44
D7G	149KW (200HP)	U	6.70	670	402	234	201	107	93	80
		SU	–	–	–	–	–	–	–	–
		S	4.20	420	252	147	126	67	58	50
D7R	171KW (230HP)	U	8.34	834	500	291	250	133	116	100
		SU	6.86	686	411	240	205	109	96	82
		S	5.16	516	309	180	154	82	72	61
D8R	228KW (305HP)	U	11.70	1170	702	409	351	187	163	140
		SU	8.68	868	520	303	260	138	121	104
		S	–	–	–	–	–	–	–	–
D9R	302KW (405HP)	U	16.40	1640	984	574	492	262	229	196
		SU	13.50	1350	810	472	405	216	189	162
		S	–	–	–	–	–	–	–	–

Table 7. Average volumic mass values of some types of soil

Type of soil	Volumic mass (kg/m^3)	
	Natural, in place	Loose, abundant
Dry clay	1600	1200
Wet clay	2200	1600
Dry earth	1600	1300
Wet earth	2000	1600
Dry gravel	1800	1600
Wet gravel	2200	1900
Dry sand	1600	1400
Wet sand	2100	1900
Limestone rock	2600	1500
Gypsum rock	2800	1700

For example, if these last two tables (Tables 6 and 7) are taken into account, the theoretical production for earthmoving or stacking at the limestone rock quarry with a D6R blade bulldozer (SU) over an average delivery distance of 50m is equal to $196 \times 1300/2600 = 98\text{m}^3/\text{h}$.

2.1.4. Theoretical production for rocket work or smashing the rock

Powerful bulldozers equipped with single-tooth rippers, today make it possible to disaggregate several categories of rock which formerly required blasting [6]. If necessary, a preliminary backfiring allows to fragment the material and allow good penetration of the ripper tooth. Theoretical production for rocket or smashing the rock depends on the hardness of the rock to be fragmented [6]. This hardness is determined using seismographs with refractions that measure the speed of sound in the ground. At a seismic speed not exceeding 3000m/s, the rocks are practically knocked off by bulldozer rippers. Above 3000m/s their blasting is essential [6]. For a better cleanup with bulldozers, it is better to use those with a power greater than or equal to 228KW (305HP) [6, 10].

Tables 8 and 9 show the seismic speed limit for each type of bulldozer and their hourly theoretical production.

Table 8. Seismic speed limit for each bulldozer

Bulldozers equipped with ripper	Available power at the wheel	Seismic speed above which rocket work is impossible
D8R	228KW (305HP)	2000m/s
D9R	302KW (405HP)	2500m/s
D10R	425KW (570HP)	2700m/s
D11R	634KW (850HP)	3000m/s

Table 9. Hourly theoretical production of fragmented rock

Bulldozers with single-tooth rippers	Power (KW)	Theoretical production in m^3/h of fragmented rock according to the seismic speed							
		800 (m/s)	1000 (m/s)	1250 (m/s)	1500 (m/s)	1700 (m/s)	2000 (m/s)	2500 (m/s)	2700 (m/s)
D8R	228	1700	1500	1250	950	750	500	–	–
D9R	302	1900	1700	1300	1100	900	600	250	–
D10R	425	2300	2100	1750	1350	1100	750	350	–

Unfortunately, the information received at the office of Geological and Mining Research prove the nonexistence of a seismograph in the study area. This is why the contractors use the means available to them for the cleanup work. So, it can be concluded that, certain accurate machines are lacking during construction projects. This situation can result in bad construction despite the good quality of the pavement materials.

2.1.5. Theoretical production of graders by task

2.1.5.1. Theoretical production for preparatory work for the Subgrade, the implementation of the wearing course and the cleaning of the area

The production corresponds to the surface cleaned or worked per hour [6, 10]. This production is calculated by multiplying the working speed by the effective cutting width of the blade as shown in Equation (3).

$$P_T = L_C \times s/10, \tag{3}$$

where P_T is the theoretical production (ha/h); L_C is width of the cut (m); s is the speed (km/h).

As the shield which carries the blade is generally oblique during the movement of the material, the actual width of material swept by the shield corresponding to the effective width of cut of the blade is a function of the angle of inclination α expressed in degrees as shown in Equation (4).

$$L_C = L_B \times \sin\alpha, \tag{4}$$

where, L_C is width of the cut (m); L_B is length of the blade; α is the angle between the front frame and the front point of the shield.

