Determining the Efficiency of the Government of Ghana's Network of Grain Storage Facilities

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Abstract

Governments in developing countries design networks of grain storage facilities to help farmers store excess agricultural produce to prepare for climate induced crop failures. The efficiency of such networks has serious economic and food security implications on respective countries. Periodic review of the efficiency of such networks is necessary to identify lapses and opportunities for optimization. Past studies on efficiency of networks of facilities, which usually assume scenarios peculiar to the developed world used data that are usually unavailable or unreliable in developing countries. This work therefore developed an integrated approach that relies solely on readily available and reliable governmental and open source data to compute the short and long-term efficiencies of networks of grain storage facilities. This approach was used to analyze the efficiency of the government of Ghana's network of forty-eight grain storage facilities. A transportation model was used to compute the total transportation cost within the existing network. A P-median model was then used to develop and compute the transportation cost of a theoretically optimal network. Outputs from a forecasting model were used with the transportation and P-median models to study the short and long-term efficiencies of the existing and optimal networks. The average short and long term efficiencies of the existing network were 66% and 26% respectively. The study also investigated the efficiencies of a rank network which is created by siting GSF's in only high grain production districts. The short and long-term efficiencies of this network were 87% and 72% respectively. The study showed that Ghana's GSFs were sub-optimally sited hence farmers would have to travel excessively longer distances than necessary to use it. This offers some explanation for its low patronage. Furthermore, the study shows that a rank network was not as efficient as the optimal network. This study therefore demonstrates the use of this integrated approach coupled with readily available data to analyze networks of grain storage facilities in developing countries.

Introduction

In developing countries, grain storage facilities (GSF) are built by governments for commodity price stabilization, inflation control, climate change mitigation, etc. (Coulter, Sondhi, & Boxall, 2000). However, since not all farming clusters can have a facility, the facilities are sited to as much as possible, reduce the traveling distance of all farming clusters. The strategic siting of these facilities across a geographic space to achieve this distance minimization objective enables these facilities to be described as constituting a network. It is possible through modeling and simulation to estimate the minimum total transportation cost ($T_{Optimal}$) theoretically attainable in a network when the locations of farming clusters and GSF are known. Similar techniques can also be used to estimate the total transportation cost ($T_{Existing}$) in an existing network. The efficiency ($T_{Optimal}$ / $T_{Existing}$) of an existing network therefore quantifies how the transportation cost within that existing network approximates that of a theoretically optimal network with similar configurations. Hence, the decision maker is able to judge based on this figure whether he/she is offering the best services possible with the resources at hand.

The literature is replete with works on determining the efficiency of a network of facilities. Some however require data (detailed financial reports, queuing times, operational parameters, environmental parameters, etc.) that are mostly inaccessible, unavailable or unreliable in developing countries (Ahi, Jaber, & Searcy, 2016; Chibeles-Martins, Pinto-Varela, Barbosa-Póvoa, & Novais, 2016; Harris, Mumford, & Naim, 2014). Others also measure efficiency in the economic sense hence focus on designing these networks and making operational decisions so as to use the least resources for maximum profit (Bargos, Lamas, Bargos, Neto, & Pardal, 2016; Cai, Wang, & Xu, 2015; Dweiri, Kumar, Khan, & Jain, 2016; Izadikhah & Farzipoor Saen, 2016; Lai, Potter, Beynon, & Beresford, 2015). Governments in developing countries however prioritize access (as a form of social intervention) over profitability. Hence, they seek to answer the question of providing coverage for farmers before they consider profitability. This approach is however not always optimal as some users might have to be neglected for optimality. The approach results in serious sustainability problems when access does not significantly translate into patronage. Coulter et al. (2000) reports of instances where GSF are becoming unsustainable as a result of low patronage. Ghana, for instance, has a network of 48 state-owned grain storage facilities scattered across the country. Most of these facilities are in deplorable shape partly because of low patronage from farmers (Bani, Deyang, & Panni, 2005). Knowledge of the efficiency of this network will significantly boost the effectiveness of the government's next line of action concerning the existing and any future networks. This is especially important as donor agencies and private entities are still putting up storage facilities. The purpose of this research was to develop a context relevant integrated approach to computing the efficiency of GSF networks in developing countries and use that to analyze Ghana's existing network of grain storage facilities.

