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Supporting Product Distribution Decisions of Smallholder Farmers

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Abstract Smallholder farmers are usually very constrained in terms of market access, due to, among other factors, the low production volumes and subsequent lack of economies of scale, variable quality, difficulty in planning and unavailability of distribution channels. In some countries, alternative markets have emerged, in order to facilitate smallholder farmers' access to markets. These can take the form of government feeding programs, that aim at providing an outlet for the smallholder farmer products, giving them priority in supplying public sector organisations. Such a program is the PNAE in Brazil, where local smallholder farmers can supply schools with raw materials for meals. This work aims to support smallholder farmers in distribution related decision-making. More specifically, it aims to allow farmers to maximise the profit from their participation in the government feeding programs through guiding them in the complex supply decision-making and product distribution planning processes. The paper presents the related method developed, as well as the results from a preliminary application of the method in a case study of a rural settlement in Brazil.

Keywords: Smallholder farmers; Distribution; Logistics; Decision Support;

1 Introduction

Smallholder farmers are one of the most vulnerable societal groups in most developing countries (Moellers and Bîrhală, 2014). Their vulnerability stems mostly from the fact that they do not have consistent access to markets for their products (Graeub et al., 2016), therefore facing large uncertainty over whether their produce can be sold. This can have a detrimental effect on their family income and security and limits their ability to plan (Graeub et al., 2016; Wilk et al., 2013).

Smallholder farmers are usually very constrained in terms of market access, due to, among other factors, the low production volumes and subsequent lack of economies of scale, variable quality, lack of planning skills and unavailability of remunerative distribution channels (Hazell et al., 2010; Medina et al.,

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2015; Mpanza, 2015; Wilk et al., 2013). In some countries, authorities, realising the extent and implications of this problem, have supported the emergence of institutional markets, in order to facilitate smallholder farmers access to markets. These can take the form of government feeding programs, which aim at providing an outlet for the smallholder farmer products, giving them priority in supplying public sector organisations. Such a program is the PNAE in Brazil, where local smallholder farmers can supply schools with ingredients for meals (Ferraz et al., 2018).

According to the Brazilian law, schools have to spend at least 30% of the budget allocated to meals to purchase food produced from socially disadvantaged groups, such as smallholder farmers, thus create a protected institutional market for such groups (Ferigollo et al., 2017). The PNAE works through a two-stage process. First, farmers express their interests by bidding for specific schools and products to supply. Second, once the outcome of the bids is revealed and a ranking of priority for supplying is generated, farmers can select whether to take on the awarded bids and deliver the products or reject to supply specific products and/or schools. From the farmers' perspective, this translates in a bid/no-bid decision and on a set of distribution-related decisions once the outcome of the bids is public, as highlighted in Figure 1.

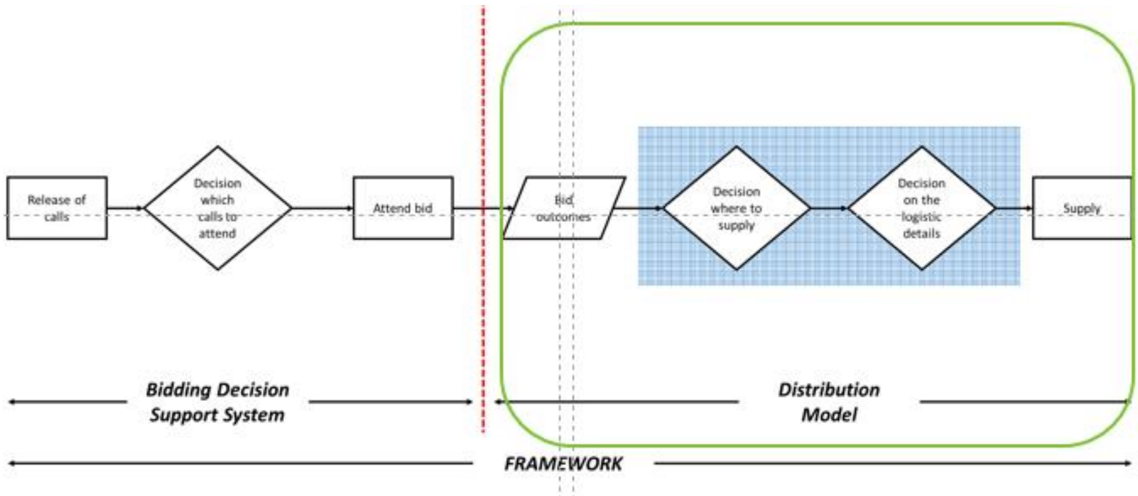

Fig. 1 PNAE-related decision making process for smallholder farmers

This work focuses on the second set of decisions (to the right of the red dotted line in Figure 1), aiming to support smallholder farmers in selecting the successful bids to accept and also distribution related decision-making. It aims to allow farmers to maximise the profit from their participation in the government feeding programs through guiding them in the complex supply decision-making and product distribution planning processes.

