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Sustainable Production Planning Model of Crude Palm Oil Industry Under Uncertainty

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Abstract- **Despite obvious benefits of crude palm oil industry for economic development, it contributes to environmental degredation. This paper addresses a multi-objective stochastic programming model of the sustainable production planning of crude palm oil. The model takes into account conflicting goals such as return and financial risk and environmental costs. The uncertainty comes from the reliability of financial risk. Starting from it two single objective models are formulated: a maximum expected return model and a minimum financial risk (pollution penalties) model. We transform the stochastic programming model into a deterministic multi-objective model using covariance approach.**

Keywords - rude-Palm oil, Environmental Production Planning, Stochastic Programming, Modeling, Financial risk.

1. INTRODUCTION

The oil palm has its origin in the tropical rain forest of West Africa, where it has been used as a source of oil and vitamins. It has been consumed for more than 5,000 years. Today the oil palm tree can be found in many tropical countries in Asia, Africa and Latin America. The important areas of oil palm cultivation in South East Asia is in the countries Malaysia, Indonesia, and Thailand, which produce about 80% of the world's palm oil [6]. Oil palm seeds of the Dura variety were introduced to Indonesia and Malaysia in 1848 and 1875 respectively.

Refined palm oil is used in both food and non-food applications. To most users, palm oil is familiar as refined golden yellow oil. In the refining process, palm oil can be divided in fractions at room temperature; liquid and higher- melting point substance. Various grades of oleins and stearins are available commercially. Palm oil is used in various food products, such as cooking oil, margarine, frying fats, shortenings, non-dairy creamer, etc. Palm oil is also used in non-food products. It can be substitute products derived from petrochemicals. Due to an increasing environmental awareness, these products have a bright future.

The crude palm oil industry plays an important role for economic development Despite obvious benefits of this industrial development, it contributes to environmental degradation from both input and output sides of its activities. On the input side, crude palm oil mill uses much water in production process and consumes high energy. On the output side , manufacturing process generates large quantity of wastewater, solid waste/ by-product and air pollution.

In production planning problems mathematical models can be broadly classified into two classes: deterministic models and stochastic models. Deterministic models assumes that the data are known and typically model the uncertainty using ”best guesses” of uncertain values. Although various human judgment based and quantitative models have been developed to forecast these variables with uncertainty such as demand, these deterministic models typically end up solving ”mean-value” or ”worst-case” problems The solution to such ”worst-cast” or ”mean-value” problems are often inadequate – large error bounds arise when one solves ”mean value” problems and ”worst-case” formulations that can produce very conservative and expensive solutions [3]. Without considering uncertainty, the deterministic production planning models, though widely studied in the literature, are less acceptable and deployed in practice.

Currently consumers, companies and governments have increased their attention towards the environment. Increased exposure in the media on environmental issues in conjunction with the escalating increase in the environmental resources depletion, human toxicity levels and ecosystem quality deterioration have made our entire society more aware of environmental damage. Companies, in turn, are investing more in the assessment of the environmental impact of their products and services.

Industrial waste handling is the final and critical step for industrial pollution control. It is also an important issue to cleaner production and sustainable development. Industrial eco-systems are the environmental friendly systems for industrial waste recycling, resembling the food chains, food webs and the nutrient recycles in natural environment [11]. They are much more environment friendly compared to other waste treatments such as incineration, solidification and landfill because:

a. It transforms the harmful component of waste into usable substance.

b. It slows down the depletion of primary resources in industrial production.

On the normative and qualitative terms, these questions have led to the concept of trade-offs and efficient frontiers for business and the environment [7, 4]. The rationale is to determine the set of solutions in which it is not possible to decrease environmental burden or increase total environmental quality of each environmental category, unless increasing the costs. From a methodological perspective, however, there is not much developed on determining such a frontier or assessing the trade-offs in sustainable logistics networks, despite the extensive existing literature in the field of multi-criteria programming. We intend to bridge this gap by an approach that is sounded to capitalize the decision maker's most effective cognitive capabilities: visual representation. In order to explore the efficient frontier in feasible time (for the intractability of determining all extreme efficient solutions in a multi-objective linear program), see [20] and [19].

In every production process, whether agricultural or nonagricultural, inputs are used to create a finished product or commodity. Inevitably, some inputs are not fully used and are released into the environment in forms that may be considered pollutants. Whenever the level of pollution exceeds the environment's ability to absorb and process these discharges, environmental risks develop.

The oil palm tree can be regarded as natural resources. Therefore we can apply nenvironmental economics concept in discussing its production planning. [21] suggest that the management of natural resources involves three important objectives, i.e., economics, environmental quality and intergenerational concerns.

