DESIGN OF A LOGISTIC PLATFORM THROUGH DE OPTIMIZATION OF AGRICULTURAL DISTRIBUTION NETWORKS IN PANAMA

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ABSTRACT

One of the main challenges of the agricultural sector in Panama is the weakness that can be found in the links of the agricultural supply chain. The objective of this project, funded by the National Secretariat of Science, Technology and Innovation of Panama, was to model, for the first time, the supply chain of produces and to design and propose the corresponding policies for the logistic platform that would optimize distribution of agricultural products in the country. Specifically lettuce was used as the main product for the analysis, and an optimization model was developed in order to validate the decisions made, not only with respect to volume but also with respect of the type of vehicle used. A cost analysis was performed in order to study the implications for the different elements of the supply chain. Finally, a decision for a new distribution center was made for different scenarios.

Keywords: Agricultural supply chain, transportation, distribution networks, linear programming applications

1. INTRODUCTION

Panama has been considered a logistics center point for the American Continent. Different publications have mentioned Panama from this stand point. Projects such as the Panama Canal expansion, the Colon Free Zone (one of the largest in the world) the Tocumen International Airport and the Copa Airlines Hub of the Americas, the Panama Canal Railroad and the different container ports located in the Pacific and the Caribbean side of the Canal are just examples of logistics initiatives in the country.

On the other hand, according to the Panamanian Comptroller Office (2013), agriculture and other related activities are the main sources of employment in the rural areas represent over 20% of total employment nationwide the Agricultural Gross Domestic Product (AGDP - 2013) represents just 3% of total Gross Domestic Product (GDP). One of the results of this situation has been the lack of attention that has been provided to the analysis, modeling and optimization of the internal agricultural supply chain.

Boudahri, et al (2012) define the term agri-food supply chains (ASC) to describe the activities from production to distribution that bring agricultural or horticultural products from the farm to the table. ASC are formed by the farmers, distribution, processing, and marketing of agricultural products to the final consumers. In Panama, the interface between producers and supermarkets or municipal supply centers (final destination) is completely monopolized by intermediaries (carriers) which seem to increases the final product cost. All of these intermediates make up almost all the distribution networks for agricultural products in the internal food supply. This carriers transport the products of more than 60% of total producers and the remaining 40% is transported by private companies. In addition, there are losses of 40% of transported products. Therefore, these wastes in produce are transferred to the final customer (Secretariat of the Cold Chain, 2012).

The Province of Chiriquí (see map in figure 1) provides almost 80% of the vegetables consumed in Panama. It is located in the western sector of the country and it is the main supplier node in the food distribution network of the country. On the other hand, the Province of Panama at about 500 kilometers east of Chiriquí is the largest market with 1.71 million habitants (little less than 50% of the nation's population), hence an optimal distribution networks system is required throughout the country to serve the rest of the province in an efficiently way. In addition, Veraguas, Herrera, Los Santos and Coclé are the central province of Panama with an overall population of approximate 660,246 according to the National Institute of Census and Statistics. Together with Chiriquí, with a population near 300,000 complete the main market area for agricultural products.

The objective of this paper is to develop a mathematical model that depicts both the behavior of the agricultural supply chain and to analyze the transportation equipment used in the logistic chain in order to obtain an optimal transportation policy of agricultural products from the main production center to the different consumption points in Panama. This optimization model is the main result for a project funded by the National Secretariat of Science, Technology and Innovation of Panama (Orozco and Tuñon 2012, Álvarez and Orozco 2013) that is aimed to study the distribution network of agricultural products and propose a making decision model for optimal locations of modal interchange facilities and logistics platforms "hubs". The rest of the document will present a brief literature review of work done in this area, the methodology used and some of the main results of the project.

