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# MULTI-OBJECTIVE OPTIMIZATION FOR THE INTEGRATED SUPPLY AND PRODUCTION PLANNING IN OLIVE OIL INDUSTRY

**Abstract**

Sustainable agriculture, among other things, implies encouraging a diverse and decentralized system of family farms rather than corporate concentration. The challenge is to find a way to organize coalitions improving the food system. The case study that inspired this work originates from Istria, a Croatian region with 25 olive oil producers and about 5,000 mostly small farmers growing and harvesting olives. To account for all the objectives of the agri-food supply chain participants, this work aims to set up a model for its integrated optimization, give its mathematical formulation and suggest a method for solving the problem.

**Keywords:** Perishable goods, agri-food industry, olive oil, production planning, multi-objective optimization

## 1. Introduction

As in many other countries, the structure of the Croatian agri-food market is currently undergoing major changes, largely due to globalization. In the past, the main participants in the country's olive oil industry were small family-owned firms, which made the market fragmented and locally oriented. However, today, the supply chains in the industry need to be better coordinated and more efficient in order to stay competitive and able to respond to the demands of the global market. Also, consumers are more aware of the importance of healthy nutrition and they are sensitive about food quality and safety, which affects demand and price variability. To incorporate increased traceability and generally higher expectations about production standards for perishable food, producers need to review their use of inventory and move towards more integrated approaches, as suggested also by Amorim et al. (2013).

Supply chain models used in the management of fresh farming products tend to be more complicated than the models used in the supply chain of non-perishable products. This is because the amount of harvestable fresh products depends on the growing process of the related plants, and also because fresh products start deteriorating immediately after harvesting (Widodo et al., 2006). Deterioration has a significant influence on all the elements of a production process which is characterized by uncertain demand, complex technical matters, variabilities or disruptions of production (Pahl et al., 2007).

This paper seeks to analyze the supply chain in olive oil industry which includes the farmers as suppliers on the one side, and the olive oil producers on the other. The case study that inspired this work originates in Istria, a Croatian region with 25 olive oil producers and about 5,000 mostly small farmers growing and harvesting olives. Presently, the suppliers decide on the harvesting time and quantities mostly by themselves, without consulting the producers who want to process olives as fast as possible upon delivery. Such a situation is far from optimal, so the goal of this research is to examine the possibilities of improving the processes in the studied supply chain by creating a model and a method for optimization of integrated supply and production planning for the olive oil industry.

The model and the method we propose have to take into account the perishability issues since the production of olive oil includes handling raw material (olives) which is perishable due to physical deterioration after the harvest. Olive perishability may result in decreasing customer value and a significant fall in the value of the final product (olive oil). Namely, the quality of olive oil is often measured by the percentage of free fatty acids, which depends on two factors: fruit maturity and storage (Koprivnjak, 2006). This means that the harvesting date should be carefully chosen, and then olives either have to be processed shortly after the harvest, or they should be stored in a controlled environment (cold storage). Hence, the raw material and the final product both undergo physical deterioration and a reduction in customer value when deviating from the appropriate time interval of the harvest.

Since the supply chain includes the farmers as suppliers on the one side, and the olive oil producers on the other, to account for all of the objectives of both sides, we set up a multi-objective model and a method for multi-objective optimization. Thus, the research questions are whether it is possible to construct a model and offer a method for integrated planning of olive harvesting, supply and oil production and to improve the processes in the studied supply chain.

The paper is organized as follows. Section 2 reviews the literature related to the issues of interest. After formally defining the considered problem of the olive oil industry, a mathematical model is proposed and commented on in Section 3. Section 4 provides a description of the method implemented for solving the problem, i.e. the Non-Dominated Sorting Genetic Algorithm II (NSGA-II). Section 5 provides the computational results. The conclusion and suggestions for future work are given in Section 6.

## 2. Related work

As seen from the literature review presented by Arshinder et al. (2011), it seems that the problem of agri-food supply chain coordination has not received serious attention, or these efforts have not been widely reported in the literature. Several recent examples of an integrated approach show that the scientific community has started putting more effort into resolving such problems (Baldo et al., 2014; Deng et al., 2014). Factors such as food quality and safety, weather related variability, limited shelf life of agri-food products, their demand and price variability make the agri-food supply chains more complex and harder to manage than other supply chains (Ahumada, Villalobos, 2009). In their review of the related work Ahumada and Villalobos (2009) also notice that there is a limited number of models addressing operational planning needs, especially in integrated models that aim to plan more than one aspect of the agri-food supply chain. The reviewed models are mostly created for only one group of target users, usually suppliers or producers, and they usually perform single objective optimization.

