More than just chocolate

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ABSTRACT
Côte d'Ivoire produces about 42 percent of the world's total Cocoa but processes only a very few amount of the production. A big part of the country depends on the commercial benefits of the Cocoa production and supply chain of it. For that reason, the World Bank asked the simulation group of the Amsterdam U. of Applied Sciences in collaboration with the Port of Amsterdam to develop a simulation model that allows the politicians assess the performance of the supply chain of the Cocoa in that region of the world. The simulation model gave light to the potential of improvement in the supply chain by identifying inefficiencies, bottlenecks and blockers that hinder the efficient transport of Cocoa in the chain with the consequence of low productivity. The most important results are presented in the article together with suggestions for improvement in order to increase the wellbeing of the farmers in that region of Africa.

Keywords: logistics modelling, Ivory Coast, developing countries, transport

1. INTRODUCTION

Côte d'Ivoire produces about 42,4 percent of the world's total Cocoa but processes only 0.51 million tons of Cocoa beans in the country (2015). The main importer of Cocoa from Côte d'Ivoire is the Netherlands. The last years, Côte d'Ivoire has gained a larger market share, both in production of Cocoa beans and grinding, respectively, from 36.7 percent in 2013 to 39.3 percent in 2015, and from 11.3 percent in 2013 to 12.6 percent in 2015 (Port of Amsterdam 2016). Seventy percent of the total Cocoa production in Côte d'Ivoire is obtained from the following production zones: Soubré, San Pedro, Dalao, Divo and Gagnoa.

There are many challenges facing the development of Cocoa sector and performance of the logistics system in Côte d'Ivoire. The organisation of the Cocoa's supply chain suffers from various problems such as limited traceability, poor quality and congested transport roads, increasing waste, lack of storage facilities/warehouses and time-consuming administrative processes. Furthermore, the market of Cocoa sector is highly concentrated in the sense that the bulk of trade and processing of the market of Cocoa is dominated by a limited number of foreign exporters. Because the multinational companies are strong in terms of capital and use of sophisticated technologies, barriers of entry are higher for local firms to enter the export market as economies of scale require large investments and volumes of export, especially in case of shipping Cocoa in liquid or solid forms.

Others main challenges that the Cocoa sector is facing are:

- The Cocoa supply chain in Côte d'Ivoire is dysfunctional and not favourable to the majority of Cocoa farmers that receive frequently low market prices. The supply chain is often too long and characterized by the proliferation of many stakeholders, with most operators not performing any marketing function that adds value to Cocoa beans, while taking a share of the market prices.
- Farmers often do not have access to market information and technology and their understanding of the quality requirements of the market is very limited. This translate into low productivity, low income and decreasing yield.
- A fragmented and inappropriate functioning of the market that results in a trading system in which quality is often compromised.
- The majority of Cocoa farmers sell their Cocoa beans individually to itinerant buyers (not necessarily retailers), which often operate in areas where it is difficult for farmers to transport the Cocoa themselves.
- A widespread practice of mixing good and bad quality Cocoa beans to meet minimum market quality standards.
- Limited access of farmers to productivity-enhancing inputs and resources such as fertilizers, agrochemicals, seedlings, farm tools and credits, which affect the productivity and competitiveness of the Cocoa sector.

Côte d'Ivoire has made significant progress in the development of roads, power and ICT networks during the 1990s. After 1999 this progress slowed down because of a lack of investments, and political turmoil. Spending on infrastructure was less than 5 percent of GDP in the mid-2000s, which is about half of what many neighbouring West African countries have been devoting to infrastructure in this period. Various empirical studies show that improvement of country's infrastructure endowment, such as energy supply, roads networks, rail infrastructure and terminal capacity of ports and airports could rise growth at a rate of 2%.

Road network (82.000 km) is relatively well developed in Côte d'Ivoire and although of a low density, it provides sufficient connectivity to link the capital cities, secondary towns and international borders. In opposition, rail network is not developed. The country has only one rail link for transporting goods which connects Abidjan with the capital of Burkina Faso (Ouagadougou).

Besides low density and low quality of road network, there are several problems that have direct effect on transport and logistics sector in Côte d'Ivoire such as the increasing transport prices, high operational costs and unpredictable delays to the transport of goods due to the extraction of significant bribes from trucks along the roads by police. As result, transporters tend to overload their trucks to compensate for the costs of the bribes and other additional charges (for example, charge load per axle).

In order to develop and implement a wide logistics (supply) chains and network that capture various dimensions of performance at various levels in a consistent way, there is the need of using adequate and valuable tools (i.e. set of indicators) covering several levels; the strategic level, the tactical and the operational level together with novel techniques and methodologies that allow more transparency in the expected outcomes of policy processes.