As for the working speed, it should be noted that for all work intensive with machines, the first forward speed is the recommended working speed because working at low speed reduces wear and breakage of certain parts and prolongs the service life of the machine. Only light reprofiling can be done using the second speed.

Table 10 gives the theoretical production of graders caterpillar for the cleaning of the area, the preparation of the platform and the implementation of the wearing course with the blade tilted at 60 degrees.

Table 10. Hourly theoretical production of caterpillar graders commonly for cleaning the area with a blade pass

Caterpillar grader model	Power at the wheel	Blade or shield length (m)	Effective blade cutting width for an angle of 60 degrees (m)	Working speed: First forward speed (m)	Production (ha/h)
120G	93KW (125HP)	3.66	3.17	3.9	1.2
120B	93KW (125HP)	3.66	3.17	4.2	1.3
130G	101KW (135HP)	3.65	3.17	3.7	1.1
140G	112KW (150HP)	3.66	3.17	3.9	1.2
12G	101KW (135HP)	3.67	3.17	3.7	1.1
14G	134KW (180HP)	4.27	3.7	3.7	1.3

2.1.5.2. Theoretical production for reprofiling work, creation and cleaning of ditches and so on

Theoretical production corresponds to the number of linear kilometers of reprofiled pavement, implemented platform or created ditches [6, 10]. This production is a function of the average speed of the grader and the number of passes of the blade as shown in Equation (5).

$$P_T = s \times N_P, \tag{5}$$

where P_T is the theoretical production (km/h); s is average speed (km/h), N_P is number of passes.

Light reshaping work can be done with first speed or second speed with three (3) regulatory passes on a 5 to 7m pavement, while the other aforementioned work must be done at first speed with a number of passes which takes into account the nature of the soil [6]. Table 11 shows the Hourly theoretical production of caterpillar graders commonly used in the study area for the reshaping of a 5 to 7m pavement.

Table 11. Hourly theoretical production of caterpillar graders commonly used for the reshaping of a 5 to 7m pavement

Caterpillar grader model	Power at the wheel	First speed (km/h)	Second speed (km/h)	Average speed (km/h)	Number of blade passes	Hourly production (km/h)
120G	93KW (125HP)	3.9	6.2	5	3	5/3 = 1.6
120B	93KW (125HP)	4.2	6.4	5.3	3	5.3/3 = 1.7
130G	101KW (135HP)	3.7	6	4.3	3	4.3/4 = 1.6
140G	112KW (150HP)	3.9	6.3	5.1	3	5.3/3 = 1.7
12G	101KW (135HP)	3.7	6	4.8	3	4.8/3 = 1.6

2.1.5.3. Theoretical production of wheel loaders

The loaders are mainly used for loading and transport of materials over very short distances [2, 6]. The theoretical production of the loaders is given by tables. This production depends on the capacity of the bucket; cycle time and fill factor [10] as shown in Equation (6).

$$P_T = B_V \times \zeta, \tag{6}$$

where P_T is the theoretical production $(\mathrm{m}^3/\mathrm{h})$; B_V is bucket volume (m^3), ζ is fill factor.

Furthermore, the filling factor of the bucket depends on the nature of the material. This coefficient is equal to 100% when the material to be loaded or to be transported is ordinary soil abundant. In other cases, the filling factor is 95% for ordinary earth; 85% for compacted earth; 75% for well dynamited rock and 60% for rock block.

As for the cycle time for a loader, it is equal to the time necessary to load the bucket, turn the machine, move it, empty the contents of the bucket and return the machine to its initial position [6]. This cycle time varies between 0min; 40min and 0.60min, taking into account the type of material, for wheel loaders (the kind mainly used in the study area for loading material) [10]. This made it possible to find the number of cycles per hour and to establish in Table 12, the theoretical production for abundant material [10].

Table 12. Theoretical production in m^3/h of abundant lateritic material

Caterpillar loader model		906	924	928G	938G	950G	966F	970F
Bucket volume (m^3)		1	1.5	2	2.5	3	3.5	4
Duration of cycle (min)	Number of cycles/hours							
0.40	150	150	225	300	375	450	525	–
0.45	133	133	200	268	332	400	466	530
0.50	120	120	180	240	300	360	420	480
0.55	109	109	164	218	272	328	386	436
0.60	100	100	150	200	250	300	350	400

2.1.5.4. Theoretical production of compactors

The production of compactors is expressed in cubic meters compacted per hour (m^3/h) [6]. This production depends on three essential factors which are: soil type, water content and thickness of the layer to be compacted [6, 7].