Regarding to the importance of the sustainable production planning of crude palm oil (CPO) creates a stimulus for the research in the mathematical programming model. [16] propose a multi objective model for solving sustainable production planning, which take into account environmental constraints. This is a general production model. [15] use an optimization model approach to solving production planning of CPO in order to reduce fresahwater usage. The production of CPO and palm kernel (PK) is a complex problem, due to the influence of processing variables and environmental impacts. [1] address a model using fuzzy expert system to solve the problem. Recently, [14] propose a linear prograsmming model for CPO production planning. But they do not include environmental factor in their model.

Due to the fact that the sustainable production planning of CPO consists of several objectives, such as, economics, environmental quality and environmental risk, in this paper we propose a multi objective model for solving such problem. Further more for the environmental risk we impose a probability constraint in such a way to make the environmetal risk reliable.

2. CRUDE PALM OIL MANUFACTURING

2.1 Production Process

The two main products derived from the oil palm fruit are crude palm oil (CPO) and crude palm kernel oil (CPKO). CPO is obtained from the mesocarp (fiber) and CPKO is obtained from the endosperm (kernel). Each oil mill applies a conventional oil milling process, beginning with the steaming of FFB under high pressure (sterilization) for a prescribed period of time to condition the fruits. The sterilized bunches are then threshed to separate the fruits from the bunch stalks. The fruits are subsequently pressed to obtain the crude oil. This oil–water mixture undergoes a separation process before the oil is purified and dried prior to storage. The water phase forms the bulk of the raw palm oil mill effluent, which is treated in a waste water treatment plant or a treatment pond.

2.2 Environmental Problems

The entire crude palm oil process does not need any chemicals as a processing aid. However, there are a number of environmental problems at the factories, such as high water consumption, the generation of a large amount of wastewater with a high organic content, and the generation of a large quantity of solid wastes and air pollution. The waste generation (per ton FFB production) from the crude palm oil industry shows that only 22.8% of the raw material input consists of valuable products (CPO and CPKO). Palm oil mills also produce significant quantities of by-products/solid waste, such as empty fruit bunch, fibres, shell, decanter cake and ash from the boiler. Only 23% of raw materials are products, the rests are waste/ by-products. Most of the by-products can be reused in the production process or in other industries. Fibres (14%) are used as fuel in boilers to generate steam and energy, required for the mill operation. Shell (6%) and empty fruit brunch (EFB) (24%) are sold for use in other industries. However, there is a lot of solid waste that has to be treated before disposal. These wastes include 0.03 million ton/ year of decanter sludge and 0.05 million ton/ year of ash. The problems of solid waste management in factories are improper storage and handling of solid waste material and improper land application techniques or practices for solids waste. These wastes consequently cause bad smell and dust that affect the surrounding communities.

2.3 Existing Industrial Ecosystems in the Crude Palm Oil Industry

The crude palm oil industry has developed a number of industrial ecosystem practices for its waste recycling. The nature of these practices can be divided into in-plant industrial ecosystem (clean technology) options and possibilities for external waste exchange, which includes recycling of wastes between the industrial sector and other sectors such as agriculture. There are various technical options for an industrial ecosystem approach.

3. MODEL FORMULATION

We formulate the sustainable production planning model of CPO and PK that take into account several environmental constraints. As we adopt environmental economics concept, then there are three objectives which are necessarily to be met. Therefore the formulation would take the form of a multi-objective programming model. The three objectives represent the expected return of the production plan and the penalties for the case when the cumulative effect of each emission overcome some environmental levels and the financial risk of the production plan due to the waste charge. The manager tries to find a production plan that maximize the expected return of it, minimize the pollution penalties and satisfies the environmental constraints. The framework of the model is from [16].

Consider an industrial CPO milling enterprise has the possibility to manufacture products of types T_1 for CPO and T_2 for PK. For each type we denote by c_i the selling price of a product of type T_i. Note that all c_i are random variables.

The milling industry generates none, one or several pollution emissions F_1, F_2, …, F_n and requires p resources R_1, R_2, …, R_p

Let b_{ij} denotes the amount of pollution emission F_j when is manufactured a product of type T_i and c_{ik} the amount of resource R_k required for manufacturing a product of type T_i. Let r_k be the maximum availability of resource R_k. Note that b_{ij} and c_{ik} are nonnegative numbers. The enterprise manager wants to invest a sum M of money in the range $[M_1, M_2]$ in order to manufacture products of types $T_1, T_2, \ldots, T_n$. The milling manager desires to obtain a production plan $\mathbf{x} = (x_{11},x_{12},,,,,x_{1n}, x_{21},x_{22}, \ldots, x_{2n})$ that gives him a maximum expected return, a minimum risk for the environment pollution and a minimum financial risk.