Globally, the focus on the Cocoa's logistics chain and network in Côte d'Ivoire may be approached by looking at the following indicators dedicated to evaluate performance and trends in logistics practices:

- Physical state of road infrastructure and transport intensity (tonnes-km/total output).
- Freight volume through load capacity/factor of vehicle by mode (ton/vehicle).
- Distance by transport mode (km).
- Vehicle utilization (vehicle-km/ton-km).
- Freight movements and energy and emissions by supply chain link (energy consumed/vehicle-km).
- Energy consumption/emissions.
- Time (total time for transport and storage and related procedures, average and maximum number of hours/days).
- Cost (total costs of transport and storage and related procedures).
- Variability (total time of document processing hours/days).
- Complexity (total number of documents per trade transaction).
- Financial cost of logistics services and hidden costs (costs of delays and uncertainties). These costs include financial charges, obsolescence, and loss of damaged or stolen goods.

In addition, the domestic Cocoa supply chain is formed by approximately 800.000 farmers, 500 cooperative companies, 5400 traders (5000 pisteurs and 400 traitants), 50 exporters and about 6 local grinders and local processing firms (see Figure 1 below). What characterizes the Cocoa supply chain in Côte d'Ivoire is that farmers sells their crop to three different actors: to domestic processing firms through cooperatives, to traders (pisteurs and traiteurs) or market them through traders to exporters. The domestic processing firms sells processed Cocoa products directly on international market.

Due to the complex nature of the supply chain of Cocoa, the only approach that enabled to assess all the important aspects and the variability of the chain was Simulation. In the current work, we present a simulation model of the supply chain of Cocoa in Cote D'Ivoire which can be also used as a decision-support tool. The model represents the different relationships already mentioned, so that it enables the decision-makers with a wide-angle view for policy making.

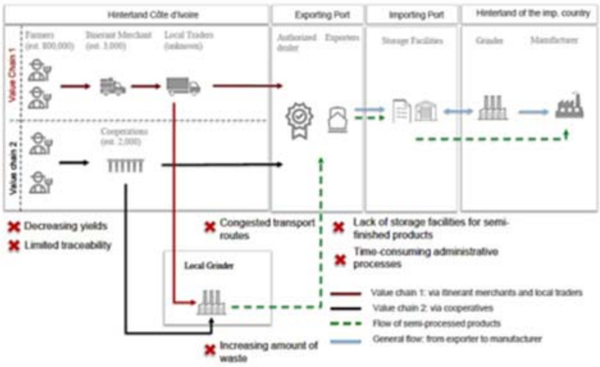

Figure 1: Conceptual Model of Supply Chain

2. STATE OF THE ART

Modelling and simulation is a technique that has been widely used for supply chain management (SCM), as it is mentioned in Longo (2011), it is "a powerful tool for analysis, investigation, examination, observation and evaluation of real-world industrial and logistics systems". In the work of Ingalls (1998), the author makes a review of the simulation technique applied to SCM where he outlines the advantages of using simulation. In his work he points out that simulation fits best for tactical planning, usually where the time horizon is long, and for supply chains affected by variance. Supply chain is usually modelled as a multi-agent and in a dynamic fashion (Swaminathan et al. 1998; Kahiara 2003) in order to be able to consider all the interactions between the different actors of the supply chain. Simulation models for SCM are usually based on agent-based simulation (ABS) and discrete-event simulation (DES), and even a combination of the two as it is proposed by Lee et al. (2002). Regarding ABS models we can find many of them in the literature, considering different policies and objectives. In the work of Gjerdrum et al. (2001) an ABS model was presented with the objective of simulating different demand-driven supply chains. They included an optimization model for the manufacturing component, with the objective of reducing operative costs and keeping a high level of customer order fulfilment. Albino et al. (2007), modelled a supply chain by focusing on cooperation between supply chain actors in industrial district. The concept of industrial district consists of an area where many small and medium enterprises (SMEs) are located and work together in the supply chain; this concept has been also translated in the model proposed in this work by clustering the production sites. In other works we can find supply chain modelled using ABS focusing on different strategies such as: analysis of alternative production-sales policies (Amini et al. 2012) and different combined contract competition (Meng et al. 2017). DES models have been also widely exploited in the SCM, as it can be found in Longo and Mirabelli (2008), where they proposed a decision-making tool for different supply chain scenarios. Their scenarios were based on multiple performance measures and user-defined set of data input parameters. In the work of Mensah et al. (2017) another DES model was developed for a resilient supply chain with the aid of ICT implementation. The model follows a six sigma approach to improve the overall supply chain resiliency against disruption.