These factors have a direct influence on the number of passes required. Theoretical production is calculated by Equation (7).

$$P_T = L_w \times s \times T_{CL}/N, \tag{7}$$

where P_T is the theoretical production (m^3/h); L_w is working width at each pass (m) (for compactors with two smooth drums, the working width at each pass is twice the width of a drum); s is average speed (km/h), T_{CL} is thickness of the compacted layer (mm); N is number of passes required to obtain the desired compaction (can only be determined from a test section).

Compaction equipment is often chosen based on the type of soil [6]. For dirt roads in tropical area such as at the study area, tire compactors and those with smooth or vibrating cylinders are commonly used because they are well suited for compacting lateritic gravels or ordinary soils. Equation (7) is used to determine the results shown in Table 13 for tire compactors commonly used in studied areas.

Table 13. Theoretical production of tire compactors for a single pass (m^3/h)

Compactor of tire	Compaction width	Number of passes	Average speed	Thickness of the compacted layer			
				100mm	150mm	200mm	250mm
Ps 150 and Ps 200	1.73	1	6.5	1122	1684	2245	2806
			9.5	1640	2460	3280	4100
			13	2245	3367	4490	5612
Ps 300 and PF 300	1.9	1	6.5	1235	1852	2470	3087
			9.5	1805	2707	3610	4512
			13	2470	3705	4940	6175
Ps 500	2.42	1	6.5	1573	2359	3146	3932
			9.5	2299	3448	4598	5747
			13	3146	4719	6292	7865

2.2. Practical machine production

It is almost impossible for a construction machine to work continuously for 8 hours a day [6, 7]. There are always interruptions and unforeseen events due to the operator. The competence of the driver, the working conditions and the organization of the site are the main factors which determine the efficiency of the machines at work [6]. The efficiency coefficient depends on the correction coefficient for working conditions, the production correction coefficient due to the operator and the coefficient due to the condition or age of the machine and the organization set up [6]. The practical production of the machines is calculated by Equation (8):

$$P_P = P_T \times \alpha_C, \tag{8}$$

where P_P is Practical production; P_T is theoretical production; α_C is appropriate correction coefficient.

Since nothing can be done perfectly even in the best-case scenario, it should be noted that it is almost impossible on a construction site to have at the same time an excellent driver, ideal working conditions and excellent organization. This is why, under the favorable working and organizational conditions with an excellent driver, specialists use 0.83 as the efficiency coefficient which is suggested by [6]. This gives an average usage period of 50 minutes per hour. In difficult working conditions, after combination, they retain 0.67 as the efficiency coefficient; or a usage time of 40 minutes per hour which is suggested by [6]. Below this value, it is necessary to review the factors which influence the working efficiency of the machines during the execution of the works.

By this result, a contractor sure of his organization and the means to implement can apply at his risk, a correction coefficient in the range from 0.67 to 0.83; which will allow it to be competitive in the market [6].

On the other hand, for a contractor who is taking his first steps in this field, the practical production to be considered in the calculations must be as low as possible [6]. Thus, the correction coefficient for theoretical production must fall outside this range from 0.67 to 0.83 for the following aspects:

(1) At the beginning, most of the equipment will be rented,

(2) the driver has never been tested by the contractor who will rent the machine,

(3) the condition of the equipment is not known in advance,

(4) Diesel theft cases on site,

(5) The advance that the rental company will claim.

Clearly the young contractor will work in very difficult conditions and he will want to put a profit margin.

For these cases of uncertainty of a beginner contractor, the aspects listed above obliges him to apply a reduction of 0.20 on the correction coefficient 0.67, which is initially expected in difficult working conditions. Consequently, this contractor finds himself in a safety margin which, once the contract has been obtained, will take all the necessary measures to have a production above 37% of the theoretical maximum production of the machines whatever the site conditions.

By putting us in the cases of this contractor, all the theoretical maximum productions initially known in the catalog Caterpillar will be brought back to 37% of their value to find the practical productions to be considered to improve the performance of soil or pavement.

For this case study a practical production of 0.37 was applied to the maximum theoretical production of the machines as shown by Equation (9).

$$P_P = 0.37 P_T, \tag{9}$$

where P_P is practical production; P_T is theoretical production.