Integrated Methodology

Data Acquisition and Processing

The grain used in this analysis was maize as it constitutes about 55% of all grains produced in Ghana (Akramov & Malek, 2012). The first step of this process was to aggregate the individual farming communities into clusters. The farmers were clustered by administrative districts that existed from 1997 - 2011 for which agricultural data is available. The relevant data for each administrative district was the district maize production tonnage for the 15 years period as well as the interconnecting distances within the respective districts. The district maize production data for the period was obtained from the Ministry of Food and Agriculture whiles the interconnecting distances were obtained using the Google Distance Matrix Api® service for free. Since storage facilities only receive surplus grain, the surplus tonnage of grains per district had to be computed. This was done using the following relation:

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

Where

S= Surplus grain in kilogram per annum

HP= Human population of a district

PC= Per capita consumption inkilogram per annum

GBP= Gross biological production

0.7 = 70 % of the gross biological production that is not lost post-harvest as estimated by the Ministry of Food and Agriculture

The district human population (HP) data for the period was acquired from the Ghana Statistical Service whiles the per capita grain consumption (PC) and gross biological production (GBP) for the same period was obtained from the Ministry of Food and Agriculture of Ghana. The surplus grain tonnage for the districts were then computed and used as input for all the models.

Three models were used to generate the inputs for the computation of the efficiency of the network of GSF. These were the transportation, forecasting and p-median models. These models were used because they are a standard means of measuring the parameters needed for the computation of the efficiencies.

Transportation Model

This is a mixed integer linear programming model that is used to compute the total transportation cost farming clusters in the existing network have to incur. Given the location of farming clusters and that of GSF (with their corresponding surpluses and interconnecting distances), this model computes the total transportation cost farmers will incur in sending their produce to the various storage facilities assigned to them. The model can be stated as follows:

$$\textbf{\textit{Minimize}}$$

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

$$\textbf{\textit{Subject to}}$$

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

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

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

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

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

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

The objective function (Eq. (1)) is the total transportation cost which is a product of the distance each respective farm cluster travels to access its assigned GSF ($D_{WH,D}$), the amount of grain being moved to the GSF ($A_{WH,D}$) and the vehicular cost for moving a kilogram of grain per kilometer. A binary variable $Y_{WH,D}$ is introduced into the computation of the total transportation cost to regulate the assignment of GSFs to districts. This variable takes a value of 1 when a particular district is assigned to a GSF and 0 otherwise. The first constraint (Eq. (2)) ensures that all GSF are assigned to at least one district. The second and third constraints (Eq. (3) and Eq. (4)) also ensure that districts are strictly assigned to GSF. The fifth constraint (Eq. (5)) is used to stipulate the locations of the GSFs in the network. The last two constraints (Eq. (6) and Eq. (7)) are declarations of $Y_{WH,D}$ and $Site_{WH}$ variable as being binary. Hence they take a value of 1 or 0 depending on other variables in the model.

P-median Model

The P-median model was used to design an optimal network of grain storage facilities which offered the farming clusters the least total transportation cost attainable. This model takes as input a set of candidate farming clusters among which one wants to choose the most optimal places to site storage facilities. The respective surplus grain capacities and interconnecting distances of these candidate districts are also necessary inputs to the P-median model. The model uses the surplus capacities of farming districts and the traveling distances between these districts to decide which districts to site grain GSFs to reduce the total transportation cost of all farmers. The model can be stated as follows:

