A GRASP METAHEURISTIC FOR PLANNING FRESH PRODUCE HARVEST AND TRUCK ARRIVALS TO AGROINDUSTRIAL PROCESSING PLANTS

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RESUMO

Os produtos frescos deterioram-se facilmente depois de colhidos, portanto, reduzir os tempos de espera dos caminhões na área de recepção das plantas de processamento pode permitir a redução dos resíduos dos produtos frescos. Neste artigo, desenvolvemos uma metaheurística baseada em GRASP como um método de solução para um modelo matemático que visa manter um fluxo contínuo de produtos frescos às plantas de processamento, coordenando a colheita, transporte e agendamento de chegadas dos caminhões. A metaheurística desenvolvida é utilizada em um caso real de uma empresa de molho de tomate, obtendo a mesma solução ótima que o método exato, porém em um tempo computacional menor.

PALAVRAS CHAVE. Metaheurística GRASP. Agendamento de Chegada de Caminhões. Planejamento de Colheita.

AG&MA, PO na Indústria, L&T

ABSTRACT

Fresh produce easily deteriorates once harvested. Therefore, the reduction of trucks' waiting times in the receiving area of processing plants can allow reducing fresh produce waste. In this article, we develop a metaheuristic based on GRASP as a solution method for a mathematical model that aims to keep a continuous flow of fresh produce to processing plants, coordinating harvest, transport and truck arrivals scheduling. The developed metaheuristic is used in a real case of a tomato paste company, obtaining the same optimal solution than the exact method, but in a shorter computational time.

Keywords: GRASP Metaheuristic. Truck Arrivals Scheduling. Harvest Planning.

AG&MA, OR in the Industry, L&T

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1. Introduction

In this paper, an algorithm for solving the problem of trucks congestion at the receiving area of a fresh produce processing plants is presented. This problem causes high trucks' waiting times and deterioration of the transported raw material. Many researchers have addressed the supply chain planning and coordination of agrifood produce. Ahumada and Villalobos (2009), Díaz-Madroñero et al. (2015) and Soto-Silva et al. (2016) presented reviews of optimization models that support decisions in different stages of the supply chain, and for different kind of agricultural products.

Related to harvest planning coordination, in the literature is possible to find a considerable number of articles devoted to the sugarcane industry (Higgins, 2006, López-Milán, and Plà-Aragonés, 2015, Pathumnakul and Nakrachata-Amon, 2015, Lamsal et al., 2016, among others). However, these models are usually specific to each country and industry, because of differing levels and different infrastructures of vertical integration, as specified by Lamsal et al. (2016). In their work, Higgins (2006) and Lamsal et al. (2016) presented optimization models that aim to reduce trucks' waiting times.

Higgins (2006) presented a mixed integer programming model to schedule road transport vehicles to pick up full trailers of cane from the loading pads located on the farms. This model deals with the trucks congestion problem in the sugar mills of Australia. The model seeks to minimize the trucks' queue time and the sum of the mills' idle time. This model is NP-hard, because it involves the scheduling of several vehicles from the mill to pick up full trailers and return to the mill. For this reason, Variable Neighborhood Search (VNS) and Tabu Search algorithms were developed to solve it.

Lamsal et al. (2016) proposed a model to plan trucks movement between harvest and plants. This model is applicable when there are multiple and independent producers and it is not convenient to store fresh produce in the place of the harvest. The methodology used by these authors was divided in two stages. In the first stage, a model to determine the harvest start times was run. In the second stage, an algorithm for determining the number of trucks to transport raw materials was executed. Gerbier *et al*. (2017) proposed a mathematical model to optimize the arrival of trucks with raw material to a processing plant. The objective of the model is to take care of the raw material quality, to reduce truck-waiting times and to use the process plant capacity in a constant manner throughout the day.

In this article, we develop a metaheuristic based on GRASP for solving the MIP model proposed by Gerbier *et al*. (2017).

The paper is structured as follows. In Section 2, the description of transport and harvest problem is presented. In Section 3, the model presented by Gerbier *et al.* (2017) is formulated. In Section 4, the proposed algorithmic method based on GRASP is described. Section 5 presents the results for a case study obtained from a Chilean tomato paste company. Finally, the main conclusions are presented in Section 6.

2. Fresh Produce Harvest Planning and Transport in the Tomato Industry

The problem of fresh produce harvest planning and truck arrivals scheduling to processing plants is especially relevant in the tomato industry. The major world exporters are USA and China, with 35% and 13% of world production, respectively. These countries exert a strong prices pressure (ODEPA, 2016).

