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The Efficiency of the Government of Ghana's Network of Grain Storage Facilities with Respect to Market Traders

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Abstract: *One of the primary aims of the government of Ghana's network of grain storage facilities is to assist farmers to process and store their grains. However, low utilization of the storage facilities by farmers poses a significant threat to the sustainability of this network. There is therefore the need to ascertain the possibility of other stakeholders such as market traders concurrently using the network to boost its profitability. One of the key factors a stakeholder will consider before using a network is the transportation cost that will come with it. This work estimated the efficiency in terms of transportation cost market traders will incur if they choose to use the existing network of grain storage facilities as opposed to using an optimal network of storage facilities. Using the transportation, pseudo p-median and forecasting models to determine the transportation cost and optimal locations respectively, the simulations showed that if market traders choose to use the existing network of storage facilities as temporal storage spaces, their efficiency with respect to transportation cost will be 45% in the short term. Thus they will incur a transportation cost 55% higher than they would have if they were operating in an optimal network. Their efficiency in the long term is however 64% as they will have to pay 36% higher than they would have in an optimal network. This work discusses solutions to this problem of inefficiency.*

1. INTRODUCTION

Maize constitutes a vital component of numerous local Ghanaian dishes. Even in the northern regions of Ghana where sorghum and millet are the preferred cereal, maize is the de-facto alternative in the lean season (Akramov & Malek, 2012). The importance of this crop is further underscored by the fact that it makes up about 55% of the country's total grain production (Abdul-Rahman & Donkoh, 2015; Ragasa, Chapoto, & Kolavalli, 2014).

In Ghana, the crop is usually produced on a small to medium scale. The small scale producers mostly cultivate for subsistence with barely enough to sell whiles medium scale producers cultivate enough to sell even during the lean season. Because of the comparatively small scale of production, there are aggregators who operate within and across farming communities. Some have purchase agreements with farmers whiles others just buy at the primary and secondary markets. The primary markets are essentially small village markets where farmers bring their produce to sell. They tend to be seasonal and occur on specific days of the week. Aggregators therefore move across these primary markets to gather substantial volumes of the commodity at very low prices. These aggregators then cart the commodities to secondary markets where people from all over the country come to retail. Food processing companies sometimes purchase from these markets because of the large volumes available (Akramov & Malek, 2012). The main secondary maize markets in Ghana are in Sunyani, Nkoranza, Techiman, Ejura-Sekyedumase, Kintampo, and Wenchi. The insufficiency of standard grain handling and storage system (dryers, silos, mechanical cleaners, etc.) in or near these market areas affects the productivity of these secondary markets. The resulting poor handling of the grains affects the quality and economic value of the grains. It also hastens deterioration thereby compelling traders to sell off the commodity to avoid further post-harvest losses. This problem persists despite the existence of the government's network of 48 grain storage facilities spread across the country with resources to properly process and store these commodities. If the traders at the secondary markets are incentivized to use these facilities it will significantly reduce post-harvest losses whiles boosting their profit margins. This work therefore determines the efficiency in transportation cost the traders will incur if they choose to use the grain storage facilities as temporal processing and storage centers. Efficiency as used here is the ratio of the total transportation cost the market traders will incur if the network of

GSF were an optimal network to the actual total transportation cost they will incur in using the existing network of GSF. An optimal network is a configuration of warehouses locations that gives the market traders the least total transportation cost in using the facilities. Thus the efficiency is a measure of what they will actually incur in this existing network to the least cost they could have incurred in an optimal network of GSF. This estimate will then inform the next line of action with respect to enhancing the sustainability of the existing network of grain storage facilities.

Several mathematical techniques have been used in the literature to compute one property or the other about network of facilities. Game theory has, for instance, been used to design a network of chemical plants to reduce the impact of terrorist attacks (Feng, Cai, Chen, Zhao, & Chen, 2016). The property being computed here was the impact and resilience to terrorist attacks of a particular configuration of chemical plants. There are also instances where the property in question is more than one, in which case a multi-criteria modeling technique is used. Several applications of these techniques are also reported in the literature (Ahi, Jaber, & Searcy, 2016; Al-Sudairi & Al-Motairi, 2010; Alzorba, Günther, & Popovici, 2013; Avci & Selim, 2016). Although the applications of these techniques reported in the literature do not directly relate to grain storage facilities, they demonstrate the plethora of tools that can be repurposed to compute the efficiency of any network of grain storage facilities. However in choosing the mathematical tool to use care was taken to choose one which will present a reasonable learning curve for any decision maker who may want to use the models developed. The researchers were also cognizant of the limited amount of reliable public data and computational systems found in developing countries. The models developed for this work therefore relied on mostly available and free data. The models themselves also require the use of relatively cheaper and easy-to-learn computational tools to allow for easy adoption by decision makers.