$$\textbf{\textit{Minimize}}$$

$$\sum_{i,j} D_{i,j} \times Y_{i,j} \times A_i \times Cost_{i,j} \quad (8)$$

$$\textbf{\textit{Subject to}}$$

$$\sum_{j} Y_{i,j} = 1 \quad \text{for all i} \quad (9)$$

The objective function (Eq. (8)) minimizes the total transportation cost within the network of GSFs. The first constraint (Eq. (9)) ensures that when the GSF are sited, each district is assigned to at least one facility. The second constraint (Eq. (10)) ensures that exactly 'P' number of locations are selected for the siting of GSF as specified by the decision maker. The third constraint (Eq. (11)) essentially links the location binary variable to the allocations binary variable whiles the fourth and fifth

$$\sum_{j} X_j = P \qquad (10)$$

$$Y_{i,j} - X_j \leq 0 \qquad for\ all\ i\ and\ j \qquad (11)$$

$$Y_{i,j} \in \{0,1\} \qquad (12)$$

$$X_j \in \{0,1\} \qquad (13)$$

constraint (Eq. (12) and Eq. (13)) specifies the location (X_j) and allocation ($Y_{i,j}$)) variables as being binary. The vehicular cost represented as $Cost_{WH,D}$ and $Cost_{i,j}$ in the Transportation and P-median models respectively is assumed to be 0.330712 $km^{-1}kg^{-1}$ U.S. dollars as reported by Essien (2013).

Forecasting Model

Grain surpluses of the respective districts (represented as variables $A_{WH,D}$ and A_i in the transportation and P-median models respectively) directly affect the long-term efficiency of any network of grain storage facilities. Significant and consistent changes in grain surpluses can render a hitherto optimal network in-optimal. Thus, a GSF serviced by a high surplus district, may eventually become redundant if the high surplus district gradually becomes a district with grain deficit. This could happen as a result of urbanization, farmers growing more lucrative crops, migration, climate change, etc. The forecasting model is therefore necessary to capture the long-term behavior of the surplus grain production tonnage of respective districts. The forecasted surplus grain of districts is used as inputs for the transportation and p-median models to understand the short and long-term efficiency of any given network. A seasonal Autoregressive Integrated Moving Averages (ARIMA) forecasting model was developed and used to compute the forecasted district surplus grain production volume for 55 years. The detailed development of the forecasting model is described in Essien (2013).

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

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A comparison of the prevalent transportation cost in the existing and optimal networks under varying scenarios of district grain surpluses show a consistently lower cost within the optimal network (Table 1). The simulations showed that farmers within the existing network of GSF are on the average paying 34% higher transportation cost than is necessary. This finding offers some explanation as to the low patronage of the

Figure 1: Map showing existing network of state owned grain storage facilities and relative surplus maize production per district in Ghana.

The optimal network (the same size as the existing network) designed using the p-median model was also visualized on the map alongside the respective district grain surpluses. Expectedly, most of the high surplus districts either had facilities or were near a district with a facility (Fig 2).

Figure 2: Map showing existing network of state owned grain storage facilities, an optimal network and the relative surplus maize production per district in Ghana.

facilities as the high transportation cost will eat into the already meager profit margin of farmers.

The simulation also showed that farmers in the optimal network on the average incurred transportation cost which is 26% cheaper than those within the existing network across a 55 year period (Table 2). This was despite the fact that there were fluctuations in the optimality of both networks due to changing grain production patterns. Thus, the optimal network remains resilient in its ability to resist grain production shocks.

A rank network was generated by initially ordering districts according to surplus grain production volumes and then siting warehouses hierarchically. The transportation cost within this rank network was compared to that which will prevail in the optimal networks with the same number of facilities.

