Lexicographic Weighted Tchebycheff Approach for Multi-objective Workforce Planning Optimization in Rice Seed Harvesting

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Abstract—A multi-objective optimization model for workforce planning in rice seed harvesting is proposed in this research. The problem is based on a case study of a group of rice field owners in Ubonratchathani province, Thailand, who are entrusted with planting registered rice seeds of the photoperiod-sensitive rice type. Since mechanical harvesters might harm rice seeds, hand harvesting is required to achieve certified production requirements as well as harvesting period should not take longer than 14 days of the last peak period. As a result, all rice field owners had to hire a lot of harvesting workers on a short notice. The working circumstances of the harvest are different in three types of rice fields. Therefore, the workers' levels of satisfaction vary according to the challenges they encounter. The purpose of this paper is to distribute the benefits to the workers and the owners of the rice fields. The model's two proposed objectives are to maximize workers' overall job satisfaction while also decreasing the entire costs to rice field owners. To get the Pareto-optimal solution for choosing the most compromised solution, the model is solved using Lexicographic Weighted Tchebycheff.

Index Terms—lexicographic weighted Tchebycheff, multi-objective optimization, rice seed harvesting, workforce planning.

Introduction

Thailand has always been known as the kitchen of the world for many years as it is one of the top countries of food producers particularly rice. Recently, Thai rice export has tended to trend upward [1] due to the popularity of Thai rice,foreign importers have been importing Thai rice into their countries, especially in the Middle East countries.Thus, the cultivation of rice especially for the export purpose must be carefullypracticed as the exported rice requires a very high quality.The main factor that directly affects the quality of rice is rice seeds. The remaining purity of rice seeds must be particularly concerned to maintain the genuine characteristics of rice. A governmental unit of Thailand, so-called the Rice Department (RD), is a unit that is responsible for managing the production of rice seeds. RD consists of two centers namely the Rice Research Center (RRC) and the Rice Seed Center (RSC). Rice seeds can be categorized into three generations or stages. The first-, second-, and third-generation rice seeds are called foundation rice seed, registered rice seed, and certified rice seed, respectively [2]. The type of rice seed studied in this paper on harvest workforce planning is scoped at the registered rice seeds.

The critical stage of the production gained from planting the registered rice seeds that affects the quality of the production is the harvesting step after growing the registered rice seeds in the rice fields. Since crop harvested by hand has

The type of rice in this study is a photoperiod-sensitive type of which the overdue harvesting time significantly downgrades its quality. For the photoperiod-sensitive rice type, once the rice stalks reach the heading stage, the seed quality peaks four to five weeks after heading, and the harvesting of seeds must be performed during the last two weeks of this peak period, otherwise the seed quality will be declined [4]. Hence, all rice field owners need to harvest the photoperiod-sensitive rice seeds within the last 14 days of the peak period.

By the reason of harvestingrice seeds by hand in a certainnumber of rice fields within a tight period, the harvest workforce must be planned properly so that the harvest in all rice fields can be finished in time. There are two main groups of the workforce in this case study which are local and non-local workforcewho will be hired by rice field owners. The local workforce means the workforce that live in the same area (the same village in this case) of therice fields whereasthe non-local workforce live in the different areas of the rice fields. Non-local workforce can be separated into two subgroups which are differentiated by distance. The workers in the first subgroup live further away than another subgroup. Normally, rice field owners hire the local workforce prior to the non-local ones. However, the number of local workers is sometimes insufficient, rice field owners have to hire non-local workforce until they have enough workers. This causes high harvesting costs for the rice fieldownersbecause theworkers' traveling cost is afforded by rice field owners as well as the research of Ferrer et al. [5]stated thatone effect of hiring and firing the workers for wine grape harvesting planning is thehigh total costs.

Additionally, theland of rice seed fields in this case study is not even and can be differentiated into three rice stalk natures causing different harvesting difficulty levels. Three natures of rice stalks ranked from the easiest to the most difficult level are upright, lodged, and inundated rice stalks. Three different rice stalk natures require different working postures which causes different injury risk levels to the workers. Thus, the workers are satisfied to different degrees depending on the difficulty they face both physically and mentally. Kassem et al. [6] conducted research regarding the factors of farmers' satisfaction with the quality of agriculture, that the farm size is the first rank of satisfaction.