2.3. Cost of operating machines using 0.37 as appropriate correction coefficient

Because of the inability to attach the complete dossier for this study to call for tenders to our case study, the quantitative estimate of this study of call for tenders, making it possible to estimate the operating cost of the equipment necessary for the execution of this work. The machines were chosen according to the role assigned to them.

After the site visit, and using the data from the call record of offers, a list of the necessary equipment was drawn up in order to deduce, with regard to the fleet, the additional equipment. Thus, rental commitments could be raised from potential rental companies, such as the Public Works equipment company or other companies.

It is important to note that, since the equipment rental prices vary from one company to another and that the prices are charged by the public works equipment Company are representative of the fact that they are close to the average, also practiced by other companies, the contractor may decide to rent the equipment from the latter or even take as a reference the rental rate thereof.

In addition, as for the calculation of the practical production of the machines to be mobilized, knowing that everything is not perfect in the best of all worlds, the contractor will choose a correction coefficient for the theoretical production of the machines [190]. In this specific study case, the coefficient 0.37 is used to correct the theoretical productions of the machines to be mobilized. Besides, to determine the hourly consumption the Equation (10) is used.

$$Z = \frac{Y \times P}{\rho}, \tag{10}$$

where Z is hourly consumption (l); Y is consumption (g/CV/h); P is power (CV); ρ is fuel volumic mass (g/l).

3. Results and Discussion

3.1. Basic fuel consumption of the machines

The Table 14 shows the basic fuel consumption values of the machines in studied area. It is important to notify that:

(1) The price of a liter of diesel at the pump during the research is 0.63 USD,

(2) Concerning the choice relating to the brand and the type of truck to be used, it is impossible to give in this Table 14, the brand and the type of trucks and vehicle carrier, that mentioned constitutes the average.

Table 14. Basic fuel consumption values of the machines

Material designation	Power (CV)	Hourly consumption	
		Volume (liter)	Price (USD)
Bulldozer Cat. D6R	167	29	18.14
Bulldozer Cat. D7G	203	35	21.89
Bulldozer Cat, D7R	233	41	25.64
Grader Car. 12G	162	28	17.51
Grader Car. 120B and l20G	126	22	13.76
Chargeuse Car. 924	126	22	13.76
Self-propelled compactor PF200 and PF300	109	1 9	11.88
Hand vibrating compactor	2 to 3	01	0.63
Cement mixer (300L)	2 to 3	01	0.63
Motor pump $30m^3/h$	2 to 3	01	0.63
Generator	24	04	2.50
Machine carrier		30	18.76
Dump truck 6/7m		15	9.38
Water tank truck 10/12		15	9.38
Diesel tanker truck		15	9.38

3.2. Estimated cost of operating machine

The equipment rental price of the works public material company, served as the basis for determining the elementary hourly price of the following machines [11]. The public works equipment company is the only structure in the study area, which has a national scope and agencies in all departments of the country to respond quickly to the rental needs of companies. No other company has agencies everywhere. This is why the rental prices of the public works material company are known almost everywhere in the study area. Table 15 shows the rental rate of the public works material company from 2013 in Republic of Benin. And, Table 16 shows the hourly basic price of equipments.

Table 15. Material rental rates (excluding taxes)

Designations	Hourly price (USD)	Daily price (USD)
Bulldozer CAT D7G	91.28	
Bulldozer CAT D6D	57.31	
Grader KOMATSU GD 623 A	63.84	
Grader CAT 120B / Fiat G70G	56.25	
Loader CAT 950	57.71	
Self-propelled compactor PS 300	42.88	
Self-propelled compactor PS 200	38.21	
Vibrating Compactor	9.55	
Towed compactor	24.41	
Road tractor RVI KERAX 380	41.64	
Road tractor RVI KERAX 380 + RQ	55.54	
Road tractor MITSUBISHI FV 415	33.28	
Road tractor MITSUBISHI FV 415 + RQ	47.17	
Towed compactor + agricultural tractor	38.21	
Agricultural tractor	13.80	
Agricultural tractor + agricultural trailer	41.39	
Machine carrier trailer	13.89	
Agricultural trailer	27.60	
Dump truck 7m^3	23.98	96.49
Dump truck 5m^3	15.67	85.77
Truck point in time	33.96	
Workshop truck	38.21	
Truck crane	27.60	
Tray truck	22.29	
Service station truck	31.84	
Tank Truck 10/12m^3	31.84	128.65
Tank Truck 6m^3	28.66	96.49
Mobile tank	2.01	

