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CONTRIBUTION TO OPTIMIZATION OF SUPPLIES PROGRAMMING OF CONSTRUCTION SITES LOCATEDIN ENCLOSED AREAS: CASE OF CAMEROON

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ABSTRACT

Numbers of projects are carried out beyond contractual deadlines or abandoned, and the feedback shows that it's principally due to problems of refuelling materials. Indeed, in construction sites, the management of physical flows is strongly linked to road transport parameters, which is more complex in developing countries because the road network is embryonic and unsafe at certain times of the year. This article deals with this great difficulty by relying on a construction supply programming model that takes into account the fluctuating composite state of the road network due to the heterogeneity of pavement degradation and state of traffic on road's sections. In order to achieve this goal, we have developed a formula for estimating trucking time whose parameters accommodate the temporal and spatial distributions of the different states of degradation and traffic on the tracks. Then replenishment rules have been proposed through the order date and the minimum quantity of materials required. The application of our model to a construction site located in Bengbis, at 285 KM from Yaounde shows a total travel time of 680 minutes including 500 minutes for crossing of the route and 180 minutes for stopping time. From the forecast on trucking times, we better controlled the uncertainty in supply programming.

KEYWORDS: Physical flows, road network, trucking time, replenishment rules.

1. INTRODUCTION

Generally, civil engineering worksites are intimately linked to material supply mechanisms, and it is noted that the poor mastery of these leads to delays in construction.[12] In fact, the completion of construction sites in time is problematic in many developing countries such as Cameroon. Among the causes of this situation, we have often forgotten the nature of supply mechanisms for building sites in isolated areas. Yet, the feedback from the abandoned building sites shows that many of them are in rural areas where access difficulties are significant. Also, several sources of materials are found in cities where traffic congestion hinders transport. This causes an unavailability in the required time of building materials, evidence of the lack of control of the physical flows of materials and which generates significant additional costs.[18] Which additional costs come mainly from the transport because it represents approximately 40% of the logistic expenses.[2] As a result, managers cannot effectively combine actions aimed at planning, optimally managing transport, the circulation of physical flows of supply and storage of materials on the building site.[1] Indeed, the path linking the supply point to the construction point, has a composite state and non-homogeneous especially to the enclosed areas. It is therefore necessary to take into account these factors, which fluctuate both with the state of the traffic and the state of the roadway. Figure 1 gives out an illustration of the inhomogeneity of the road surface and traffic, between a refuelling point located in the urban centre and construction point located in an enclosed area. Trafficdetails can be displayed on road network maps that are topographic-type maps.[21]

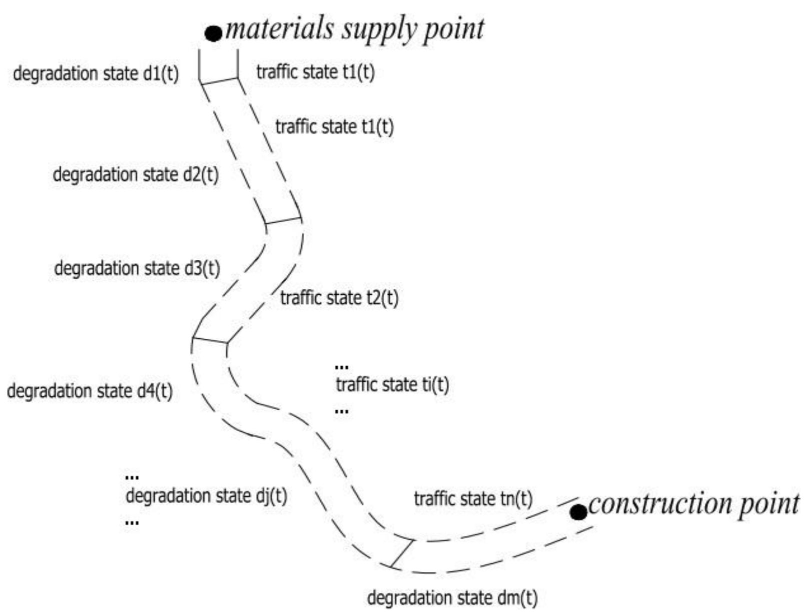

Figure 1: Arrangement of the road sections.

