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# Client selection and combination for farm perishable products

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**Abstract:** This paper deals with the problem of selecting the most profitable combination of clients to sell a given perishable production of a vegetable farm. A farmer has pre-qualified a pool of potential clients, characterized by specific product mixes, prices, supply contract durations and farm workers requirements to prepare and deliver the order. The farmer is allowed to purchase products from surrounding farms to meet the contracts specifications, if the farm production is not sufficient. We present a Mixed Integer Linear Programming model to maximize the profit of farm sales with production and workforce capacities. We develop submodels to describe the demand characteristics of four targeted clients categories: farmers' market, community supported agriculture, contract demand and wholesalers. Theoretical complexity of the model and preliminary computational results are discussed.

*Keywords:* Perishable products, Client selection, Job and activity scheduling, Agriculture

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## 1. INTRODUCTION / PROBLEM STATEMENT

Eating local and with as few intermediates as possible, has been on the wish list of an increasing number of consumers. But supplying local fresh products to consumers can be quite a challenge for urban or peri-urban farmers.

First, there is a strong link between the targeted markets and the choice of products and production methods. A farmer who sells products via a Community Supported Agriculture Network<sup>1</sup>, needs to produce a wide range of products all year-long, whereas he can specialize in a few products if he chooses to sell to a wholesaler. The complexity of the production system is very different in this two cases, as are the equipment investments. The farmer has to consider the trade-off between low-volume/high-value markets (like in direct-selling via the CSA) and high-volume/low-value markets like in wholesale market. Second, in industrialized countries like France, workforce is expensive. Direct selling and diversified production are labor intensive activities. Multiple competing production, delivery and selling activities cause extra labor needs.

We develop a decision support system to help diversified market gardeners producing and selling fresh vegetables in local supply chains. Our model selects the most profitable combination of clients to supply over a one-year horizon given the farm production, the daily demand specificities and the farm resources. We take account of fresh product perishability and the seasonal nature of the production.

The remainder is organized as follows: after an literature review in section 2, the model is described in section 3, with a focus on the different demands characterization. Thereafter, we analyze theoretically the model structure and its complexity. Computational results are reported in section 5.

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<sup>1</sup> CSA, see section 3.3

## 2. STATE OF THE ART

Agri-food supply chains are complex to manage due to the product long lead times and limited shelf-life and to the demand and price variability (Ahumada and Villalobos (2009)). The farmer is advised to select clients able to conclude contracts ensuring volumes and prices, in order to secure his profitability. Client selection problems, as well as supplier selection problems, are typical multi-criteria problems, involving both qualitative and quantitative criteria (Singh (2014), Aghdaie and Alimardani (2015)). Many models have been developed for the supplier selection problem, by using different techniques to make a compromise from the conflicting criteria. In their supplier selection methods review, De Boer et al. (2001) presented linear weighting models, total cost of ownership models, statistical and artificial intelligence models, as well as mathematical programming models. Mathematical programming models consider several products simultaneously. Multiple criteria decision models (MCDM) provide effective frameworks for supplier or client selection. Shyur and Shih (2006) developed an five-step MCDM hybridizing analytic network process (ANP) and technique for order performance by similarity to idea solution (TOPSIS) approaches. The steps they define differed from the ones identified in the review of De Boer et al. (2001): 1. Identification of necessary criteria for vendor selection; Recognition of the interdependence between criteria; Eliciting the weights of criteria; Evaluation of vendors; Negotiation for the purchase.

Wetzstein et al. (2016) distinguished two kinds of supplier selection problems: Single sourcing supplier selection, where the only decision to make is "which supplier is the best?" and multiple sourcing supplier selection, where order quantities are split among different suppliers with

