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# Multi-Objective Model to Improve the Quality and Freshness of Sold Vegetables through Retailer Funding

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**Abstract.** This paper proposes a novel multi-objective model to support the distribution of retailers' funds among farms by considering the vegetables' perishability and the dependence of prices on the vegetables' freshness, being a novelty of the proposal. The multi-objective model simultaneously optimizes five objectives: maximization of SC profits, minimization of generated waste, minimization of the economic unfairness among farmers, minimization of the unfairness in the distribution of funds, and the maximization of the freshness of vegetables at their sale moment. This last objective as well as the joint optimization of the five objectives are novelties of this proposal. The multi-objective model is solved by using the  $\varepsilon$ -constraint method being the non-linear objectives linearized. Results show that interesting trade-offs can be found among objectives, with solutions that decrease the unfairness perception and increase the freshness of sold vegetables at the expense of a small reduction in profits.

**Keywords:** Agri-Food, Perishability, Quality, Unfairness, Collaboration, Optimization.

## 1 Introduction

Vegetables consumers are increasingly looking for fresher and higher quality products. However, some farmers do not have the resources or knowledge to improve the quality and freshness of their products. This problem is widespread among small farmers with plantation areas of less than two hectares that are responsible for the 80% of the world's agricultural production [1]. As a solution, some authors propose to create a collaboration program between retailers and farmers to improve the quality of agri-food products through funds given by retailers to farms.

Most of them consider that retailers directly select the farmers on which invest by maximizing the SC profits to be obtained [2–5]. However, these approaches do not consider the role of farm cooperatives in the distribution of funds. This detail was considered in [6] who proposed four models to distribute the funds among farmers, two of them being multi-objective models considering the maximization of SC profits and the

minimization of the economic unfairness among farms, and the maximization of SC profits and the minimization of the unfairness in the distribution on funds, respectively. For this, they used the weighted sum method, through which weights are assigned to the considered objectives according to their relative importance.

In this paper, a multi-objective model to support the distribution of funds among farms is proposed in which, the perishability of vegetables and the price dependence on the vegetables' freshness are also considered, being novelties of this paper. Other novelty lies in the joint optimization of the SC profits, the economic unfairness among farms, the unfairness in the distribution of funds, the generated waste and the freshness of vegetables sold. This last two objectives have neither been previously modelled in the analysed papers. To solve the multi-objective model, the  $\varepsilon$ -constraint method is used to obtain several non-dominated solutions.

The rest of the paper is structured as follows. Section 2 briefly describes the problem under study. Section 3 formulates the multi-objective model to distribute retailers' funds among farms considering the freshness of sold products and proposes its resolution methodology. Section 4 analyses the obtained non-dominated solutions. Finally, Section 5 outline conclusions and future research lines.

## 2 Problem Description

The SC under study is composed by small farmers, cooperatives, retailers, and markets. Small farms cultivate and harvest vegetables and classify them according to their quality. Once classified, vegetables can be stored at farms until their shelf-life is consumed. Farmers transport vegetables to the cooperatives to which they belong, who decide to which retailers transport first quality vegetables. Retailers transport first quality vegetables to markets, who sell vegetables to end consumers. Simultaneously, cooperatives can directly send second quality vegetables to markets, where are sold at a lower price.

In this context, retailers can fund farmers to increase the proportion of first quality vegetables to be obtained from harvest. Each retailer has a limited budget for this type of investments and classifies farmers into levels according to their skills. Farmers pass from one to the following skill level with each fund perceived. Each farmer can perceive a maximum number of funds.

In addition, the commercialized vegetables are perishable, what means that their shelf-life decreases as time passed between their harvest and sale. Vegetables should have a minimum remaining shelf-life at the time of their sale to ensure a minimum freshness. In case this freshness cannot be assured, vegetables are wasted.