Table 15. (Continued)

Designations	Hourly price (USD)	Daily price (USD)
Fuel Tank		23.22
Motor Pump $30m^3/h$		21.23
Generator	5.83	
Compressor	3.41	
Factory Coated	16.51	
Cement mixer 100L/300L		63.68
Cement mixer 280L		94.34

Table 16. Hourly basic price of equipments

Designations	Hourly price (USD)	Fuel (USD)	Basic price (USD)
Bulldozer CAT D7G	91.28	21.89	113.17
Bulldozer CAT D6D	57.31	18.14	75.45
Grader KOMATSU GD 623A	63.84	18.14	81.98
Grader CAT 120B / Fiat G70G	56.25	13.76	70.01
Loader CAT 950	57.71	13.76	71.47
Self-propelled compactor PS 300	42.88	11.88	54.77
Self-propelled compactor PS 200	38.21	11.88	50.09
Vibrating compactor	9.55	0.63	10.18
Towed Compactor	24.41		
Road tractor RVI KERAX 380	41.64	18.76	60.41
Road tractor RVI KERAX 380 + RQ	55.54	18.76	74.30
Road tractor MITSUBISHI FV 415	33.28		
Road tractor MITSUBISHI FV 415 + RQ	47.17	18.76	65.93
Towed compactor + Agricultural tractor	38.21		
Agricultural tractor	13.80		
Agricultural tractor + Agricultural trailer	41.39		
Machine carrier trailer	13.89		

Table 16. (Continued)

Designations	Hourly price (USD)	Fuel (USD)	Basic price (USD)
Agricultural trailer	27.60		
Dump truck $7m^3$	23.98	9.38	33.36
Dump truck $5m^3$	15.67	9.38	25.05
Truck point in time	33.96	9.38	43.34
Workshop truck	38.21	9.38	47.59
Truck crane	27.60	9.38	36.98
Tray truck	22.29	9.38	31.67
Service station truck	31.84	9.38	41.22
Tank truck $10/12m^3$	31.84	9.38	41.22
Tank truck $6m^3$	28.66	9.38	38.04
Mobile tank	2.01		
Fuel tank			
Motor pump $30m^3/h$		0.63	
Generator	5.83	2.50	8.33
Compressor	3.41		
Factory coated	16.51		
Cement mixer 100L/300L		0.63	
Cement mixer 280L		0.63	

3.2.1. Determination of intermediate prices

The development of unit prices requires the determination of certain prices, not contained in the tender documents, but which the informed entrepreneur calculates upstream because of their involvement in one or more prices of the price list [11]. These prices, not contained in the tender documents, are often called intermediate prices [11]. As intermediate prices, it can be quoted for example, the price of water returned on site and of the stacking of gravelly [11].

The production of the $12m^3$ tanker truck is estimated at $12m^3$ of water per hour for:

(1) an average transport distance equal to 15km;

(2) an average speed of 60km/h;

(3) filling and watering time equal to 1 hour.

Thus, $1m^3$ of water brought to the site is done in 0.08 hours such as shown in Table 3-17.

The stacking of lateritic gravels initially requires the stripping of top soil [7-11]. Thus, practical production for stacking lateritic gravels in the difficult conditions for bulldozer D7G cat blade U is equal to $45m^3/h$ or $360m^3$ per day of 8 working hours. This gives 0.022 hours of work for $1m^3$ of material such as shown in Table 18.

Concerning the supply of gravel over an average distance of 5km, the practical production of the 924-cat loader for a cycle time of 0.60 min in difficult conditions is equal to $55m^3/h$ or $440m^3$ per 8h/day [7-11].

In our case, it was estimated that a $7m^3$ truck, over an average distance of transport equal to 5km, can in difficult conditions deliver two loads per hour. Which gives a practical production of $14m^3/h$ or 0.071h for $1m^3$ of material such as shown in Table 19.