The congestion of the roads in urban areas and the isolation of the rural sites thus make the duration of the transport a non-Cartesian element which depends therefore on several variables of the road transport. This gives the logistics system a dynamic character that strongly influences the scheduling of tasks in advance.

In addition, the organization of supplies is one of the ISO 9000 standards which makes it possible to judge the effectiveness of a company's Quality Management System, since each construction site is considered as an agency of the company for the period of the contract.[7] Business competitiveness depends on the quality of their supply chain management system. Therefore, engineers and civil engineering professionals must not only focus their expertise on the technical aspect, but also in the management and management of physical flows of materials incorporating the parameters of road transport. This is why we opted to propose an approach that optimizes the supply programming taking into account the state of the road network and the state ofthe traffic.

This article is intended to be the showcase of a new operational and reliable supply planning tool, allowing the site manager to have adequate quantities of the different materials for the execution of the tasks on expected dates in the planning. The modelling of the construction project in sub- structures that[15,13] proposed for the case of the buildings, makes it possible to carry out a complete inventory of each quantity of material necessary to each sub-structure and according to the progress of the works. We've exploited the management of logistics circuits by schematizing different suppliers around a central point (construction site) through a georeferencing operation called *Workshops Mapping.*[5]

This article is organized into two main parts. The first part presents our approach to estimating travel time (trucking time) according to the apparent state of the road network and the traffic situation. It follows a supply planning model based on the estimation of travel time and practical inventory management techniques. In the second part, the application of the model to a construction project in an enclosed area of Cameroon is given by a simulation of its supply chain.

2. MODEL-BUILDING

The modelling concerns the computation of the transportation time (trucking time) based on the definition of a road network. Which is composed of a set of links (or sections of road) and a set of nodes (intersections between links) that we consider as a graph (X, U), where X is the set of vertices and U the set of arcs.[14] The arcs of the graph have attributes to translate the functionality of the part of the network that they represent. It is: i) the link state including the nature of the coating, the state of degradation; the length of the link; ii) the link capacity including the capacity of flow in Passenger Car Unit (PCU); iii) the position of roadside checks and road tolls, and possibly the rain barriers. Concerning the link state, we give in Table 1 the images of states of deterioration of the coating translated by the visual aspect of the link surface.

Table 1: Presentation of different categories of the link surface.[6]

Nature of the coating / State of link surface	Natural track	Dirt road	Paved road
Good			
Average			
Bad			

Mapping by Geographic Information System (GIS) mapping provides real-time traffic status and load.[8] When the itinerary is chosen, we can guide the trucker via a simplified map, a sub graph of G which presents in a more caricatured way, the nodes and links of the paths of interest. In each of these mapped supply circuits, it is necessary to know how to estimate the trip time indicator.

The transportation or trucking time of a path $\overrightarrow{AB}$ noted $TT_{\overrightarrow{AB}}$, is the duration that a mobile leaving a point A, puts to arrive at another point B. In the context of trucking, we break down this duration into two components which are **the travel time** TP_{AB} and **downtime** $TT_{\overrightarrow{AB}}$,

$$TT_{\overrightarrow{AB}} = TP_{\overrightarrow{AB}} + TA_{\overrightarrow{AB}} \qquad (1)$$

We cut the route into several arcs such as on each of them, the traffic is in a state as stationaryas possible, and the state of the road is more or less uniform.[3]

$$\overrightarrow{AB} = \bigcup_{j=0}^{n-1} \overrightarrow{A_j A_{j+1}} \text{ avec } A_0 = A \text{ et } A_n = B \qquad (2)$$

Without undermining the generality, we can illustrate this sectioning by the Figure 1.