## 3 Multi-Objective Model Formulation

The nomenclature used to formulate the model to solve the above problem is defined in Table 1, where  $v$  refers to vegetables,  $q$  to quality of vegetables,  $f$  to farmers,  $c$  to cooperatives,  $r$  to retailers,  $m$  to markets,  $t$  to the periods of time,  $h$  to harvest periods,  $x$  to the freshness of vegetables, and  $FC_{fc}$  refers to the set of farmers  $f$  belonging to a cooperative  $c$ .

**Table 1.** Nomenclature.

Parameters			
$a_f$	Area of farm $f$ .	$sl^v$	Shelf-life of vegetable $v$ after harvest.
$s_f^{vh}$	Quantity of vegetable $v$ harvested in farm $f$ at harvest period $h$ .	$msl^v$	Minimum shelf-life that vegetable $v$ needs to have to be sold.
$g_f^{vh}$	Proportion of first quality vegetable $v$ harvested by farm $f$ at period $h$ .	$sp_c^{vqt}$	Unitary income for selling vegetable $v$ with quality $q$ to cooperative $c$ at $t$ .
$cp_f^v$	Unitary cost for producing vegetable $v$ at farm $f$ .	$ci_f^{vt}$	Unitary cost for storing vegetable $v$ at farm $f$ at period $t$ .
$ctc_{fc}^{vt}$	Unitary cost for transporting $v$ from farm $f$ to cooperative $c$ at period $t$ .	$ctm_{rm}^{vt}$	Unitary cost for transporting $v$ from retailer $r$ to market $m$ at period $t$ .
$ctr_{cr}^{vt}$	Unitary cost for transporting $v$ from cooperative $c$ to retailer $r$ at period $t$ .	$ctd_{cm}^{vt}$	Unitary cost for transporting $v$ from cooperative $c$ to market $m$ at period $t$ .
$p_m^{vqxt}$	Unitary price for vegetable $v$ with quality $q$ and freshness $x$ at market $m$ at period $t$ .	$up_m^{vqt}$	Unitary penalty cost for not meeting demand of vegetable $v$ with quality $q$ at market $m$ at period $t$ .
$de_m^{vqt}$	Demand of vegetable $v$ with quality $q$ at market $m$ at period $t$ .	$\beta$	Improvement of the first quality vegetable proportion per skill level.
$l_f$	Initial skill level of farm $f$ .	$N$	Number of skill levels.
$cf$	Cost of increasing one skill level.	$b_r$	Budget of retailer $r$ for funding.
Decision variables			
$QH_f^{vqh}$	Quantity of vegetable $v$ with quality $q$ harvested at farm $f$ at period $h$ .	$Inv_f^{vqh}$	Inventory of vegetable $v$ with quality $q$ harvested at farm $f$ at period $h$ stored at period $t$ .
$QR_{cr}^{vqht}$	Quantity of vegetable $v$ with quality $q$ harvested at period $h$ transported from cooperative $c$ to retailer $r$ at period $t$ .	$QC_{fc}^{vqht}$	Quantity of vegetable $v$ with quality $q$ harvested at farm $f$ at period $h$ transported to cooperative $c$ at period $t$ .
$QM_{rm}^{vqht}$	Quantity of vegetable $v$ with quality $q$ harvested at period $h$ transported from retailer $r$ to market $m$ at period $t$ .	$QD_{cm}^{vqht}$	Quantity of vegetable $v$ with quality $q$ harvested at period $h$ transported from cooperative $c$ to market $m$ at period $t$ .
$W_f^{vqht}$	Quantity of vegetable $v$ with quality $q$ harvested at farm $f$ at period $h$ wasted at period $t$ .	$QS_m^{vqht}$	Quantity of vegetable $v$ with quality $q$ harvested at period $h$ sold at market $m$ at period $t$ .
$UD_m^{vqt}$	Unmet demand of vegetable $v$ with quality $q$ at market $m$ at period $t$ .	$FI_{fr}$	Number of funds given by retailer $r$ to farm $f$ .
$CL_f$	Current skill level of farm $f$ .	$MF_f$	Margin obtained by farmer $f$ .

