SINGLE CRITERION SUPPLY CHAIN MANAGEMENT IN OLIVE OIL INDUSTRY

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Abstract

In this work we consider the supply chain management in olive oil industry. We construct the mixed-integer programming model connecting the optimization of olives harvesting and storage and olive oil production. The goal is to maximize the olive oil producer profit consisting of revenue, production cost and storage cost. In the same time, we have to take into the consideration the farmers' (suppliers') utility too. Namely, the suppliers want to maintain the harvest delay and delivery cost as minimal as possible. In the case of single criterion optimization problem we suppose that the producer is taking care of all five goals, so the objective function consists of the producer's revenue, storage cost, production cost, harvest delay and delivery cost with the appropriate sign. Due to the big dimension of the problem two heuristics are proposed for solving it. Some simulations are performed and the results show good heuristics behavior.

Key words: *agri-food supply chain, olive oil industry, single criterion problem optimization, heuristics, decision support system*

1. INTRODUCTION

1.1. Agri-food supply chains

Supply chain management (SCM) models of agricultural fresh products are more complicated than the SCM models of the usual industrial products with no deterioration, because the amount of harvestable fresh products depends on the growing process of the related plants on farmland, and because the deteriorating process of the fresh products starts immediately after harvested (Widodo, Nagasawa, Morizawa, Ota, 2006). In general, the supply chain of agri-foods, as any other supply chain, is a network of organizations working together in different processes and activities in order to bring products and services to the market, with the purpose of satisfying customers' demands (Christofer, 2005). What differentiates agri-food supply chains from other supply chains is the importance played by factors such as food quality and safety, and weather related variability (Salin, 1998). As mentioned above, very important factor making agri-food supply chain harder to manage is the limited shelf life of the products. Because of all these issues, in the context of agri-food supply chain, in this paper, we identify three main functional areas: harvesting, storage and production. Also, the paper will consider highly perishable commodities such as fresh fruits and vegetables and illustrate the model for olives. Decisions made in harvesting include the timing for collecting fruits and their appropriate quantities. Storage-related decisions include the inventory control of the fruits before the production, namely, to store the fruits in the cold storage or leave the fruits waiting for the production, but not more than some days. The third function is production which includes the machine scheduling.

1.2. Decision support systems in agri-food supply chain

The structure of agri-food market is currently under great changes and transformations, especially in the framework of globalization. In the past, the main players were small family based firms, the market was very fragmented and locally oriented. Today, in the circumstances of expansion, the agri-food supply chains need more coordination. Only in that way they will be more efficient, competitive and be able to adjust rapidly to changing conditions. But, to have more coordination in the supply chain one needs to have good planning models. Moreover, the supply chain participants need to create very specific planning models that incorporate many functional areas, such as mentioned above (that is, for example, harvesting, storage and production). The agri-food sector is facing global challenges that can only be met with support of information technologies (IT), (Schiefer, 2004). IT opportunities are key tools in the agri-food supply chain activities and contribute to the optimization and to an efficient decision making process. The decision support systems involve the storage and processing of collected information, methods and techniques giving the new information useful for efficient decision making and in this way make the planning process more structural and promising. The most famous decision support systems are Enterprise Resource Planning (ERP) and Supply Chain Analitics (SCA), or Advanced Planning Systems (APS). The problem with all these systems is that they are not sufficiently generic. In a specific situation other procedures need to be added and implemented using the specific characteristics of the considered problem.

1.3. Olive oil industry

In the case of agri-food supply chains one deals with the perishable agricultural commodities where the processing time is very limited. The factors such as food quality and safety, limited shelf life and demand and price variability are very important and should be taken into the consideration while optimizing the supply chain. In order to illustrate the problems that could arise and be solved in an efficient way using the appropriate decision support system, in this work we will consider the case of olive oil industry. The problem is inspired by a small olive farm and a small olive oil producer, but we extend it to the case of a large olive oil industry. The production of a small firm is characterized by high production costs and low profit level. In order to be more competitive the small firms should integrate in a larger system and take part on the market as an industry. In this work we will consider small farms grooving and harvesting olives which will participate in the supply chain as suppliers. On the other hand we will have olive oil producers being small firms in the present situation and propose the decision support system how to integrate them and develop their partnership in order to be more efficient and competitive on the global market.