2. METHODOLOGY

Farmers in the country were clustered according to the 110 administrative districts that existed from 1997 to 2011. This was because the maize production data obtained from the Ministry of Food and Agriculture were in terms of these administrative districts. The data was then converted to district surplus maize production using the relation:

$$S = (GBP * 0.7) - (HP * PC)$$

Where

S= Surplus grain in kilogram per annum

GBP= Gross biological production (i.e. the actual recorded production volume)

HP= Human population of a district

PC= Per capita consumption in kilogram per annum

The human population data for each district was obtained from the Ghana Statistical Service whiles the per capita maize consumption data for the period was obtained from the Ministry of Food and Agriculture. The interconnecting distances between these districts and the 48 grain storage facilities were then obtained through the use of the Google ® maps distance matrix service.

As stated earlier, the efficiency, E of the existing network of grain storage facilities is given by the relation:

$$E = T_{Optimal} / T_{Existing}$$

Where $T_{Optimal}$ is the total transportation cost in an optimal network designed specifically for market traders and $T_{Existing}$ represents the total transportation cost in the existing network of GSF. The optimal network was designed using a pseudo p-median model whiles its total transportation cost was estimated using the transportation model. The same transportation model was then used to estimate the total transportation cost within the existing network of GSF. The details of these models are provided below:

I. Transportation Model

Notation

$D_{WH,MKT} = Distance\ between\ specific\ market\ and\ warehouses$

$Y_{WH,MKT}$ = Binary variable

$A_{MKT} = Amount\ of\ grain\ available\ at\ a\ storage\ facilityto\ be\ sent\ the\ market$

$Site_{WH} = Binary\ variable$

$Cost_{WH,MKT} = Vehicular\ cost\ per\ kilometer\ per\ kilogram\ between\ warehouse\ and\ market$

$$\textbf{Minimize}$$

$$\sum_{WH,MKT} D_{WH,MKT} \times Y_{WH,MKT} \times A_{MKT} \times Cost_{WH,MKT} \quad (1)$$

$$\textbf{Subject to}$$

$$\sum_{WH} Y_{WH,MKT} \geq 1 \qquad \text{for all MKT} \quad (2)$$

$$\sum_{MKT} Y_{WH,MKT} \geq Site_{WH} \qquad for\ all\ WH \quad (3)$$

$$Site_{WH} \geq Y_{WH,MKT} \qquad for\ all\ WH\ and\ MKT \quad (4)$$

$$Site_{WH} = 1 \qquad for\ all\ warehouses \quad (5)$$

$$Y_{WH,MKT} \in \{0,1\} \quad (6)$$

$$Site_{WH} \in \{0,1\} \quad (7)$$

This model essentially computes the total transportation cost (Equation 1) involved in moving maize from the markets to the GSF or vice versa. The total transportation cost is therefore a product of distance between the market and a storage facility ($D_{WH,MKT}$) in kilometers, the amount of surplus grain available at a storage facility to be sent to the market (A_{MKT}) and the vehicular cost of transporting a kilogram of grain across a kilometer ($Cost_{WH,MKT}$). The amount of grain available to be sent to the market is the amount of surplus grain available at the district with the warehouse. The vehicular cost is assumed to be 0.330712 $km^{-1}kg^{-1}$ U.S. dollars as reported by Essien (2013). Equation 2 ensured that all markets are assigned to districts with warehouses whiles equations 3, 4, and 5 ensure that all districts are assigned to warehouses. Equations 6 and 7 only specifies $Y_{WH,MKT}$ and $Site_{WH}$ as being binary.

II. Pseudo P-median Model

Notation

D = Districts

MKT = markets

$D_{D,MKT} = Distance\ between\ specific\ districts\ and\ markets$

$Y_{D,MKT}$ = Binary variable

$A_D = Production\ capacity\ of\ a\ particular\ district$

$C_{MKT} = Commercial\ capacity\ of\ a\ particulr\ market$

$Site_D = Binary\ variable$

$P = Number\ of\ warehouses\ to\ site$

$\text{Cost}_{D,MKT} = Cost\ of\ moving\ grain\ from\ district\ with\ warehouse\ to\ market$

$$Minimize$$

$$\sum_{D,MKT} \text{D}_{D,MKT} \times \text{Y}_{D,MKT} \times \frac{1}{\text{A}_\text{D}\,\text{X}\,\text{C}_\text{MKT}} \times \text{Cost}_{D,MKT} \quad (8)$$