### 3.1 Objective Function

The proposed multi-objective model considers five objectives:

**Maximization of SC profits ( $Z_p$ ):** The SC profits are comprised by sales, costs related to the production, storage and transport of vegetables, the investments made by retailers, and penalty costs related to unmet demand (1).

$$\begin{aligned}
Max Z_P = & \sum_v \sum_q \sum_n \left( \sum_m \sum_{t \geq h} \sum_{x=t-h} p_m^{vqxt} \cdot QS_m^{vqht} - \sum_f cp_f^v \cdot QH_f^{vqh} \right. \\
& - \sum_f \sum_{t \geq h} ci_f^{vt} \cdot Inv_f^{vqht} - \sum_f \sum_{c \in FC_{fc}} \sum_{t \geq h} ct_{fc}^{vt} \cdot QC_{fc}^{vqht} \\
& - \sum_c \sum_r \sum_{t \geq h} ctr_{cr}^{vt} \cdot QR_{cr}^{vqht} - \sum_c \sum_m \sum_{t \geq h} ct_{cm}^{vt} \cdot QD_{cm}^{vqht} \\
& \left. - \sum_r \sum_m \sum_{t \geq h} ct_{rm}^{vt} \cdot QM_{rm}^{vqht} \right) - \sum_m \sum_v \sum_q \sum_{t \geq h} up_m^{vqt} \cdot UD_m^{vqt} \\
& - \sum_f \sum_r FI_{fr} \cdot cf
\end{aligned} \tag{1}$$

**Minimization of waste ( $Z_W$ ):** Waste is produced when vegetables perish (2).

$$Min Z_W = \sum_f \sum_v \sum_q \sum_n \sum_{t \geq h} W_f^{vqht} \tag{2}$$

**Minimization of economic unfairness among farmers ( $Z_{EU}$ ):** Absolute difference between the margin per hectare obtained by each farm and the mean margin per hectare for all farms (3). The margin is composed by sales to cooperatives, and costs related to the production, storage, and distribution of vegetables (4).

$$Min Z_{EU} = \sum_f \left| \frac{MF_f}{a_f} - \frac{\sum_f MF_f}{\sum_f a_f} \right| \tag{3}$$

$$MF_f = \sum_f \sum_v \sum_q \sum_n \left( \sum_c \sum_t (sp_c^{vqt} - ct_{fc}^{vt}) \cdot QC_{fc}^{vqht} - cp_f^v \cdot QH_f^{vqh} - \sum_t ci_f^{vt} \cdot Inv_f^{vqht} \right) \tag{4}$$

**Minimization of the unfairness in the distribution of funds ( $Z_{FU}$ ):** Absolute difference between the number of funds received by each farm and the average number of funds received by all farms (5).

$$Min Z_{FU} = \sum_f \left| \sum_r FI_{fr} - \frac{\sum_f \sum_r FI_{fr}}{\sum_r b_r / cf} \right| \tag{5}$$

**Maximization of freshness of sold vegetables ( $Z_{FR}$ ):** To accurately represent the average freshness, the denominator should be equal to the quantity of sold vegetables instead of the demand of vegetables (6). A strict calculation of the average freshness would imply solving a non-linear model, which would complicate its resolution [7].

$$Max Z_{FR} = \frac{\sum_m \sum_v \sum_q \sum_h \sum_t (sl^v + h - t) \cdot QS_m^{vqht}}{\sum_m \sum_v \sum_q \sum_t dem_m^{vqt}} \tag{6}$$

### 3.2 Constraints

The model is subjected to the following constraints. Vegetables ready for harvest in a harvest period needs to be harvested and classified according to their quality (7).

$$s_f^{vh} = \sum_q QH_f^{vqh} \quad \forall f, v, h \tag{7}$$

The quantity of first quality vegetables ( $q=1$ ) is calculated by multiplying the amount of vegetables ready for harvest by the initial proportion of first quality vegetables produced at the farm plus the improvement of such proportion through received funds (8). The rest of harvested vegetables are second quality vegetables (9).