Some of the applications in the agri-food industry described in literature are a mixed-integer programming planning model for fruit industry (Masini et al., 2011), a linear programming model for planning the production of flowers (Caixeta-Filho et al., 2002), and a linear programming model that determines how to harvest oranges in order to maximize the revenue (Caixeta-Filho, 2006). Ruiz-Torres et al. (2012) propose planning models for floriculture operations and present a heuristic strategy that gives a solution close to the optimal. A paper that considers a problem similar to ours presents a practical tool for optimally scheduling wine grape harvesting operations taking into account both the operational costs and grape quality (Ferrer et al., 2008). Grape quality is measured by a quality loss function, which is a way of measuring potential reduction in the quality of wine due to the use of grapes which were not harvested on the optimal maturity date. Bohle et al. (2010) suggest how to deal with different types of uncertainties in scheduling the wine grape harvesting using a robust optimization approach. Vlah Jerić and Šorić (2011) modeled the problem of scheduling olive harvesting, delivery, storage and olive oil production as a single objective mixed integer programming problem and they presented some preliminary results for the two proposed heuristics for solving it. Rong et al. (2011) integrated food quality in decision making involved in production and distribution in a food supply chain. They proposed a single objective mixed integer programming model with around 1,500 integer variables and applied CPLEX 10.2. Also, Ahumada and Villalobos (2011) presented an operational model designed for providing decisions for harvesting, packing and distribution of crops with the objective of maximizing the revenue of the farmer. Cai et al. (2008) developed both a model and an algorithm for the production of sea food products. Due to a deadline constraint and the raw material perishability, the manufacturer determines the product types to be made, the machine time to be allocated for each product type, and the sequence to process the products selected.

The literature considering the agri-food supply chain or its parts as a multi-objective optimization problem is scarce despite numerous conflicting objectives typically related to the issue. Multicriteria decision making methods are mostly used to measure the performance of the agri-food supply chain, but they do not use the techniques of multiobjective programming for optimizing the supply chain processes. These techniques are sometimes used for solving problems in farming, but not in fruit processing[1]. For example, Sarker and Ray (2009) formulated a crop-planning problem as a multi-objective optimization model, and they proposed a multi-objective constrained algorithm for solving the problem and compared its performance with ε-constrained method and a variant of NSGA-II. A hybrid genetic algorithm based on NSGA-II was developed by Amorim et al. (2011) to solve the problem of multi-objective lot-sizing and scheduling dealing with perishability issues in relation to a dairy company producing yogurt. Amorim et al. (2012) considered the problem of production and distribution planning with the objective of minimizing the total cost and maximizing the mean remaining shelf-life of products at distribution centers over a planning horizon. They compared the results for two scenarios, i.e. the integrated model and decoupled production and distribution model, both for the fixed shelf-life and loose shelf-life cases. Also, some authors have already given suggestions about the importance of using a multiobjective framework to investigate the perishability problems (e.g. Arbib et al., 1999; Lütke Entrup, 2005). Nevertheless, to the best of our knowledge, our work is the first to address the integrated supply and production planning for perishable goods in a multi-objective framework. Thus, the scientific contribution of this research is development of a new multi-objective mixed-integer programming problem model that encompasses the objectives of both the suppliers and the producers in terms of economic gains and product quality. Moreover, another scientific contribution is the design of a method that approximates the Pareto frontier of the multi-objective optimization problem, thus offering an insight into the trade-offs between the conflicting objectives. More specifically, we propose a specific design of the crossover operator, as a component for the NSGA-II algorithm.