$$Subject\ to$$

$$\sum_{D} Y_{D,MKT} \geq 1 \qquad \text{for all MKT} \quad (9)$$

$$\sum_{MKT} Y_{D,MKT} \geq Site_D \qquad for\ all\ D \quad (10)$$

$$Site_D \geq Y_{D,MKT} \qquad for\ all\ D\ and\ MKT \quad (11)$$

$$\sum_{D} Site_D = P \quad (12)$$

$$Y_{D,MKT} \in \{0,1\} \quad (13)$$

$$Site_D \in \{0,1\} \quad (14)$$

The objective function (Equation 8) is used to describe the variables one wants to minimize ($\text{D}_{D,MKT}, \text{Y}_{D,MKT}\ and\ \text{Cost}_{D,MKT}$) and those one want to maximize (A_D and C_MKT). Equations 9 - 11 are used to ensure that all markets are assigned to districts and vice versa. Equation 12 is used to state the "P" number of facilities one wants in the optimal network. Equation 13 and 14 declares $Y_{WH\ ,\text{MKT}}$ and $Site_{WH}$ as binary variables.

III. Forecasting model

The surplus grain production per district is an integral parameter in the transportation and pseudo p-median models. There was the need to investigate the effect of varying surplus grain production on the efficiency of the existing network. The surplus grain production data from 1997 to 2007 was used to develop a Seasonal Autoregressive Moving Averages (SARIMA) forecasting model. This model was validated using district surplus grain production data from 2008 to 2011. The validated model was then used to provide a 55 year forecast of district surplus grain production. These forecasts were then used sequentially as input to the transportation and pseudo p-median models to determine the transportation cost within the existing and optimal networks. A detailed description of the development, validation and forecasting can be found in Essien (2017).

The forecasting model was developed and run in Matlab® R2016b whiles the transportation and pseudo p-median models were developed using the GAMS® Distribution 24.8.3 software. The Software was run on an HP Mini 110-1100 Intel ® Atom™ CPU N270 @1.60GHz 1.60 GHz.

3. RESULTS AND DISCUSSION

An optimal network of grain storage facilities were developed for eleven (11) scenarios of district surplus grain production using the pseudo p-median model. The transportation cost of the resulting optimal network was computed using the transportation model. The same transportation model was used to compute the transportation cost within the existing network of grain storage facilities using the same scenarios of district surplus grain production volumes. On the average, the optimal network had a total transportation cost which was 55% cheaper than that of the existing network. This translates into the market traders having to endure an efficiency of 45% if they choose to use the existing network of grain storage facilities (Table 1).

Table1. Short term transportation cost for market traders

Scenario	Existing Network (USD)	Optimal Network (USD)	Percentage improvement	Efficiency
1	2.41E+06	8.20E+05	66%	34%
2	2.74E+06	8.20E+05	70%	30%
3	2.37E+06	1.14E+06	52%	48%
4	2.33E+06	1.39E+06	40%	60%
5	2.50E+06	8.25E+05	67%	33%
6	2.51E+06	1.03E+06	59%	41%
7	2.84E+06	6.80E+05	76%	24%
8	2.13E+06	9.56E+05	55%	45%
9	1.76E+06	1.23E+06	30%	70%
10	1.56E+06	7.99E+05	49%	51%
11	2.42E+06	1.45E+06	40%	60%
Average	2.32E+06	1.01E+06	55%	45%

The next phase of the simulation designed an optimal network of grain storage facilities using a particular configuration of district surplus grain production. Different configurations of district surplus grain production were then fed into this optimal network to examine the effect of changing the original configuration. The different configurations used were the 55 year forecasts given by the forecasting model. The simulation showed market traders will still incur about 36% higher than necessary transportation cost in the long term if they choose to use the existing network of grain storage facilities (Table 2). A plot of the locations of the optimal and existing network on a map shows several disparities in the locations. The optimal network had storage facilities at high surplus districts which were neglected by the existing network (Figure 1).

Table2. Long term transportation cost for market traders

Year	Existing Network (USD)	Optimal Network (USD)	Percentage improvement	Efficiency
5	2.41E+06	8.20E+05	66 %	34%
10	2.74E+06	1.10E+06	40 %	60%
15	2.37E+06	5.23E+05	22 %	78%
20	2.33E+06	1.51E+06	65 %	35%
25	2.50E+06	2.75E+05	11 %	89%
30	2.51E+06	2.51E+05	10 %	90%
35	2.84E+06	1.99E+06	70 %	30%
40	2.13E+06	8.93E+05	42 %	58%
45	1.76E+06	5.61E+05	32 %	68%
50	1.56E+06	3.12E+05	20 %	80%
55	2.42E+06	3.87E+05	16 %	84%
Average	2.32E+06	7.83E+05	36 %	64%