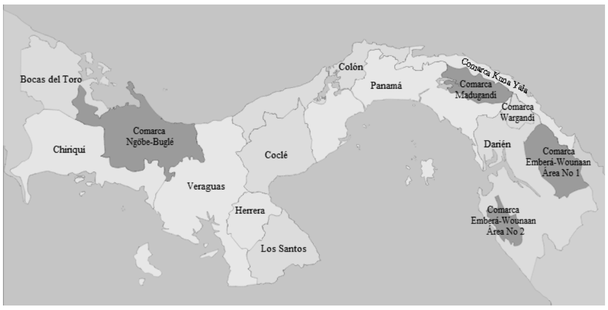

Figure 1: The geography of the Republic of Panama

2. LITERATURE REVIEW

Studying food distribution systems becomes an important point in supply chain management for several reasons. First of all, food scarcity becomes critical nowadays due to climate changes. For example, due to recent draughts in the United States and Russia, or constant floods in Colombia, Mexico, Central America or Central and South Europe yields in crops and cattle are decreasing. Thus, cost of food and produces are increasing. On the other hand, people need food to be accessible and safe, in terms of availability, effects in health and costs, becoming a strategic issue for governments. For example, Pietro and Timpanaro (2012) affirm that the issue of agricultural logistics is the subject of great interest because it is considered strategic for the development of a country especially on the possible transport links between different areas of the country.

Moving agricultural products between different points in the country implies handling issues regarding perishability of products, long and tortuous supply chains marked by the presence of several operators, the need to maintain a cold chain to guarantee the quality of the final product, consumption behavior and habits, and the role that health aspects and organoleptic quality play in purchasing decisions of consumers, among others. According to the same authors, the cost the agricultural logistics varies between 20-30% of the cost of the product. This can be even higher depending on the type of chain involved, *e.g* the distance from origin and the type of transportation considered. Thus, it is important to view the transportation and logistics system as a whole since, as Tan (2012) affirms, "the production, exchange, distribution and consumption of agricultural products constitute the organic chain of agriculture reproduction. Any deficiency of them will affect the development of agriculture (p. 106)".

In addition, it is important the study of distribution networks in order to address the different issues existing between the diverse parties involved in the transportation and distribution systems of products. Daganzo (1992), for example establishes the principle of distribution network application with the goal of uniting one origin with one destination, one origin to many destinations and many to many systems using transshipment centers and providing methods to solve it. On the other hand, Agra (2008) demonstrated that the costs associated with the transport of goods represent a large part of the final cost. Estrada (2007), on the other hand, asserted that there are different types of distribution networks, depending on the product, the transportation mode or the demand points.

Several papers have been found in the literature concerning the modeling of the agri-food supply chain. Boudahri, et al (2012) for example, presented a document concerned with the planning of a real agri-food supply chain for chicken meat for the city of Tlemcen in Algeria. The agri-food supply chain network design is a critical planning problem for reducing the cost of the chain. More precisely the problem is to redesign the existing supply chain and to optimize the distribution planning. The authors applied the Allocation Problem Model in order to define points in the network with the objective of minimizing the total distance between customers and these sites, or to minimize the maximum distance.

Moreover, Jones, et al (2001) consider a production-scheduling problem arising when there are random yields and demands as well as two sequential production periods before demand occurs. The paper presented a two-period model with random yield and random demand in which production can occur in either or both periods. The model is solved optimally as a sequential decision problem and it demonstrated that the two-period production strategy has substantial economic payoff for the seed industry.

Shu-quan and Ling (2010) focused the research in the multi-dimension and uncertainty of logistics performance evaluation for agricultural products distribution centers and the lack of evaluation methods. The authors proposed a hierarchy model of evaluation factors that combines fuzzy analytical hierarchy process (FAHP) with fuzzy comprehensive evaluation to generate quantitative comprehensive evaluation of logistics performance for agricultural products. In addition, it finally proves the rationality and application of this method through a practical case. Jang and Klein [(2011), develop models for supply chain issues facing small enterprises, solve them, and suggest their uses and future considerations, focusing the model based on more stochastic issues of risk and return on investment.

More specifically related with the purpose of this paper, Mejia and Castro (2007) worked in the logistics optimization in a Colombian frozen and refrigerated food company. The authors developed a decision model based on linear programming to determine packing and distribution policies of frozen products. Zhang, et al (2011), on the other hand, focused on the research of a distribution model and vehicle routing optimization of fresh agricultural products. On the basic of detailed researching of agricultural products logistic characters, the paper establishes a vehicle optimization model suitable for transferring kinds of perishable agricultural products, to solve the severe losing of fresh produce logistics with transportation distance. The model is solved by genetic algorithm and the algorithm's effectiveness is verified using different examples.

3. PROBLEM DESCRIPTION AND DATA GATHERING METHODOLOGY

The objective of this paper is to present an optimization model that helps finding not only the minimum cost of satisfying supply and demand of agricultural products, but also to implement the minimum transportation cost of a vehicle assignment policy for the minimum allocation of products. In addition, to analyze different scenarios in order to select the best location of main distribution center in Panama City. No previous study about the distribution network of agricultural products has been previously conducted in Panama.