## *3. Problem formulation*

### *3.1 Problem description*

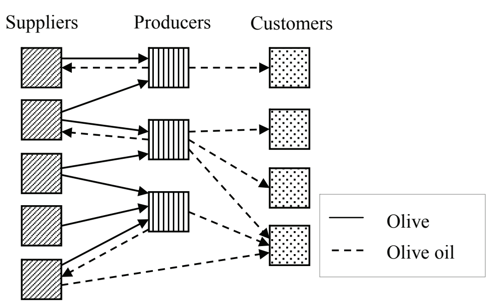
In Croatia, olive suppliers are usually small farmers who often grow olives as a part-time job. Farmers harvest and then deliver olives as raw products to producers, so they have to decide about the time and quantities of harvesting and delivery. Some suppliers sell olives to producers only to make a profit on the sale of the raw material, and others use the service of processing olives into olive oil and then take the oil for their own consumption or for selling it under their name.

When using olive processing services, some suppliers mix their olives with those provided by other suppliers, and some insist on obtaining oil exclusively from their own raw material. Namely, oil producers sometimes offer to mix olives because the production run time is constant and it does not depend on the quantity of the raw material. Since the raw material is perishable, it has to be delivered shortly after the harvest. Moreover, the highest-quality olive oil will be obtained if olives are harvested within a given time window. Therefore, suppliers (farmers) have adopted a system of successive harvesting and delivering of olives, so small amounts of olives are delivered for processing day after day. Delivery costs do not depend significantly on the quantity, so the focus is on minimizing the costs of organizing olive harvest and delivery, as well as on reducing the number of working days to a minimum. Also, it is important to note that the region observed in our case study is very small, so we disregard the distances when calculating the olive delivery costs. For example, the suppliers and the producers in the data used in the experiments lie in the radius of about 20 km.

On the other hand, producers have to decide whether to process the delivered fresh products immediately, to store them in cold storage or to leave them for a few days. Maintaining cold storage is typically too costly for producers, so in the region under our consideration only the biggest producer owns such a facility. Due to the high costs of cold storage and the fact that, if improperly stored, olives lose their desirable features very fast, producers need to carefully time the collection of olives from suppliers and their processing. After the processing, a certain amount of olive oil is given to suppliers, and the remaining part is sold on the market under the producer's name.

A graphical representation of the problem is given in Figure 1. We model the decisions concerning the flows between the suppliers and the producers, while the flows toward the customers are not considered. Namely, the production is concentrated in a few consecutive months during the harvest season, and the distribution of the finished olive oil can be planned separately.

***Figure 1 The concept of a supply chain in the olive oil industry***




*Source: Authors*

To construct a multi-objective mixed-integer programming problem, we define sets of suppliers, olive oil types and olives needed for oil production. For input parameters we take the time horizon, machine number, upper and lower bound on the supply, cold storage and machine capacities, unit production revenue for a final product type, delivery cost, unit storage and production cost, and unit cost associated to deviation with respect to the preferred supply periods. The latter is the quality factor i.e. the cost defined through the reduction in olive oil quality due to the use of olives which were not harvested and supplied on the optimal date.

In order to understand the loss of quality, it is necessary to note that olive oil is categorized into several quality groups: extra virgin olive oil as the premium category, virgin olive oil as the medium-quality category, and olive oil lampante as a category considered suitable for human nutrition only after refining and adding a small amount of edible virgin olive oil. The categories are differentiated according to the percentage of free fatty acids and the sensory properties, which are the measures of olive oil quality that highly depend on olive maturity as well as on olive storage conditions and duration. The sequential degradation process of the olives results in a loss of revenue for the business, since the profit on extra virgin olive oil is much higher than in the case of other olive oil categories. Thus, harvesting on the optimal date has no quality penalty; harvesting before or after the optimal date generates a cost associated with the potential deterioration of olives, which affects oil quality. In this way we incorporate the notion of quality in the model by using a quality loss function, which is a concept originally developed by Taguchi and Clausing (1990). The optimal date of harvesting and supply is defined by olive oil suppliers based on the known effects of farming and storage factors on olive oil quality (from e.g. Koprivnjak, 2006) and their experience.

### 3.2 *Multi-objective mixed-integer programming problem*

In order to present the multi-objective mixed-integer programming problem, it is necessary to list the sets and indices needed to introduce the parameters and the variables for the studied problem.