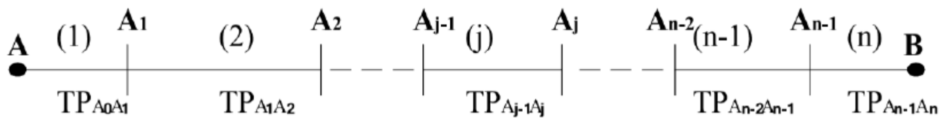

Figure 1: Sectioning of the itinerary in n arcs (for n≥2).

$$TP_{\overrightarrow{AB}} = \sum_{j=0}^{n-1} TP_{\overrightarrow{A_j A_{j+1}}} \qquad (3)$$

The formalization of the travel time on an arc is based on the 4 fundamental assumptions below: i) the arc $Lj = A_j A_{j+1}$ is well defined, i.e. the points $A_j$and A_{j+1} are geographically locatable and linked by a section of road drawn; ii) the driver is rational; iii) the traffic regimes considered arefluid diets and traffic regimes. In other words, we study the congestion by "friction" caused by the local volume of traffic; iv) we don't study the saturated regimes provoked by external causes such as incidents, accidents, queuing up from a point downstream. In other words, one does not take into account the congestion by "shock" or impact of shock.

Three great ideas have been developed in traffic engineering**[10]**, we focused on one of them: the fundamental diagram. Here, the travel time is a function $Y = TP$ defined by Equality (4).

$$Y = F(A, \Phi) \qquad (4)$$

With: A vector of endogenous parameters at the road segment such as: the type of pavement $r_m \in \{track, dirt, paved\}$; distance (length) and width dj, $lj \in \mathbb{R}+*$ in meter; the maximum speed allowed $v_j \in \mathbb{N}^*$ in km/h; the capacity of the road $Cj \in \mathbb{R}+*$ (en PCU/m); the state of the roadway $e_n \in \{bad, average, good\}$;

Φ vector of variables exogenous to the road section such as: the density of road traffic $\rho_j = \rho(t)$ (en PCU/m) and the flow of circulation q_j (en PCU/h).

From empirical observations[9], we can consider that the law TP $TP_{\overline{A_jA_{j+1}}} = \Psi(q)$ is well defined. We choose the function proposed by the US Bureau of Public Roads (BPR).

$$\Psi_{t_0,\gamma,\alpha}(x) = t_0\left(1+\gamma x^\alpha\right) \quad (5)$$

Where: $x = x_j = \frac{q_j}{C_j}$ the ratio observed flow / theoretical capacity of the arc j or reduced flow; $t_0 = t_{0_j}$ the free travel time on section j which applies when the traffic is low ($x \cong 0$), that is to say when only the state of the road degradations is taken into account; $\gamma \geq 0$ is the proportion of increase of the saturation travel time (x = 1), $\alpha \geq 0$ describes the rate of growth of the travel time when the reduced flow rate varies from 0 to 1.

Whence substituting each term, we have:

$$\Psi_{t_0,\gamma,\alpha}(x) = t_{0j}\left(1+\gamma\left(\frac{q_j}{C_j}\right)^\alpha\right) \quad (6)$$

The duration is defined a priori by d_j/v_j. But with each arc j whose coating and surface stateare defined by (r_m, e_n), we associate a slowing coefficient or **degradation parameter** $k_{F_j} = k_F(r_m, e_n)$ as[6]:

$$t_{0j} = k_{F_j} \cdot \frac{d_j}{v_j} \quad (7)$$

Hence,

$$TP_{\overline{A_jA_{j+1}}} = k_{F_j} \cdot \frac{d_j}{v_j} \cdot \left(1+\gamma\left(\frac{q_j}{C_j}\right)^\alpha\right) \quad (8)$$

We put the coefficient t_{uj} which represents the unit time or time put by meter of length of road, it is defined by:

$$t_{uj} = \frac{k_{F_j}}{v_j} \cdot \left(1+\gamma\left(\frac{q_j}{C_j}\right)^\alpha\right) \quad (9)$$