In the present work, a DES model has been implemented to describe and analyse the supply chain of Cocoa products from producers, distribution centre and final centre of collection and shipment. Because of the nature of the network and operations modelled and also the tactical nature of the analysis, DES was considered as a best approach by the authors. DES allowed us to make a scenario-based analysis based on different policies, and it enabled us to measure the performance of the supply chain based on different aspects (productivity, economic, and environment).

3. METHODOLOGICAL APPROACH

In this work, we simulated the different links of the supply chain, the main boundary is the Port of San Pedro where the exporting function is performed. The model was based on the supply chain mapping made by the Port of Amsterdam (Port of Amsterdam 2017). Figure 1 presents the description of the supply chain relationships that will be considered for the developed model.

The farmers produce the Cocoa beans which in turn are transported by a merchant or the production is concentrated by a cooperative of producers (Farmers) in warehouses. In the next link, the product is transported as raw material directly to the Port and some percentage is transported to the Grinders (30% of the production). In the grinder or refinery, the raw Cocoa is transformed into Cocoa butter and then transported as a higher-value product to the Port of San Pedro. The next link in the supply chain is the transport of either the raw material (beans) or the refined product (butter or oil) by sea to the destination Port, in our study the destination Port in Europe corresponds to the Port of Amsterdam. However, as mentioned before, the transport to the Port of Amsterdam will be out of the scope of the developed model.

3.1. Conceptual Modelling

The first modelling phase corresponds to the conceptual development in which the relationships between the main elements are identified based on public information and the discussion with subject-matter experts. The following table presents the elements that are included in the simulation model.

Table 1: Main elements of the conceptual model

Element	Description
Production quantities	The quantities of Cocoa beans produced in the specific region under study
Transport routes	The routes of transport that are used by the different transports
Grinder Facilities	Cocoa that is transported in the grinder facilities as well as the added value to the product for evaluating the impact of decisions
Transport trucks	The trucks that transport the products for being export at the Port. The speeds and capacities will be considered as well
Warehouses	The warehouses dwell time will be considered
Checkpoints along the transport routes.	These points will be considered since they hinder the smooth flow of trucks towards the Port.
State of roads and pavement	The quality of the road will be considered, since it has a direct impact in the transport time from the different locations in the region to the Port
Market value of the products	The market value of the modelled products will be considered
Emissions	In the model the green-house pollutants are considered, mainly CO_2 and NO_2

3.2. Production modelling

Some functionality is key for the correctness of the developed mode. Production is one of them, as it is appreciated in Figure 2, the production varies with the region of the country. Due to the objectives pursued, the production at an atomic level was not considered, instead, a high-level model was developed. The complexity of the production network was coped by developing clusters within the region under study (San Pedro Region), taking into consideration the production zones and the political boundaries.

The production of Cocoa in the model is generated in batches of 6 tons within the cluster and located randomly within the cluster. The model developed has stochastic, dynamic and flexible characteristics; the amount of entities is generated in such a way that they match the amount of production of the region within a year.

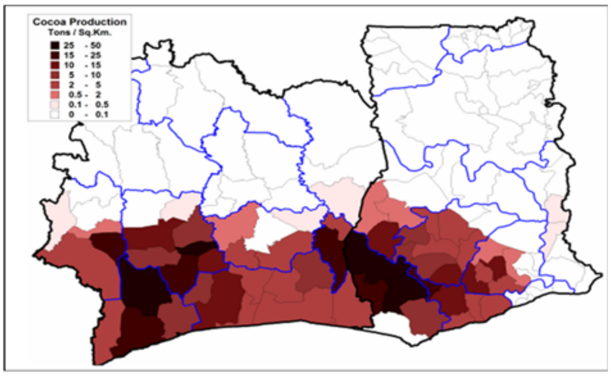

Figure 2: Production of Cocoa in Cote D'Ivoire

The production is modelled assuming a Poisson process where the main probability distribution is an exponential one with the average inter-arrival time of 3.33 minutes (1).

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$$f(x) = \begin{cases} \frac{1}{\beta} e^{\frac{-x}{\beta}} & x \geq 0 \\ 0 & x < 0 \end{cases} \quad (1)$$

Assuming this inter-arrival time, the average production of a year will be 946 000 tons. It is important to mention that this production is stochastic meaning that every time the model is run, the production might vary, due to the interlinks and causal relationships present in the supply chain model. However, the average mean will be around 946 000 tons/yr.