Sets and indices:

- $T$ – number of working days ($t$ =1,…,$T$);
- $M$ – number of machines ($m$=1,…,$M$).
- $P$ – number of combinations of suppliers and olive types they supply ($j$ =1,…, $P$);
- $U$ – number of olive oil types ($u$ =1,…,$U$);

- $V_u$ – set of olives that the olive oil of type $u$ is made of, i.e., supplier/olive type combinations that are used to produce the olive oil of type $u$ ($V_u \subseteq \{1,\ldots,P\}$); the sets are mutually exclusive;

Parameters:

- $A_j$ – total supply of olives from supplier $j$;
- $D_{jt}$ – upper bound on the supply of olives from supplier $j$ on day $t$;
- $G_{jt}$ – lower bound on the supply of olives from supplier $j$ on day $t$;
- $N_t$ – working hours in day $t$;
- $C_m$ – capacity of machine $m$;
- $H$ – capacity of cold storage;
- $p_u$ – unit revenue obtained from olive oil of type $u$;
- $e_{mt}$ – cost of processing a full or a partial batch on day $t$ on machine $m$;
- $f_t$ – unit storage cost on day $t$ (the same for all olive types);
- $w_{jt}$ – unit cost of supplying in non-preferred period (quality cost of olives $j$ on day $t$);
- $b_{jt}$ – delivery cost of supplying olives $j$ in period $t$.

Variables:

- $I_{ut}$ – storage quantity of olives that the olive oil of type $u$ is made of at the end of day $t$, with $I_{u0} = 0$, for all $u$;
- $Q_{umt}$ – quantity of olives processed for olive oil of type $u$ on machine $m$ in day $t$;
- $S_{jt}$ - quantity of olives $j$ supplied at the beginning of day $t$;
- $Y_{umt} \in \mathbb{N}$ – number of working hours in day $t$ in which olive oil of type $u$ is processed on machine $m$ (the number of batches);
- $X_{jt} = \begin{cases} 1, & \text{if the olives } j \text{ are supplied at the beginning of day } t \\ 0, & \text{otherwise;} \end{cases}$
- $R_{jt}$ – oversupply of olives $j$ in day $t$ i.e. the quantity of olives that are supplied in a period that is not preferred (unlike other variables in this model that are the decision variables, this is an auxiliary variable which calculates the surplus of the quantity of the supplied olives and the demand).

As has been said, suppliers want to minimize both the cost of supply in non-preferred periods (quality cost i.e. oversupply cost) and the delivery cost, while producers attempt to maximize the profit depending on revenue, production cost and storage cost. Hence, the *producers' objective* can be formulated as follows:

$$\max z_1 = \left( \sum_{u=1}^{U} p_u \sum_{m=1}^{M} \sum_{t=1}^{T} Q_{umt} - \sum_{m=1}^{M} \sum_{t=1}^{T} e_{mt} \sum_{u=1}^{U} Y_{umt} - \sum_{u=1}^{U} \sum_{t=1}^{T} f_t I_{ut} \right),$$

while the *suppliers' objective* is:

$$\min z_2 = \left( \sum_{j=1}^{P} \sum_{t=1}^{T} w_{jt} R_{jt} + \sum_{j=1}^{P} \sum_{t=1}^{T} b_{jt} X_{jt} \right).$$

There are three types of *constraints* in this problem: the constraints related to the raw materials in 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.

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

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

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

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

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

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

$$S_{jt} \leq D_{jt} + R_{jt}, \; j = 1,...P, \; t = 1,...,T \quad (7)$$

$$S_{jt} \geq G_{jt} X_{jt}, \; j = 1,...P, \; t = 1,...,T \quad (8)$$

$$I_{ut} \geq 0, Q_{umt} \geq 0, S_{jt} \geq 0, R_{jt} \geq 0, X_{jt} \in \{0,1\}, Y_{umt} \in \mathbb{N} \quad (9)$$

Constraints (1) represent the cold storage balancing constraints for each item, i.e., olives from each supplier used to produce the olive oil of type *u*, in each period. Constraints (2) refer to the cold storage capacity. The variables *Y* are defined by the set of constraints (3), which also guarantees that the total quantity of olives used to produce olive oil of type *u* on machine *m* in period *t* is lower than the machine capacity. Constraints (4) ensure that the upper bounds on the daily number of batches are respected. The set of constraints (5) guarantees that the total supply of olives does not exceed the given upper bounds, while the set of constraints (6) defines the binary variables *X* (supply set up variables). The oversupply variables *R* are defined by constraints (7). Also, the same set of constraints imposes that the daily supply of olives is lower than the given upper bound in the case of no oversupply. Finally, constraints (8) ensure that the lower bounds on the daily supply of olives *j* are respected (minimum volume that is profitable to handle, below this number it makes no sense to harvest).