In the early 19th century, the agricultural crop harvesting planning problem was solved by a mathematical programming approach. The optimal solution was applied to improve the efficiency of harvesting planning as many researchers have proposed the single objective optimization model for crop harvesting decisions. For example, He et al. [7] proposed a model to minimize a wheat harvesting period of combine harvesters scheduling for fragmental farmland; Ferrer et al. [5] solved the wine grapes harvesting scheduling problem to minimize cost; González-Araya et al. [8] solve the apple harvesting problem to find the minimal cost; Herrera-Cáceres et al. [9] presented an olive harvest schedule to maximize the total amount of the oil extracted in the factory. Apart from the single objective optimization model, some researchers have developed the harvesting planning problem intoa multi-objective optimization model as Florentino et al. [10] considered three objectives of the sugarcane harvesting problem to reducesoil compaction and travel cost of harvesting machinery; Jain et al. [11] applied a hybrid optimization algorithm for crop pattern optimization in agriculture; and Waranyoo et. al. [12] formulated rice seed collaborative harvest workforce planning problem as a 4-objective optimization model.

The rice seed harvesting addressed in this paper is aimed at sharing the benefit of rice field owners and hand workers. Hence, a multi-objective optimization model for the workforce planning problem of rice seed harvesting is developed in this research. Two proposed objectives of the model are minimizing the total costs paid to all harvesting workers by allrice field owners and maximizing total job satisfaction scored by all workers while remaining in the quality of rice seeds as it is a manual and an in-the-peak-period harvest.The lexicographic weighted Tchebycheff (LWT), a method for solving multi-objective optimization problem (MOP) developed by Steuer is applied in this research. Steuer [13] proposed that the LWT method can obtain efficient solutions (Pareto solutions). Besides, decision makers can add their preference information during the calculation stage to focus on the part of interest [14].Waranyoo et. al.[12] solved multi-objective rice seed workforce planning by using the weightedTchebycheff (WT) method also proposed bySteuerand Choo [15] and which is less effective as it cannot obtain a Pareto solution, unlike the LWT method. Recent researchers applied the LWT method such as Khalilpourazari and Khalilpourazary [16] as they solved four objective functions by LWT obtaining a Pareto solution for the surface grinding process and Samanlioglu [17] used LWT to solve a model of the industrial hazardous waste location-routing problem.

The main contributions of this paper are to build a collaboration of farmers who own the rice fields and promote a sustainable community in the registered rice seeds production as the benefits of the employers (rice field owners) in terms of cost and of the employees (workers) in terms of job satisfaction are considered simultaneously.

I. Optimization Model and LWT Formulation

The workforce planning problem for rice seeds harvesting is solved in this paper as the decisions are which worker is assigned to work on which rice field and on which day in the 14-day time horizon. The workforce has different harvesting abilities based on their physical health and age. The RSC assigned each rice field owner to fulfill the rice production in different quantities based on their rice field size.

Each rice field owner has to estimate the minimum daily quantity of product that gains from the harvest and prepare enough meals and drinks for all workers which are not considered as costs. However, if the product is lower than the estimation, the rice field owner will consider the meals and drinks for all workers as costs which are categorized as 'loss cost' in this paper.

When all rice field owners hire local and, sometimes, non-local workforce to harvest rice seeds in their rice fields but they have no collaborative harvesting plan as they individually seek their workforce, thus, the harvest is always inefficient and not optimized such as a delay from the peak period of harvesting, the high cost that rice field owners must pay, and the workers are not satisfied as they have no choice to choose their preferred jobs. The benefit-sharing-oriented concept is brought out to plan the rice seeds harvesting by the workforce more sustainable. This section presents a multi-objective optimization model and an LWT formulation of the problem. The assumptions of the model are as follows:

1) Harvesting rice seeds in each rice field is independent.
2) A farmer owns only one rice field. Hence, rice field owner and rice field are interchangeable in some contexts.
3) The weather conditions have no effect on the performance of workers and the rice seeds production.
4) The worker cannot switch to harvest in the other rice fields during a period.
5) The workers can work continuously without fatigue until their daily assigned jobs are finished. In other words, the rest period of working in a day is not considered.
6) A hand rice seed harvesting in one rice field in one day means a job of a worker.
7) One rice field has only one type of rice stalk nature.

