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ON DEVELOPING EFFICIENT SUPPLY CHAIN FOR BASE COURSE LAYER IN ROAD CONSTRUCTION USING STOCHASTIC SIMULATION APPROACH

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Abstract

The development of an efficient supply chain for base course layer has become a reoccurring phenomenon in the delivery of road construction project. This study intends to provide an efficient and economical supply chain for base course layer used in road construction through investigating individual stations and their order, as well as their time data. The study offers a stochastic simulation approach based on Monte Carlo technique, using the Visual Basic Application (VBA) in Microsoft Excel based on RND Generator to analyze the three weeks data obtained from physical observation, GPS data and questionnaires distributed on site. The study revealed that non efficient and non-economical supply chain was mainly due to the introduction of many trucks in the supply chain. The simulation result also shows that the higher the number of trucks introduced in the supply chain, the more the waiting or idle time, which in turn result in lesser number of rounds per truck per day. This study provides a practical and realistic stochastic simulation model for developing efficient and economical supply chain for base course layer in road construction. Subsequently, the number of trucks needed and the time required to transport estimated volume of crushed stones needed for base course layer can be determined.

Keywords: *Supply chain, stochastic simulation, road construction, base course layer*

1. Introduction

An indispensable foundation for good working economies lies in the well-developed transport and communication systems. Often, these systems are designed as complex, network-like structures that form the backbone of modern infrastructures. These networks include roads like Highways, Dual carriageways or Expressway. To build, maintain, or rehabilitate major district road or state/national highway, crushed stones are needed for the base layer. The development of an efficient supply chain, in particular for base layer, has become a reoccurring phenomenon in the delivery of road construction projects. Road construction projects are endeavors that involve capital expenditure, which is either borrowed or self-financed by clients. The expected outcome of such expenditure is value for money, which is usually dictated by project cost, time and quality. Project costs in which time play a crucial role are the fundamental determinant of project success in the prevailing economic challenges being experienced globally.

The construction industry has a great impact on the economy of all countries [1]. It is one of the sectors that provide crucial ingredients for the development of an economy. According to Chitkara [2], the construction industry in many countries accounts for69% of the Gross domestic Product (GDP), and according to Bhimaraya [3]; it reaches up to 10% of the GDP of most countries. It is widely acknowledged that the construction industry is a vital element of an economy and therefore has a significant effect on the efficiency and productivity of other industry/sectors. One cannot think of the widespread investment in manufacturing, agricultural or other service sectors unless the construction results of infrastructural

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facilities like roads are in place. In some of the developing countries, the growth rate of construction activities outstrips that of population and GDP [2]. A reoccurring factor highlighted by researchers on the causes of poor projects performances in the construction industry has be overrun in cost, which is largely as a result of extension of time often caused by non efficient and non-economical supply chain. Cost is one of the primary measures of project success [4]. This is true, especially for the public projects in developing countries like Nigeria were public road construction projects are executed with scarce financial resources [5]. A project may not be regarded as successful until it satisfies the cost, time, and quality limitations applied to it[6].Achieving these measuring criteria often referred to as the project “Iron triangle” [4], has remained a major challenge for construction industry in developing countries like Nigeria.

Cost effective supply chain under various market logistics and production uncertainties is a critical issue for construction companies[7]. In general, such uncertainties often result in multiple planning and operational issues that challenge planners. In order to optimize the performance of a supply chain in road construction, various planning approaches has been proposed. Besides the linearize approach, which tries to optimize the supply/product flow by solving a linearized version of the network [8], several different possibilities to linearize such networks, as well as several applications of network flow models, which are solved through linearization has also been proposed[9]. Doganand Goetschalckx [10]showed that larger supply chain design problems can be also solved using decomposition. A case study about a supply chain for the pulp industry modeled as a mixed-integer programming (MIP) is given by Gunnarsson et al. [11]. In general, supply chain problems solved with LPs and MIPs usually include several simplifications in order to keep them solvable. Santoso et al. [12] considered a stochastic programming approach for the supply chain network design. They used a sample average approximation and Benders decomposition to solve problems associated with supply chain while considering future operational costs. For that purpose, they developed a linear model with uncertain cost factors and demand. Although they used a fast algorithm, realistic problems with sample sizes of up to 60 scenarios need several hours to be solved. Alonso-Ayuso[13] also considered a similar combined design and operation problem. Their stochastic programming approach was able to solve medium sized problems with binary decisions within 1 hour. Leung SCH[14] presented a robust optimization model for a simultaneous production planning for several sites in a supply chain under uncertainty. But still they are restricted to rather small models and consider only four different scenarios. Almeder et al. [15] developed a new solution approach by applying a LP/MIP formulation in the context of a discrete-event simulation that combine the advantages of models from all categories mentioned above. However, they assume that there is a central planner with perfect information such as for intra-company supply chains or supply chains with a dominant member which is often not fixable.