$$QH_f^{vqh} = s_f^{vh} \cdot (g_f^{vh} + \beta \cdot CL_f) \quad \forall f, v, q = 1, h \tag{8}$$

$$QH_f^{vqh} = s_f^{vh} \cdot (1 - g_f^{vh} - \beta \cdot CL_f) \quad \forall f, v, q = 2, h \tag{9}$$

Once harvested, products can be stored, wasted, or transported to cooperatives (10). Vegetables shelf-life should be taken into account when storing vegetables (11), so when the vegetables shelf-life is consumed, vegetables would be wasted.

$$Inv_f^{vqht} = QH_f^{vqh} - \sum_c QC_{fc}^{vqht} - W_f^{vqht} \quad \forall f, v, q, h, t = h \quad (10)$$

$$Inv_f^{vqht} = Inv_f^{vqht-1} - \sum_c QC_{fc}^{vqht} - W_f^{vqht} \quad \forall f, v, q, h, h < t \leq h + sl^v - msl^v \quad (11)$$

$$Inv_f^{vqht} = 0 \quad \forall f, v, q, h, t \geq h + sl^v - msl^v \quad (12)$$

First quality vegetables received by cooperatives are sent to retailers (13) while second quality vegetables are directly sent from cooperatives to markets (14). Vegetables received by retailers are sent to markets (15). The transport of second quality vegetables from cooperatives to retailers and from retailers to markets is not allowed (16). Similarly, first quality vegetables cannot be transported from cooperatives to markets (17).

$$\sum_f QC_{fc}^{vqht} = \sum_r QR_{cr}^{vqht} \quad \forall c, v, q = 1, h, h \leq t \leq h + sl^v - msl^v \quad (13)$$

$$\sum_f QC_{fc}^{vqht} = \sum_m QD_{cm}^{vqht} \quad \forall c, v, q = 2, h, h \leq t \leq h + sl^v - msl^v \quad (14)$$

$$\sum_c QR_{cr}^{vqht} = \sum_m QM_{rm}^{vqht} \quad \forall r, v, q, h, h \leq t \leq h + sl^v - msl^v \quad (15)$$

$$\sum_r \sum_v \sum_h \sum_{t \geq h} \left( \sum_c QR_{cr}^{vqht} + \sum_m QM_{rm}^{vqht} \right) = 0 \quad \forall q = 2 \quad (16)$$

$$\sum_c \sum_m \sum_v \sum_h \sum_{t \geq h} QD_{cm}^{vqht} = 0 \quad \forall q = 1 \quad (17)$$

Vegetables that arrive to markets are finally sold (18). In case there is not enough supply to meet demand, unmet demand would be generated (19).

$$\sum_r QM_{rm}^{vqht} + \sum_c QD_{cm}^{vqht} = QS_m^{vqht} \quad \forall m, v, q, h, h \leq t \leq h + sl^v - msl^v \quad (18)$$

$$\sum_{h \leq t} QS_m^{vqht} + UD_m^{vqt} = de_m^{vqt} \quad \forall m, v, q, t \quad (19)$$

The proportion of first quality vegetables obtained at each farm is lower or equal to the unit (20). The skill level of farmers is equal to their initial skill level and the levels improved with retailer funds and cannot exceed the maximum level defined in the CP (21). Finally, investments made by retailers cannot exceed their CP budget (23).

$$g_f^{vh} + \beta \cdot CL_f \leq 1 \quad \forall f, v, h \quad (20)$$

$$CL_f = l_f + \sum_r FI_{fr} \leq N \quad \forall f \quad (21)$$

$$\sum_f FI_{fr} \cdot cf \leq b_r \quad \forall r \quad (22)$$

Finally, constraint (24) shows the nature of decision variables.

$$\begin{array}{l} QH_f^{vqh}, Inv_f^{vqht}, W_f^{vqht}, QC_{fc}^{vqht}, QR_{cr}^{vqht}, QD_{cm}^{vqht}, QM_{rm}^{vqht}, QS_m^{vqht}, UD_m^{vqt} \\ FI_{fr}, CL_f \end{array} \quad \begin{array}{l} CONTINUOUS \\ INTEGER \end{array} \quad (23)$$