Thus,

$$TP_{\overline{A_jA_{j+1}}} = d_j \cdot t_{uj} \quad (10)$$

The evaluation of the downtime can be done by feedback in dry condition, which will constitute the downtime value TA_0: $TA_{AB_{min}} = TA_0$. In case it rains on n_0 sections of dirt road, the downtime will be:

$$TA_{AB_{max}} = TA_0 + n_0 t_{attente} \quad (11)$$

Thus, starting from the definition of the trucking time (Equation 1), and introducing the expressions obtained in equations 10 and 11, we obtain:

$$TT_{\overrightarrow{AB}} = \sum_{j=0}^{n-1} d_j \cdot t_{uj} + TA_{\overrightarrow{AB}} = \vec{d} \cdot \vec{t_u} + TA_{\overrightarrow{AB}} \quad (12)$$

The expression of the travel time depends on: the parameter of degradations state (k_F) and congestion parameters (γ and α). We conducted experiments to describe the surface condition of theroad and to estimate k_F. It is also a question of providing the values of γ and α which clearly reflect the state of the traffic. Road damage requires any driver traveling at a given speed v_{ref}, to slow downits pace of a certain fraction which we admit depends solely on the surface condition of the road. Theparameter k_F accounts for the time lost during braking on a roadway of type r_i and this, according toits degree of degradation e_j. For a reference speed for heavy vehicles v_{ref} given, we will measure the effective duration T_{eff} of path for each study of characteristics (r_i, e_j) and length $L = 100\ m$; the coefficient will be calculated by Equation 13.

$$k_F\left(r_i, e_j\right) = \frac{T_{eff} \times v_{ref}}{L} \quad (13)$$

The results of the computation of the degradation factor are presented in Table 2.

Table 2: Degradation factor.[6]

	State of link surface	Natural track		Dirt road		Paved road	
Vitesse v_{ref} (km/h)	Good	30	50	30	50	30	50
	Average	30	50	30	50	30	50
	Bad	30	50	30	50	30	50
Free travel time (min)	Good	3.50	2.10	3.50	2.10	3.50	2.10
	Average	3.50	2.10	3.50	2.10	3.50	2.10
	Bad	3.50	2.10	3.50	2.10	3.50	2.10
Effective measured time(min)	Good	4.20	3.00	3.75	2.28	3.56	2.11
	Average	7.00	4.20	4.77	2.63	4.20	2.33
	Bad	9.55	8.75	5.25	5.00	4.20	3.89
Degradationfactor	Good	1.20	1.43	1.07	1.09	1.02	1.01
	Average	2.00	2.00	1.36	1.25	1.20	1.11
	Bad	2.73	4.17	1.50	2.38	1.20	1.85

To calibrate the proportion of increase in travel time to saturation γ, it is sufficient to take the measurement of the travel time T at speed v on the study road (length d) when engorged.

$$T = \frac{d}{v} \cdot (1+\gamma) \Rightarrow \boldsymbol{\gamma} = (\boldsymbol{T} \cdot \boldsymbol{v} - \boldsymbol{d}) / \boldsymbol{d} \quad (14)$$

In practice, this value varies with the relief and is determined by experimentation.[11] In real situation, we can adopt the numerical value γ = 3 which gave us satisfactory results of the traveltimes for our experimental cases. The parameter α is 1 for heavy goods vehicles.[11]

Supply chain management of building materials cannot be limited only to the computation of the transportation time following a given supply path (from suppliers to the construction site). It's essential to have good inventory management practices which incorporate the developed trucking time calculation model for the logistics system.

The supply chain of a construction site is a succession of operations that stretch between the material suppliers and the construction site. These are the two poles that generate logistic flows in a construction site, the primary source being the site through its demand for materials. The requirement is the management of these supply flows as they support the rate of materials consumption at the site planned over the forecast period. This exercise is schematized as follows (Figure 2).