A. Indices

i index of rice field owners in set $\boldsymbol{I} = \{1, 2, \dots, I\}$

notably, each rice field is owned by only one rice filed owner, i.e., rice filed owner i owns ricefield$i$

j index of workforce locations in set $\boldsymbol{J} = \{1, 2, \dots, J\}$

k_j index of workers in set $\boldsymbol{K}_j = \{1, 2, \dots, K_j\}$. All $\boldsymbol{K}_j$where $j \in \boldsymbol{J}$are exclusive, and $\bigcup_{j=1}^{J} \boldsymbol{K}_j = \boldsymbol{K}$ where $\boldsymbol{K}$ is the set of all workers from all locations

t index of time periods in time horizon set $\boldsymbol{T} = \{1, 2, \dots, T\}$ (1 time period = 1 day)

o index of objective functions where $o = 1, 2, \dots, m$

B. Parameters

Cap_{ijk_j} quantity of rice seeds that worker $k_j$from workforce location j can harvest from the rice field$i$(tons/day)

CH_j wage of a worker from workforce location$j$ (THB (Thai Baht)/ton)

CP loss cost if the quantity of rice seeds harvested from any rice field is less than the expected minimum daily quantity of that rice field (THB/ton)

D_i quantity of rice seeds demanded by the RSC from rice field$i$(tons)

Q_i maximum quantity of rice seeds that can be harvested from the rice field i throughout the planning horizon (tons)

λ_o weight of objective function o

s_{ijk_j} job satisfaction level scored by worker k_j from workforce location j if assigned to work in rice field$i$

V_i expectedminimum daily quantity of rice seeds to be harvested from rice field$i$(tons/day)

C. Decision Variables

$$X_{ijk_j}^t = \begin{cases} 1, \text{ if rice field } i \text{ is harvested by worker } k_j \text{ from workforce location } j \text{ in day } t \\ 0, \text{otherwise} \end{cases}$$

C total costs of rice filed owners (THB)

S total job satisfaction scores of workers

D. Multi-objective Optimization Model

$$Min\ C = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k_j=1}^{K_j}\sum_{t=1}^{T} CH_j Cap_{ijk_j} X_{ijk_j}^t + CP\left(\sum_{i=1}^{I}\sum_{t=1}^{T} max\left(V_i - (\sum_{j=1}^{J}\sum_{k_j=1}^{K_j} Cap_{ijk_j} X_{ijk_j}^t),0\right)\right) \quad (1)$$

$$Max\ S = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k_j=1}^{K_j}\sum_{t=1}^{T} s_{ijk_j} X_{ijk_j}^t \quad (2)$$

Subject to

$$\sum_{j=1}^{J}\sum_{k_j=1}^{K_j}\sum_{t=1}^{T} Cap_{ijk_j} X_{ijk_j}^t \geq D_i, \forall\ i \quad (3)$$

$$\sum_{j=1}^{J}\sum_{k_j=1}^{K_j}\sum_{t=1}^{T} Cap_{ijk_j} X_{ijk_j}^t \leq Q_i, \forall\ i \quad (4)$$

$$\sum_{i=1}^{I} X_{ijk_j}^t \leq 1, \forall\ j, k_j, t \quad (5)$$

$$X_{ijk_j}^t \in \{0,1\}, \forall\ i, j, k_j, t \quad (6)$$

Equation (1) is the first objective function which is minimizing the total costsof the rice field owners. The total cost consists of total wage and total loss cost. The wage of a worker also includes travelingcost of a worker from their location to the rice field they work for. The total wage is the wage of local and non-local workforce working in all rice fields throughout the planning horizon.Another expense that each rice field owner has to pay for workers is meals and drinks, which is actually an allowance that the rice field owner can afford but is not considered as a cost. This expense is converted to be a minimum rice seeds quantity that should be gained, but only if the harvested quantity is lower than this minimum quantity, it is considered as a loss cost.

Equation (2) is the second objective function which is maximizing the total job satisfaction of all workers. Different workers may perceive the same rice stalk conditions with different degrees of satisfaction. Thus, good matches between the workers and rice stalk conditions can result in a high satisfaction score.This objective accumulates all job satisfaction scores from all workers working over different rice stalk conditions in all rice fields throughout the planning horizon.

To ensure that the total quantity of rice seeds gained from each rice field satisfies the total demand agreed with the RSC, and is not beyond the maximum quantity of rice seeds that can be harvested from each rice field, these canbe expressed in (3) and (4). Equation (5) restricts a worker to work in only one rice field on any given day. Equation (6) means that all decision variables are binary numbers.

The second objective function can be transformed into a minimization problem by rewriting *Max S = Min -S*. This minimization problem is used later to reformulate this model so that it can be usedby the lexicographic weighted Tchebycheff method.