The transportation cost within the optimal network is 13 % cheaper than that of the rank network in the short term (Table 3). A simulation of the long term efficiency of the two networks revealed the optimal network to have a 28 % cheaper transportation cost as compared to the rank network over the long

TABLE 1

Short term transportation cost for the existing and optimal networks of grain storage facilities for farmers

Scenario	Existing Network (USD,$)	Optimal Network (USD,$)	Percentage Improvement	Efficiency
1	5.27E+07	3.53E+07	33%	67%
2	3.18E+10	1.82E+10	43%	57%
3	1.39E+10	1.20E+10	14%	86%
4	7.95E+09	4.51E+09	43%	57%
5	6.38E+09	3.82E+09	40%	60%
6	6.16E+09	3.94E+09	36%	64%
7	7.06E+09	4.89E+09	31%	69%
8	9.39E+09	7.23E+09	23%	77%
9	6.93E+09	4.63E+09	33%	67%
10	7.48E+09	6.50E+09	13%	87%
11	5.48E+09	2.03E+09	63%	37%
Average	9.32E+09	6.16E+09	34%	66%

TABLE 2

: Long term transportation cost incurred by farmers in the existing and optimal networks

YEAR	Existing Network (USD,$)	Optimal Network (USD,$)	Percentage Improvement	Efficiency
5	5.27E+07	3.53E+07	33%	67%
10	3.18E+10	2.04E+10	36%	64%
15	1.39E+10	1.04E+10	25%	75%
20	7.95E+09	7.14E+09	10%	90%
25	6.38E+09	6.25E+09	2%	98%
30	6.16E+09	3.94E+09	36%	64%
35	7.06E+09	6.84E+09	3%	97%
40	9.39E+09	6.04E+09	36%	64%
45	6.93E+09	2.78E+09	60%	40%
50	7.48E+09	4.76E+09	36%	64%
55	5.48E+09	5.14E+09	6%	94%
Average	9.32E+09	6.70E+09	25.75%	74%

term (Table 4). Therefore although the rank network is easy and somewhat intuitive, its long term efficiency is not reliable.

The simulations therefore suggest that the optimal network has superior performance compared with the existing and rank networks. Since the existing and rank networks are all designed by intuition, this result further suggests that intuition might not be the best approach when it comes to designing networks. This is because of the plethora of alternatives one has to evaluate to approximate any optimality. For instance, the network evaluated in this work had 110 districts and 48 of them needed to be chosen to have a grain storage facility. The number of possible outcomes for this small problem is 4.07E+31. It is therefore difficult for any decision maker to adequately evaluate all these outcomes to choose the optimal configuration by intuition. However, when the models are properly described in their respective softwares it takes a maximum of 2 minutes to run each simulation. Although not demonstrated in this work, in deciding on how to improve the current network, decision makers could collapse certain facilities within the model to see their impact on the total transportation cost. Knowing the impact of each facility on the entire network will greatly inform the next line of action for the decision maker. This approach will therefore allow decision makers to simulate several scenarios to better understand the consequences of their decisions. The flexibility to simulate several scenarios allows decision makers to maximize their time and profit. This is consistent with benefits demonstrated in the literature when decision makers resort to the use of such decision support systems in making their siting decisions (Amiama, Cascudo, Carpente, & Cerdeira-Pena, 2015; Ayadi, Cheikhrouhou, & Masmoudi, 2013; Costa, Gomes, Carvalho, & Barbosa-Póvoa, 2014; Filip & Duta, 2015; Ngai, Peng, Alexander, & Moon, 2014).

TABLE 3

Short term transportation cost incurred by farmers in the optimal and rank networks

Scenario	Optimal Network (USD,$)	Rank Network (USD,$)	Percentage Improvement	Efficiency
1	4.46E+07	4.97E+07	10%	90%
2	2.71E+10	2.83E+10	4%	96%
3	1.10E+10	1.30E+10	15%	85%
4	6.38E+09	7.95E+09	20%	80%
5	8.29E+09	9.31E+09	11%	89%
6	6.59E+09	7.01E+09	6%	94%
7	1.15E+10	1.72E+10	33%	67%
8	7.14E+09	7.27E+09	2%	98%
9	3.65E+09	3.97E+09	8%	92%
10	5.06E+09	5.95E+09	15%	85%
11	4.93E+09	6.38E+09	23%	77%
Average	8.34E+09	9.66E+09	13.36%	87%

TABLE 4

: Long term transportation cost incurred by farmers in the optimal and rank networks