3.3. Road Network Infrastructure

According with Openstreets (OpenStreets.org 2017), the road infrastructure of Côte d'Ivoire consists of 5 classifications of roads, however, for reducing the complexity, the model accounts with three types of roads:

- Primary Road (Paved). These roads are paved roads, with good maintenance, the achievable speeds of the trucks could get up to 100-120 km/hr. However, the maintenance of these roads is very scarce, thus, the roads are filled with potholes and stones making the vehicles reduce their speed and sometimes break their tires, decreasing drastically the average speed in the road. For the paved motorways we specified a stochastic speed following a Triangular distribution of T(40,50,60) km/hr.
- Secondary Road(s). The secondary roads are roads that are unpaved. In these roads, the average expected speed is also very uncertain. In this roads we assumed a stochastic speed following a triangular distribution of T (20,30,40) km/hr.
- Tertiary Road(s). These roads are also unpaved, and these types of roads are the ones used by the primary producers (individual and local families), in these roads, the farmers can use small vehicles or even bicycles for the transport of Cocoa beans. For the modelling of these tertiary roads, we specified also a stochastic speed of T (10, 15, 20) km/hr.

The road infrastructure is modelled as a set of nodes and edges with two directions at a certain scale in which the edges correspond to the direction, sense and length of the actual roads. The links (edges of the network) in turn are placed over a GIS map from OpenStreet.org, then the entities modelling the production and the trucks transporting the product are placed over the GIS layer. Thus, two layers are used, one which is a GIS layer of the region under study and the second layer which is composed by the entities, nodes, edges and other objects like servers that model the performance of the production once it enters to a warehouse, location or to the Port (simulation layer). Figure 3 illustrates the layers used for constructing the scaled model of the regions of San Pedro.

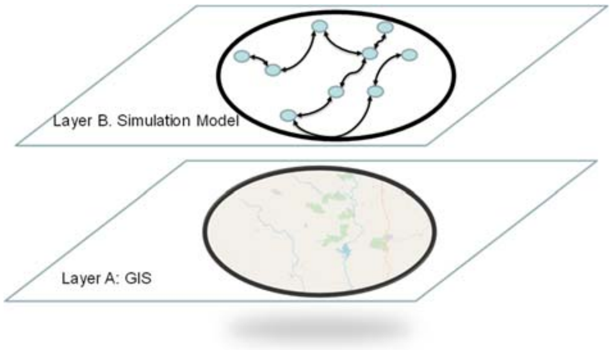

Figure 3: The GIS from OpenStreet.org for Côte d'Ivoire

The simulation layer has been developed using a discrete-event systems approach, using a commercial simulator called SIMIO (SIMIO 2018).We took the advantages of the functionalities of the simulator for making a more detailed model of the supply chain.

3.4. Grinders, warehouses and Ports

These elements are represented by functional nodes that are connected via the edges that model the roads, in addition, these nodes will have some functionalities. These functionalities, model characteristics such as capacity, delays of all the internal processes that the product undergo when they get to the node (e.g. grinding, loading, unloading, packing, unpacking, sorting, etc.). Figure 4 illustrates the network approach model of the supply chain under study.

The links or segments are geographically aligned with the GIS layer so that they have the right proportion and length that the vehicles need to traverse in order to go from one location to the other. Some of the nodes also have functionalities that are used to model operations performed in the locations of the GIS Map such as check points, warehouses, grinding operations or check points along the road.

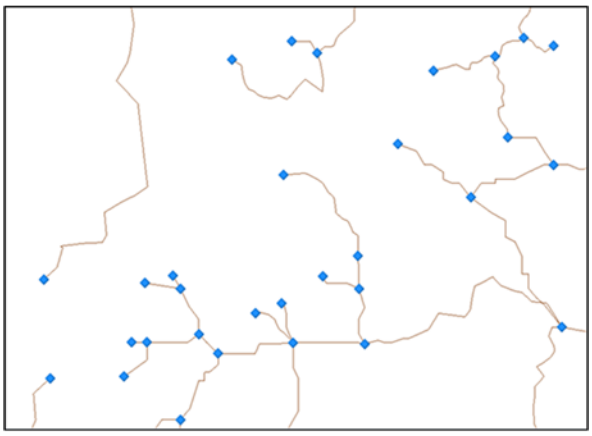

Figure 4: model of the road network

The warehouses and location nodes will have as main functions, the storage, transformation and transhipment of the product in the network layer. The processes related to those activities, consist of loading, unloading, processing, and storing. Table 2 illustrates the characteristics of these elements in the system.