E. LWT Formulation

The LWT method is implemented to obtain efficient solutions to the problem.

Definition 1:A decision vector $x^* \in S$ is a weakly efficient optimal solution (weakly Pareto optimal) for a MOP model if $x \in S$ cannot be determined, where $f_i(x) < f_i(x^*)$for all *i* indices.

Definition 2: A decision vector $x^* \in S$ is an efficient optimal solution for a MOP model if $x \in S$ cannot be determined, where $f_i(x) \leq f_i(x^*)$ in which $f_i(x) < f_i(x^*)$ for at least one i index.

Definition 3: For a Pareto-optimal solution, if positive $\lambda_1, \lambda_2, \ldots, \lambda_n$ weights can be found, where the solution is optimal considering the linear combination model. The formulation of the LWT method for a bi-objective mathematical model is presented in (7) - (10):

$$lex\,min\{\alpha, (C - C^*), (S^* - S)\} \quad (7)$$

$$Subject\ to$$

$$\alpha \geq \lambda_1(C - C^*) \quad (8)$$

$$\alpha \geq \lambda_2(S^* - S) \quad (9)$$

$$Contraints\ (1) - (6) \quad (10)$$

Where $\lambda_o > 0$ are the weight $\sum_o \lambda_o = 1$

C^* is a minimized C individually solved using the model in which its objective is (1) and constraints are (3)-(6), and S^* is a maximized S individually solvedusing the model in which its objective is (2) and constraints are (3)-(6).

The original multi-objective functions are not normalized. In order to scale (normalize) the objective functions, (11) must be applied as follow:

$$Normalized\ \frac{1}{Z_o - Z_o^*} \quad (11)$$

Where Z_o is Upper bound of Pareto frontier and $Z_o^* = f_o^*(x)$

II. NUMERICAL EXAMPLE

The sample problem consists of 20 rice fields. The rice stalk in the field can be categorized into three different types differentiating harvest difficulty levels. Harvest difficulty level of upright rice stalkfield is the lowest one among the three types. The second difficulty level is harvesting in lodged rice stalkfield. An inundated rice stalk field is the field type that most difficult harvest level.There are 3 workforce locations with 90 workerstotal, and 14 harvesting periods (days). Demand and maximum production of rice and rice stalk nature in each rice field are shown in Table I.

The quantities of rice that a worker can harvest per period [18] are shown in Table II. It is not equal for all workers depending on their capability. Presumably, the probability distribution of rice quantity harvested by each worker is a uniform distribution. The data is obtained by random number in the range distributed uniformly.

The wages of local, non-local group 1, and non-local group 2 are 1,200; 1,300 and 1,500 THB/ton. The loss cost is 500 THB per one lower ton than the expected quantity. The minimum quantity of rice expected from a worker is 0.125 tons/day.

Table I. Demand and maximum quantityfor rice seeds

Rice Field No.	Demand (tons)	Maximum Quantity (tons)	Rice Stalk Nature
1	8	8.80	Upright
2	12	13.20	Upright
3	9	9.90	Inundated
4	8	8.80	Lodged
5	10	11.00	Upright
6	9	9.90	Inundated
7	8	8.80	Upright
8	7	7.70	Lodged
9	8	8.80	Lodged
10	11	12.10	Upright

11	9	9.90	Inundated
12	12	13.20	Upright
13	10	11.00	Upright
14	8	8.80	Inundated
15	6	6.60	Upright
16	8	8.80	Upright
17	10	11.00	Lodged
18	7	7.70	Standing
19	8	8.80	Upright
20	10	11.00	Inundated

Table II.Rice quantities that a worker can harvest per period.

Rice Stalk Nature	Rice Quantity (tons/period)
Upright rice stalk	Uniform(0.16-0.22)
Lodged rice stalk	Uniform(0.13-0.19)
Inundated rice stalk	Uniform(0.09-0.15)

The rating scale for job satisfaction of workersin each rice field is scored between 1 (not prefer) to 5 (much prefer) which are shown in Table III.

Table III. The rating scale of job satisfaction of worker

Rating scale	Meaning
1	Not prefer
2	Less prefer
3	Normal
4	Prefer
5	Much prefer

III. Results and Discussion

The models are solved by What'sBest! (Version 16.0.2.5) on a PC with an Intel Core i7-6700 CPU @ 3.40 GHz and 8.00 GB RAM, to find the optimal solution.