1.4. Organization of the paper

In the next section (Section 2) we present the description of the problem, while in the Section 3 we give the mathematical formulation of it. The heuristics are described and computational results presented in the Section 4. In the Section 5, the future work is given, while the conclusions are listed in the Section 6.

2. PROBLEM DESCRIPTION

2.1. Agri-food supply chain players: suppliers and cluster of producers

As was mentioned above the big problem of an agri-food market is the fragmentation of the suppliers, but also of the producers. In this work, we will consider small suppliers of the olives and small producers of the olive oil, but integrate the small producers in one big company in order to be more competitive and efficient. In a certain region, the suppliers will harvest their olives and supply the olive oil producers according to the schedule obtained as the optimal solution of the problem. The point is that the optimal production scheduling will be obtained for all the producers simultaneously and in this way they will deal with the production as one single, big company with many machines of different capacities. Acting as one big company, the cluster of small producers will be more efficient and more competitive at the global market from two points of view: they will be more able to maximize suppliers' utility (suppliers want to supply in the preferred period) and, also, they will use their machines at the full capacity as much as possible. Thus, from one side there are small suppliers and from the other side there are producers acting as one big company or cluster. Both of this players in described supply chain have their conditions and requests as follows.

2.2. Suppliers

There is a considerable number of olive suppliers that have a preferred period of supplying the olives which depends on the time intervals they consider the best for harvesting in order to get the oil of desired properties and quality. Moreover, some of the olive suppliers are also the buyers of the final product, i.e. olive oil. On one hand, among them there are those who want their oil to be produced exclusively from their olives. Also, it might be the case that they want to buy only one portion of the oil produced from their olives, while the rest of the olive they supply is sold to the producer who then sells the olive oil to other buyers, e.g. consumers that are not olive suppliers. On the other hand, some of the suppliers allow their olives to be mixed with others' when producing olive oil. Finally, there are suppliers who only sell the olives to the olive oil producers and do not buy the olive oil. However, even in such cases where suppliers are not interested in whether their olives will be mixed with others or not, there are some rules stating which olive types can be mixed. Then, it is the olive oil producers' concern since the quality of the olive oil they will sell in the market highly depends on the mixtures. Therefore, olives from some suppliers are not allowed to mix with others' at all, and some are allowed to be mixed with some other types of olives. Thus, the olive oil type is defined by the olive types that it is produced from.

2.2. Cluster of producers

The harvesting of olives is made over days in a time horizon of about two months. However, the processing of oil on machines is to be scheduled over hours, since the processing time on any machine is one hour. The machines can differ in their capacities, but it only means that they can be loaded with a certain maximum amount of olives, measured in kg's of weight. However, the processing time of the olives on a machine does not depend on the amount of olives it is loaded with. Thus, the model considers that the planning horizon is divided into T macro-periods (days) and to obtain the production sequence, each macro-period is divided into a number of micro-periods (hours). Another issue has to be addressed when taking into account the fact that the olives are perishable goods. Namely, the quality of the olive oil rapidly decreases when olives are not processed immediately after they are harvested, i.e., after a day or two. This is avoided if the oil producer stores them in a cold storage until the olives undergo processing. However, due to the very high costs of using the cold storage, the producer desires a good synchronization between harvesting the olives from the side of suppliers and processing the olives from the side of the producers, which would minimize the use of the cold storage.

2.3. Objectives

In the next section, we construct the mixed-integer programming model connecting the optimization of olives harvesting and storage and olive oil production. The goal is to maximize the olive oil producer profit consisting of revenue, production cost and storage cost. In the same time, we have to take into the consideration the farmers' (suppliers') utility too. Namely, the suppliers want to maintain the harvest delay and delivery cost as minimal as possible. In the case of single criterion optimization problem we suppose that the producer is taking care of all five goals, so the objective function consists of the producer's revenue, storage cost, production cost, harvest delay and delivery cost with the appropriate sign.