### 3.3 Optimization method

Although the hours of optimization would still be acceptable for finding a problem solution in some situations, this would be impractical for industrial applications, especially for repetitive optimization which is needed when a change in circumstances occurs. Moreover, solution times and even the number of non-dominated solutions for this kind of problem are hard to predict. It is important to mention that we tried to solve the scalarized problem of the presented supply chain in the olive oil industry (with a weighted sum of both objectives as a single objective) using only CPLEX 12.1, but this did not reach an optimal solution in 30 minutes. Thus, we did not even try to obtain the exact Pareto frontier which could require finding many optimal solutions using CPLEX. Instead, we decided to apply approximate approaches in order to deal with the difficulties arising from the high dimensionality of the problem and from having more than one objective.

The method we propose is based on the usual scheme of Non-Dominated-Sorting-Genetic algorithm NSGA-II (Deb et al., 2002). The main idea of NSGA-II is to update the population by sorting the solutions according to the level of non-domination and their crowding distance.

The initial phase is used to initialize the solutions of the population. However, since the size of the population in the genetic algorithm is fixed, even the dominated solutions are accepted to form the population for the NSGA-II method. The Crowded Tournament Selection Operator (Deb, 2001) is used to form a mating pool. The crossover operator used for generating a new population of the offspring fixes the variables whose values agree in both feasible solutions that are subjected to the operator, while the values for the other variables are determined by optimizing the remaining problem using CPLEX within a given time. Thereby, CPLEX is here also used for solution improvement. The solutions are evaluated using the weighted-sum of the normalized objective values, where the weights are set randomly. The best feasible solution found is checked for efficiency and included in the source set if efficient. Also, if some previously efficient solutions became dominated, they are expelled from the source set. In performing the mutation, the variables which will be fixed are randomly chosen with a probability of 0.01, while the values for the other variables are determined by solving the remaining problem using CPLEX 12.1. The solutions are here again evaluated using the weighted-sum of the normalized objective values, where the weights are set randomly.

## 4. Computational results

The purpose of the computational experiments is to evaluate and compare the proposed NSGA-II method, illustrate the obtained results and obtain managerial insights. The data sets for the experiments are created following the structure of the real data. The information on the parameters for the creation of the problem instances was obtained in communication with the Croatian olive oil experts who also provided valuable guidance for the construction of the proposed model (Koprivnjak, 2006; Koprivnjak, Cervar, 2010).

The producers can have more than one machine for processing olives and their plant capacities vary from 50 kg/h to 3,500 kg/h. Also, since the harvest period lasts from the beginning of September to the end of November, there are 91 time periods (days). For the purpose of the experiments, we used the following:

- 1,000 suppliers,
- 500 olive oil types,
- 5 producers,
- 10 machines with capacities of 300, 600 and 1,000 kg/h and
- 30 days of the planning horizon.

Consequently, the number of the binary variables was 30,000, while the number of the integer variables was 150,000.

The data that varied in simulations were the quantities, the preferred periods of harvesting, olive mixtures and the combinations of machine capacities:

- The quantities of olives that the supplier wishes to offer on a given day ranged from 5 to 14 hundred kilograms, which was set randomly.
- The maximum length for the harvesting periods was set to six.
- The actual days of the preferred harvesting periods were not uniformly distributed. Instead, as it generally happens in reality, there were periods with a lot of suppliers offering olives as the raw material, and periods when the raw material was offered by only a few suppliers.
- The olive type mixtures were created in the way that all the oil types except one consisted of a maximum of five types/suppliers of olives. Thus, only one olive oil type was made by processing oil from many different olive suppliers. This corresponds to the oil that would be sold on the market on a large scale usually as a brand provided by a single olive oil producer.