Each of the twoobjective functions is optimized separately and their solutions are obtained in Table IV. Table V. shows the efficient solutions when solving LWT formulation and it is obvious that solution number 8 is the most compromised solution among 27 solutions which can be graphically shown in Fig.1.In Fig.1, solution number 8 is displayed in a diamond shape, whereas the circle-shape points stand for the other solutions. Table VI. and VII. summarizes the whole workforce planning as it shows the number of total workers tasked in each rice field in each period. The three numbers in parenthesis mean the numbers of worker typed local, non-local group 1, and non-local group 2, respectively.

Table IV. Individual solutions obtained for each objective function

	Minimizing *C*	Maximizing *S*
*C**	236,449.80	3,743
*S**	259,652.00	5,527

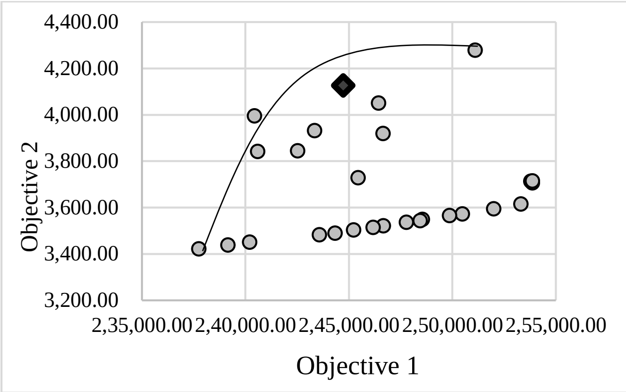

Fig. 1 The Pareto frontier

Table V. The Representative efficient solutions from the Pareto frontier

Solution No.	λ_1	λ_2	Solution	Objective Value of the First Objective (THB)	Objective Value of the Second Objective (Score)
1	0.90	0.10	0.00132	237,740.00	3,422
2	0.80	0.20	0.00107	239,154.00	3,439
3	0.70	0.30	0.00087	240,205.00	3,451
4	0.60	0.40	0.00059	244,320.00	3,490
5	0.50	0.50	0.00042	247,765.00	3,536
6	0.40	0.60	0.00042	253,857.00	3,715
7	0.30	0.70	0.00064	246,422.00	4,050
8	0.20	0.80	0.00019	244,717.00	4,128
9	0.10	0.90	0.00105	251,087.00	4,278
10	0.11	0.89	0.00052	243,342.00	3,932
11	0.12	0.88	0.00051	240,586.00	3,842
12	0.13	0.87	0.00051	242,517.00	3,845
13	0.14	0.86	0.00060	253,854.00	3,707
14	0.15	0.85	0.00056	253,299.00	3,615
15	0.16	0.84	0.00049	240,437.00	3,996
16	0.17	0.83	0.00048	246,648.00	3,920
17	0.18	0.82	0.00058	253,791.00	3,714
18	0.19	0.81	0.00047	245,434.00	3,729
19	0.21	0.79	0.00051	250,483.00	3,573
20	0.22	0.78	0.00050	249,853.00	3,566
21	0.23	0.77	0.00050	251,983.00	3,595
22	0.24	0.76	0.00048	248,539.00	3,549
23	0.25	0.75	0.00047	248,431.00	3,544
24	0.26	0.74	0.00046	246,653.00	3,521
25	0.27	0.73	0.00045	246,159.00	3,515
26	0.28	0.72	0.00044	245,217.00	3,503
27	0.29	0.71	0.00043	243,560.00	3,483

Table VI. Workforce planning of rice seeds harvesting from Pareto frontier (day 1 -7)