3. MATHEMATICAL FORMULATION OF THE PROBLEM

3.1. Sets and indices

- $\mathcal{P}$ – set of olive suppliers ($j=1,\ldots,P$);
- $\mathcal{U}$ – set of olive oil types ($u=1,\ldots,U$);
- V_u – set of olives that olive oil of type u is made from, i.e., suppliers whose olives can be mixed with each other to produce the olive oil of type u ($V_u \subseteq P$);

- T – macro-periods, i.e. working days (*t=1,…T*);
- M – number of machine (*m=1,…,M)*.

3.2. Parameters

- A_j - total supply of olives from supplier *j*;
- D_{jt} - upper bound on supply of olives from supplier *j* in day *t*;
- G_{jt} - lower bound on supply of olives from supplier *j* in day *t*;
- N_t - micro-periods in a macro period, i.e., working hours in a day ($r=1,\ldots, N_t$);
- C_m - capacity of machine *m*;
- H – capacity of the cold storage;
- p_u - the unit revenue obtained from the olives from V_u;
- e_{mt} - the cost for producing (processing olives) a full or partial batch in day *t* on machine *m*;
- f_t - the unit storage cost in day *t* (the same for all olive types);
- w_{jt} - the unit cost of supplying in not preffered periods (the unit oversupply cost of olives *j* in period *t*);
- b_{jt} - the setup cost of supplying olives *j* in period *t*.

3.3. Decision variables

- I_{ut} - the storage quantity of olives that olive oil of type *u* is made from at the end of day *t*, with $I_{u0} = 0$, for all *u*;
- Q_{umt} - the quantity of olives processed for olive oil of type *u* on machine *m* in day *t*;
- S_{jt} - the quantity of olives *j* supplied at the beginning of day *t*;
- R_{jt} - oversupply of olives *j* in day *t*;
- $Y_{umt} \in Z_+$ - the number of hours in day *t* in which olive oil of type *u* is processed on machine *m* (the number of batches);
- $X_{jt} = \begin{cases} 1, & \text{if the olives } j \text{ are supplied at the beginning of day } t \\ 0, & \text{otherwise.} \end{cases}$

3.4. Objective

The objective is to maximize the profit described as stated in Section 2.3. Hence, the objective can be formulated as follows:

$$\sum_{u=1}^{U} p_u \sum_{m=1}^{M} \sum_{t=1}^{T} Q_{umt} - \sum_{m=1}^{M} \sum_{t=1}^{T} e_{mt} \sum_{u=1}^{U} Y_{umt} - \sum_{u=1}^{U} \sum_{t=1}^{T} f_t I_{ut} - \sum_{j=1}^{P} \sum_{t=1}^{T} w_{jt} R_{jt} - \sum_{j=1}^{P} \sum_{t=1}^{T} b_{jt} X_{jt}$$

3.5. Constraints

There are three types of constraints: the constraints related to the raw materials in the cold storage (constraints (1)-(2)); those related to machine processing (constraints (3)-(4)); and finally the constraints concerning the supply of olives (constraints (5)-(8)). The constraints (9) define the variables domain.

$$I_{ut} = I_{u(t-1)} + \sum_{j \in V_u} S_{jt} - \sum_{m=1}^{M} Q_{umt}, \quad u = 1,\dots,U, t = 1,\dots,T \tag{1}$$

$$\sum_{u=1}^{U} I_{ut} \le H, \quad t = 1,\dots,T \tag{2}$$

$$Q_{umt} \le C_m Y_{umt}, \quad u = 1,\dots,U, \ m = 1,\dots M, \ t = 1,\dots,T \tag{3}$$

$$\sum_{u=1}^{U} Y_{umt} \le N_t, \ m = 1,\dots M, \ t = 1,\dots,T \tag{4}$$

$$\sum_{t=1}^{T} S_{jt} \le A_j, \ j = 1,\dots P \tag{5}$$

$$S_{jt} \le A_j X_{jt}, \ j = 1,\dots P, \quad t = 1,\dots,T \tag{6}$$

$$S_{jt} \le D_{jt} + R_{jt}, \ j = 1,\dots P, \quad t = 1,\dots,T \tag{7}$$

$$S_{jt} \ge G_{jt} X_{jt}, \ j = 1,\dots P, \quad t = 1,\dots,T \tag{8}$$

$$I_{ut} \ge 0, Q_{umt} \ge 0, S_{jt} \ge 0, R_{jt} \ge 0, Y_{umt} \in Z_+, X_{jt} \in \{0,1\} \tag{9}$$