Year	Optimal Network (USD,$)	Rank Network (USD,$)	Percentage Improvement	Efficiency
5	1.50E+07	2.11E+07	29 %	71%
10	8.67E+09	1.20E+10	28 %	72%
15	4.42E+09	5.53E+09	20 %	80%
20	3.04E+09	3.38E+09	10 %	90%
25	2.66E+09	3.96E+09	33 %	67%
30	1.67E+09	2.98E+09	44 %	56%
35	2.91E+09	7.31E+09	60 %	40%
40	2.57E+09	3.09E+09	17 %	83%
45	1.18E+09	1.69E+09	30 %	70%
50	2.02E+09	2.53E+09	20 %	80%
55	2.18E+09	2.71E+09	19 %	81%
Average	2.85E+09	4.11E+09	28.18 %	72%

The major limitation within this work is that we evaluated efficiency solely from the perspective of one stakeholder. There are however other stakeholders (market traders, exporters at harbors and airports, etc.) in the grain value chain that use the GSF as well. Although the existing network is inefficient with respect to farmers, further studies should be conducted to ascertain its efficiency with respect to the other stakeholders. This is especially important as agriculture in developing countries is mostly seasonal hence other stakeholders must use the facility during lean seasons to guarantee sustainability (Coulter et al., 2000).

Conclusion

This paper demonstrated the development and application of an integrated approach to determining the efficiency of a network of grain storage facilities in developing countries. The approach relied on three models (Transportation, P-median and forecasting models) to compute the efficiency of three different networks (Optimal, Existing, Rank). The results show that the optimal network offered a cheaper transportation cost for farmers over the short and long term compared to the existing and rank networks. This work also demonstrated that the intuitive method of siting facilities results in in-optimal networks due to the high number of possibilities involved in such decision making. The approach demonstrated in this work could also be used to compute the efficiency of any existing network of facilities. This approach should therefore be adapted to analyze other agricultural supply chains in areas where one is saddled with insufficient or unavailable data.

References

Ahi, P., Jaber, M. Y., & Searcy, C. (2016). A comprehensive multidimensional framework for assessing the performance of sustainable supply chains. *Applied Mathematical Modelling,* 40(23–24), 10153–10166. https://doi.org/10.1016/j.apm.2016.07.001

Akramov, K., & Malek, M. (2012). Analyzing profitability of maize, rice, and soybean production in Ghana: Results of PAM and DEA analysis. *Ghana Strategy Support Program (GSSP) Working, 28.*

Amiama, C., Cascudo, N., Carpente, L., & Cerdeira-Pena, A. (2015). A decision tool for maize silage harvest operations. *Biosystems Engineering*, 134, 94–104. https://doi.org/10.1016/j.biosystemseng.2015.04.004

Ayadi, O., Cheikhrouhou, N., & Masmoudi, F. (2013). A decision support system assessing the trust level in supply chains based on information sharing dimensions. *Computers & Industrial Engineering*, 66(2), 242–257. https://doi.org/10.1016/j.cie.2013.06.006

Bani, R., J., Deyang, A., & Panni, J. (2005). *Report on the status of Government owned grain storage facilities in Ghana. Ministry of Food and Agriculture, Ghana.*

Bargos, F. F., Lamas, W. de Q., Bargos, D. C., Neto, M. B., & Pardal, P. C. P. M. (2016). Location problem method applied to sugar and ethanol mills location optimization. *Renewable and Sustainable Energy Reviews*, 65, 274–282. https://doi.org/10.1016/j.rser.2016.06.079

Cai, T., Wang, S., & Xu, Q. (2015). Monte Carlo optimization for site selection of new chemical plants. *Journal of Environmental Management*, 163, 28–38. https://doi.org/10.1016/j.jenvman.2015.08.002

Chibeles-Martins, N., Pinto-Varela, T., Barbosa-Póvoa, A. P., & Novais, A. Q. (2016). A multi-objective meta-heuristic approach for the design and planning of green supply chains - MBSA. *Expert Systems with Applications,* 47, 71–84. https://doi.org/10.1016/j.eswa.2015.10.036

