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Modeling a distribution network of agricultural products in Panama

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Abstract

Even though Panama is recognized as an international logistic center, internal supply chains lack of deep analysis to understand their behavior. The current paper presents the partial results of a project funded by the National Secretariat of Science, Technology and Innovation of Panama. The objective of this project is to analyze and model the supply chain of certain agricultural products considering that although near 80% of the market is in the great metropolitan area of Panama City, the production areas are located at about 500 km west of there. The current stage of the project presents an optimization model that considers aspects such as minimum transportation costs for a unit load and availability of transportation equipment in order to fulfill demand in different areas of the country and in the great metropolitan area. It analyzes the behavior of the supply chain of a specific product. At this stage preliminary data is used to validate the model and verifies the data needed to define different transportation and logistics policies.

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 magazines and journals across the area 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. In fact, according to the Panamanian Government Five Year Strategic Plan, it has been considered to create in the country a world class center of logistics added value services, luxury tourism, high value agriculture and thus enhance its privilege geographical position and the comparative advantages, decreasing the unemployment rate and increasing the economic growth between 6% and 9% annual, also to generate approximately 500,000 new jobs [1].

On the other hand, although agriculture and other related activities are the main sources of employment in the rural areas, providing the 19% of total employment nationwide the Agricultural Gross Domestic Product (AGDP - 2011) represents just 3% of total Gross Domestic Product (GDP) [2]. Thus, lack attention has been provided to the analysis, modeling and optimization of the internal agricultural supply chain.

Boudahri, et al [3] 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 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 [4].

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, 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.

Figure 1: The geography of the Republic of Panama

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 a partial result for a project funded by the National Secretariat of Science, Technology and Innovation of Panama [5] entitled "Designing a logistic platform through the optimization of distribution networks for the agricultural sector," 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 a first approach to the model and its solution.

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 [6] 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 Pietro and Timpanaro [6], 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 [7] 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 [8], 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 [9] demonstrated that the costs associated with the transport of goods represent a large part of the final cost. Estrada [10], 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 [3], 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 [11] 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 [12] 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 [13], 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 [14] 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 [15], 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. 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 at the Technological University of Panama (UTP), and students from the International Logistic and Transportation Master Program at the International Maritime University of Panama (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 Secretary 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, which sends lettuce to the province, and also sends the product to other areas in the middle of the country, that serve also as distribution centers. Finally, they send product 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.

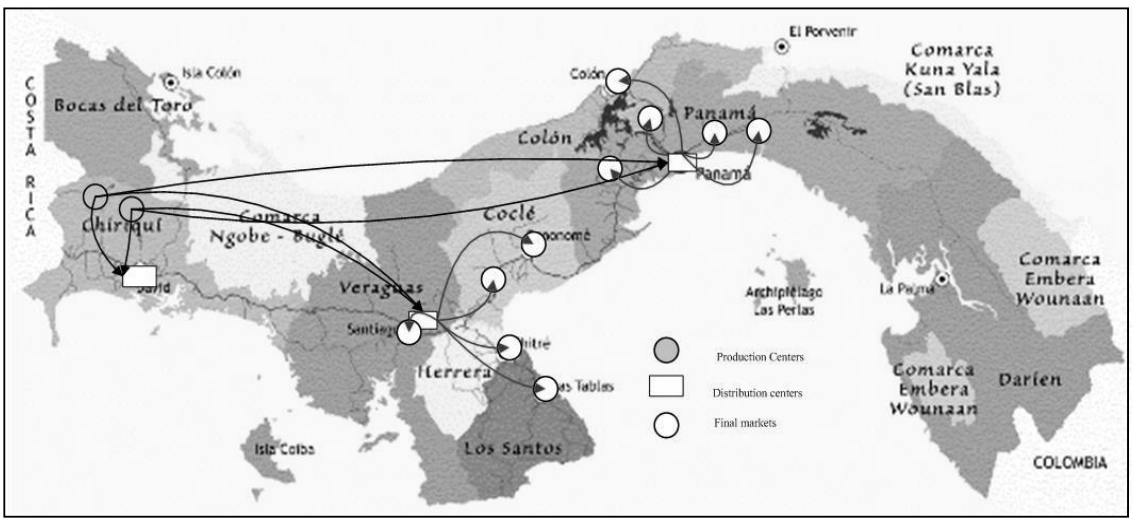

Figure 2: Distribution network of the lettuce

At this stage of the project several assumptions were made:

- 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. crate of lettuce, as seen in figure 4.
- No returning of products.
- The cost is divided on two: 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.

Figure 3: 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.