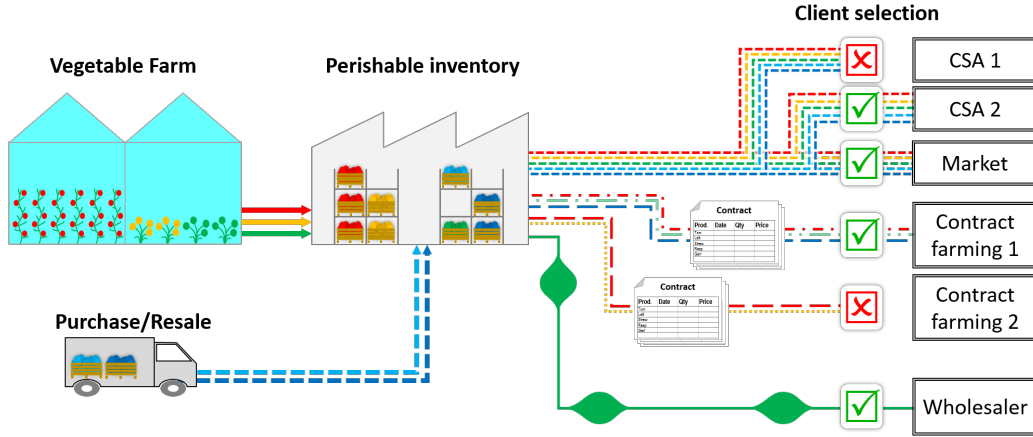


Fig. 1. The farmer has to select the most profitable combination of markets.

different limitations. The problem we study falls into the second category, as different clients are combined to sell a given production according to their time-varying demands and prices.

Client selection problem has not received much attention in the production system and operations research literature. Moreover, inventory management is seldom considered in the client or supplier selection models (De Boer et al. (2001)), despite its obvious importance, especially when dealing with perishable products. Yet, He et al. (2009) pointed out that combining different categories of clients gives the chance to exploit the different timing of the producing and selling season at the various markets. Ahumada and Villalobos (2011) developed a tactical model to determine the area of tomato and pepper to grow and to manage the product shipment to warehouses, distribution centers or directly to final clients, to satisfy client demands. Customer selection problems are linked to market segmentation and targeting and are mainly addressed in marketing sciences for problems such as direct marketing problems (see Kaishev et al. (2013) or Liao et al. (2011)). In most models, studied problems can be considered as 'single-deal' or 'package' models, to cite De Boer et al. (2001). Models dealing with interdependent product demand and product mix over-time variations, which are frequent in agriculture, are scarce.

### 3. THE VEGETABLE FARM CLIENT SELECTION MODEL

We consider a farmer producing a range  $P^f$  of perishable products  $p$ , such as vegetables. At each of the time horizon period  $t \in T$ , the farm yields  $Y_{p,t}$  kg of product  $p$ . The farmer can target several markets in a reasonable distance of his farm, each of them having specific characteristics. The farmer wants to know which markets to select to get the best profit from its production (figure 1). We here consider four categories of markets:

- (1) *Farmers' market*: Farmers can sell their products directly to consumers on farmers' markets if they can get a market spot. They need to have sufficient diversity and quantities for the market to be profitable, since market fixed costs are high: allocation of several vendors, rent for the spot, transport.

- (2) *Community supported agriculture (CSA)*: in CSA system, customers are contractually engaged with one or several farmers in a season-long commitment to receive at defined dates a given quantity of vegetables, bread or other food products. The farmer expects direct selling high-value added but he has to produce a great diversity of products all year long and to dedicate time to prepare and deliver the products.
- (3) *Contract demand*: business clients, such as public catering or grocery stores, launch calls for tenders defining the products, quantities and prices needed on defined delivery dates for the next year(s). Prices are lower than in direct selling, but the contract enables the farmer to plan high volumes production efficiently.
- (4) *Wholesales*: wholesalers can buy high volumes with low prices when the farmer can not target other markets high volumes to high value markets or when workforce is scarce to prepare, deliver and sell the products.

To target clients such as CSA, farmers' markets or contract demand, the farmer has to meet the entire demand, in quantity, quality and diversity of products during all the contract duration. Clients may ask for products that are not produced on the farm or not available at a specific period; the farmer can purchase quantity  $pr_{p,t}$  of products from surrounding farms to meet the contract specifications.

The Mixed Integer Linear Programming model presented in the following sections aims at helping the farmer to select the most profitable combination of clients, considering a given farm production, perishable inventories and workforce capacity. This decision support model orientates the farmer's production and distribution systems at the beginning of a farming season. Depending on the type of the targeted markets, the model is used as a strategic or tactical decision support. We do not consider operational uncertainties, such as changes of delivery days, or vehicle routing problems.