In the tomato paste industry, during 2012 Chile ranked tenth in volume of export of, with about 100 thousand tons exported. On the other hand, the main consumer markets of the Chilean tomato paste are located in Europe, Africa, Asia and Middle East. Because of this, the Chilean companies are constantly seeking to increase their productivity and reduce their production costs. Since tomato paste plants work 24 hours, the coordination among harvesting, transportation and production stages is necessary, allowing a continuous flow of fresh tomato to the plants, reducing trucks' waiting times and

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avoiding fresh tomato deterioration. A good coordination provokes that fresh produce conversion into tomato paste increases and so, the production and transportation costs diminish.

During the tomato harvest season, the harvesting machines are outsourced and assigned to the farms according to a harvest plan established by the company. The truck flee that transports fresh produce from the farms to the processing plants is also outsourced.

The selection of tomato farms to be harvested every day is carried out according to the information obtained from the farms about tomato ripening and the daily demand of each plant. The trucks allocation to the farms depend on each transport contractor, which is assigned to one or more harvesting machines. The contractor is responsible for determining which truck will transport fresh tomato to a plant, based on the number of daily truckload per harvesting machine estimated by the company. There does not exist a decision support system for carrying out this activity.

Each company determines the working hours of tomato harvesting machines, but it is very common that the companies have fixed shifts during the day. Most of the harvesting machines are used during the morning and the afternoon, involving high trucks demand during these periods.

Once a truck arrives to the receiving area of a plant, a download code is assigned to it. Subsequently, the truck is weighed and recorded at the gathering place, where trucks must wait their shift to the next stage. Once the plant requires its fresh raw material, the truck goes to the quality control process, where the percentage of damage is determined based on a sample of 20 kilograms. Finally, the truck is directed to a defined placement area where it proceeds to unload the tomato.

The plants operate 24 hours every day, therefore, they require a continuous flow of raw material and, consequently, a continuous flow of trucks. However, because of work shifts are mainly concentrated during the morning and the afternoon, the truck arrivals to the receiving area of the plants are concentrated from the afternoon. This situation causes trucks congestion, so each truck waits in the receiving area on average four hours. This problem involves an increase of transportation costs due to the number of hours spent by trucks in the receiving area and implies a tomato deterioration during waiting time, because of juice and flesh loss.

3. Mathematical Model for Harvest Planning and Truck Arrivals Scheduling

In this section, we present the mathematical model proposed by Gerbier et al. (2017) and adapted from Lamsal et al. (2016), which aims to keep a continuous flow of fresh produce to processing plants and, at the same time, to decrease trucks' waiting times in the receiving area.

For formulating the model, the following sets are used:

C_i: set of loads at farm i, $i \in I$, $j \in C_i$.

I: set of farms to be harvested.

The parameters considered in the model are the following:

n: number of blocks of time in which the day is divided.

a_k: start time of the block k, for k= 0, 1, …, n. Furthermore $a_0 < a_1 < a_2 \ldots < a_n$, where a_n represents the end time of the delivery window.

h_i: time required to harvest a load at farm i, $i \in I$.

N_k: unloading capacity in the plant for each block k=0, 1, …, n-1.

t_i: travel time between farm i and the plant, $i \in I$.

α: penalization associated with the deviation of the plant's unloading capacity.

lmt: maximum number of farms that can be harvested in shift 3.

The decision variables of the model are:

x_{ij}: arrival time at the plant of *i*th farm's *j*th load, i ∈ I, j ∈ C_i.

y_i: time when the harvesting starts at farm *i*, i ∈ I.

λ_{ij}^k: ∈ R+ and expresses the instant in which the *j*th load of the *i*th farm lies between the time a_k and a_{k+1}, i ∈ I, j ∈ Ci and k= 0, 1, …, n.

b_{ij}^k: ∈ {0,1}, where b_{ij}^k = 1 if the *i*th farm's *j*th load arrives between a_k and a_{k+1}, b_{ij}^k = 0 otherwise.

CS_k: surplus capacity or positive deviation from the plant's unloading capacity, k= 0, 1, …, n-1.

CF_k: slack capacity or negative deviation from the plant's unloading capacity, k= 0, 1, …, n-1.

MX_i: ∈ {0,1}, where MX_i = 1 if the shift 3 is available to be assigned in the farm i, MX_i = 0 otherwise.