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:

$$\sum_i x_{i,l} = \sum_j x_{li} \ \forall l \tag{4}$$

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:

$$\sum_l x_{i,l} \leq W_l \tag{5}$$

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:

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

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:

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

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:

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

5. Model Solution Methodology and Results

Students from UTP-Georgia Tech dual M. Sc. Program y Supply Chain Engineering developed the solution using an Excel Solver approach. This approach was used to see the solvability of the model, and if the preliminary solutions had a plausible answer.

The solution shown in the following tables depict the optimal solution of the problem divided in two sections:

- The first section shows the amount of crates moved from the supply to demand points.
- The second section shows the amount of vehicles used to comply with the distribution program.

Table 1 shows the distribution policy for the lettuce. As seen, the total demand is 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 Mercado that are then delivered to the final consumption points.

Table 1: Crates Moved (x_{ij})

From/To	David	Santiago	Chitré	Las Tablas	Aguadulce	Penonomé	Chorrera	Mercado	San Miguelito	Panamá Este	Colón	Total	Supply (S_i)
Boquete	0	770	0	0	0	0	0	5,500	0	0	0	6,270	6,500
Cerro Punta	2,000	1,980	0	0	0	0	0	3,200	0	0	0	7,180	8,000
Mercado	0	0	0	0	0	0	1,200	0	1,400	600	1,000	4,200	5,500
Santiago	0	0	750	200	250	350	0	0	0	0	0	1,550	3,200
Total	2,000	2,750	750	200	250	350	1,200	8,700	1,400	600	1,000	19,200	23,300
Demand (Dj)	2,000	2,750	750	200	250	350	1,200	8,700	1,400	600	1,000		

Tables 2 to 4 show the optimum amount of vehicles recommended to accomplish the distribution policy shown in table 1. As seen, 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 one product, not to share space with other products, since the model is limited to one product.

Table 2: Pick-ups used

From/To	David	Santiago	Chitré	Las Tablas	Aguadulce	Penonomé	Chorrera	Mercado	San Miguelito	Panamá Este	Colón	Total	Available Pickups (N_{ki})
Boquete	0	9	0	0	0	0	0	0	0	0	0	9	12
Cerro Punta	1	0	0	0	0	0	0	0	0	0	0	1	15
Mercado	0	0	0	0	0	0	7	0	0	6	0	13	45
Santiago	0	0	0	0	0	0	0	0	0	0	0	0	20
Total	1	9	0	0	0	0	7	0	0	6	0	23	

Table 3: Trucks used

From/To	David	Santiago	Chitré	Las Tablas	Aguadulce	Penonomé	Chorrera	Mercado	San Miguelito	Panamá Este	Colón	Total	Available Trucks (N_{ki})
Boquete	0	2	0	0	0	0	0	6	0	0	0	8	8
Cerro Punta	0	0	0	0	0	0	0	9	0	0	0	9	9
Mercado	0	0	0	0	0	0	4	0	6	2	0	12	12
Santiago	0	0	3	1	1	2	0	0	0	0	0	7	10
Total	0	2	3	1	1	2	4	15	6	2	0	36	

Table 4: Trailers used

From/To	David	Santiago	Chitré	Las Tablas	Aguadulce	Penonomé	Chorrera	Mercado	San Miguelito	Panamá Este	Colón	Total	Available Trailers (N_{ki})
Boquete	0	0	0	0	0	0	0	4	0	0	0	4	4
Cerro Punta	2	2	0	0	0	0	0	1	0	0	0	5	5
Mercado	0	0	0	0	0	0	0	0	0	0	1	1	2
Santiago	0	0	0	0	0	0	0	0	0	0	0	0	2
Total	2	2	0	0	0	0	0	5	0	0	1	10	

Finally, table 5 shows a summary of the optimal solution for the problem. Minimum cost for delivering 19,200 crates per week is $80,790. The distribution program uses 23 pick-ups, 36 trucks and 10 trailers at a total weekly transportation cost of $6,190.

Table 5: Optimal Solution

Objective Function	$ 80,790
For delivering 19,200 Lettuce Crates per week	
Using	At a total weekly cost of:
23 Pick-ups	$ 415.00
36 Trucks	$ 1,825.00
10 Trailers	$ 3,950.00

**Solved using Solver with Simplex LP*

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.

At his stage of the project several important conclusions can be drawn from this paper. 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 is very difficult to validate the results of 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 efficient and effective for all, producers, suppliers, and final consumers.

Since this is the first stage of a more ambitious project, work is still pending. For example, the model has to be feed with more current data, and more variables and constrains need to be tested in the model. For instance, to see what might happen if time and more frequencies are added.

Furthermore, it is necessary to add more products, thus the problem becomes a multicommodity flows problem [16] 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 load in each transport, because the load in each transport has to be the optimal combination of products. Henceforth, the problem becomes a multicriteria, multicommodity minimum flow problem with equipment assignment.

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