### 3.3 Resolution methodology

To solve the proposed model, it is necessary to first linearize the non-linear. To linearize these expressions, variables  $EU_f$  y  $FU_f$  are created to represent the absolute differences related to objectives  $Z_{EU}$  and  $Z_{FU}$ , respectively (24-25).

$$\text{Min } Z_{EU} = \sum_f EU_f \quad (24)$$

$$\text{Min } Z_{FU} = \sum_f FU_f \quad (25)$$

Variable  $EU_f$  is calculated as the absolute difference between the margin per hectare per farm and the average margin per hectare of the whole farming region. Constraints (26)-(27) are formulated to linearly ensure the variable  $EU_f$  to acquire absolute values.

This same process is made to variable  $FU_f$  representing the absolute difference between funds received by each farmer and the average funds received by farms (28)-(29).

$$EU_f \geq \frac{MF_f}{a_f} - \frac{\sum_f MF_f}{\sum_f a_f} \quad \forall f \quad (26)$$

$$EU_f \geq \frac{\sum_f MF_f}{\sum_f a_f} - \frac{MF_f}{a_f} \quad \forall f \quad (27)$$

$$FU_f \geq \sum_r FI_{fr} - \frac{\sum_f \sum_r FI_{fr}}{\sum_r b_r/cf} \quad \forall f \quad (28)$$

$$FU_f \geq \frac{\sum_f \sum_r FI_{fr}}{\sum_r b_r/cf} - \sum_r FI_{fr} \quad \forall f \quad (29)$$

Once objectives are linearized, the  $\varepsilon$ -constraint method is applied to solve the model. This method transforms the multi-objective model into a single-objective model by selecting one objective as the objective function and transforming the rest of objectives into constraints [8]. The new model is formulated as follows:

$$\text{Max } Z_p$$

subject to:

$$\sum_f \sum_v \sum_q \sum_h \sum_t W_f^{vqht} \leq \varepsilon_w \quad (30)$$

$$\sum_f EU_f \leq \varepsilon_{EU} \quad (31)$$

$$\sum_f FU_f \leq \varepsilon_{FU} \quad (32)$$

$$\frac{\sum_m \sum_v \sum_q \sum_h \sum_t (sl^v + h - t) \cdot QS_m^{vqht}}{\sum_m \sum_v \sum_q \sum_t dem_m^{vqt}} \geq \varepsilon_{FR} \quad (33)$$

and Eqs. (4), (7)-(23), (26)-(29)

## 4 Experimental Design

The model was implemented in the optimization software MPL® 5.0.8 and solved with the solver Gurobi™ 8.1.1. Microsoft Access Databases were used to import data. Data used was extracted from [6] where a four months horizon in a daily basis was considered. In addition, it is assumed that vegetables have a limited shelf-life equal to 14 days and vegetables' prices decrease as the freshness of vegetables do so.