The formulation of the model for harvest planning and truck arrivals scheduling to processing plants is the following:

$$\text{Min } Z = \sum_{k=0}^{n-1} (\alpha * CF_k + (1-\alpha) * CS_k) \quad (1)$$

s.t.

$$x_{ij} = y_i + j * h_i + t_i \quad \forall i \in I, j \in C_i \quad (2)$$

$$x_{ij} = \sum_{k=0}^{n} (\lambda_{ij}^k * a_k) \quad \forall i \in I, j \in C_i \quad (3)$$

$$\sum_{k=0}^{n} \lambda_{ij}^k = 1 \quad \forall i \in I, \quad j \in C_i \quad (4)$$

$$\lambda_{ij}^0 \leq b_{ij}^0 \quad \forall i \in I, \quad j \in C_i \quad (5)$$

$$\lambda_{ij}^k \leq b_{ij}^{k-1} + b_{ij}^k \quad \forall i \in I, j \in C_i, \; k \in 1, \dots, n \quad (6)$$

$$b_{ij}^n = 0 \quad \forall i \in I, j \in C_i \quad (7)$$

$$\sum_{k=0}^{n} b_{ij}^k = 1 \quad \forall i \in I, j \in C_i \quad (8)$$

$$\sum_{i \in I} \sum_{j \in C_i} b_{ij}^k + CS_k - CF_k = N_k \quad \forall k \in 0, \dots, n-1 \quad (9)$$

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$$b_{ij}^{k} \in \{0,1\} \quad \forall i \in I, j \in C_i, k \in 0, \dots, n \qquad (10)$$

$$\lambda_{ij}^{k} \in [0,1] \quad \forall i \in I, j \in C_i, k \in 0, \dots, n \qquad (11)$$

$$CF_k, CS_k \geq 0 \quad \forall k \in 0, \dots, n-1 \qquad (12)$$

$$y_i \geq 0 \quad \forall i \in I \qquad (13)$$

$$x_{ij} \geq 0 \quad \forall i \in I, j \in C_i \qquad (14)$$

The objective function minimizes the positive and negative deviations from the plant unloading capacity. Depending on the case can be penalized just one of the deviation or more heavily in one direction than the deviation on the other side. For example, to achieve a high utilization of the plant should be penalized the slack capacity (CF_k) and to minimize the downtime of the trucks should be penalized specially the surplus capacity (CS_k).

Constraint (2) states that the arrival time at the plant of *i*th farm's *j*th load depends on the harvest start time in the farm *i*, the harvest rate at that farm and the travel time between the farm and the plant. Constraint (3) – (8) determine the arrival time through a convex combination of the beginning and the end time of each block into which the arrival falls.

Constraint (9) determines the slack or surplus capacity in each block by comparing the quantity of inputs with the unloading capacity.

Finally, the constraints (10) – (14) stablish the nature of the decision variables.

4. Proposed Metaheuristic Based on GRASP

The model presented in Section 3 requires high computational time when solved by an exact method when segmenting the day into blocks whose difference is less than 2 hrs. For this reason, an algorithm based on the Greedy Randomized Adaptive Search Procedure (GRASP) metaheuristics is developed, which corresponds to a multi-start metaheuristic (Dolado and Arana, 2004). This metaheuristic has the following advantages: it only requires a single initial solution, it has a single parameter to be calibrated (α), being multi-start, it is possible to obtain very different solutions, since the algorithm does not always start from the same solution (Resende and Ribeiro, 2014). This metaheuristic has two phases: a constructive phase, where an initial solution is built, and a local search phase, where the solution is improved (Resende and Ribeiro, 2014).

Figure 1 shows the pseudo-code of the GRASP metaheuristic, whose entries correspond to the parameters of the model proposed by Garbier *et al.* (2017), which is shown in Section 3. The outputs of the metaheuristic correspond to the decision variables solution obtained by the model. The process is initiated by establishing a pre-processing step of the algorithm. This is achieved by choosing a property randomly and assigning a start time of the harvest (variable y_i), then the arrival time of each load of that property is inferred according to the constraints of the mathematical model.

The constructive phase of the method is carried out by building a list of possible candidates to be added to the partial solution. These candidates are "valued" by a sensitivity function, and the list adds those elements whose "value" belongs to the range $[S_{min}, S_{min} + \alpha (S_{max} - S_{min})]$, where S_{min} corresponds to the minimum value among the candidates, S_{max} at the maximum value and α is an initial parameter that establishes the randomness of the selection criterion. This process is carried out each time that an element is added to the partial solution until a final solution is achieved. Therefore, the construction phase is completed. The pseudo-code is presented in Figure 1.

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From the final solution obtained in the previous step, we proceed to execute the improvement phase through a local search. In practice, there is a movement (or exchange) of the start time of harvesting of the land, taking care that it satisfies all the model constraints. In this way, a slight variation can be observed in the loads that arrive at a certain time to the processing plant and likewise a change in the objective function.