#### 3.1 Farm profit and resources

The model aims at maximizing the farmer revenue  $Rev$  which is composed of the revenues of farmers markets

( $R^{\text{fm}}$ ), CSA systems ( $R^{\text{csa}}$ ), contract demands ( $R^{\text{cd}}$ ) and wholesales ( $R^{\text{ws}}$ ) (1). The cost of hiring workers (2) and the cost of purchasing products from other farms (3) are subtracted from the revenues.

$$\max Rev = R^{\text{fm}} + R^{\text{csa}} + R^{\text{cd}} + R^{\text{ws}} \quad (1)$$

$$- \sum_t C_t^H - \sum_t h_t \cdot C_t^h \quad (2)$$

$$- co^{\text{pr}} \quad (3)$$

The choice of the clients is limited by two capacities: workforce and production. In this paper, we consider a given available workforce  $H_t$ , associated with a daily cost  $C_t^H$ . Extra workforce  $h_t$  can be hired punctually at higher per-hour cost  $C_t^h$ . Total available workforce have to be greater than the workforce needed to prepare, deliver and sell products to the different clients (eq. 4).

$$H_t + h_t \geq \gamma_t^{\text{fm}} + \gamma_t^{\text{csa}} + \gamma_t^{\text{cd}} + \gamma_t^{\text{ws}} + \gamma_t^{\text{pr}}, \quad \forall t \quad (4)$$

$$z_{p,t} \leq \sum_{\beta} x_{p,\beta,t}, \quad \forall p \in P, t \quad (5)$$

$$\bar{z}_{p,t} \leq \sum_{\beta} \bar{x}_{p,\beta,t}, \quad \forall p \in P, t \quad (6)$$

$$x_{p,\beta,t} = Y_{p,t} + pr_{p,t}, \quad \forall p \in P, t, \beta = 0 \quad (7)$$

$$x_{p,\beta,t} = \bar{x}_{p,\beta,t} = 0, \quad \forall p, t, \beta > t \quad (8)$$

$$x_{p,\beta,t} = \bar{x}_{p,\beta,t} = 0, \quad \forall p, t = 0, \beta = B_p \quad (9)$$

$$x_{p,\beta+1,t+1} \leq (1 - L_{p,\beta}) \cdot (x_{p,\beta,t} - z_{p,\beta,t}) \\ \forall p, t < t_{\text{max}}, \beta \in 0..B_p - 1 \quad (10)$$

$$\bar{x}_{p,\beta+1,t+1} = (\bar{x}_{p,\beta,t} - \bar{z}_{p,\beta,t}) \\ + (x_{p,\beta,t} - z_{p,\beta,t}) \cdot L_{p,\beta} \\ \forall p, t < t_{\text{max}}, \beta \in 0..B_p - 1 \quad (11)$$

$$z_{p,t} = \sum_{c \in C^{\text{fm}}} \omega_{c,p,t}^{\text{fm}} + \sum_{c \in C^{\text{csa}}} \omega_{c,p,t}^{\text{csa}} * K_c^{\text{csa}} \\ + \sum_{c \in C^{\text{cd}}} \omega_{c,p,t}^{\text{cd}} + \omega_{c,p,t}^{\text{ws}}, \quad \forall p \in P, \beta, t \quad (12)$$

Concerning production, the sum of the quantities delivered to all the clients  $z_{p,t}$  can not exceed the available quantities  $x_{p,\beta,t}$  in the cold room inventory at each period  $t$  (eq. 5). Thrown out quantities of lost products  $\bar{z}_{p,t}$  respect a similar constraint (eq. 6). Products from farm production  $Y_{p,t}$ ,  $p \in P^f$  and from other farms  $pr_{p,t}$ ,  $p' \in P^{\text{rs}}$  enter the inventory at maturity, with time index  $\beta = 0$  (eq. 7); no initial stock is considered (eq. 8). We impose a maximum storage duration  $B_p$  as we deal with perishable products, for both marketable and lost products (eq. 9). To get a relevant perishability modeling, we define lot-sizing constraints with a loss function  $L_{p,\beta-1}$  depending on the time index  $\beta$  (eq. 10,11). The delivered quantity  $z_{p,\beta,t}$  of each period is the sum of the quantities delivered to the different clients of each category (eq. 12).

In the following sections, we define successively the constraints for the different categories of clients.

### 3.2 Farmers market model

Farmers's markets are a direct way of selling products to clients, on a regular basis. The farmer presents a great

diversity of products  $\Delta^{\text{fm}}$  to attract the customers (eq. 15). Products can be delivered only on the delivery week-day defined by the client (eq. 13) during the market opening season (markets can take place all year long, from spring to autumn or only during summer).