2 Methodology

A Decision Support Method was developed to support farmers on two key decisions, once the outcome of the bids is revealed:

1. Which of the successful bids to supply (Schools) and for which products: farmers can select which of the awarded bids to accept to supply based on economic convenience. Bids that the farmers do not select, go to the second bidder or are covered by spot purchases in the market
2. How to organise the distribution: vehicle type selection and vehicle routing, in order to understand which schools should be visited in each trip and for which products and quantities.

The Decision Support Method was formulated based on a Mixed Integer Linear Programming optimisation model. The problem under consideration features characteristics of several existing vehicle routing problems, however it does not match of any of the existing models available in the literature, giving the specific context of the PNAE. While being more closely associated to the Capacitated Profitable Tour Problem due to the similar objective function, this work includes several unique features, most noticeably the multiple products to be delivered, as highlighted in Table 1.

Table 1 Variants of the optimisation problem

Problem Variant	Heterogeneous Vehicle Routing Problem with Vehicle Dependant Costing Route	Split Delivery Vehicle Routing Problem	Vehicle Routing with Profits (Prize-collecting Vehicle Routing Problem), a.k.a. Capacitated Profitable Tour Problem	This work
Source	(Golden et al., 2008)	(Golden et al., 2008)	(Ahmadi-Javid et al., 2018; Archetti et al., 2009, 2013, 2014)	/
Objective function	Cost minimization	Cost minimization	Net profit maximization	Net profit maximization
Profits	No	No	Yes	Yes
Decision variables	Binary: 1 if vehicle of type k travels directly from customer i to customer j	Binary: 1 if vehicle v travels directly from customer i to customer j	Set packing formulation based: Binary: 1 if route r is travelled. Complemented by binary parameters if customer i is visited by route r and if arc i,j is included in route r	a_{ikhv}: amount of the product i delivered to school k at the trip h by the vehicle type v; z_{klh} =1 if the route k–l is to be travelled at the trip h and 0 otherwise; v_{hv}^{trip} =1 if the trip h is done by the vehicle v and 0 otherwise
Vehicles type	Multiple types	Homogenous	Homogenous	Multiple types
Vehicles capacity	Capacitated	Capacitated	Capacitated	Capacitated
Fleet size	Limited	Unlimited in the main formulation. Upper bound can be included.	Limited	Limited
Routing costs	Dependent on the vehicle	/	/	Dependent on the vehicle
Frequency of visiting the customer	Exactly once	Minimum once	Maximum once	Minimum once
Split delivery	Not allowed	Allowed	Not allowed	Allowed
Demand of customers	To be fully satisfied	To be fully satisfied	Customers to be served is a decision variable	Customers to be served is a decision variable
Products	Single	Single	Single	Multiple

Therefore, a tailored solution methodology is required to solve the optimisation problem at hand. The following assumptions guided the development of the model:

1. A finite number of schools are found in a region. Their location is known.
2. The distances between any two locations are symmetric and satisfy the triangle inequality.
3. The demand of each school for each product is deterministic and known in advance.
4. Serving all customers is not mandatory. However, when a school is served for a specific product, the entire demand for that school and that specific product needs to be satisfied.

5. A set of vehicles is available for the farmers, each with its own capacity and cost per distance travelled. Each vehicle starts and ends its route at the farmers' settlement. Each vehicle travel cost is proportional to the distance travelled.