A Two- lane highways, Dual carriageways or Expressway consists of several different layers. The lower layer, the ballast support layer (or base course layer) which is not bound by a binder, and the upper layers which consist of a ballast mixture bounded with bitumen. The mixture of this asphalt is produced in a special mixing plant often located close to the construction site. In contrast, the ballast layer (often required in thousands of volume in cubic meters) is produced directly in the quarry which is often located hundreds of kilometers away from most road construction site. Consequently, this results in logistics problem that is further aggravated by dispersion losses due to transport as well as volume reduction by compression. Hence the need for an efficient and economical supply chain for the supply of base course layer used in road construction cannot be overemphasized.

This paper proposes a stochastic simulation approach that will provide an economical solution for the transportation of crushed stones for the base course layer or ballast support layer used in road construction. To this end, the proposed approach is divided into two steps. The first step involves the establishment a supply chain for the logistical task. These include verbal description of the individual stations and their order, which are displayed in a flowchart, as well as their time measurement which was statistically described and tabulated. In the second step, the simulation software was created using MS Excel and Visual Basic for Applications (VBA). The software is based on the RND Generator tool, which allows generation of non-linear distributed random numbers. The supply chain was then translated into a computer-comprehensible manner with the help of the simulation software. The rest of this paper is structured as follows. Section 2 describes the proposed approach for obtaining an economical solution for the transportation of crushed stones for the base course layer or ballast support layer in road construction. Section 3 presents the results and discussions based on the simulated data, while Section4 presents the concluding remarks.

2. Methodology

2.1 Study Area

This study was carried out on a proposed road construction project in Cross Rivers State in the south-east of Nigeria. The construction project (Dualization of Calabar Road) is a four-lane highway with the regular cross-section RQ 20 (according to "Road Construction Directive" RAS-Q ", 1996) with a total length of 12 kilometers. The existing Calabar Road is to be dismantled and then rebuilt with the road construction "SV" (for "heavy traffic").For this purpose, an estimate of 30,000 m3 of gravel from any nearby stone quarry is required for the ballast support layer. This material is to be delivered with Mercedes Tippers to the construction site.

2.2 Data Collection

2.2.1 The stations and processes of the material supply chains

Figure 2 shows a flow chart with an overview of all the stations, as well as the sequence of the stations. Once a truck from station #10 (loading) reaches station #90 (offloading), the tour is counted as a round trip. Therefore, these two stations are highlighted in color.