Product delivered quantity  $\omega_{c,p,t}^{\text{fm}}$  must respect a weight range  $[w_{\text{min},p}^{\text{fm}}, w_{\text{max},p}^{\text{fm}}]$  to be delivered to a market (eq. 14). The total weight of the delivery has to belong to a given weight range  $[W_{\text{min},p}^{\text{fm}}, W_{\text{max},p}^{\text{fm}}]$ , with respect to delivery vehicle characteristics (eq. 16,17). The revenue of farmers' market is composed of product sales profit minus the product deterioration and the transportation costs to and from the delivery point (eq. 18). We consider fixed transportation costs, corresponding to one vehicle in a hub-and-spoke network.  $\gamma_t^{\text{fm}}$  labor time is needed to prepare and deliver the market  $c$  and serve customers (eq. 19).

$$\nu_{c,p,t}^{\text{fm}} \leq Av_{c,t}^{\text{fm}} \cdot \lambda_c^{\text{fm}} \quad \forall c, p, t \quad (13)$$

$$w_{\text{min},p}^{\text{fm}} \cdot \nu_{c,p,t}^{\text{fm}} \leq \omega_{c,p,t}^{\text{fm}} \leq w_{\text{max},p}^{\text{fm}} \cdot \nu_{c,p,t}^{\text{fm}} \quad \forall c, p, t \quad (14)$$

$$\sum_p \nu_{c,p,t}^{\text{fm}} \geq Av_{c,t}^{\text{fm}} \cdot \Delta^{\text{fm}} \cdot \lambda_c^{\text{fm}} \quad \forall c, t \quad (15)$$

$$\sum_p \omega_{c,p,t}^{\text{fm}} \geq W_{\text{min},p}^{\text{fm}} \cdot Av_{c,t}^{\text{fm}} \cdot \lambda_c^{\text{fm}} \quad \forall c, t \quad (16)$$

$$\sum_p \omega_{c,p,t}^{\text{fm}} \leq W_{\text{max},p}^{\text{fm}} \cdot Av_{c,t}^{\text{fm}} \cdot \lambda_c^{\text{fm}} \quad \forall c, t \quad (17)$$

$$R^{\text{fm}} = \sum_{c,p,t} \Pi_{p,t}^{\text{fm}} \cdot (1 - L_{p,t}^{\text{fm}}) \cdot \omega_{c,p,t}^{\text{fm}} \\ - \sum_{c,t} Ct_c^{\text{fm}} \cdot Av_{c,t}^{\text{fm}} \cdot \lambda_c^{\text{fm}} \quad (18)$$

$$\gamma_t^{\text{fm}} = \sum_c Av_{c,t}^{\text{fm}} \cdot \Gamma_c^{\text{fm}} \cdot \lambda_c^{\text{fm}} \quad \forall t \quad (19)$$

### 3.3 Community supported agriculture

Community supported agriculture (CSA) refers to direct selling system in which clients pay in advance for a share of the season harvest of a farm. CSA and Farmers' markets (FM) submodels have many constraints in common (i.e. eq. (13)-(17), (19)) and we refer to the FM constraints presented above for reasons of conciseness and clarity. Index "fm" is simply replaced by "csa" in the related constraints.

The farmer delivers every week (eq. 13), at a delivery point,  $K_c^{\text{csa}}$  boxes containing a seasonal mix of farm products, with a minimum product diversity  $\Delta^{\text{csa}}$  (eq. 15). The products have to be in reasonable proportions (eq. 14). By contract, the total weight of the box has to belong to a given weight range  $[W_{\text{min},p}^{\text{csa}}, W_{\text{max},p}^{\text{csa}}]$  (eq. 16,17) and the box value has to respect a minimum target price  $\Psi_{c,p,t}^{\text{csa}}$  (eq. 20). The revenue of CSA clients is composed of the sales of  $K_c^{\text{csa}}$  CSA boxes minus the transportation costs  $Ct_c^{\text{csa}}$  to and from the delivery point (eq. 21).  $\gamma_t^{\text{csa}}$  labor time is needed to prepare the boxes, deliver the order and welcome clients (eq. 19).