To find the contextual description for the model, preliminary data from the different distribution points was gathered. Students from the logistic program and Industrial Engineering at the Universidad Tecnológica de Panamá (UTP), and students from the International Logistic and Transportation Master Program at the Universidad Marítima Internacional de Panamá (UMIP) gathered the preliminary information in Panama City. Further, students from different regional campuses of the UTP conducted an exploratory research in several locations around the country in order to know the situation and understand the behavior of the distribution of lettuce, potatoes, tomatoes and onions at these points. The information from these sources was collected through interviews and questionnaires applied to a group of stakeholders that were selected more by convenience than by random selection. Data such as transportation costs, operation costs, vehicles availability, production capacities, market demand, warehouses and distribution capacities were gathered.

In addition, data from the National Secretariat of the Cold Chain and the Agro-Marketing Institute allowed the researchers to have production data since the collection of this information is pending of time availability from the researches to travel to the production areas. Furthermore, the data collected from these organizations helped the researchers to compare this information with the one collected from the suppliers and consumers. At this point, the information is being carefully analyzed since there are significant differences between the information collected. Lettuce was selected as the product to be studied in the model due to recommendations from the National Secretary of the Cold Chain.

With the information provided, a map of the distribution network was developed. This map is shown in figure 2. As seen, two production areas were located, both in the Province of Chiriquí, 500 km west of Panama City. Lettuce is transported from these areas to different distribution points. These points are David, the largest city of Chiriquí, which distributes lettuce to the rest of the province. Also, lettuce is sent to Santiago, in the Province of Veraguas, where lettuce is sent to the province and to other areas in the middle of the country, thus it serves also as distribution centers. Finally, the products are shipped to the main distribution point in Panama City, the Supply Central Market that supplies products to the west, east, north and central areas of the Province of Panama, and also to the Province of Colon, located in the Caribbean area of Panama

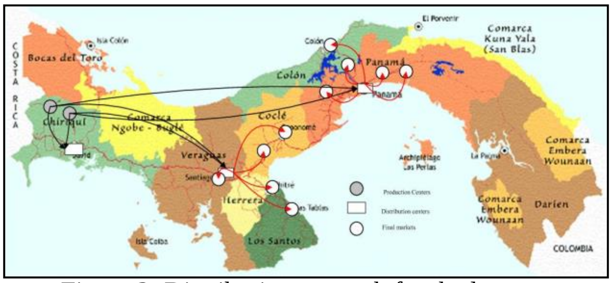

Figure 2: Distribution network for the lettuce

The main suppositions for the model are:

- Only one product is to be studied. In this case the product will be lettuce.
- Supplies and demands at different sources, transshipments and destinations will be considered weekly.
- No inventories are allowed in intermediate points.
- Only three types of vehicles will be considered: pick-ups, trucks and trailers, as seen in figure 3.
- All costs, demands, supplies and availability of vehicles are known.
- No unloading and downloading times are considered.
- The unit load considered is the 40 lbs. (18 kg) crate of lettuce, as seen in figure 4.
- No returning of products.
- The cost is divided in two elements: the transportation cost, that considers production and loading costs, and the vehicle related cost that considers fuel, operation costs and depreciation.
- Production cost is constant and does not depend on the final destination. Thus, it is a fixed cost and has no influence on the model.
- Both production and demand can be assumed constant every week.
- There is no limitation in the availability of vehicles, but a minimum amount is needed in every source.

Figure3: vehicle types

Figure 4: Unit load

4. MODEL DESCRIPTION

To develop the mathematical model, the Minimal Cost Network Flows approach was used, considering the different elements involved in the network. Thus, points as production centers, distribution points and final markets will be introduced, and a transshipment approach will be structured, and the optimal amount of lettuce through the network will be determined. In addition, a minimal flow problem consisting on modeling the optimal amount and types of vehicles used to deliver the lettuce will be included in the general model.

Consider a general network $G = (V, A)$ where V is a vertex set representing either production centers, distribution centers of final markets, and A a set of directed arcs connecting different points in the set V. Every arch A is defined by the pair of indexes i, j indicating the origin and destination of such arch.