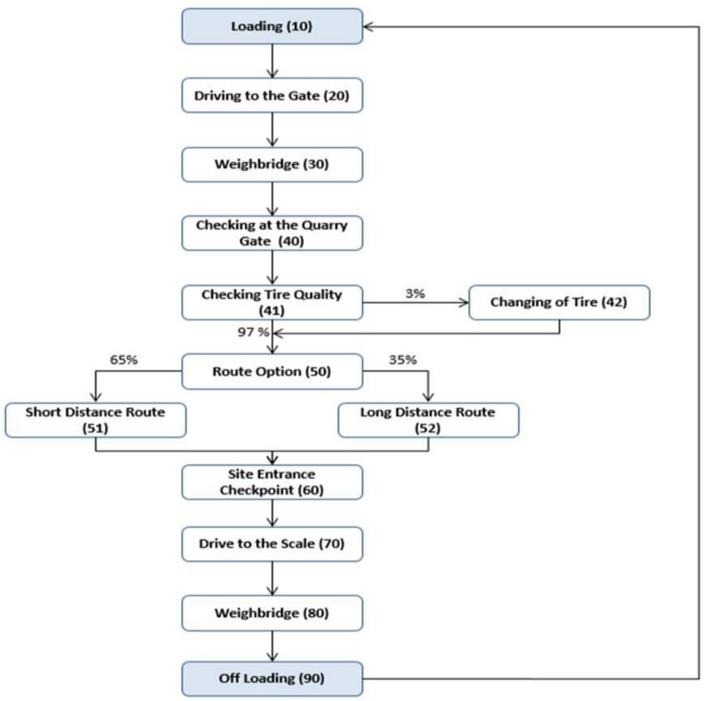

Figure 1: Flow chart of the material supply chain.

2.2.2 Time Data

The time data of most of the stations as shown in Table 1 were collected within a three-week period. The data for the routes were partially determined using Google Maps, while the values for the tyre change (station 42) are based on estimates.

Table 1: Time data of the individual stations (in minutes)

No	Station	Min	Max	Mean	Std. Dev.
10	Loading	04:11	08:36	05:13	01:07
20	Drive to gate	03:46	05:59	04:46	00:35
30	Weighbridge	01:20	02:40	01:55	00:25
40	Checking tire quality	04:39	12:04	07:17	02:03
42	Changing tyre	30:00	45:00	37:30	10:36
51	Short route	16:40	48:14	25:53	06:26
52	Long route	38:37	16:48	51:12	09:28
60	Site entrance check point	01:01	01:25	01:12	00:07
70	Drive to scale	02:21	11:44	06:10	03:34
80	Weighbridge	01:28	02:48	02:00	00:24
90	Offloading	01:11	01:53	01:25	00:13

2.2.3 Cost data

In order to be able to evaluate the results of the simulation economically, corresponding costs are recorded in the simulation of the supply chain. A distinction is made between the following cost types:

- **i. Stretch cost:** The stretch cost depends on the length of the distance traveled. We internalize e.g. the fuel consumption or the wear of the truck. Practically, the same distance is traveled on the way from the quarry to the construction site; the stretch costs per round were calculated.
- **ii. Truck cost:**Truck cost include the cost of truck rental or the driver's wage charged per day for each truck used
- **iii. Installation costs:** These costs which are independent of the used trucks and rounds include costs for installation of the stone quarry or building site yard, wages for transport management or the occupation of the weigh bridges

Summaries of all categories of costs data used for this study are shown in Table 2. For confidential reason, all cost data in this study are not shown in real currency.

Table 2:Cost data used for the study

No.	Type	Cost (Monetary unit)	Unit
1	Stretch cost	40	Per trip
2	Truck cost	300	Per truck per day
3	Installation costs	1,200	Per day

2.3 Data Generation (Simulation)

The Visual Basic Application (VBA) in Microsoft Excel based on RND Generator was used to analyze the three weeks data obtained from physical observation and questionnaires distributed on site. Using the VBA, we first generated artificial random number using a Monte Carlo technique in order to simulate the supply chain. Since VBA has no standard generator for non-uniform distributed random numbers, we then adopted a very clever method known as the Acceptance-Rejection Method which is a notable acknowledgedmethodfor transforming uniformly distributed random numbers into non-uniform distributions.

2.3.1 Acceptance-Rejection Method

We start by assuming the F we wish to simulate from, has a probability density function $f(x)$. The basic idea is to find an alternative probability distribution G, with density function $g(x)$, from which we already have an efficient algorithm for generating from (e.g., inverse transform method or whatever), such that the function $g(x)$ is "close" to $f(x)$. In particular, we assume that the ratio $f(x)$ / $g(x)$ is bounded by a constant $c>0$; $\sup_x\{f(x)/g(x)\}\le c$ (And in practice we would want c as close to 1 as possible). The algorithm for generating X distributed as F is given as follows:

Step1: Generate random variable Y distributed as G.