Costa, P., Gomes, M. I., Carvalho, A., & Barbosa-Póvoa, A. (2014). Decision Support Tool for Strategic Planning in Supply Chains. In P. S. V. and P. Y. L. Jiří Jaromír Klemeš (Ed.), *Computer Aided Chemical Engineering* (Vol. 33, pp. 895–900). Elsevier. Retrieved from http://www.sciencedirect.com/science/article/pii/B9780444634566501502

Coulter, J., Sondhi, J., & Boxall, R. (2000). The economics of grain warehousing in sub-saharan Africa. *African Review of Money Finance and Banking*, 97–116.

Dweiri, F., Kumar, S., Khan, S. A., & Jain, V. (2016). Designing an integrated AHP based decision support system for supplier selection in automotive industry. *Expert Systems with Applications*, 62, 273–283. https://doi.org/10.1016/j.eswa.2016.06.030

Essien, E. (2013). *Development of a Decision Support System for Siting Grain Storage Facilities to Reduce Transportation Cost.* Kwame Nkrumah University of Science and Technology, Kumasi.

Filip, F. G., & Duta, L. (2015). Decision Support Systems in Reverse Supply Chain Management. *Procedia Economics and Finance*, 22, 154–159. https://doi.

org/10.1016/S2212-5671(15)00249-X

Harris, I., Mumford, C. L., & Naim, M. M. (2014). A hybrid multi-objective approach to capacitated facility location with flexible store allocation for green logistics modeling. *Transportation Research Part E: Logistics and Transportation Review*, 66, 1–22. https://doi.org/10.1016/j.tre.2014.01.010

Izadikhah, M., & Farzipoor Saen, R. (2016). Evaluating sustainability of supply chains by two-stage range directional measure in the presence of negative data. *Transportation Research Part D: Transport and Environment, 49*, 110–126. https://doi.org/10.1016/j.trd.2016.09.003

Lai, P., Potter, A., Beynon, M., & Beresford, A. (2015). Evaluating the efficiency performance of airports using an integrated AHP/DEA-AR technique. Transport Policy, 42, 75–85. https://doi.org/10.1016/j.tranpol.2015.04.008

Ngai, E. W. T., Peng, S., Alexander, P., & Moon, K. K. L. (2014). Decision support and intelligent systems in the textile and apparel supply chain: An academic review of research articles. *Expert Systems with Applications*, 41(1), 81–91. https://doi.org/10.1016/j.eswa.2013.07.013

NOMENCLATURE

I = Source or origin of a commodity
J = Destination of a commodity
$Cost_{i,j}$ = Transportation cost between source and destination of commodity , $km^{-1}kg^{-1}$\$
$Cost_{WH,D}$ = Tranportation cost between warehouse and district, $km^{-1}kg^{-1}$ \$
$A_{WH,D}$ = Amount of Surplus grain from a particular district sent to the warehouse, kg
A_i = Surplus Grain capacity of a district, kg
$D_{WH,D}$ = Distance between specific districts and warehouses, km
$D_{i,j}$ = Distance between source (i)and destination (j) of commodity, km
$Site_{WH}$ = Binary variable(This variable becomes 1 if a warehouse is sited and 0 if otherwise)
X_j = Binary variable
$Y_{WH,D}$ = Binary variable (This variable takes a value of 1 when a particular district is assigned to a GSF and 0 if otherwise)
$Y_{i,j}$ = Binary variable (This variable takes a value of 1 when surplus grain is move from a source (i) to destination (j) and 0 if otherwise)
ARIMA = Autoregressive Integrated Moving Averages
GBP = Gross biological production
GSF = Grain Storage Facilities
HP = Human population of a district
PC = Per capita consumption in kilogram per annum
S = Surplus grain in kilogram per annum
T Existing = The total transportation cost, \$
T Optimal = The minimum total transportation cost, \$