The constraints (1) represent the cold storage balancing constraints for each item, i.e., olives from each supplier, in each period. The constraints (2) refer to the cold storage capacity. The variables Y are defined by the constraints (3), which also guarantee that the total quantity of olive oil of type u produced on machine m in period t is less than the machine capacity. The constraints (4) ensure that the upper bounds on daily number of batches are respected. The set of constraints (5) guarantee that the total supply of olives does not exceed the given upper bounds, while the set of constraints (6) define the binary variables X (supply set up variables). The oversupply variables R are defined by constraints (7). Also, the same set of constraints impose that the daily supply of olives is less than the given upper bound in the case of no oversupply. Finally, the constraints (8) ensure that the lower bounds on daily supply of olives j are respected.

4. HEURISTICS

4.1. Relax-and-Fix

This heuristic supposes that the 0-1 variables can be partitioned into a certain number of disjoint sets of decreasing importance. The criteria of constructing this partition can vary. In this work we propose two partitions. The first one consists of disjoint sets $A^1,...,A^T$ where $A^t = \{X_{1t}, X_{2t},..., X_{Pt}\},\ t = 1,...,T$.

The second one consists of disjoint sets $B^1,...,B^{\left\lfloor \frac{T}{5} \right\rfloor}$, where $B^1 = \{X_{1t}, X_{2t},..., X_{Pt}\},\ t = 1,...,5$, $B^2 = \{X_{1t}, X_{2t},..., X_{Pt}\},\ t = 6,...,10$, … , $B^{\left\lfloor \frac{T}{5} \right\rfloor} = \{X_{1t}, X_{2t},..., X_{Pt}\},\ t = \left\lfloor \frac{T}{5} \right\rfloor - 4,..., \left\lfloor \frac{T}{5} \right\rfloor$.

The last set in the second partition includes 0-1 variables having the remaining time indices. After constructing the partition, we solve sequentially an appropriate number of mixed-integer programming problems. With the first partition, we solve *T* problems where the first problem supposes the integrality of 0-1 variables from the set A^1, while the other 0-1 variables are relaxed. Then we fix the variables from the set A^1 at their optimal values and proceed with assuming the integrality of the 0-1 variables from A^2, while relaxing all the other variables from $A^3,...,A^T$. And so on till assuming the integrality of the 0-1 variables from the set A^T. With the second partition we work in the analogous way with fewer number of steps. The heuristic using the first partition is called RF_1t, while the second heuristic using the second partition is called RF_5t.

4.2. Exchange (Fixed-and-Optimize)

In general, exchange is an improvement version of the relax-and-fix heuristic. We keep the same decomposition of 0-1 variables . At each step, all the 0-1 variables are fixed at their value in the best solution found so far, except the variables in the chosen set from the current step which are restricted to take 0 or 1. The heuristic using the first partition is called FO_1t-1run, while the second heuristic using the second partition is called FO_5t-1run. Also, these heuristics are passing through every set of the partition just ones (because of this fact, they have the term "1-run" in their names). In this work, with these two heuristics, we do not improve the solution obtained by the relax-and-fix heuristic, but use the fixed-and-optimize heuristic for improvement of the first feasible solution found by Cplex 12.1. The heuristic improving the solution obtained by the relax-and-fix heuristic is called RF_5t_FO_1t.