Step2: Generate U (independent from Y).

Step3: If $U = f(Y)/cg(Y)$,

then set $X = Y$ ("accept")

else go back to Step 1 ("reject").

This algorithm depends on the following assumptions:

- i. $f(Y)$ and $g(Y)$ are random variables, so is the ratio $f(Y)/cg(Y)$ and this ratio is independent of U in Step (2).
- ii. The ratio is bounded between 0 and 1; $0 < f(Y)/cg(Y) \le 1$
- iii. The number of times N that steps 1 and 2 need to be called (e.g., the number of iterations needed to successfully generate X) is itself a random variable and has a geometric distribution with probability of "success" P = P($U \le f(Y)/cg(Y)$); P($N = n$) = $(1-p)$n−1p, with $n \ge 1$. Thus, on average the number of iterations required is given by E(N) = 1 $/p$.
- iv. In the end we obtain our X as having the conditional distribution of Y given that the event $\{U \le f(Y)/cg(Y)\}$ occurs.

A direct calculation yields that $p = 1/c$, by first conditioning Y :

$$P\left(U \le \frac{f(Y)}{cg(Y)} \mid Y = y\right) = \frac{f(Y)}{cg(Y)}$$

thus, unconditioning and recalling that Y has density $g(Y)$ yields,

$$P = \int_{-\infty}^{\infty} \frac{f(y)}{cg(y)} \times g(y)dy$$

$$= \frac{1}{c}\int_{-\infty}^{\infty} f(y)dy$$

$$= \frac{1}{c}$$

where the last equality follows since f is a density function and by definition integrates to 1. Thus $(N) = c$, the bounding constant, and we can now indeed see that it is desirable to choose our alternative density g so as to minimize this constant $c = Sup_x\{f(x)/g(x)\}$.The expected number of iterations of the algorithm required until an X is successfully generated is exactly the bounding constant $c = Sup_x\{f(x)/g(x)\}$.

2.3.2 Proof that the algorithm works

Proof: We show that the conditional distribution of Y given that $U \le \frac{f(Y)}{cg(Y)}$ is indeed F ; that is $P\left(Y \le y \mid U \le \frac{f(Y)}{cg(Y)}\right) = F(y)$.

Letting, $B = \left\{U \le \frac{f(Y)}{cg(Y)}\right\}$, $A = \{Y \le y\}$ recalling that P(B) = p = 1/c, and then using the basic fact that P(B|A) P(A)/P(B) yields

$$P\left(U \le \frac{f(Y)}{cg(Y)} \mid Y \le y\right) \times \frac{G(y)}{1/c} = \frac{F(y)}{cg(y)} \times \frac{G(y)}{1/c} = F(y)$$

Therefore,

$$P\left(U \le \frac{f(Y)}{cg(Y)} \mid Y \le y\right) = \frac{P\left(U \le \frac{f(Y)}{cg(Y)}, Y \le y\right)}{G(y)}$$

$$= \int_{-\infty}^{y} \frac{U \le \frac{f(y)}{cg(y)} \mid Y = \omega \le y}{G(y)} g(\omega)d\omega$$

$$= \frac{1}{G(y)} \int_{-\infty}^{y} \frac{f(\omega)}{cg(\omega)} g(\omega)d\omega$$

$$= \frac{1}{cG(y)} \int_{-\infty}^{y} f(\omega)d\omega$$

$$= \frac{F(y)}{cG(y)}$$

2.3.3 Processing time, waiting time and total time of a station

If a truck arrives at a station, its processing takes a certain amount of time. This is on the one hand dependent on whether the station is currently occupied by a truck (waiting time), as well as the time required for the station to weigh or load the truck (processing time). The duration of the processing time was generated by stochastic simulation. With the aid of the RND generator developed in advance, and the statistical description of the original data of the stations, normally distributed stochastic processing times of each station was generated. Figure 2 shows the relation between these different times.