Rice Field No.	Planning Horizon						
	1	2	3	4	5	6	7
1	1 (0-0-1)	3 (3-0-0)	2 (1-0-2)	3 (0-2-1)	5 (2-1-2)	3 (0-2-1)	5 (1-3-1)
2	7 (5-0-2)	7 (4-3-0)	4 (4-0-0)	6 (5-1-0)	6 (1-3-2)	2 (1-0-1)	3 (2-0-1)
3	4 (4-0-0)	5 (2-3-0)	7 (6-1-0)	4 (3-1-0)	6 (3-2-1)	3 (3-0-0)	5 (4-1-0)
4	2 (1-1-0)	4 (1-1-2)	2 (1-1-0)	5 (2-2-1)	4 (3-1-0)	4 (3-1-0)	6 (4-2-0)
5	5 (3-1-1)	5 (3-1-1)	4 (1-2-1)	3 (2-0-1)	5 (3-2-0)	4 (4-0-0)	1 (1-0-0)
6	8 (6-2-0)	5 (5-0-0)	5 (2-3-0)	4 (3-1-0)	6 (4-1-1)	3 (3-0-0)	5 (3-2-0)
7	3 (2-0-1)	4 (2-2-0)	3 (1-1-1)	4 (1-2-1)	4 (2-2-0)	3 (2-0-1)	1 (1-0-0)
8	3 (0-2-1)	5 (4-1-0)	4 (2-2-0)	5 (3-2-0)	2 (0-2-0)	4 (3-0-1)	3 (2-1-0)
9	8 (2-4-2)	4 (2-2-0)	3 (1-0-2)	2 (1-1-0)	6 (4-0-2)	5 (2-3-0)	3 (0-1-2)

Table VI. Workforce planning of rice seeds harvesting from Pareto frontier (day 1 -7)(cont'd)

Rice Field No.	Planning Horizon						
	1	2	3	4	5	6	7
10	5 (2-1-2)	3 (2-1-0)	5 (2-2-1)	6 (2-2-2)	6 (5-0-1)	4 (4-0-0)	6 (4-2-0)
11	5 (2-1-2)	5 (2-1-2)	5 (3-0-2)	8 (6-2-0)	6 (1-2-0)	5 (2-2-1)	7 (5-1-1)
12	3 (2-1-0)	5 (2-2-1)	4 (2-1-1)	6 (3-2-1)	4 (1-3-0)	5 (3-2-0)	3 (2-1-0)
13	5 (2-2-1)	6 (3-1-2)	5 (3-1-1)	1 (1-0-1)	4 (2-1-1)	4 (2-0-2)	3 (2-0-1)
14	3 (3-0-0)	5 (1-4-0)	3 (1-1-1)	2 (1-0-1)	4 (2-2-0)	7 (3-3-1)	5 (2-1-2)
15	2 (1-1-0)	4 (3-1-0)	6 (2-3-1)	3 (2-1-0)	3 (2-1-0)	5 (3-1-1)	3 (1-1-1)
16	3 (2-1-0)	2 (1-0-0)	5 (3-2-0)	3 (1-0-2)	3 (2-0-1)	5 (2-1-2)	2 (1-1-0)
17	3 (1-1-1)	4 (2-0-2)	5 (2-1-2)	4 (3-0-1)	6 (4-0-2)	3 (1-1-1)	5 (2-1-2)
18	3 (3-0-0)	2 (2-0-0)	1 (1-0-0)	4 (3-1-0)	1 (1-0-0)	3 (2-0-1)	2 (2-0-0)
19	5 (2-3-0)	2 (2-0-0)	4 (2-1-1)	1 (1-0-0)	2 (1-1-0)	4 (2-2-0)	4 (1-3-0)
20	6	9	6	9	5	5	9

Rice Field No.	Planning Horizon						
	1	2	3	4	5	6	7
	(5-1-0)	(6-1-2)	(4-2-0)	(5-3-1)	(4-0-1)	(3-1-1)	(5-2-2)
Total Number of Workers	**84** (47-23-14)	**86** (48-24-14)	**82** (44-24-14)	**84** (48-23-13)	**85** (47-24-14)	**81** (46-21-14)	**81** (45-23-13)

Table VII. Workforce planning of rice seeds harvesting from Pareto frontier (day 8-14)