4.3. Data

For each of four heuristics RF_1t , RF_5t , FO_1t-1run and FO_5t-1run, we perform the simulations with 30 instances of input data. We also propose two combinations of given heuristics, RF_5t_cplex and RF_5t_FO_1t and perform the same number of simulations. The data for the known parameters are chosen according to the real ones. We consider the period of 60 days with 80 types of olives (e.g., 80 suppliers) and 50 olive oil types. The cold storage capacity is randomly chosen from the set $\{0{,}1000{,}2000{,}3000\}$, machine number from the set $\{1,2,3\}$, machine capacities from the set $\{150{,}300{,}600\}$, working hours in a day from the set $\{5,...,10\}$ and the suppliers' olive quantities from the set $\{5,...,40\}\cdot 100\ kg$. The simulations are performed at FUJITSU SIEMENS AMILO PRO V8010 Intel Celeron M 1.6 MHz 512 RAM, while the programming cod is written in language c#.

4.4. Computational results

The results of the simulations are summarized in Table 1. In the white part of the Table 1, we compare four heuristics mentioned and described above. We can notice that the first partition gives better results regarding the objective function value, but the computational time does not behave in the same way.

Table 1: Computational results.

	RF_1t		RF_5t		FO_t-1run		FO_5t-1run		Cplex	RF_5t_cplex	RF_5t_FO_t
Instance	Obj. value	Time (s)	Obj. value	Time (s)	Obj. value	Time (s)	Obj. value	Time (s)	(Obj. value after 300 s)		
1	235489,66	271,30	236133,67	237,83	219115,75	121,80	227746,33	243,30	235959,21	236133,67	236157,67
2	190940,67	216,52	191258,49	224,48	175995,56	125,77	184368,46	231,81	191412,54	191258,49	191410,49
3	252161,02	209,72	252239,62	188,83	242073,30	154,59	244464,13	342,06	252734,22	252582,35	252375,46
4	301538,37	145,45	301956,42	236,48	278554,07	91,61	287854,48	274,03	302680,27	302154,03	302128,65
5	39157,03	54,66	39174,78	31,20	38154,55	49,52	38358,29	38,67	39255,35	39255,35	39174,78
6	329361,56	100,16	330203,19	172,20	309096,94	112,84	321995,81	217,67	330701,60	330636,24	331087,12
7	273261,06	292,17	274589,43	171,78	256007,73	166,52	264197,91	242,44	274344,69	274661,61	274590,93
8	273282,37	126,59	274000,90	199,84	254622,34	86,08	263259,38	230,16	274142,14	274000,90	274058,11
9	263145,42	176,44	264161,87	214,05	240763,39	123,78	248976,00	277,66	264269,20	264308,23	264294,42
10	177742,38	131,70	178472,82	221,94	172516,09	117,59	176234,19	302,58	178305,92	178472,82	178517,81
11	223492,44	174,59	224563,49	250,91	209012,08	92,33	217137,12	226,17	224477,82	224563,49	224764,49
12	135249,17	218,05	135938,43	270,63	133181,24	95,17	134831,56	272,83	135871,55	135938,43	136017,85
13	158926,76	71,33	159100,92	102,64	156712,57	75,75	158212,59	149,42	159178,90	159162,49	159154,07
14	261729,61	198,92	262214,37	260,08	246678,63	124,45	256258,17	299,58	262588,86	262264,77	262381,45
15	251733,33	160,25	252862,70	234,83	239827,36	83,48	244759,74	274,80	253266,66	253227,53	253053,11
16	114979,20	112,02	115084,82	146,14	113087,78	110,55	113931,52	151,98	115175,91	115172,36	115184,82
17	258734,07	201,16	259444,33	241,00	243911,86	117,41	254028,58	298,17	260261,78	260376,93	260546,22
18	117679,43	36,23	117941,84	57,14	116238,78	48,27	116714,06	64,61	117891,03	117941,84	117943,14
19	110843,14	103,97	111372,09	241,45	109960,16	53,52	110802,51	186,56	111354,47	111372,35	111372,35
20	260871,19	158,25	261936,95	220,70	251462,96	91,34	256992,32	288,73	261744,42	261936,95	262038,24
21	259748,49	142,23	261151,07	142,53	242668,71	119,17	249739,65	209,50	261272,50	261551,30	261732,07
22	198411,94	202,13	199226,26	251,38	183940,67	109,30	196636,89	286,52	199581,21	199226,26	199526,26
23	191986,83	210,55	191864,92	347,94	179387,03	116,42	181630,17	286,50	191853,32	191864,92	191986,83
24	317334,70	177,16	318024,24	216,28	296129,51	85,23	308666,97	252,59	318843,29	318185,25	318276,82
25	179153,53	284,05	179714,10	286,47	176145,15	91,84	177334,45	251,88	180062,85	179714,10	179721,10
26	255325,94	177,53	255714,11	172,13	242581,66	117,55	250203,75	234,48	256149,87	256258,34	255911,19
27	225553,14	239,81	225951,72	229,88	210595,16	121,36	220071,59	272,91	226632,70	225951,72	226194,16
28	242427,84	149,64	243346,78	231,80	226071,72	90,28	232464,42	261,63	243593,68	243297,09	244159,28
29	357465,03	95,80	359044,88	185,97	322233,34	86,97	348931,69	242,27	359133,49	359044,88	359236,88
30	122631,41	76,09	122791,29	202,39	120368,33	52,34	119367,06	203,89	122988,71	122858,21	123001,33
mean	219345,22	163,82	219982,68	206,36	206903,15	101,09	213538,99	237,18	220190,94	220112,43	220199,90
stdev	73609,36	65,88	73868,19	64,46	66365,15	28,49	70719,37	66,35	73984,67	73939,82	73977,39
median	238958,75	167,42	239740,23	221,32	222593,74	102,23	230105,38	247,59	239776,45	239715,38	240158,48