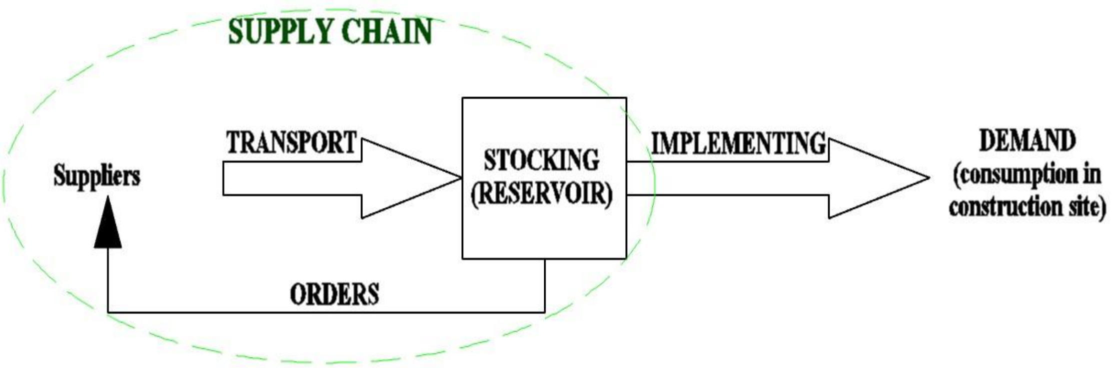

Figure 2: Representation of supply chain flux.

To manage a stock is in fact to define the rules of replenishment (date of order and quantity to be ordered) so that the cost of management is minimal taking into account the requirement to be the least often out of stock.[20] A stock level regulation mechanism is required at all times from the previous level and inputs-outputs through the fundamental equation 15.[17]

$$Stock(n) = Stock(n-1) + inputs - outputs \quad (15)$$

For each sub-structure and for any material i in the material list, we will compute the quantity needed for the site up to the planning horizon T. This quantity is the sum of two values: the tool stock and the security stock. The tool stock of the material i (So_i) is the quantity that meets the anticipated needs of the actual production on site (Formula 16). The security stock (Ss_i) is the quantity (formula 17) to cope with the hazards of delivery or consumption at the site.[19]

$$So_i = Q_i + loss = (1 + p\%) \times Q_i \quad (16)$$

Where Q_i is the quantity to be implemented, p the estimated fraction of material losses.

$$Ss_i = (maximal\ demand - average\ demand) \times replenishment\ delay \quad (17)$$

$$maximal\ demand = \max(consumptions)_{over\ T}\ [units/day] \quad (18)$$

$$average\ demand = \sum_T consumptions \Big/ T\ [units/day] \quad (19)$$

$$replenishment\ delay = transportation\ time + lading\ time + unloading\ time\ [days] \quad (20)$$

The order date t_i occurs approximately one day before the alert threshold.

$$t_i = T_i - replenishment\ delay - 1, [days] \quad (21)$$

With Ti is the horizon or period of planning.

Thus the quantity to be supplied is defined by:

$$A_i = (So_i + Ss_i) - R_i \quad (22)$$

Where Ri is the residual amount of material i in stock.

3. APPLICATION

To apply our model, we considered part of a construction of a dwelling in an enclave area of Bengbis in Cameroon. The survey conducted as part of this case study highlights a number of suppliers likely to refuel the building materials site. Inspired by[16,5], the mapping results are presented in Figure 3 and 4.