Rice Field No.	Planning Horizon						
	8	9	10	11	12	13	14
1	1 (0-0-1)	3 (3-0-0)	2 (1-0-2)	3 (0-2-1)	5 (2-1-2)	3 (0-2-1)	5 (1-3-1)
2	7 (5-0-2)	7 (4-3-0)	4 (4-0-0)	6 (5-1-0)	6 (1-3-2)	2 (1-0-1)	3 (2-0-1)
3	4 (4-0-0)	5 (2-3-0)	7 (6-1-0)	4 (3-1-0)	6 (3-2-1)	3 (3-0-0)	5 (4-1-0)
4	2 (1-1-0)	4 (1-1-2)	2 (1-1-0)	5 (2-2-1)	4 (3-1-0)	4 (3-1-0)	6 (4-2-0)
5	5 (3-1-1)	5 (3-1-1)	4 (1-2-1)	3 (2-0-1)	5 (3-2-0)	4 (4-0-0)	1 (1-0-0)
6	8 (6-2-0)	5 (5-0-0)	5 (2-3-0)	4 (3-1-0)	6 (4-1-1)	3 (3-0-0)	5 (3-2-0)
7	3 (2-0-1)	4 (2-2-0)	3 (1-1-1)	4 (1-2-1)	4 (2-2-0)	3 (2-0-1)	1 (1-0-0)
8	3 (0-2-1)	5 (4-1-0)	4 (2-2-0)	5 (3-2-0)	2 (0-2-0)	4 (3-0-1)	3 (2-1-0)
9	8 (2-4-2)	4 (2-2-0)	3 (1-0-2)	2 (1-1-0)	6 (4-0-2)	5 (2-3-0)	3 (0-1-2)
10	5 (2-1-2)	3 (2-1-0)	5 (2-2-1)	6 (2-2-2)	6 (5-0-1)	4 (4-0-0)	6 (4-2-0)
11	5 (2-1-2)	5 (2-1-2)	5 (3-0-2)	8 (6-2-0)	6 (1-2-0)	5 (2-2-1)	7 (5-1-1)
12	3 (2-1-0)	5 (2-2-1)	4 (2-1-1)	6 (3-2-1)	4 (1-3-0)	5 (3-2-0)	3 (2-1-0)
13	5 (2-2-1)	6 (3-1-2)	5 (3-1-1)	1 (1-0-1)	4 (2-1-1)	4 (2-0-2)	3 (2-0-1)
14	3 (3-0-0)	5 (1-4-0)	3 (1-1-1)	2 (1-0-1)	4 (2-2-0)	7 (3-3-1)	5 (2-1-2)
15	2 (1-1-0)	4 (3-1-0)	6 (2-3-1)	3 (2-1-0)	3 (2-1-0)	5 (3-1-1)	3 (1-1-1)
16	3 (2-1-0)	2 (1-0-0)	5 (3-2-0)	3 (1-0-2)	3 (2-0-1)	5 (2-1-2)	2 (1-1-0)
17	3 (1-1-1)	4 (2-0-2)	5 (2-1-2)	4 (3-0-1)	6 (4-0-2)	3 (1-1-1)	5 (2-1-2)
18	3 (3-0-0)	2 (2-0-0)	1 (1-0-0)	4 (3-1-0)	1 (1-0-0)	3 (2-0-1)	2 (2-0-0)
19	5	2	4	1	2	4	4

Rice Field No.	Planning Horizon						
	8	9	10	11	12	13	14
	(2-3-0)	(2-0-0)	(2-1-1)	(1-0-0)	(1-1-0)	(2-2-0)	(1-3-0)

Table VII. Workforce planning of rice seeds harvesting from Pareto frontier (day 8-14) (cont'd)

Rice Field No.	Planning Horizon						
	8	9	10	11	12	13	14
20	6 (5-1-0)	9 (6-1-2)	6 (4-2-0)	9 (5-3-1)	5 (4-0-1)	5 (3-1-1)	9 (5-2-2)
Total Number of Workers	**84** (47-23-14)	**86** (48-24-14)	**82** (44-24-14)	**84** (48-23-13)	**85** (47-24-14)	**81** (46-21-14)	**81** (45-23-13)

Conclusion

This paper presents a multi-objective optimization model for workforce planning by the LWT method of rice seeds harvesting. The problem is modeled as a binary program with two objective functions – minimizing the total costs of rice field owners and maximizing the total job satisfaction of workers. Since the registered rice seed which is a second generation of rice seed is studied, thus its purity must be particularly concerned to maintain the genuine characteristics of rice.The rice seed in this paper is a photoperiod-sensitive type and its quality depends on the method of harvest and the harvesting period. The harvest is allowed only by hand as well as the most proper period must not be later than 14 days. Workforces can be differentiated by their location and capability. They are allowed to tell their prefer jobs by giving a score of satisfaction to each rice field which has three types – upright, lodged, and inundated rice stalks.

The result of the mathematical model showed the Pareto-optimal solution to provide the schedules of workforce planning which helps the decision maker to select the best values for the decision variables. This workforce planning is beneficial to rice field owners to decrease their costs as low as possible and the harvest can be completed within 14 days to meet the good quality of rice seeds production. In addition, the workers are more satisfied with their jobs. It can conclude that this planning can promote the sustainability of the rice farmer community.

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References

[1] Thai Rice Exporters Association, World rice trade; Bangkok: Thai Rice Exporters Association, 2022.