$$\Pi_{p,t}^{\text{csa}} \cdot \omega_{c,p,t}^{\text{csa}} \geq \Psi_{c,p,t}^{\text{csa}} \quad \forall c, p, t \quad (20)$$

$$R^{\text{csa}} = \sum_{c,p,t} \Psi_{c,p,t}^{\text{csa}} \cdot K_c^{\text{csa}} \cdot Av_{c,t}^{\text{csa}} \cdot \lambda_c^{\text{csa}}$$

$$- \sum_{c,t} Ct_c^{csa} \cdot Av_{c,t}^{csa} \cdot \lambda_c^{csa} \quad (21)$$

### 3.4 Contract demand

Clients such as collective catering or grocery shops usually anticipate their orders and launch calls for tenders with product specifications. Getting such contracts can be an opportunity for the farmer as it enables ahead production and distribution planning. To serve a contract demand client  $c$ , the farmer must be able to deliver all the products the client asks for the whole contract duration (eq. 22). Clients defined specific demands  $D_{c,p,t}^{cd}$  for products associated with product prices  $\Pi_{c,p,t}^{cd}$ . Each delivery is associated with fixed setups costs depending on the delivery boolean  $\iota_{c,t}^{cd}$  (eq. 23). The revenue is composed of the products sales  $\omega_{c,p,t}^{cd}$  minus setup costs  $Ct_c^{cd}$  (eq. 24).  $\gamma_t^{cd}$  labor time needed is composed of fixed setup times  $\Gamma_{F_c}^{cd}$ -delivery time to a client  $c$ - and variable setup times  $\Gamma_{V_c}^{cd}$ -depending on the quantity of products to prepare, load and unload- (eq. 25).

$$\omega_{c,p,t}^{cd} = D_{c,p,t}^{cd} \cdot \lambda_c^{cd} \quad \forall c, p, t \quad (22)$$

$$\omega_{c,p,t}^{cd} \leq D_{c,p,t}^{cd} \cdot \iota_{c,t}^{cd} \quad \forall c, p, t \quad (23)$$

$$R^{cd} = \sum_{c,p,t} \Pi_{c,p,t}^{cd} \cdot D_{c,p,t}^{cd} \cdot \lambda_c^{cd} - \sum_{c,t} Ct_c^{cd} \cdot \iota_{c,t}^{cd} \quad (24)$$

$$\gamma_t^{cd} = \sum_{c \in C^{cd}} \iota_{c,t}^{cd} \cdot \Gamma_{F_c}^{cd} + \omega_{c,p,t}^{cd} \cdot \Gamma_{V_c}^{cd} \quad \forall t \quad (25)$$

### 3.5 Wholesalers

Wholesalers can accept important volumes of products, but they pay lower prices  $\Pi_{c,p,t}^{ws}$  as intermediates than the clients categories presented above. The farmer can be interested in wholesales when production exceeds demand, when delivery workforce is lacking or when he wants to diversify markets. We consider wholesales have unlimited demand. Each delivery is associated to setup costs (eq. 26) and setup times (eq. 29) via the boolean  $\iota_{c,t}^{ws}$ . Wholesales only function for a minimum volume of products  $w_{min,c,p}^{ws}$  (eq. 27) and the delivered quantities  $\sum_p \omega_{c,p,t}^{ws}$  can not exceed the farmer's vehicle capacity  $W_{max,c}^{ws}$  (eq. 26).

$$\sum_p \omega_{c,p,t}^{ws} \leq W_{max,c}^{ws} \cdot \iota_{c,t}^{ws} \quad \forall p, t \quad (26)$$

$$w_{min,c,p}^{ws} \cdot \iota_{c,t}^{ws} \leq \omega_{c,p,t}^{ws} \quad \forall p, t \quad (27)$$

$$R^{ws} = \sum_{p,t} \Pi_{c,p,t}^{ws} \cdot \omega_{c,p,t}^{ws} - \sum_t Ct_c^{ws} \cdot \iota_{c,t}^{ws} \quad (28)$$

$$\gamma_t^{ws} = \Gamma_c^{ws} \cdot \iota_{c,t}^{ws} \quad \forall t \quad (29)$$

### 3.6 Purchase-resale

Some of the products ordered may not be available on the farm at a certain period, either because the farmer grow a restricted selection of products or because the products are not ripe on his farm at this specific period. To overcome this deficiency, the farmer purchases products from other farms to meet his clients demand. In the version of the model we present, we consider only one product supplier,

with unlimited production. Setup costs are associated with the delivery of products (eq. 30). The delivered quantities  $\sum_p pr_{p,t}$  can not exceed the vehicle capacity  $W_{max,c}^{ws}$  (eq. 31). The cost of purchasing products includes the product price  $\Pi_{p,t}^{pr}$  and the delivery setups  $Ct^{pr}$  (eq. 32). The supplier manages the product preparation and delivery, the farmer only takes time to receive the products (eq. 33).