Table 2: Characteristics of the Warehouses, Port and Grinders

Facility	Processing Time	Capacity
Warehouse	Triangular(5,6,7) days	Unlimited
Grinder	Uniform (12, 24) hrs.	Unlimited
Port	NULL	Unlimited

3.5. Vehicles

The production and transport of Cocoa is modelled using different entities, mainly two entities. One entity will represent the amount of 6 tons of Cocoa; the other vehicle will model the heavy trucks or trailers whose capacity is maximum of 60 tons. The entities will have other characteristics besides the capacity, such as speed, CO_2, NO_2 emissions and they will move through the edges of the network layer. Table 3 illustrates the characteristics of the different vehicles used in the model.

Table 3: Vehicle characteristics

Vehicle	Capacity	Speeds
Small Truck	6 ton (Fixed)	60 km/hr *
Trailer	[0..60] tons	Triangular (30, 45, 60) km/hr *

* Maximum speed, the model will be restricted by the roads limitations

The different types of vehicles are parameterized with the characteristics of the entities they represent. These parameters, will be used as variables that can be modified during the experimental design in order to compare the impact of different policies in the system.

In the warehouses, the entities are batched up to 60 ton (10 entities) and transported by another entity with similar characteristics but with a different representation. Figure 5 presents the entities used for modelling the transport and production of Cocoa with their characteristics.

Figure 5: Vehicle characteristics

Inter-arrival time per Region

The amount of production per region was estimated based on the yearly production rate. In the case of San Pedro region, the production per year is approximately 946,000 tons/yr. In order to generate a stochastic approach for this production, it was assumed that the production follows a Poisson process where the production is modelled by an exponential distribution with an inter-arrival time with the correspondent mean. The matching value for the region under study is 3.33 min between entities for batches of 6 tons. The model assumes that during the year the number of tons is produced relatively evenly.

3.6. Check Point Implementations

The checkpoints at the roads are important elements to be considered in the model. Based on public information (World Bank, 2008), check points in the region of San Pedro have been located in the model, with a correspondent processing time and probability of being checked. The following figure illustrates the details of the check points in the road network.

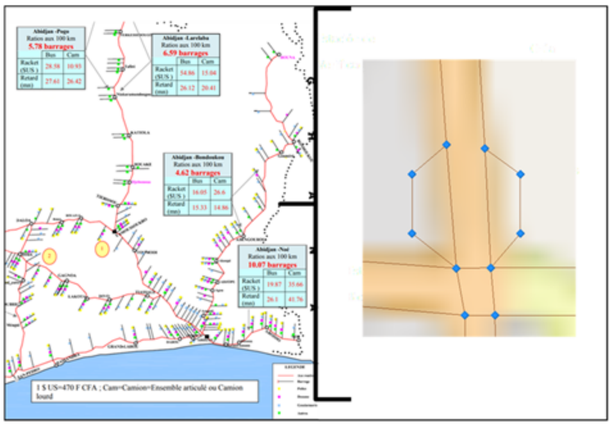

Figure 6: Check Point Implementation

For the implementation of the checkpoints, the network has a detour based on a probability for the vehicles to be checked. The checkpoint is composed by three segments with functionality where the trucks are deviated from their original route to the Port. They have a specific probability of being checked, initially is 10%. In the experiments, the variation of this probability is used to evaluate the impact of the checkpoints in the lead time of the products. In this way, it also enables the decision makers to evaluate policies that reduce the hassle or inefficiencies that the checkpoints add to the supply chain. The following table presents the characteristics of the checkpoints in the supply chain model.

Table 4: check point characteristics

Element	Processing Time	Capacity	Initial Probability of Inspection
Checkpoint enter segment	Heavy Truck: Triangular (1,2,3) hrs.		
Regular Truck : Triangular (5,10,15) mins	5 Entities	0.1	
Checkpoint parking segment	NULL	Unlimited	n/a

3.7. Emissions

In the simulation model, the CO2, NO2 and CH4 emissions were considered. A lineal equation was used according to EPA factors and following the approach of different authors (Kenney et al. 2014). The emissions are dependent on the type, age and distance travelled by the vehicles. The formulas used for estimating the emissions of the trucks are the following ones:

$$E\_tot=(RL \times NV \times EF) \quad (2)$$

Where
E_tot : Total Gas Emissions
RL: route length
NV: Kilometres traversed
EF: Emission factor

Regarding the characteristics of the vehicles, Table 5 presents the values used for the vehicles in the model (EPA 2018).