[2] National Bureau of Agricultural Commodity and Food Standards, Thai agricultural standard good agricultural practices for rice seed (TAS 4406-2014); Bangkok: Ministry of Agriculture and Cooperatives, 2015.

[3] N. Benkeblia, P. F. Tennant, S. K. Jawandha, and P. S. Gill, "Preharvest and harvest factors influencing the postharvest quality of tropical and subtropical fruits," in Postharvest biology and technology of tropical and subtropical fruits, E.M. Yahia, Ed. Woodhead Publishing, 2011, pp. 112-142e.

[4] T. Itani, M. Tamaki, Y. Hayata, T. Fushimi, and K. Hashizume, "Variation of 2-Acetyl-1-Pyrroline concentration in aromatic rice grains collected in the same region in japan and factors affecting its concentration," Plant Prod. Sci., vol.7, No.2, pp. 178-183, Dec. 2004.

[5] J. C. Ferrer, A. M. Cawley, S. Maturana, S. Toloza, and J. Vera, "An optimization approach for scheduling wine

grape harvest operations," Int. J. Prod. Econ., Vol.112, pp. 985-999. Apr. 2008.

[6] H. S. Kassem, B.A. Alotaibi, M. Muddassir, and A. Herab, "Factors influencing farmers' satisfaction with the quality of agricultural extension services," Eval Program Plann, Vol. 85, 101912, Apr. 2021.

[7] P. He, J. Li, and X. Wang, "Wheat harvest schedule model for agricultural machinery cooperatives considering fragmental farmlands," Comput. Electron. Agric., Vol.145, pp. 226–234, Feb. 2018.

[8] M. C. González-Araya, W. E. Soto-Silva, and L. G. A. Espejo, "Harvest planning in apple orchards using an optimization model," in L. M. Plà-Aragonés, Ed, Handbook of Operations Research in Agriculture and the Agri-Food Industry. Int. Ser. Oper. Res. Manag. Sci, Vol. 224, 2015, pp. 79-106.

[9] C. Herrera-Cáceres, F. Pérez-Galarce, E. Álvarez-Miranda, and A. Candia-Véjar, "Optimization of the harvest planning in the olive oil production: a case study in Chile," Comput. Electron. Agric., Vol.141, pp. 147-159. Sep. 2017.

[10] H. de O. Florentino, C. Irawan, A. F. Aliano, D. F. Jones, D. R. Cantane, and J. J. Nervis, "A multiple objective methodology for sugarcane harvest management with varying maturation periods," Ann. Oper. Res., Vol. 267, pp. 153-177, Aug. 2018.

[11] S. Jain, D. Ramesh, and D. Bhattacharya, "A multi-objective algorithm for crop pattern optimization in agriculture," Appl. Soft Comput. J.,Vol. 112, 107772. Nov. 2021.

[12] W. Thippo, C. Jaturanonda, S. Yaovasuwanchai, and C. Khompatraporn, "Multi-objective collaborative harvest workforce planning for rice seed production considering workload balance and worker satisfaction", Int J Ind Eng, vol. 29, no. 2, Apr. 2022.

[13] R.E. Steuer, "Multiple Criteria Optimization: Theory, Computation, and Application; New York: John Wiley & Sons, 1986.

[14] M. Varas, F. Basso, S. Maturana, D. Osorio, and R. Pezoa, "A multi-objective approach for supporting wine grape harvest operations," Comput Ind Eng., Vol.145, 106497, Jul. 2020.

[15] R. E. Steuer, and E. U. Choo, "An interactive weighted tchebycheff procedure for multiple objective programming," Math. Program, Vol.26, pp.326–344, Oct. 1983.

[16] S. Khalilpourazari, and S. Khalilpourazary, "A lexicographic weighted Tchebycheff approach for multi-constrained multi-objective optimization of the surface grinding process," Eng. Optim. Vol. 49, pp. 878-895. Aug. 2016.

[17] F. Samanlioglu, "A multi-objective mathematical model for the industrial hazardous waste location-routing problem," Eur. J. Oper. Res, Vol. 226, pp. 332-340. April 2013.

[18] W. Chinsuwan, S. Choun-Udom, V. Udompetaikul, W. Phayom, and N. Panya, "Capacity and costs for harvesting hommali rice by hand and use of combine harvester," KKU Res J., Vol.5, No.1, pp.33-41, Jan. 2000. (in Thai)