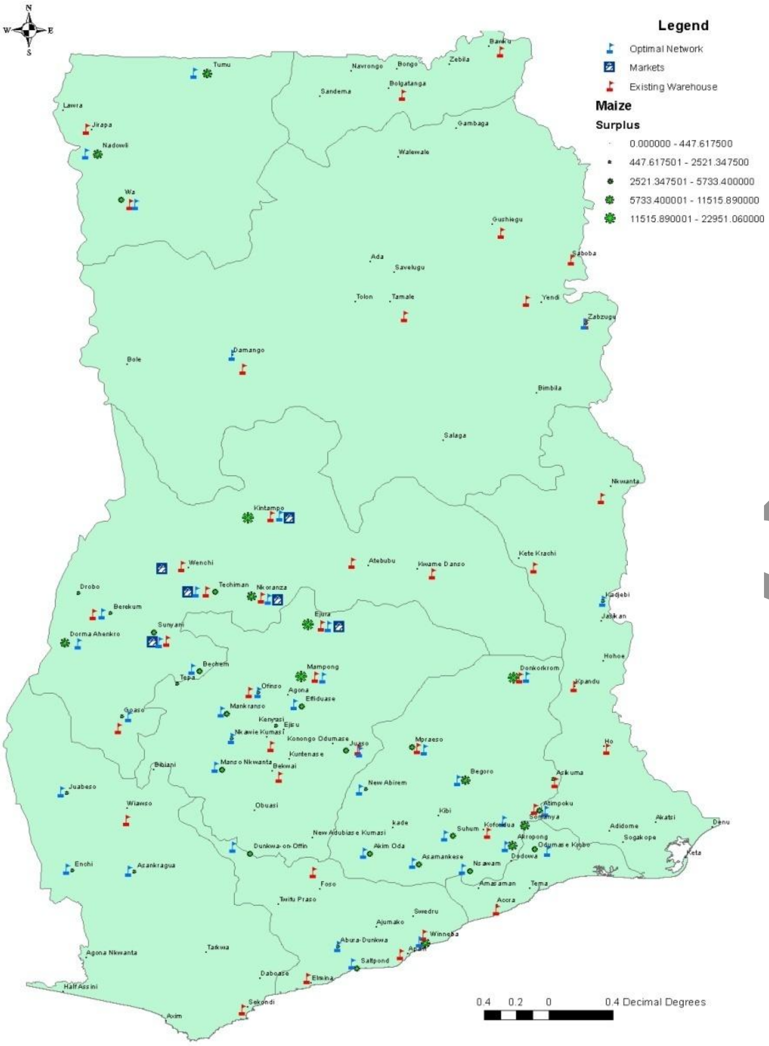

Figure1. *A map showing the Existing and Optimal networks of GSF for market traders*

The simulations suggest that the existing network of grain storage facilities is not well suited for the market traders. This was apparent in the high short and long term transportation cost estimates from the simulation runs. The decision maker (which is the government in this case) therefore has two options to making the existing network conducive for market traders. One is by siting a few new facilities at strategic locations (determined using the Pseudo P-median model) to reduce the transportation cost of the traders. Since most of the major markets concerned are found in close proximity, one can simulate the effect of providing warehouses at all those places. These simulations (using the Pseudo P-median and transportation models) will reveal the effect of respective decisions on the transportation cost of the traders. It must also be stated that since the number of markets in question are few, the number of additional facilities to be sited will most likely be few.

The second option to solving the problem of high transportation cost is to incentivize the traders to make the trip. Since the decision maker i.e. the government has offices in all the districts with agricultural extension officers, they could be equipped to mop up all surplus grains into the respective grain storage facilities. A warehouse receipt system will then be put in place to allow the traders to buy stocks and send only the amount needed to the market. This allows the traders to buy and keep for as long as necessary. They would not also have to deal with middle men/ aggregators whose poor handling of the commodity hastens deterioration. This approach will provide the market traders enough reason to use the existing network despite the huge inefficiencies.

Either of the proposed solutions will substantially boost the sustainability of the network of grain storage facilities and enhance the food security of the country. The models and approaches used in this work could be also applied to other agricultural systems such as cocoa, coffee, cashew, vegetables among others to enhance the sustainability of their supply chain.

4. Conclusion

This work develops an integrated methodology to computing the efficiency of a network of grain storage facilities as it relates to a non-primary stakeholder. This has become necessary to boost the sustainability of networks of supply chains through concurrent use by multiple stakeholders. It integrated transportation, pseudo p-median and forecasting models to compute the efficiency of Ghana's network of grains storage facilities with respect to market traders. It further proposed ways of incentivizing market traders to use the existing network. The approach could also be used to compute the efficiency of any network of facilities with respect to various stakeholders.

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