Table 5: Vehicle emission characteristics

Type of Vehicle	Year Assumed	Emission Factor CO2	Emission Factor NO2	Emission Factor CH4
Regular Truck (Gasoline)	1973 – 1974	1.67 [kg/km]	0.31 [gr/km]	0.28 [gr/Km]
Heavy Truck (Gasoline)	1981	1.67 [kg/km]	0.31 [gr/km]	0.28 [gr/Km]

4. EXPERIMENTAL DESIGN

This section presents the scenarios that have been evaluated using the supply chain model. The evaluation started with a base-case scenario which simulates the status quo of the system under study. Then with the use of the other scenario, the impact of different policies are compared. The following table illustrates the different scenarios that can be possibly analysed by modifying the factors and levels. As it can be inferred, a full factorial design was not feasible since the number of combinations would be 216 scenarios, however, based on the authors experience, we selected the scenarios that were considered most relevant for illustrating the capabilities of the tool and that allowed to identify potential areas of improvement of the whole system to bring more productivity to the region.

Table 6: Design of Experiments for the Supply Chain Model

FACTOR	LEVELS		
Speed secondary road	Low speed	Medium speed	High speed
Speed tertiary road	Low speed	Medium speed	High speed
Probability of checkpoint	10%	5 %	0%
Check point times regular trucks	Long waiting times	Short waiting times	
Check Point times heavy trucks	Long waiting times	Short waiting times	
Grinder Percentage	30 %	50%	

Regarding the Performance indicators (PI) considered, the ones used for the study are the following:

- Cocoa Productivity (Ton/day): This PI measures the amount of Cocoa that is transported to the Port of San Pedro every day. By using this PI, we evaluate the impact of different infrastructure policies. The expectation is that if one policy has good impact in the system, the amount of Tons in the Port will increase, while if it has a negative effect, the amount in the Port will be reduced.

- Cocoa Butter Productivity (ton-day): This PI is similar to the one from Cocoa, and follows the same reasoning. The difference is that butter is a more valuable product, and with the simulation model it is possible to investigate when is more economically attractive to invest in the butter than just transporting the beans.
- Cocoa Market Value (USD/Day): With this indicator, we are able to evaluate and simulate the value of the produced Cocoa in the market. The value will be correlated with the productivity of Cocoa. For the simulation model it was assumed a constant value of 3.2 USD/KG.
- Butter Market Value (USD/Day): with this indicator, we are able to compare the value of butter versus the value of Cocoa and how the policies and decisions impact this indicator. For the simulation model the value was considered constant with a value of 7.78 USD/KG
- CO2 emissions (Kg/day): This indicator is directly correlated with the distance travelled, age and type of trucks used to transport the Cocoa and the butter in the model. By using this indicator, it will be possible to measure the impact of some policies in the emissions of this pollutant.
- NO2 emissions (kg/day): This pollutant is also measured in the model. The reasoning is the same as the CO2.

The following section presents the description of the different scenarios evaluated and the explanation of why they were chosen.

4.1. Scenario I. Base Case Scenario

Every simulated scenario had 30 replications for a period of 14 weeks (3 months) in order to evaluate the performance of the considered PIs. The following table presents the main parameters and Table 8 the results obtained.

Table 7: Parameters of the base-case scenario

Parameter	Value
Speed Primary Road	Triangular(40,50,60) km/hr
Speed Secondary Road	Triangular(20,30,40) km/hr
Speed Tertiary Road	Triangular(10,15,20) km/hr
Checkpoint probability	0.1
Checkpoint times regular truck	Triangular(1 , 2 , 3) hrs
Checkpoint times heavy truck	Triangular(5 , 10 , 15) mins
Percentage of Grinding	30%

The following results are the average values out of all the 30 replications measured every day. The results mean that, for instance, the average productivity values represent the measurement of 84 days (3 months) times 30 (number of replications) therefore it is an average of 2520 measurements of the productivity.

Table 8: Simulated Results for Base Case Scenario

Parameter	Average Value	Standard Distribution
Value Beans Production (USD/day)	2,278,031	171,884
Value Butter Production (USD/day)	826,915	84,008
Productivity Beans (Ton/day)	989	474
Productivity Butter (Ton/day)	146	69
Total CO2 Emission [KG](3 months)	802	9.8
Total NO2 Emission [KG] (3 months)	14	0.18

It was considered only intensive measures (measurement/day) in order to make the results not time-dependent. The only absolute values were the emissions which measure the total emissions after the 84 days for the 30 replications. Thus, the results can also be interpreted as intervals, for example in the case of the expected market value of the Beans: assuming a normal distribution one can expect that every day, in approximately 95% of the time, the market value productivity would be within and interval of [1 934 263, 2 621 799] USD/day, using a 2 standard deviation interval.