Table 17. Hourly cost price of equipments

Designations	Unit	Quantity (m^3)	Basic price (USD)	Cost price (USD)
$12m^3$ water tanker truck	H	0.08	38.03	3.05
Motor pump $30m^3/h$	H	0.08	3.06	0.24
Equipment cost price per m^3				3.29

Table 18. Cost price of equipment for stacking lateritic gravels

Designations	Unit	Quantity (m^3)	Basic price (USD)	Cost price (USD)
Bulldozer D7G cat blade U	H	0.22	105.39	2.32
Equipment cost price per m^3				2.32

Table 19. Cost price of the equipments following the supply of gravel over an average distance of 5km

Designations	Unit	Quantity (m^3)	Basic price (USD)	Cost price (USD)
924 cat loader	H	0.018	66.58	1.20
$7m^3$ dump truck	H	0.071	30.28	2.15
Equipment cost price per m^3				3.35

3.2.2. Determination of unit prices

Besides the site installation costs which are at a fixed price, the other tasks are paid at unit prices [10, 11]. According to the designation of the tasks, the unit prices are calculated either on the basis of daily or hourly practical production or according to the intermediate prices initially calculated [10, 11].

With regard to the application price of the machines charged with backfill from borrowing showed in Table 20, this unit price is fully known from the intermediate prices. Regarding the light reprofiling of the road over 7m, the practical production of a 120B grader is 0.629km/h. Which gives 5km per day of 8 hours of work. The application price shows in Table 21, is fully known from the intermediate prices.

If for light reshaping, the grader did 5km/day, it is assumed that for heavy reshaping, it will be 2.5km per day. The 2.5km of 0.1m thick roadway gives $1.75 m^3$ of soil to compact. The PF300 compactor such as shown in Table 22, will do 10h of time (production of PF300 = $171 m^3/h$).

Table 20. Cost price of equipments of backfill from borrowing

Designations	Unit	Quantity (m^3)	Basic price (USD)	Cost price (USD)
Stacking of the gravelly	m^3	1.2	2.32	2.78
Gravel supply	m^3	1.2	3.35	4.02
Backfill layer adjustment	m^3	1.2	1.57	1.88
Total				8.68
Equipment cost price per m^3				8.68

Table 21. Cost price of equipments of light resurfacing of the road over 7m

Designations	Unit	Quantity	Basic price (USD)	Cost price (USD)
Grader	H	8	65.14	521.14
Total				521.14
Application price for unit				104.23

Table 22. Cost price of equipments of heavy resurfacing of the road over 7m

Designations	Unit	Quantity	Basic price (USD)	Cost price (USD)
Grader	H	8	65.14	521.14
PF300 Compactor	H	10	50.66	506.56
Water to bring on site	m^3	175	3.29	575.04
Cleaning of lateral ditches	km	5	84.05	420.27
Clearing divergent ditches	ml	300	0.26	78.26
Total				2101.27
Application price for unit				840.51

3.3. Evaluation and choice of correction coefficients

To show the importance of controlling the performance of equipment in road works, it will present two estimates from two different contractors. Firstly, a correction coefficient of 0.37 was applied to the theoretical production of the machines (Table 23), and secondly, a correction coefficient of 0.67 was applied to the theoretical production of the others machines (Table 24).

The second quote is more competitive than the first compared to its estimate. There was a significant difference of sixty-six thousand five hundred ninety-four point sixty-seven (66594.67) USD. With the first quote show in Table 23, to finish within the contractual period, it is important to double or triple the number of certain machines on the site, because of the low yield of machines which is applied. So, instead of two graders, it will need 3 to 4 graders to rent, which increases the cost of operating the machines, and will cause an impact on the financial offer during the tender.

Table 23. Quote on the cost of material for the correction coefficient of 0.37

Designation of work	Unit	Quantity	Unit price	Amount
Installation costs	ff	1	105208.75	105208.74
Clearance of right of way	m^2	20 000	0.04	882.69
Weeding	m^2	13 000	0.04	452.96
Clearance of work bed	U	3	432.8	1298.39
Demolition of reinforced concrete structure	m^3	44	22.89	1007.34
Demolition of unreinforced concrete structure	m^3	12	22.89	274.73
Demolition of the masonry structure	m^3	100	22.89	2289.41
Cleaning of the minor structure	U		0	0
Cleaning of gutters 0.8 × 0.5 to 1	ml		0	0
Cleaning of lateral ditches	km	10	1092.7	1092.7
Clearing of existing divergent ditches	ml	1072	0.23	241.54
Clearing divergent ditches	ml	2 080	0.33	676.42
Creation of lateral ditches	m^3	6 600	0.33	2146.32
Rock breaking for ditch creation	ml	20	9.86	197.12
Embankment from borrowing	m^3	2000	11.29	22578.22
Backfill with cuttings from excavations	m^3	0	0	0
Implementation of the wearing course	m^3	8 946	11.53	103153.53
Light reprofiling of the road over 7m	km	3.15	135.49	426.81
Heavy reprofiling of the road over 7m	km	1.85	1092.66	2021.43
Excavation	m^3	0	0	0
Concrete of cleanliness	m^2	0	0	0
Raft	ml	0	0	0
Gutters from 0.8 × 0.5 to 0.8	ml	0	0	0
Gutters from 0.8 × 0.8 to 1	ml	215	22.88	4919.74