$$pr_{p,t} \leq M_t \cdot \iota_t^{pr} \quad \forall p, t \quad (30)$$

$$\sum_p pr_{p,t} \leq W_{max}^{pr} \cdot \iota_t^{pr} \quad \forall t \quad (31)$$

$$co^{pr} = \sum_{p,t} \Pi_{p,t}^{pr} pr_{p,t} + \sum_t Ct^{pr} \cdot \iota_t^{pr} \quad (32)$$

$$\gamma_t^{pr} = \Gamma^{pr} \cdot \iota_t^{pr} \quad \forall t \quad (33)$$

## 4. THEORETICAL ANALYSIS OF THE PROBLEM

Before applying optimisation methods found in the literature, we have to study our problem structure in depth. Several subproblems can be studied independently.

*Wholesales with production capacity:* When wholesalers are the only clients and purchase-resale is not allowed, the model is a capacitated lot-sizing model with setups times and costs. Clients are delivered at a given date using the available workforce  $H_t$  or hiring extra workforce  $h_t$  if necessary. Capacity and setups can make this problem NP-hard in many cases, as shown in Hsu (1983).

*Contract demand with capacitated production:* When contract demand clients are the only client, with no purchase-resale, the problem can be considered as a multidimensional knapsack problem with setups. Each knapsack item, i.e. each long-term contract client, necessitates a certain quantity of products and workforce at each period. The optimization problem consists in selecting the set of items that maximizes the annual profit by catching interesting prices and volumes and limiting product losses. Among the two knapsack dimensions, production is fixed and workforce can be augmented by hiring extra-workforce  $h_t$  on period  $t$ . Multidimensional Knapsack Problem is a more complex variant of the classical 0-1 Knapsack Problem, known to be an NP-hard problem (Osorio et al. (2002)).

*CSAs and farmer's market with capacitated production:* When considering only these categories, the focus shifts to getting a sufficient diversity of products each week with target lot price and weight and delivery setups. The model includes many binary variables to express the presence of a product in a given delivery. This submodel can be seen as an extension of the capacitated lot-sizing problem with setups times and costs. If the problem is theoretically NP-hard, our problem and data structure could enable a rapid resolution.

*Combined markets with purchase-resale:* Combining all the markets diversity and allowing the farmer to outsource a part of the products, capacity constraints are partly relaxed. The model is then a combination of binary multidimensional knapsack problems with setups and different levels of lot-sizing models with setups, linking production, outsourcing, inventory management and client selection. The problem could become highly combinatorial and hard to solve.

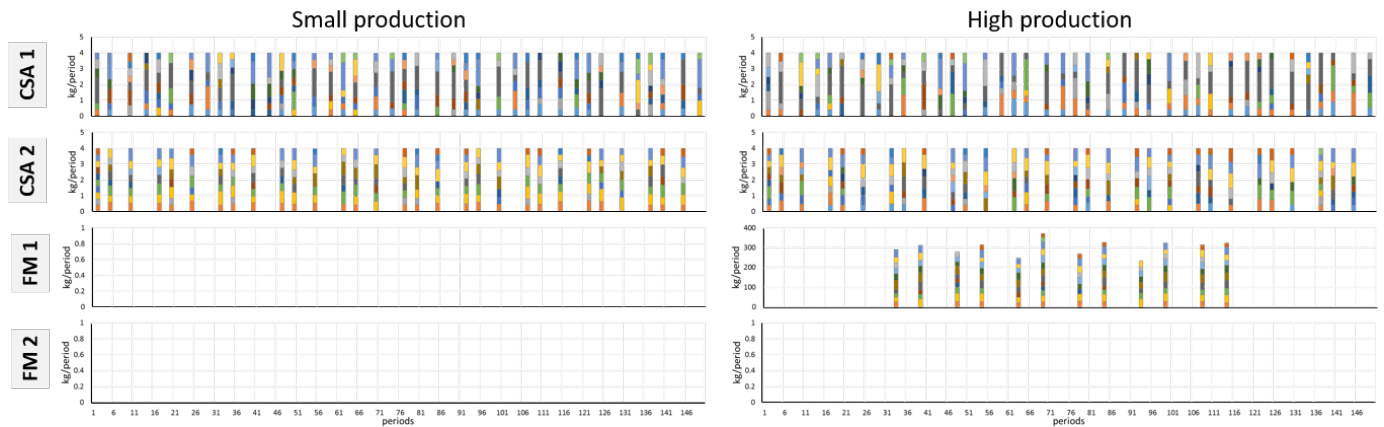


Fig. 2. Computational results for two CSAs and two farmers' markets, with increasing production. The different bar colors represent the different products in the delivery.