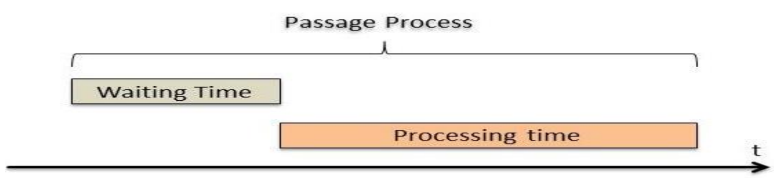

Fig 2: Relation between processing, waiting and total time.

3. Results and Discussion

In order to ascertain the number of rounds achievable per truck per day, various working days with a different number of trucks were simulated for this purpose. The results of these simulations are shown in Figure 3

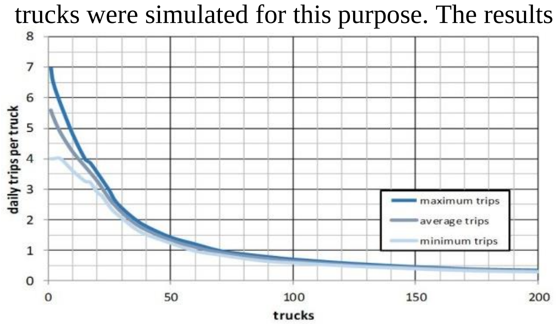

Figure 3: Daily trips per truck

In Figure 3, we observed that the maximum value with up to seven trips per truck was achieved when only one truck leaves the yard. A cursory look at Figure 3 also shows that starting from about 60 vehicles, there are so many trucks in the system that the number of trips per truck falls below the value of one trip. This means that the provision of more than 60 trucks is uneconomical. This raises the question of how many trips can be achieved in one day. Figure 4 shows the results of these simulations as function of the number of trucks.

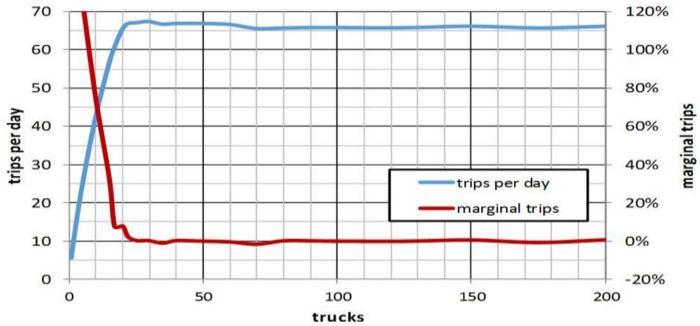

Figure 4: Trips per day and possible increase in trips

In Figure 4, the number of trips (blue) shows between 0 and 20 trucks a rising linear tendency, which is fairly close to the relation:

$$Trips\ \ perday = 3{,}2013 \times Number of\ Trucks + 5{,}8309$$

Also in Figure 4, we observed that if about 20 trucks are used, a mean value of about 66.4 trips / day is achievable. This can also be seen in the number of boundaries (red), which is close to zero in approximately 20 trucks. Therefore, the number of trips cannot be increased by a multiple use of trucks above 20. From these results, an average of approximately 45 days is required to transport 30,000 m^3 of ballast layer. That is, 30,000 [m3] / 10[m3/trip] / 66.4 [trip/day] = 45.1 [days].

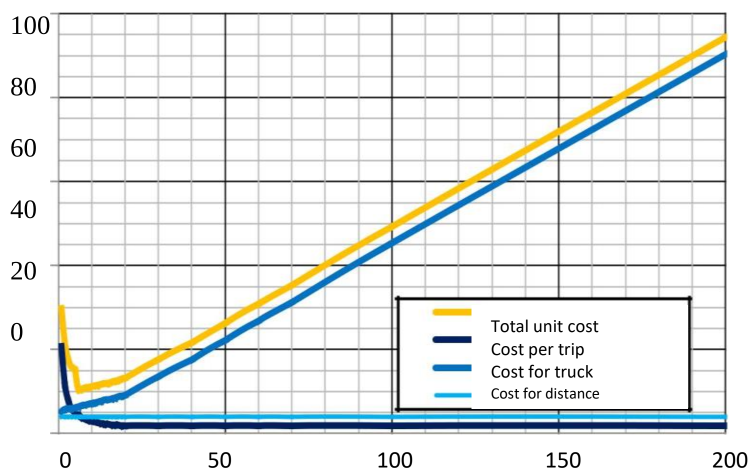

Fig. 5: Development of the costs per unit [m³].