The objective function is to maximise the profits obtained by the farmers.

$$Max\ Z = \sum_{i=1}^{n}\sum_{k=1}^{m}\sum_{v=1}^{ntypev}\sum_{h=1}^{H}(p_{ik} - c_i)a_{ikhv} - \sum_{h=1}^{H}\sum_{v=1}^{ntypev} c_{hv}^{trip} \quad (1)$$

Where Z is the profit obtained by the farmers, the first group of sums defines the gross profit before transport and the second group of sums identifies the cost of transport. The other elements of the equation (1) are defined as follows:

- i is the index of products; n is the number of different products
- k is the index of schools; m is the number of different schools;
- v is the index of vehicles; $ntypev$ is the number of different vehicles' types;
- h is the index of trips, with H being the maximum number of trips over the planning period;
- p_{ik} is the price of product i paid by school k (per kg)
- c_i is the production cost for product i (per kg)
- c_{hv}^{trip} is the cost of vehicle v for trip h, calculated from the individual cost per distance of each vehicle v and the distance covered in the trip h
- a_{ikhv}: amount of the product i delivered to school k at the trip h by the vehicle type v (decision variable)

The *constraints* of the model are as follows:

1. Total quantity to be delivered to each school for each product through all trips cannot exceed the demand stated in the public calls released from the schools; once a product for a schools is selected, the entire demand has to be delivered;
2. Capacity constraints of vehicles is respected for each trip;
3. Production capacity for each product is respected, i.e. farmers can produce a maximum quantity of each product;
4. Route consistency constraints: each route starts and ends at the farmers' settlement and each directed arc is travelled maximum once within each trip;
5. Only one vehicle is assigned to each trip;
6. Deliveries are allowed only to schools that are visited;

3 Case study

The presented Decision Support Method was applied to the case study of Canudos smallholder farmer settlement in the state of Goiás, Brazil, using real data from a past bidding process, in order to demonstrate its applicability. This is a preliminary application of the model to demonstrate its functionality. In the future, the authors are planning to apply the model on real-time cases just after the farmers have knowledge of the successful bids.

Data capture eight individual schools (SC1 - SC8) spread across four cities, as well as two cities where the bids for all municipal schools have been awarded (SC9 - SC10). Figure 2 depicts with yellow buildings cities where some individual schools are potentially to be supplied, whereas it represents with red buildings cities where all municipal schools are potentially to be supplied. The latter typically involve larger supply quantities. The circle next to yellow buildings informs about the number of schools within one city to be potentially supplied. The farmer icon represents the geographical location of the Canudos settlement, where all the distribution trips would start and end.

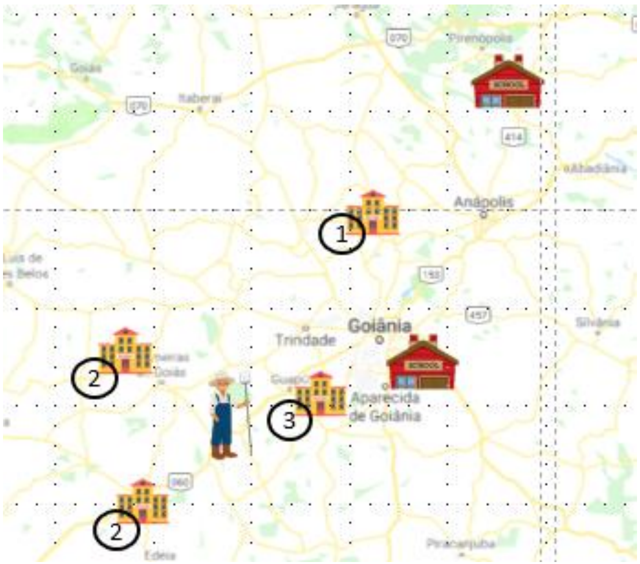

Fig. 2 Map of Goiás state, highlighting Canudos settlement and school locations

The case study uses as inputs the information from the bids farmers won through the PNAE program in the past: quantities awarded to Canudos settlement are listed in Table 2, whereas Table 3 shows the price per kg paid by each school for each product. Finally, Table 4 includes the capacity of vehicles, as well as their cost per km travelled and per ton-km transported.