Source: the authors.

The general impression is that the heuristic RF_5t is behaving in the most acceptable way. Also, both heuristics relax-and-fix are giving sufficiently good objective function value in a relatively short period. They can be used as a part of another heuristic when we want to have a good solution in a short time. If we compare fix-and-optimize heuristics we can notice that the first one, FO_t-1run, is much faster giving relatively good objective function value. In order to choose a heuristic, we then fix the time period of 300 sec and compare two heuristics constructed as a combination of previous four. The first one constructs the initial solution using RF_5t and then improves it using Cplex 12.1. The second heuristic constructs the initial solution using RF_5t and improve it using FO_1t. Since the time is limited, the heuristic FO_1t does not have defined the run numbers in advance. The results are presented in the grey part of the Table 1. These two heuristics are compared to Cplex 12.1 too. The general impression is that the heuristic RF_5t_FO_1t is giving the best objective function value.

5. FUTURE WORK

Our intention is to consider the described problem as a bicriteria programming problem where we will divide the objective function. The first objective function will consist of the producer's goals, while the second one will consist of the suppliers' goals. All the mentioned heuristics will be used as a part of a new heuristic solving bicriteria programming problem. In order to obtain as many efficient solutions as possible in a short time the fastest heuristic can be used even if the objective function value is not so good. But we feel that the trade off between optimality gap and processing time will go towards time. The second way of expanding the research is in constructing the reformulation of the mathematical model which will help the heuristics to be more efficient. We intend to follow the work done by Anily, Tzur and Wolsey, (2009).

6. CONCLUSIONS

In this work we consider an agri-food supply chain constructing the decision support system for its optimization. The problem with this kind of supply chain is the fact that it deals with the perishable agricultural commodities where the processing time is very limited. We construct the mixed-integer programming model connecting the optimization of olives harvesting and storage and olive oil production. The goal is to maximize the olive oil producer profit consisting of revenue, production cost and storage cost. In the same time, we have to take into the consideration the farmers' (suppliers') utility too.

The decision support system can be applied to many similar problems from the agri-food industry. For example, we can consider the grape harvesting, delivering and processing in order to produce wine. The problem of mixing olives is the same as the problem of mixing grapes. Or we can optimize the supply chain in the fruit industry and take into the consideration that the fruit can be distributed at the market as a fresh fruit or can be processed into certain fruit product such as juice, jam, brandy or something else. The same problem can be formulated with fresh vegetables, while the problems including grains is little bit more simple because of non limited shelf life of the commodities.

We propose a certain number of heuristics and compare them. But, we think that the real application will be more realistic if we define the problem as a multicriteria programming problem what we intend to do in the future.

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