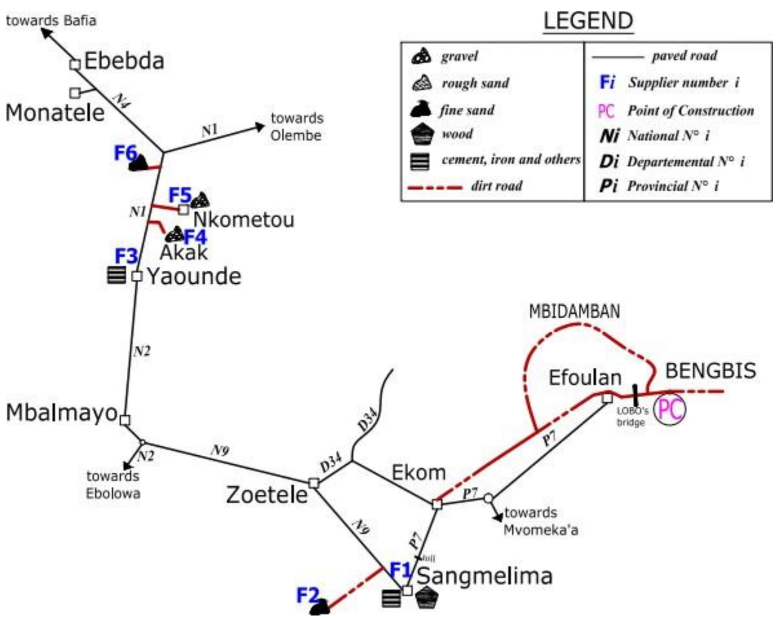

Figure 3: Workshops mapping that surrounds construction site in Bengbis.

Depending on the tasks of the structural work schedule, we simulate the site management to produce an extract of the supply plan. The first planning corresponds to the materials needed for theimplantation and prefabrication work of the foundation blocks in situ. Therefore, it only involves the slats and planks (50 and 90 pieces respectively), the quantities of sand and cement for the manufacture of basement blocks (10 x 20 x 40). There are 453 bunkers, 90 planks and 50 battens such as 1.05 tons of cement; 6 tons of Sanaga sand and 2.81 tons of wood. For a total of 9.86 tons which corresponds to a truck 10 tons.

The circuit that will have to borrow the truck is the following: Nkometou (sand Sanaga) - Sangmelima (cements and wood) -Bengbis. Assuming that the truck is at 6 o'clock instead of loading, we can make the estimated calculation of its travel time by traffic estimates. The data and calculationresults are presented in the Table 3.

Table 3: Travel time of circuit Nkometou-Sangmelima-Bengbis.

Arcs	**Coating**	**Surface state**	**Max speed**	**Reduced flow**	**Length (m)**	**Estimated time (min)**
Nkometou - N1	Dirt road	Good	50	0.1	8 000	10.43
N1 - Yaounde(Emana)	Paved road	Good	50	0.1	18 000	21.73
Yaounde (Emana) - Yaounde (Odza) *	Paved road	/	**30**	/	**24 380**	**81.13**
Yaounde (Odza) – Zoétélé junction	Paved road	Average	50	0.1	96 600	128.80
Zoétélé junction – Sangmelima	Dirt road	Average	50	0.1	40 000	60.00
Sangmelima – Meyomessala toll	Paved road	Average	50	0.1	8 870.5	11.83
Meyomessala toll – Ekom	Paved road	Good	50	0.3	15 491.31	18.70
Ekom – Mvomekaa junction	Paved road	Good	50	0.1	12 600	15.21
Mvomeka junction – Efoulan	Paved road	Good	50	0.1	44 000	53.12
Efoulan – Bengbis	Dirt road	Bad	30	0.1	17 240	51.72
Bengbis – construction site	Natural track	Average	30	0.1	500	2.00
TOTAL					**261 302 metres**	**499.68 minutes**

*: The parameters of the travel time are considered as non-uniform for crossing Yaounde (*Table* 4).

The total trucking time is 499.68 minutes for a route of 261.30 meters including 81.14 minutes and 24.38 meters for the crossing of the city of Yaoundé. We have computed the travel time of Yaounde city in details in Table 4 because we had enough of different traffic states and different road surface states.

Table 4: Travel time of Yaounde (Emana - Odza: paved road).