After trying to optimize only the scalarized problem by commercial software (CPLEX), we concluded that the exact Pareto frontier could not be obtained within a reasonable time. The time limit for the NSGA-II constructing the approximate Pareto frontier was set to 30. The source set and the population size were both set to 20. This number was determined by initial experiments where we looked for a trade-off between the computation time and solution quality. The developed method was programmed in C# using Concert Technology as interface to CPLEX 12.1. The programs ran on Intel Core Duo CPU 2Ghz 1GB RAM. This way we succeeded in obtaining multiple compromise solutions (Pareto frontier) of the problem, while using CPLEX we were not able to obtain even a single feasible solution.

In order to investigate the possible benefits of the proposed coordinated production planning approach, we compare this method to the currently practiced way of planning, i.e. the sequential planning of supply and production. Namely, supply is now determined without consulting the producers, followed by the planning of the production of olive oil, i.e. olive processing.

When comparing the solution taken from the Pareto frontier with the same weight for both the suppliers' and the producers' objective functions to the solution obtained by the sequential planning of supply and production over the ten cases, we noticed that, on average, there was a decrease in the suppliers' costs of 37.76% (st. dev. 13.57). Furthermore, an average increase of 12.44% in the producers' profits was also obtained at the same time (st. dev. 7.85). The obtained cost reductions and increase in profits show us that it is justified to consider the integration of supply and production planning as we did in this work.

We believe that the most significant aspect of our work comes from the observations of the trade-offs between the objectives of olive suppliers on the one side and olive oil producers on the other. This way, the results obtained in the form of the Pareto frontier approximations can be used for studying the supply chain dynamics.

## 5. Conclusions and future work

We have considered a problem of agri-food supply chain management in the olive oil industry inspired by a case study from Croatia. Since Croatia cannot compete on the global market with large quantities of olive oil, its potential lies in high quality. Using the proposed procedure for integrated planning of supply and production helps reduce the quantities of olive oil whose lower quality is due to the supply decisions made without consulting the producers. Such optimization would be impossible without using operational research approaches and information technology. The model we propose also incorporates quality costs associated with the potential deterioration of olives which affects the quality of the oil. A Croatian agency based in the region considered in this paper (Istria) is trying to create an olive brand of high quality, so the results of this research could help in such attempts.

In addition to the optimization of the studied supply chain through the coordinated supply and production planning approach, the presented integrated model also allows for the evaluation of the performance trade-offs between the suppliers and the producers. To handle the complexity of considering the whole supply chain and the performance trade-offs, we have proposed a genetic algorithm based method.

The main contributions of this research are the novel mixed integer programming model in which we also modeled the decision on mixing the raw material, and the method that captures the dynamics of the supply chain in an industry of increasing importance. Namely, the supply chain models in the literature have emphasized single-performance measures, i.e. single objective optimization. We have developed a procedure that can provide insights into the relation between different performance measures of the supply chain. This allows the decision makers to be more flexible and have more freedom.

The method created in this work is of a general nature, so it can also be applied to other agri-food supply chains dealing with similar problems, for example, in harvesting the industrial hemp for hemp seed production or oranges for the production of orange juice. In the future we shall try to exploit some problem specifics to alter the components of the proposed method and improve its performance. Research limitations lie in the fact that the proposed model and algorithm are designed for smaller countries like Croatia where olive suppliers are usually small farmers, but not also for big olive producing countries like Spain or Greece.

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## Endnotes

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# Višekriterijska optimizacija za integrirano planiranje nabave i proizvodnje u maslinarsko-uljarskoj industriji

## Sažetak

Održiva poljoprivreda podrazumijeva, između ostalog, poticanje razgranatog i decentraliziranog sustava obiteljskih poljoprivrednih gospodarstava umjesto velike korporacije. Izazov je pronaći način organiziranja koalicija koje poboljšavaju sustav proizvodnje hrane. Studija slučaja koja je inspirirala ovaj rad potječe iz Istre, hrvatske regije s 25 proizvođača maslinova ulja i oko 5.000 uglavnom malih poljoprivrednika koji se bave uzgojem i berbom maslina. Kako bi se uzelo u obzir sve ciljeve sudionika tog lanca dobave poljoprivredno-prehrambenih proizvoda, ovaj rad ima za cilj postaviti model za njegovu integriranu optimizaciju, dati matematičku formulaciju i predložiti metodu za rješavanje problema.

**Ključne riječi:** kvarljiva roba, poljoprivredno-prehrambena industrija, maslinovo ulje, planiranje proizvodnje, višekriterijska optimizacija