Table 23. (Continued)

Designation of work	Unit	Quantity	Unit price	Amount
Gutters from 1 × 1 to 1.5	ml	650	31.74	20630.73
Cover slab (thickness = 15cm)	m^2	200	1.73	345.64
Scupper 1m × 1m	ml	31.2	71.68	2236.45
Scupper 2m × 1m	ml	20.4	80.79	1648.05
Scupper 2m × 2m	ml	10.4	86.55	900.12
Backfill for access to structures	m^3	1200	11.33	13599.89
Upstream and downstream head for scuppers 1m × 1m	U	3	28.82	86.45
Upstream and downstream head for scuppers 2m × 1m	U	2	48.03	96.05
Upstream and downstream head for scuppers 2m × 2m	U	1	110.46	110.46
Rubble masonry	m^3	0	0	0
Rockfill	m^3	0	0	0
Metal railings	ml	0	0	0
Blackcurrant of slowing	U	6	8.65	51.87
Type A 1000 traffic signs	U	0	0	0
Type B 800 traffic signs	U	0	0	0
Reinforced concrete beacons for turns	U	0	0	0
Reinforced concrete beacons for structures	U	24	0.15	3.68
Bounds kilometer penta	U	0		
Barrier of rain	U	0		
TOTAL				288577.48

Table 24. Quote on the cost of material for the correction coefficient of 0.67

Designation of work	Unit	Quantity	Unit price (USD)	Amount (USD)
Installation costs	ff	1	80929.8	80929.8
Clearance of right of way	m^2	20 000	0.03	678.99
Weeding	m^2	13 000	0.03	348.43
Clearance of work bed	u	3	332.92	998.76
Demolition of reinforced concrete structure	m^3	44	17.61	774.88
Demolition of unreinforced concrete structure	m^3	12	17.61	211.33
Demolition of the masonry structure	m^3	100	17.61	1761.09
Cleaning of the minor structure	U			
Cleaning of gutters 0.8 × 0.5 to 1	ml			
Cleaning of lateral ditches	km	10	84.05	840.54
Clearing of existing divergent ditches	ml	1072	0.17	185.80
Clearing divergent ditches	ml	2 080	0.25	1646.02
Creation of lateral ditches	m^3	6 600	0.25	1651.02
Rock breaking for ditch creation	ml	20	7.58	151.63
Embankment from borrowing	m^3	2000	8.68	17367.86
Backfill with cuttings from excavations	m^3	0		
Implementation of the wearing course	m^3	8 946	8.87	79348.87
Light reprofiling of the road over 7m	km	3.15	104.23	328.32
Heavy reprofiling of the road over 7m	km	1.85	840.51	1554.94
Excavation	m^3	0		
Concrete of cleanliness	m^2	0		
Raft	ml	0		
Gutters from 0.8 × 0.5 to 0.8	ml	0		
Gutters from 0.8 × 0.8 to 1	ml	215	17.60	3784.42

Table 24. (Continued)

Designation of work	Unit	Quantity	Unit price (USD)	Amount (USD)
Gutters from 1 × 1 to 1.5	ml	650	24.42	15869.79
Cover slab (thickness = 15cm)	m^2	200	1.33	265.88
Scupper 1m × 1m	ml	31,2	55.14	1720.35
Scupper 2m × 1m	ml	20,4	62.14	1267.73
Scupper 2m × 2m	ml	10.4	66.58	692.40
Backfill for access to structures	m^3	1200	8.72	10461.46
Upstream and downstream head for scuppers 1m × 1m	U	3	22.17	66.50
Upstream and downstream head for scuppers 2m × 1m	U	2	36.94	73.88
Upstream and downstream head for scuppers 2m × 2m	U	1	84.97	84.97
Rubble masonry	m^3	0		
Rockfill	m^3	0		
Metal railings	ml	0		
Blackcurrant of slowing	U	6	6.65	39.90
Type A 1000 traffic signs	U	0		
Type B 800 traffic signs	U	0		
Reinforced concrete beacons for turns	U	0		
Reinforced concrete beacons for structures	U	24	0.12	2.83
Bounds kilometer penta	U	0		
Barrier of rain	U	0		
TOTAL				221982.68

If, for example, two graders are maintained, as in the case of the second quote, poor quality work will be done within the contractual period. The second quote (Table 24) is competitive, and with this quote, not only will tenders always be won, but also will make the investment profitable. This demonstrates the importance of controlling the performance of machines for road works.