Further work is now required for in-depth analysis of the problem and subproblem structure to define its complexity and identify efficient resolution strategies.

## 5. COMPUTATIONAL RESULTS

Preliminary results are shown on figure 2, for a small data set. Four clients are identified, two CSAs and two farmers' markets. Twenty products are considered for a yearly time horizon of 150 periods per year. No perishability management, nor purchase-resale activity have been considered here. This reduce model is solved in a few seconds with the use of ILOG CPLEX 12.6 (2015) on Intel Core i7-4600U 2.10 GHz processor and 8.0 Gbytes of RAM. The model here comprises 16000 continuous variables and 15000 binary variables.

As we can see in figure 2, when the production volume is small, only the more profitable markets are targeted, that is the two CSAs with respectively 15 and 30 4-kg boxes to deliver at each period. The minimum product diversity is respected. When the production increases, a summer market can be opened but, given permanent workforce capacity and extra workforce cost, it is not profitable to open the farmer's market FM2.

The preliminary results seem to be consistent with farm reality. We are currently working on building detailed client profiles, products and prices database and farm production profile based on real data from Paris region farms. Adding perishability and purchase-resale constraint will enable to precise preliminary results. Further work will consist in validating the model on real farm cases.

## 6. CONCLUSION AND PROSPECTS

We present in this paper a decision support model to help market gardeners to select the clients to deliver according to the farm production, the farm resources and the client demand characteristics. We include a specific modeling of the demand of each client category: Farmers' markets, community supported agriculture, contract demand and wholesalers. The model allows the farmer to practice purchase-resale activity to meet the client whole demand. Preliminary results are presented as we are currently working on building data sets from real farm study. The original aspect of our work is that we integrate

the impacts of selling options to different possible markets (downstream part of the supply chain) to the production phase (upstream part of the supply chain). To the best of our knowledge, this contribution is quite new in the production and the supply chain literature.

The next steps in validating the model will be to implement the model on real farm data and to integrate useful indicators for the farmers. For instance, we will consider the farm treasury, to find a client combination that reduces the producer financial risks. Further development works will be focused on finding a better modeling approach with less binary variables and setting up specific resolution methods to solve the subproblems without using a linear solver.

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## APPENDIX. PARAMETERS AND VARIABLES

### Farm profit and resources parameters

- $p \in P^f$  range of products that are produced on the farm
- $p \in P^{rs}$  range of products offered by a local supplier
- $p \in P$  range of products offered to the clients  $P = P^f \cup P^{rs}$
- $t \in T$  time periods
- $c \in C^m$  clients of market category  $m \in \{fm, csa, cd, ws\}$
- $Y_{p,t}$  farm production reaching maturity on period  $t$
- $\beta \in [0, B_p]$  perishability time index, product storage duration
- $L_{p,\beta}$  product  $p$  loss function depending on age  $\beta$
- $C_t^H$  permanent workforce cost
- $C_t^h$  temporary workforce per-hour cost

### Farmer's markets parameters

- $Av_{c,t}^{fm}$  Availability period of the market (week day chosen by clients for delivery)
- $w_{min,p}^{fm}$  min weight of product  $p$  to be sold on the market
- $w_{max,p}^{fm}$  max weight of product  $p$  to be sold on the market
- $\Pi_{p,t}^{fm}$  selling price of product  $p$  on the farmers' markets
- $L_c^{fm}$  loss rate on a market (% of products that are not sold at the end of the day)
- $\Delta^{fm}$  minimum product diversity on a market stall
- $C_t^{fm}$  transport and spot rent costs for a market  $c$
- $\Gamma_c^{fm}$  time needed to deliver and sale on market  $c$