These two phases (constructive and local search phases) are carried out in each iteration of the algorithm, saving the obtained solution and comparing it with the obtained solution of the following iteration, storing the best one obtained during the computational process. At the end of the process, the best of all the examined solutions is the result of the GRASP metaheuristic.

```
While (there are not assigned farms) Do
    GenerateCandidatesList(lFarmsList)
    chooseRamdomlyCandidate(CandidatesList)
    AddCandidatetoSolution(ChosenCandidate,FinalFarmsList)
EndWHILE
LocalSearch(FinalFarmsList)
```

Figure 1: Pseudocode of GRASP Metaheuristic

5. Results for a Case Study

The developed GRASP metaheuristic is applied to a Chilean case study. The data were obtained from a tomato paste company, which has two production plants and processes annually approximately 550,000 tons of fresh tomato. The raw material is purchased from different farmers and collected using 40 tomato-harvesting machines. These harvesting machines are mostly outsourced and are assigned to the farms according to the percentage of ripen tomato (over 90% of ripen tomato). Most of the companies do this assignment based on their experience and they not have any tool to support these decisions.

The company works with three work shifts that start at 07:00, 13:00 and 17:00 hours, respectively, and operates 24 hours per day. A more detailed description of the company can be found in Gerbier *et al.* (2017).

When applying the GRASP metaheuristic considering a segmentation of 12 blocks per day (slots of 2 hours), the results of the proposed trucks arrival to the plant are presented in Table 1. This table shows the trucks' arrival (load) to the processing plant (in hours).

	Farm																			
Load	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	9:29	15:52	10:06	20:09	9:47	21:05	19:48	9:17	9:20	10:02	15:43	15:48	20:42	21:04	20:35	20:01	10:19	22:01	9:53	21:53
2	10:44	17:32	12:06	21:24	11:13	22:31	22:18	10:32	10:46	11:28	17:23	17:28	22:22	23:04	22:15	21:41	12:19	0:01	11:08	23:53
3	11:59	19:12	14:06	22:39	12:38	23:56	0:48	11:47	12:12	12:54	19:03	19:08	0:02	1:04	23:55	23:21	14:19	2:01	12:23	1:53
4	13:14	20:52	16:06	23:54	14:04	1:22	3:18	13:02	13:38	14:20	20:43	20:48	1:42	3:04	high1:35	1:01	16:19	4:01	13:38	3:53
5	14:29	22:32	18:06	1:09	15:30	2:48		14:17	15:03	15:45	22:23	22:28	3:22	5:04	3:15	2:41	18:19	6:01	14:53	5:53
6	15:44	0:12		2:24	16:55	4:14		15:32	16:29	17:11	0:03	0:08	5:02		4:55	4:21			16:08	
7	16:59			3:39	18:21	5:39		16:47	17:55	18:37									17:23	
8	18:14			4:54				18:02											18:38	

Table 1: Arrivals of the loads to the plant (in hrs)

In Table 2, the amount of shortage an excess loads for the agroindustrial plant is presented.

Blocks	1	2	3	4	5	6	7	8	9	10	11	12	***Total Loads***
Shortage (loads)	0	0	1	1	3	2	0	2	1	0	0	0	10
Excess (loads)	11	0	0	0	0	0	0	0	0	0	0	6	17
Arrivals (loads)	0	11	11	11	15	13	11	14	12	11	11	5	125

Table 2: Shortage and excess loads per block

The objective of the model presented by Gerbier *et al*. (2017) is to maintain the nominal capacity of the process plant in a constant manner during a working day, therefore, it is sought to maintain the minimum amount of shortage or excess loads during the day.

Table 3 presents the computational information of the case study, compared with the results delivered by the MIP proposed by Gerbier *et al.* (2017) and the results proposed in this research using GRASP.

Method Solution	Number of blocks	Time (s)	F.O.(number of loads)
MIP (Gerbier *et al*. 2017)	12	283.6	27
GRASP	12	5.8	27

Table 3: Computational comparison

When applying GRASP on the case study, it is found that the execution time decreases from 283 s to 5.8 s. Regarding the objective function, GRASP finds the same optimal solution as the MIP model proposed by Gerbier *et al.* (2017).

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6. Conclusions

The GRASP metaheuristic for assigning harvest machines and determining truck arrivals obtains results in a less computational time than the exact method. In the executed instance (case study), the quality of the solution is the same. In a future research, the GRASP metaheuristic will be run using more complex instances in order to evaluate the quality of the developed metaheuristic.

For implementing this metaheuristic, a following stage is to develop decision support system, so users could interact easily with the model entering data and parameters, and getting suitable harvest plan reports.

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