In addition to economic reasons, and the delay in the works, the non performance of the machines can lead to a poor improvement of the soil. Hence, checking the quality of the machines is necessary during the construction of the pavements in order to succeed, not only a good improvement of the soil, but also for a good performance of the structures.

Furthermore, the machines are progressively accumulated into technological progress, as much for their power and their precision as for their safety and the comfort of their operators. This has made even more spectacular achievements possible in all fields (land, maritime ...) and in all climates.

Since, on arable soils, the passage of heavy machinery often causes compaction, it is important to take care of everything related to the condition and the quality of the machines during the construction works or during the improvement of the soil. Based on the results, the theoretical productions of the machines must be corrected by appropriate factors linked to the conditions under which the works will be executed. Consequently, for a reassuring determination of the operating cost of the machines, this research proposes also considers, if the machines to be used, are not new or not performant, then consider if the machines will work in difficult conditions using as a correction coefficient 0.37. But, if the machines are new or performant, then consider a correction coefficient 0.67.

4. Conclusion

This research in no way pretends to have identified the whole outline of the problems linked to the control of the performance of the machines and to the estimation of their operating cost. But this research proposes a method which certainly deserves to be refined further to assist companies specializing in road construction, to avoid the underestimation of bid prices (dumping) and the bad organization of earth road worksites.

Machines and materials hold an essential place in public works since the construction boom and changes in the dynamics of production and machinery for road works are correlated. With the demand for new roads and the development of new habitats which continue to increase, the need for roadworks equipment becomes important. For a rational use of the machines on a road construction site, their choice must be based on a excellent knowledge of the methods of construction of pavement.

To attain all soil improvements, the contractor or the engineer in civil engineering must surround himself with reassuring guarantees to avoid situational offers that do not consider the realities related to the execution of the works. This is why the present research has reported a certain number of tables and formulas that make it possible to estimate the machines' production with the works' execution conditions. A reassuring determination of the equipment's operating cost suggests to small and medium-sized enterprises in the road sector who want to try their hand in this area to consider that the machines to be used will work even under challenging conditions. The machines' theoretical productions must be corrected by an appropriate correction coefficient linked to the conditions under which the works will be executed. Therefore, this research is proposed as a proper correction coefficient of 0.37, if the machines to be used are not new or are not performant. An appropriate correction coefficient of 0.67 if the machines to be used is new or are performant. Certain endogenous factors could influence this correction coefficient 0.37 and lead the civil engineer contractor to make adjustments.

Moreover, during the works' execution, the contractor or civil engineer may also use the tables that specify the degree of influence of the machines' factors of production to check if his calculations agree with the realities of the site. This will contribute to controlling the works in their evolution and the correct keeping of the analytical accounts. The part of research in no way pretends to have identified the whole outline of the problems linked to the control of the machines' performance and the estimation of their operating cost. But this research proposes a method that certainly deserves to be refined further to avoid companies specializing in road construction underestimating bid prices (dumping), and the bad organization of earth road worksites. If this approach finds a favourable response, it could be improved by more knowledgeable and published specialists to allow its implementation by small and medium enterprises. This will contribute to their promotion, and as soon as they have mastered the techniques of building earth roads, the study area in the tropical areas state will also have to gain because the competition space would be more enlarged. As a corollary, it would not fail to influence the very high costs of inevitable roadworks. To this end, and with a view to sustainable development, the following suggestions could be studied by decision-makers:

(1) Training or retraining of contractors or/and civil engineers on an earth road construction site's organization. This training will be seen in terms of programming, mobilization, and rational use of equipment, since most business leaders do not prioritize the investment of their resources in staff training;

(2) The organization of an experience exchange workshop in the field of material management between, contractors, mechanicians, equipment rental companies and representatives of contracting authorities;

(3) The organization of brainstorming sessions on ways and means can encourage local businesses to take an interest in construction or the rehabilitation of paved roads.

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