Let $x_{i,j}$ be the amount of products sent from point i to point j. In addition, consider $y^{(k)}_{i,j}$ the type of vehicle k used to transport products from point i to point j. Let $c_{i,j}$, the cost of moving one unit of product and and $b^{(k)}_{i,j}$ the cost of moving vehicle type k from point i to point j. Moreover, consider distribution or transshipment points l that will be considered to define the transportation policy of the logistic system. The objective of the problem is to optimize the amount of products sent from the origins to destinations and the optimum amount and type of vehicles used to move the products, at a minimum cost.

Consider the following parameters:

Z : Total weekly cost of the transportation policy.
$N^{(k)}_i$: Amount of vehicles type k available at point i.
$A^{(k)}$: Capacity of vehicle type k in terms of unit loads.
S_i : Weekly supply of point i.
D_j : Weekly demand at point j.
W_l : Weekly capacity of the distribution or transshipment points.
m : Number of origins.
n : Number of destinations.
L : Number of distribution centers.
K : Vehicle types, in this case pick-ups, trucks and trailers.

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The model is expressed bellow:

$$\boldsymbol{min\, Z} = \sum_i \sum_j \boldsymbol{C_{i,j} x_{i,j}} + \sum_i \sum_j \sum_k \boldsymbol{b^{(k)}_{i,j}\, y^{(k)}_{i,j}} \qquad (1)$$

Subject to:

- Weekly capacity of the sources:

$$\sum_i \boldsymbol{x_{i,j}} \leq \boldsymbol{S_i} \ \forall \boldsymbol{j} \qquad (2)$$

The first constraint requires that the different supply points send no more than the production available at each of them, thus the upper limit of the distribution policy is the maximum supply available at the different production points.

- Weekly demand of the destination points:

$$\sum_j \boldsymbol{x_{i,j}} \geq \boldsymbol{D_j} \ \forall \boldsymbol{i} \qquad (3)$$

For every destination point, the amount sent by the sources must be at least the demand required by each destination point.

- No inventory in the transshipment points:

$$\sum_i \boldsymbol{x_{i,l}} = \sum_j \boldsymbol{x_{li}} \ \forall \boldsymbol{l} \qquad (4)$$

Due to the perishability of the lettuce, no inventory will be allowed at the different origin, transshipment and destination points. Thus, any amount sent from the origins to the transshipment points has to be sent to the destination points.

- Weekly capacity of the distribution points:

$$\sum_l x_{i,l} \leq W_l \qquad (5)$$

Each distribution or transshipment point has a specific capacity of storage that must be satisfied with every shipment of products from the production point.

- Weekly availability of vehicles:

$$\sum_k \sum_j y_{i,j}^{(k)} \leq N_i^{(k)} \ \forall k, j \qquad (6)$$

The amount of every type of vehicle used to transport lettuce at any supply point (considering also the transshipment points) must be less or equal to the available amount of vehicles at each of these points.

- Weekly transportation capacity of the vehicles at every distribution point:

$$\sum_j A^{(k)} y_{i,j}^{(k)} - \sum_j x_{i,j} \geq 0 \qquad (7)$$

At every distribution point, the capacity of all the available vehicles must be at least the amount ready to be sent to every destination point, thus vehicles are to be used only with this product.

- All variables are integer and bounded by their upper limits:

$$x_{ij};\ y_{ij}^{(k)} \in I;\ \forall \begin{cases} i = 1, \dots, n \\ j = 1, \dots, m \\ l = 1, \dots, L \\ k = 1, \dots, K \end{cases} \qquad (8)$$

5. MODEL SOLUTION AND DISCUSSION

Tables 1 and 2 show the main data of the problem, and table 3 shows a summary of the optimal solution of the problem.

Table 1: Main data for the case

	Pick up	Truck	Trailer
Capacity of the vehicles	35	75	250
Fuel	$ 70.00	$ 100.00	$ 600.00
Transportation cost	$ 1.25	$ 1.25	$ 1.25
Packing cost	$ 1.75	$ 1.75	$ 1.75
Handling costs	$ 0.05	$ 0.05	$ 0.05
Labor cost	$ 25.00	$ 25.00	$ 25.00
Cost per trip	$ 95.00	$ 125.00	$ 625.00

Table 2: Monthly demand of lettuce, in crates

David	2000
Santiago	1850
Chitré	1300
Las Tablas	500
Aguadulce	550
Penonmé	650
Chorrera	2100
Arraiján	2000
Panamá City	6000
San Miguelito	1800
Colón	2300
Total	21050

Table 3: Optimal Solution

Total cost	$ 19,442.50
For delivering 5, 264 lettuce crates per week	
Cost of moving crates	$ 11.147.50
Cost of vehicles	$ 8,295.00
Using	
23 Pick-ups 36 Trucks 10 Trailers	

**Solved using MPL*

The model was solved using MPL and was developed as part of a undergraduate thesis in Industrial Engineering (Castrellón 2013).