### CSA parameters

- $Av_{c,t}^{csa}$  Availability period of the market (week day chosen by clients for delivery)
- $w_{min,c,p}^{csa}$  min weight of product  $p$  to be included in a box
- $w_{max,c,p}^{csa}$  max weight of product  $p$  to be included in a box
- $W_{min,c}^{csa}$  min weight of a box
- $W_{max,c}^{csa}$  max weight of a box
- $\Pi_{p,t}^{csa}$  selling price of product  $p$  on the CSA markets
- $\Psi_{c,p}^{csa}$  selling price of a vegetable box
- $K_{c,t}^{csa}$  number of boxes to delivered each week to the client

- $\Delta^{csa}$  minimum product diversity in a box
- $C_t^{csa}$  transport cost to deliver the boxes to client  $c$
- $\Gamma_c^{csa}$  time needed to deliver client  $c$
- Contract demand parameters**
- $\Pi_{c,p,t}^{cd}$  selling price of product  $p$  to client  $c$  on period  $t$
- $C_t^{cd}$  transport cost to deliver the boxes to client  $c$
- $D_{c,p,t}^{cd}$  quantity of product  $p$  to deliver to client  $c$  on period  $t$
- $\Gamma_{F,c}^{cd}$  fixed time needed to deliver client  $c$
- $\Gamma_{V,c}^{cd}$  variable time needed to delivered a unit of product to client  $c$

### Wholesales parameters

- $w_{min,c,p}^{ws}$  min weight of a product batch
- $W_{max,c}^{ws}$  max weight of a delivery
- $\Pi_{c,p,t}^{ws}$  selling price of product  $p$  on period  $t$
- $C_t^{ws}$  transport cost to deliver the products
- $\Gamma^{ws}$  fixed time needed to deliver the products

### Purchase-resale parameters

- $W_{max}^{pr}$  max weight of a delivery
- $\Pi_{p,t}^{pr}$  purchase price of product  $p$  on period  $t$
- $C_t^{pr}$  transport cost to deliver the farm
- $\Gamma^{pr}$  fixed time needed to deliver client  $c$

### Farm profit and resources decision variables

- $h_t$  hours of extra workforce hired on period  $t$
- $x_{p,\beta,t}$  available quantity of marketable products of age  $\beta$
- $z_{p,t}$  delivered quantity of marketable products
- $\bar{x}_{p,\beta,t}$  available quantity of lost products of age  $\beta$
- $\bar{z}_{p,t}$  quantity of lost products removed from stock on period  $t$

### Farmer's markets decision variables

- $\nu_{c,p,t}^{fm}$  boolean = 1 if product  $p$  is sold on the market  $c$  on period  $t$
- $\lambda_c^{fm}$  boolean = 1 if the farmers' market is selected
- $\omega_{c,p,t}^{fm}$  quantity of product  $p$  delivered on period  $t$  to market  $c$
- $\gamma_t^{fm}$  time need to deliver and serve the selected clients on period  $t$

### CSA decision variables

- $\nu_{c,p,t}^{csa}$  boolean = 1 if product  $p$  is included in box for client  $c$  on period  $t$
- $\lambda_c^{csa}$  boolean = 1 if the client is selected
- $\omega_{c,p,t}^{csa}$  quantity of product  $p$  delivered on period  $t$  to client  $c$
- $\gamma_t^{csa}$  time need to deliver and serve the selected clients on period  $t$

### Contract demand decision variables

- $\lambda_c^{cd}$  boolean = 1 if the client is selected
- $\iota_{c,t}^{cd}$  boolean = 1 if a delivery occurs on period  $t$
- $\omega_{c,p,t}^{cd}$  quantity of product  $p$  delivered on period  $t$  to client  $c$
- $\gamma_t^{cd}$  time need to deliver and serve the selected clients on period  $t$

### Wholesales decision variables

- $\iota_{c,t}^{ws}$  boolean = 1 if a delivery occurs on period  $t$
- $\omega_{c,p,t}^{ws}$  quantity of product  $p$  delivered on period  $t$
- $\gamma_t^{ws}$  time need to deliver and serve the selected clients on period  $t$

### Purchase-resale decision variables

- $pr_{p,t}$  quantity of product  $p$  delivered to the farm on period  $t$
- $\iota_t^{pr}$  boolean = 1 if a delivery occurs on period  $t$
- $co^{pr}$  cost of the purchase-resale activity
- $\gamma_t^{pr}$  time need to deliver and serve the selected clients on period  $t$