4.2. Scenario II. Impact of reducing the checkpoints on the roads

This scenario evaluates the impact of reducing the check points along the road. As it has been mentioned, the checkpoints produce inefficiencies in the supply chain, since it increases the lead time of the Cocoa. However, it is not known exactly how much is the impact in the potential of productivity of the system. The following results help to give light on this matter and on what impact would it have in the system if the government reduces the checkpoint frequency. This situation was modelled by reducing the checkpoint probability on 50% (from 10% to 5%). The other parameters of the model were left the same as the base-case scenario.

The results of the simulation are presented in the following table. In this scenario, the other parameters than checkpoint probability were left intact.

Table 9: Results of Scenario II

Parameter	Average Value	Standard Distribution
Value Beans Production (USD/day)	2,355,652	43,117
Value Butter Production (USD/day)	871,415	25,969
Productivity Beans (Ton/day)	1,289	231
Productivity Butter (Ton/day)	190	34
Total CO2 Emission [KG](3 months)	1057	13
Total NO2 Emission [KG] (3 months)	19.64	0.25

In comparison with the base case, the productivity of transported beans and butter increases around 30%, the value increases approximately 3% and 5% for Beans and Butter respectively. On the other hand, the pollution is increased with the increase of transport activity.

4.3. Scenario III. Impact of Improvement in Road infrastructure

This scenario evaluates the impact that the improvement in maintenance of the secondary and tertiary road might have. As it has been mentioned and illustrated, the road infrastructure is in a very bad shape in the country. This situation impacts directly the supply chain efficiency. This policy has been modelled by matching the speeds of the secondary and tertiary roads to the speed of the primary roads; Triangular(40,50,60) km/hr. Table 10 presents the results of this policies.

Table 10: Results of Scenario III

Parameter	Average Value	Standard Distribution
Value Beans Production (USD/day)	2,302,323	159,967
Value Butter Production (USD/day)	848,185	66,620
Productivity Beans (Ton/day)	1,083	424
Productivity Butter (Ton/day)	159	62
Total CO2 Emission [KG](3 months)	873	10
Total NO2 Emission [KG] (3 months)	16.21	0.20

It can be appreciated that the productivity of Beans and Butter is increased with 9.5% and 9% respectively, while the increase in value is only 1%. It is noticeable as well, that in this case the investment in secondary and tertiary roads does not have a big impact as with the previous scenario.

4.4. Scenario IV. Impact of Improvement in road infrastructure and check points

This scenario evaluates the impact of the combined effect of improving the road infrastructure and reducing the checkpoints at the same time. By having a combined policy of maintenance and more efficient flow of goods the expected impact is important as the following results illustrate.

Table11: Results of Scenario IV

Parameter	Average Value	Standard Distribution
Value Beans Production (USD/day)	2,353,241	54,509
Value Butter Production (USD/day)	869,877	21,440
Productivity Beans (Ton/day)	1,262	251
Productivity Butter (Ton/day)	186	36
Total CO2 Emission [KG](3 months)	1,036	13
Total NO2 Emission [KG] (3 months)	19.25	0.25

As it was expected, with this scenario, the values increased as well. However, it is noticeable that on the contrary as to what was expected, the combination of reducing the checkpoint values and investing in improving the secondary and tertiary roads does not produce a higher value than the one from only reducing the checkpoint probability. The standard distributions are also similar, thus, it is an interesting result that needs to be further investigated.

4.5. Scenario V. Impact of investment in producing more butter than Cocoa

The Cocoa butter has more value in the market than the Cocoa beans. For that reason, this scenario investigates what the impact would be if the butter percentage is increased by diverting more production to the grinders. For this scenario the percentage of beans that go to grinder is 50%, the other parameters are left the same as with the base-case scenario. This scenario also assumes that the grinders have enough capacity to process the beans and that 20% of the mass of the beans is transformed into butter. The characteristics and results are presented in the following tables.

The results show that since half of the beans now are converted to butter, the productivity of butter is increased. It is noticeable that beans productivity also increase a bit in comparison with the base case scenario. This is another interesting result that requires further investigation. The most remarkable result is that despite the butter value production is increased, the combined average productivity value (beans and butter) is decreased in comparison with the base case. This might be due to the market value of both products and also because in the simulation model other side products such as Cocoa oil or secondary products were not considered.