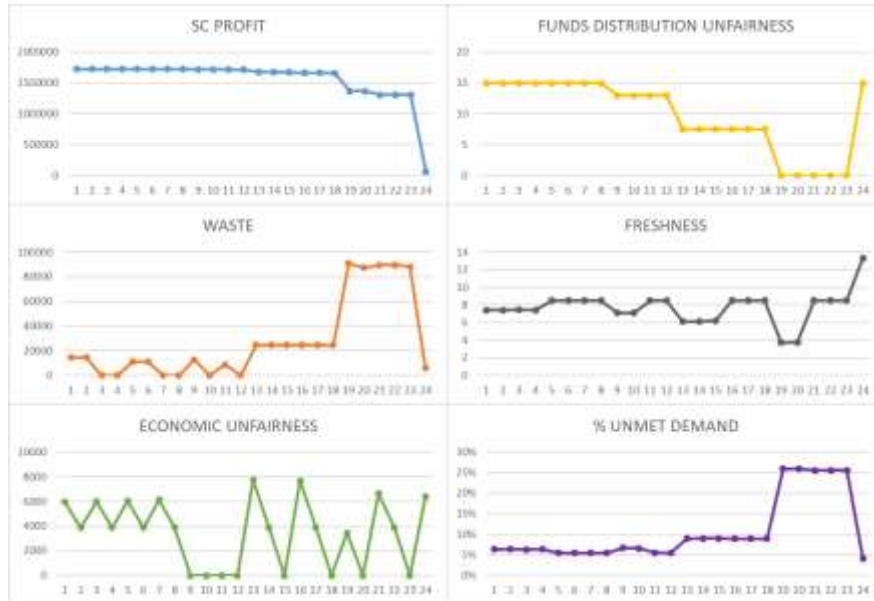
First, it is verified that considered objectives are not aligned. If two or more objectives were aligned, an improvement of one of them would necessarily imply the improvement of the other, not being necessary to apply a multi-objective approach. To do this, a partial correlation analysis is performed on a set of non-dominated solutions obtained through lexicographic optimization. Lexicographic optimization consists of sequentially optimizing the objectives by fixing the value acquired by previously optimized objectives [8]. For example, in a case with two objectives ( $f_1$  and  $f_2$ ), the objective  $f_1$  would be optimized and later the objective  $f_2$  would be optimized by setting the value of  $f_1$  to its optimal value. By performing this process with all the possible sequences in this paper, a total of 120 solutions are obtained, which are refined to 40 non-dominated solutions after eliminating duplicates. The partial correlation analysis (Table 2) is performed on these solutions which are not shown due to lack of space.

**Table 2.** Partial correlation analysis.

	$Z_P$	$Z_W$	$Z_{EU}$	$Z_{FU}$	$Z_{FR}$
$Z_P$	1				
$Z_W$	-0.066	1			
$Z_{EU}$	-0.364	-0.113	1		
$Z_{FU}$	-0.019	-0.958	0.203	1	
$Z_{FR}$	-0.660	-0.596	0.358	0.634	1

For two objectives to be aligned, values greater than 0.9 should be obtained for objectives optimized in the same sense (maximization-maximization or minimization-minimization), or less than -0.9 for objectives optimized in the opposite sense (maximization-minimization). After this analysis it is shown that objectives are not aligned, and, in case of objectives  $Z_W$  and  $Z_{FU}$  (both minimized) are in conflict, so that when one of them improves the other necessarily worsens. Once it is verified that objectives are not aligned, it is possible to continue with the multi-objective proposal.

For this, the  $\epsilon$ -constraint method previously exposed is applied.  $\epsilon$ -values are obtained by calculating equal intervals between the objectives' minimum and maximum values obtained by the lexicographic optimization. Figure 1 shows the results for 24 non-dominated solutions in terms of SC profits, waste, economic unfairness, unfairness in the funds distribution, vegetables freshness when sold, and unmet demand. The mean resolution time to obtain these solutions was of 80 seconds.

**Fig. 1.** Non-dominated solutions for the multi-objective model.

Results show that similar SC profits are obtained for most of the non-dominated solutions. Therefore, the SC members could choose which solution to implement based on the aspects they consider more relevant (waste, unfairness, freshness, unmet demand) without making a big difference in SC profits. On the other hand, it is observed



that minimizing the unfairness in the distribution of funds to zero has a negative impact on the SC profits, generated waste, and the percentage of unmet demand. Therefore, these solutions seem undesirable for SC interested in reducing waste and ensuring a high service level. Finally, solution 24 offers the best freshness of vegetables at their sales time but makes the rest of objectives considerably worse. Thus, it is concluded that this solution may also be inappropriate for the SC.

## 5 Conclusions

A multi-objective model to support the distribution of retailers' funds among farms to improve the quality and freshness of sold vegetables is proposed. After checking that objectives are not aligned, the  $\epsilon$ -constraint method is applied to solve the model, and 24 non-dominated solutions are obtained. Results show that good results can be obtained for the waste generated, the unfairness perceptions and the freshness of vegetables while slightly reducing the SC profits.

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