Figure 5 shows the development of unit costs, i.e., the cost per cubic meter of material delivered. The entire unit cost (i.e. the yellow line) decreases with increasing number of trucks, and rises from about 12 trucks, and exhibits a linear coursewith more than 20 trucks. In order to determine the minimum total costs, the range between 5 and 20 trucks was considered separately. Figure 6 shows the results of this analysis.

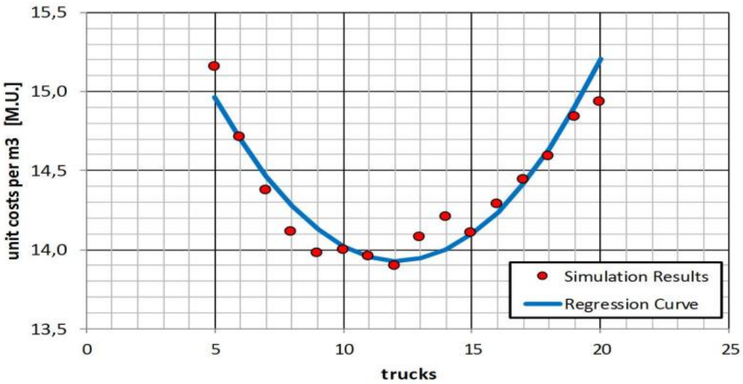

Fig. 6: Development of the total unit costs with 5 - 20 trucks.

Figure 6 reveals that the results of the simulation seem to be parabolic. The observed regression parabola (blue) has the form:

$Y = 0.0205X^2 - 0.49464X + 16.933$

anda coefficient of determination $R^2 = 0.9133$ .For the parabola shown in Figure 6, an absolute minimum is thus obtained at the point $X = 12.11$,and $Y = 13.93$. Where X is the number of trucks used and Y is the unit cost in Naira / m3.If the costs are considered, one achieves an economic optimum with approximately 12 trucks.

Besides the simulation of the system capacity, total unit cost with 5 to 20 trucks, we also looked at how the entire waiting period of the system evolves. For this purpose, the simulation of the sum of the waiting times as a function of the used trucks was simulated. The resultis shown in Figure 7.