Table 12: Results of Scenario V

Parameter	Average Value	Standard Distribution
Value Beans Production (USD/day)	2,053,387	67,685
Value Butter Production (USD/day)	1,002,133	32,503
Productivity Beans (Ton/day)	1,021	290
Productivity Butter (Ton/day)	199	57
Total CO2 Emission [KG](3 months)	956	11
Total NO2 Emission [KG] (3 months)	17.75	0.21

4.6. Scenario VI. Impact of Investment in road infrastructure and Butter production

This scenario explores the situation of investing in improving the road infrastructure and increasing the butter production at the same time. This is simulated by modifying the speeds of the secondary and tertiary roads and increasing to 50% the percentage of beans that go to the grinders. This scenario again provides better results than the base-case scenario, but as the results show, it is not the best configuration for improving the PIs of the system.

Table 13: Results of Scenario VI

Parameter	Average Value	Standard Distribution
Value Beans Production (USD/day)	2,048,255	47562
Value Butter Production (USD/day)	999873	34182
Productivity Beans (Ton/day)	959	317
Productivity Butter (Ton/day)	189	62
Total CO2 Emission [KG](3 months)	903	10
Total NO2 Emission [KG] (3 months)	16.76	0.20

This final scenario illustrates that the change to producing more butter increases the productivity of butter but reduces the one of the beans, and the total sum of the average values of the combined production is less than the value for the base-case scenario. Furthermore, it illustrates that even though the productivity of butter is increased, the sum of the final market values do not, which means that for the improvement of the wellbeing of the population, probably the first policy impacts more than this one.

5. CONCLUSIONS

The current paper presents a novel approach of the analysis of the supply chain of the Cocoa in Côte d'Ivoire . The model presents an approach for modelling and simulating the evolution of production of the current system taking into consideration public information. The developed model considers the most important stakeholders of the system and it enables the evaluation of different policies for the current system. Several scenarios from the total combination are proposed in which different policies are analysed. They explore different policies like improving the road infrastructure, increasing the amount of production of butter or reducing the check in points in the road network. These policies are evaluated using different performance indicators. The following table summarizes the main findings of the study.

Table 14: Summary of results

Scenario	Comparison with current situation
Sc. II: Reducing check points on the roads	•Productivity increased by 30% •Value increased 3% and 5% of beans and Butter
Sc. III: Investing in improving secondary and tertiary roads	•Productivity increased by 9% •Value increased 1%
Sc. IV: Impact of Improvement in road infrastructure and checkpoints	•Productivity increased by 27% •Value increased by 3%
Sc. V: Increasing butter production	•Increase in productivity Beans by 3.2% and Butter by 36% •Value of Beans reduced by 10%, value of butter increase by 21%
Sc. VI: Investment in road infrastructure and butter production	•Reduction of productivity beans by 3%, increase by productivity in butter 29% •Value of Beans increased by 11%, value of butter increased by 21%
Pollution in all the cases increased, and the smallest contribution was achieved in scenario III followed by scenario VI	

Some results from the study were expected and other were counter-intuitive, for instance, the results suggest that by only decreasing the frequency of checkpoints by 50%, the productivity is increased by 30% and the monetary value at the Port by 5% in the case of the beans. This increase in value is translated into approximately 200,000 USD more per day of operation. The results also suggest that by investing in the least developed road infrastructure like secondary and tertiary roads will not have a big impact. This might be because there might be a bottleneck in the warehouses. On the other hand, by making the last link of the chain more efficient, which in this case is the transport to the Port, will have a big impact. Another interesting result is that from the environmental point of view, the results suggest that the investment in secondary and tertiary roads will reduce the pollution, however, the increase in market value will not be high. This might be due to the amount of trucks that are required to take the product from the farms to the warehouses, which will be reduced once the investment takes place. Last but not least, with the current market values of butter and Cocoa, the investment in butter apparently does not increase the total value of the supply chain. However, in the model it was assumed that only 20% of the beans mass is transformed into butter taking out other products that might make the transformation to butter and other products more economically attractive. This should be further investigated.

As it can be perceived, the simulation model of the supply chain of Cocoa is a valuable tool that allows decision makers and analysts having more insight into the operation of the supply chain. The tool is flexible enough to incorporate new elements in addition to the variability of the system which plays a key role in the performance of it. With the inclusion of the variability factor in the different operations and links of the supply chain, it is possible to evaluate and reduce the risk of wrong, small-value or even dangerous decisions that might put at stake the wellbeing of the population that depends on the production of Cocoa. Moreover, the developed model of supply chain of Cocoa can be easily translated into the evaluation of another type of agro-logistic product. This approach can be used as a tool that allows to have more informed decisions with the consequence of reducing the risk of making wrong decisions on the management of public or private money.

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