Table 2 Quantities awarded to Canudos settlement for the winning bids [kg]

City	City 1			City 2		City 3		City 4	City 5	City 6	Total [kg]
School	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	
Pineapple	130	0	40	50	30	100	100	100	8000	100	*8650*
Garlic	40	50	0	0	10	30	13	15	500	200	*858*
Banana	150	189	100	250	120	100	140	150	8000	900	*10099*
Lettuce	90	0	0	50	10	100	0	20	3000	200	*3470*
Manioc Flour	100	0	50	0	0	80	0	0	1000	350	*1580*

Table 3 Prices paid by each school for each product for the winning bids [BRL]

City	City 1			City 2		City 3		City 4	City 5	City 6	Unitary cost [BRL]
School	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	
Pineapple	4.40	0.00	4.12	5.00	3.27	5.51	4.68	4.50	3.66	4.63	*0.84*
Garlic	18.91	17.30	18.00	0.00	20.99	20.00	19.66	21.00	23.67	17.97	*5.39*

Banana	3.29	2.17	3.50	2.50	5.67	2.83	3.55	4.50	3.28	3.06	*0.94*
Lettuce	6.43	0.00	0.00	3.67	3.20	5.23	0.00	5.00	3.50	2.22	*1.00*
Manioc Flour	4.03	0.00	7.20	0.00	0.00	7.46	0.00	0.00	6.66	6.70	*5.00*

Table 4 Vehicles: capacity and costs

Vehicle	Motorcycle	Car	Small pick-up	Large pick-up	Van	Truck
Capacity [kg]	50	300	500	900	1200	2500
Cost per km travelled	1.0	1.8	2.0	2.6	5.0	7.0
Cost per ton-km transported (when fully loaded)	20.0	6.0	4.0	2.9	4.1	2.8

4 Results

The model was solved to optimality for the representative case study, with the profit of the farmers equalling to 39,941 BRL. Overall, the optimal solution includes 14 trips, which are due to be travelled using the three larger vehicles, namely large pick-up, van and truck. The model thus forces to cluster delivery together in seek of efficiency in order to use the larger vehicles, which, despite having a higher cost per distance travelled, have lower costs per ton-km travelled, if fully loaded. Moreover, all five products were selected to be produced and distributed, while nine out of ten schools were selected, as highlighted in Table 5. School 8 (SC8) was the only one not selected, due to the combination of relatively small quantities with large distance from the settlement, which makes the supply unattractive due to the high relative impact of transport costs. Moreover, also "Manioc Flour" is not supplied to School 1 (SC1), due to the low price paid by SC1 for this product, which does not even cover the production costs for the product. All other combinations of schools and products have been selected by the model leading to a supply coverage spanning from a minimum of 93.67% coverage of the potential supply for manioc flour to a maximum of 99.42% coverage of the potential supply for lettuce.

Table 5 Selected schools and products to be supplied

City	City 1			City 2		City 3		City 4	City 5	City 6	
School	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	Coverage
Pineapple	130	0	40	50	30	100	100	100	8000	100	*98.84%*
Garlic	40	50	0	0	10	30	13	15	500	200	*98.25%*
Banana	150	189	100	250	120	100	140	150	8000	900	*98.51%*
Lettuce	90	0	0	50	10	100	0	20	3000	200	*99.42%*
Manioc Flour	100	0	50	0	0	80	0	0	1000	350	*93.67%*

The routing of trips involves visiting multiple schools for a single trip visiting individual schools with smaller quantities in order to cluster the distribution and achieve economies of scale (e.g. combining SC2 and SC5) or visiting a single school (e.g. SC10) wherever larger quantities have to be transported that fill the vehicle's capacity.

5 Conclusions

The proposed Decision Support Method can effectively support farmers in deciding which successful bids to turn into actual supply contracts by taking into account the costs associated with distribution of produce. At the same time, it supports the distribution planning defining where to supply their products and how to distribute them, in order to maximise their income, as well as providing insights on the routing of vehicles. The decision making process is currently too complicated for the farmers, due to many reasons: firstly, they do not have an understanding of the distribution costs, which is even more complicated as these costs are a function of the vehicle loading factor and distance. Secondly, they do not have a good understanding of the profit margin considering the production costs and distribution costs; in many cases they assume that each bid they have secured will be profitable for them, which is not always the case, as demonstrated by the model application. Finally, organising the distribution in trips while also selecting the appropriate type of vehicle to maximise the profit is a very complex problem, that either requires highly expert knowledge, or the application of optimisation techniques. Ultimately, the farmers currently do not have a way of understanding where to supply and how, which leads to reduced profits and in some cases, supplying at a loss. Since these farmers are financially vulnerable and the PNAE instrument was designed to support them financially, it is critical that they manage to make a profit from this supply to support their livelihoods and families.

As a future direction, the method should ideally be implemented in an easy-to-use interface for the smallholder farmers, to boost the use of the method without the support of researchers. The application of the method could lead to improving the livelihoods of millions of vulnerable smallholder farmers in Brazil.

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