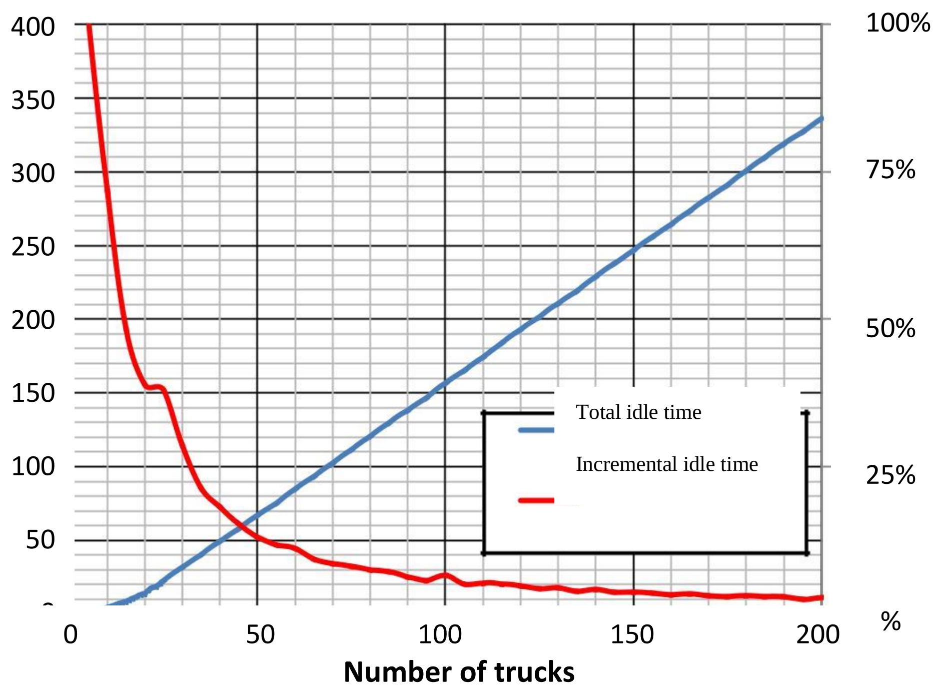

Fig. 7: Development of the total waiting times of the trucks.

In Figure 7, it can be seen that the increase of the waiting times in the range up to 20 trucks is parabolic and from 20 trucks is linear. That is, the more trucks used, the more the waiting or idle time. This is also shown by the limit waiting time, which decreases, but never drops to 0% within the data under consideration.

Judging from the results, the capacity and cost-effectiveness of the supply chain can be improved through further measures. These measures can then be divided according to whether they concern the distance (the individual stations) or the trucks with which the transports are carried out. Improvement measures concerning the trucks may include: (1) instead of a 10m3 rear dumper "Zetros", the model "Actros" with a load volume of14m3 could be used to increases the volume per each trip, (2) extension of the working hours would lead to a scalene effect, since some of the fixed costs would be spread over several trips, and (3) use of new-quality trucks that do not break so fast would ensure less failure. In terms of improvement measures concerning the stations:

(1) if the road project is worth the purchase of a second scale, having a second scale will reduce the waiting time before the weighbridge, and (2) If night work is conceivable, fewer transports will be carried out in parallel, waiting time before the Weigh-bridge would be much lower, and will in turn leads to fewer traffic jams since there are also fewer vehicles on the public roads at night.

4. Summary and Conclusion

This paper approaches the problem of providing an economical solution for the transportation of crushed stones for the base course layer or ballast support layer in road construction using a stochastic simulation approach. The capacity and cost-effectiveness of the supply chain were examined. For the capacity of the supply chain, it was found that more than 60 trucks are uneconomical as shown in Figure 3. Taking the border rounds into account as shown in Figure 4, it is not worthwhile to include more than 20 trucks in the transport chain, due to the non-increase in the number of revolutions. Also, Figure 4 reveals that an optimal mean value of about 66.4 trips / day is achievable. From these results, an average of approximately 45 days is required to transport 30,000 m^3 of ballast layer. If the costs are considered, one achieves an economic optimum with approximately 12 trucks.

Although the results support the applicability and merit of using stochastic simulation, the modeling of the supply chain was also somewhat simplified. For example, the complete failure of vehicles, e.g. accident or breakdown was completely negated. The return of the truck is simplified only as a return journey across the street. Actually, the way would have to be longer, since the trucks are also driven in the quarry. Also, it was assumed that at the end of the working time, the driver again drives into the quarry. Probably the driver, however, would end his tour despite exceeding the working time, and the extra work would be paid out as overtime. We also assumed that the trucks do not interfere with each other in this model. All process times were considered as normal. Is that correct? Would it perhaps be more sensible to simulate the transport processes on the road as log-normal distributed? In addition, some values in the simulation are based on estimates. So the question is: how good are these estimates in reality? Lastly, the special climatic characteristics of Nigeria were not taken into account: In Nigeria, there is rainy season from April to October, which heavily floods and partly destroys the roads. This often leads to traffic restrictions. These seasonal traffic restrictions were not been included in the model. Since the input data for the simulation were collected in November (that is, during the dry season), it can be assumed that the simulation results should be maximum values.

Despite all the inadequacies and possibilities for improvement, this study provides a practical and realistic stochastic simulation model for developing efficient and economical supply chain for base course layer in road construction. This study will help managers and planners to determine the number of trucks needed and the time required to transport estimated volume of crushed stones needed for base course layer in road construction that many prior researchers are yet to explore. Thus a new approach on supply chain planning for transport of crushed stone for base course layer used in road construction may be found.

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