The final results show that the minimum cost for delivering 5,264 crates per week is $19,442.50. The distribution program uses 23 pick-ups, 36 trucks and 10 trailers at a total weekly transportation cost of $8,295

The model provides that the total demand will be satisfied using all the supplies from the different distribution points. This distribution policy takes into account the amount delivered to the intermediate points, Santiago and Central Market that are then delivered to the final consumption points.

In addition, the model provides the optimum amount of vehicles recommended to accomplish the distribution policy. The amount of vehicles used satisfies the availability of the corresponding vehicles: pick-ups, trucks and trailers. Further, the model recommends the use of large transport for longer routes rather than small vehicles, taking advantage of the low unitary cost of transportation in large vehicles.

It is important to recall that the model considers that the vehicles are dedicated to only transport lettuce, and they do not share space with other products, since the model is limited to one produce.

After the model was executed, a cost analysis was performed. The summary is shown in table 4. As seen, the logistic costs are near 31% of the total cost, which confirms the fact of the influence of intermediaries in the final cost of agricultural products in Panamá.

Table 4: Cost analysis for the model

Average price of the crater	$ 12.00
Total crates shipped	5,264
Total weekly cost	$63,168.00
Transportation costs	$19,442.50
Fraction of total cost	30.80%

Finally, several scenarios for different locations for logistic platforms were analyzed. Figure 5 (Orozco 2014) shows them.

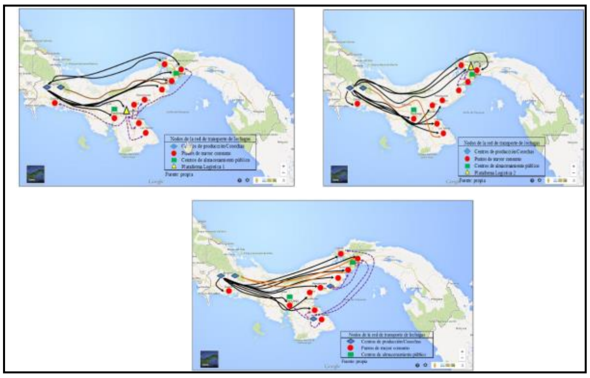

Figure 5: Scenarios for different location of logistic platforms (Orozco 2014)

The model determined that locating the logistic platform close to the central market (or in it) will diminish the logistics costs near 4%. This percentage can be improved if other production areas are implemented and better transportation policies as applied by the producers. With the right policies, costs can diminish up to 12% from the current 31%, so it is important for producers, shippers and government to put together policies that guarantee not only availability of food, but also at a cost accessible for consumers.

6. CONCLUSIONS AND FUTURE WORK

The model provided a solution with a distribution policy consisting on both amounts to be moved from origins to destinations and vehicles, sizes and amounts, to be used. All these variables are tied to costs, such that the result provides, in addition, the minimum cost of the policy.

From the model, it is possible to conclude that any distribution policy must consider not only the supplies and demands but also the facilities for transportation, storage and distribution. Hence, future models should include variables that tie transportation systems with distribution patterns.

Several important aspects have to be mentioned here. First of all, the lack of information on costs, routing, demands and supplies makes really difficult to gather valid information to formulate and evaluate de model. Further, there are no congruence between data from the producers and official institutions. Thus, it was very difficult to validate the results from the model. Finally, it is necessary for the different organizations involved in the agro-food supply chain, to work in a more united manner since it is important to maintain the supply chain in an efficient and effective manner for all, producers, suppliers, and final consumers.

For future work, it is necessary to add more products, thus the problem becomes a multicommodity flows problem (Bazaraa et al 2005) which increases the complexity of the problem adding a number of variables and constraints proportional to the amount of products. In addition, it is necessary to include an additional objective since it is important to maximize the value of the shipment, and to minimize the total cost of the shipment policy. Henceforth, the problem becomes a multicriteria, multicommodity minimum flow problem with equipment assignment.

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