Arcs	Surface state	Max speed	Reduced flow	Length (m)	Estimated time (min)
Emana - Camp SIC Nlonkak (onNational N°1)	Good	30	0.1	4 200	8.54
Omnisport road - Pakita junction	Good	30	0.2	8 600	22.74
Pakita junction - Acropole newroad (Mvog Ada)	Average	30	0.6	1 500	9.00
Acropole new road - Acropole(N2)	Average	30	0.3	200	0.77
Acropole - total Mvan (N2)	Average	30	0.3	4 200	16.13
Total Mvan – Mvan junction	Average	30	0.3	280	1.08
Mvan junction – Odza junction	Good	30	0.6	3 900	19.83
Odza junction - Total Odza	Good	30	0.1	1 500	3.05
Total				**24 380**	**81.14**

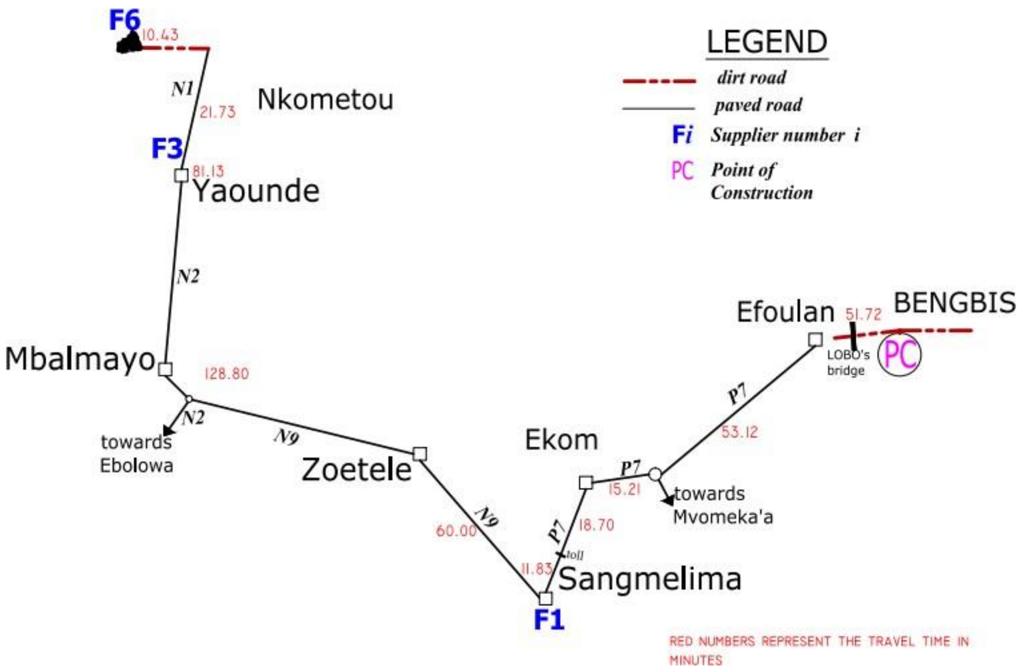

Figure 4: Drawing of Bengbis's supply chain network with arcs weights.

By adding the loading times to Nkometou and Sangmélima which are respectively 2h and 1h, we have a total estimated time of 3h. The total transportation time is finally estimated at 11h20 min. We've given in Figure 4 a schematic view of this circuit with TP of each arc or section of road(weight of the arc).

4. CONCLUSION

Entrepreneurs in developing countries find it difficult to set up a logistic supply system adapted to their context. This is because of the embryonic and fluctuating nature of the traffic way. This study aimed to establish a supply planning model based on the state of the road network. We have proposed a formula for estimating the circulation time of the physical flows of materials delivered by suppliers to the site taking into account certain factors strongly governing road transport. According to an operational planning approach, this evaluation appeared as a metrology tool for replenishments. This makes it possible to make forecasts on the transportation times taking into account the state of circulation and the state of degradation of the roadway. Thus, the manager can better control the hazards of the logistics system of his site. It is very important to point out that it isthe information flows that enable the overall coordination of physical flows in the supply chain.[4] Our study could be completed in the future by taking into account the disruptive elements of the stateof the traffic that cause shock congestion (incidents caused by motorists, accidents). As well as measuring the distribution of travel times, in order to measure their variability.[3]

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