In the present paper the pollution risk is measured by the penalties paid by the manager for the environment pollution. Denote by d_{j1} the desirable or target pollution level for the pollutant emission F_j. Denote by d_{j2} the alarm level of pollution for the pollutant emission F_j. Denote by d_{j3} the maximum acceptable limit of pollution for the pollutant emission F_j. Of course $0 \le d_{j1} \le d_{j2} \le d_{j3}$ for every $j = 1, 2, \ldots, m$. A small overcome of the level d_{j1} represent no danger for the environment. It represents only a warning that the pollution process had already began. A small overcome of the level d_{j3} represent a warning that the pollution process may have consequences for the environment. An overcome of the level represents a warning that the pollution process had already produced bad consequences for the environment and urgent measures must be taken in order to stop the process.

Let $\mathbf{x} = (x_{11},x_{12},,,,,x_{1n}, x_{21},x_{22}, \ldots, x_{2n})$ be the output plan of the manager. Here x_{ij} represents the number of products of type T_i, $i = 1, 2$, and milling j. Denote by p_{ij} the production cost of a product of type T_i at milling j and by q_{ij} a minimum quantity of products of type T_i at milling j that should be produced. Of course p_{ij} are positive real numbers and q_{ij} are natural numbers for all $i = 1,2$, and $j = 1,2,\ldots,n$. The production cost for the production plan $\mathbf{x} = (x_{11},x_{12},,,,,x_{1n}, x_{21},x_{22}, \ldots, x_{2n})$ is equal to $\sum_{i=1}^{2}\sum_{j=1}^{n} p_{ij}\,x_{ij}$. We shall call $\mathbf{q} = (q_1, q_2, \ldots, q_n)$ the vector of demand. If a is a real number we shall denote by a_+ the positive part of a, that is:

$$a_+ = \max(a,0) = \frac{|a|+a}{2} \qquad (1)$$

Therefore if the environmental penalty paid in the case the output plan $\mathbf{x} = (x_{11},x_{12},,,,,x_{1n}, x_{21},x_{22}, \ldots, x_{2n})$ is applied then it would be proportional to the amount of pollutant that overcomes the pollution level. Consequently in the case of pollutant emission and pollution level it is equal to

$$a_{js}\left(\sum_{i=1}^{n} b_{ij}x_{ij} - d_{js}\right)_{+} \qquad (2)$$

where a_{js} the proportionality factor from the environmental penalty. In this case the overall environmental penalty can be expressed as

$$f_1(\mathbf{x}) = \sum_{i=1}^{2}\sum_{j=1}^{m} a_{js}\left(\sum_{i=1}^{n} b_{ij}x_{ij} - d_{js}\right)_{+} \qquad (3)$$

The expression (3) is to consider a desirable pollution level and environmental penalties which is proportional to the amount of pollutant that overcome the pollution level. The manager must take into account environmental constraints. In our paper we shall consider constraints that impose some bounds on the expected amount of pollutant emissions:

$$\sum_{i=1}^{2} b_{ij}x_{ij} \le d_{j4} \quad j = 1,2,\dots,n \qquad (4)$$

Here we denoted by d_{j4} a number smaller or equal than d_{j3}. It measures the aversion against a polluted environment. The smaller is d_{j4}, the cleaner will be the environment. We shall denote by E_1 the set of all nonnegative vectors $\mathbf{x} = (x_1, x_2, \dots, x_n)$ having integer components that satisfy: the inequalities $x_i \ge q_i$ for all i, the environmental constraints (4) and the resource constraints

$$\sum_{i=1}^{2}\sum_{j=1}^{n} c_{ij}x_{ij} \le r_k \quad k = 1,2,\dots,p \qquad (5)$$

Denote by σ_{ij} the covariance of the random variables and . Let $C = (\sigma_{ij})$ be the covariance matrix. We shall define the financial risk of the production plan **x** as the variance of the its return $\sum_{i=1}^{2}\sum_{j=1}^{n} c_{ij}x_{ij}$. One can easily see that

$$Var\left(\sum_{i=1}^{n} c_i x_i\right) = \sum_{i=1}^{2}\sum_{j=1}^{n} \sigma_{ij}x_i x_j = \mathbf{x}^{\mathbf{T}}\mathbf{C}\mathbf{x} \qquad (6)$$

We should have a constraint on fund for investment. Let M be the sum of money to be invested in the production plan. Assume that M is in the range of M_1 and M_2, the constraint on investment is expressed as

$$M_1 \le \sum_{i=1}^{2}\sum_{j=1}^{n} p_{ij}x_{ij} \le M_{2,} \quad x \in E_i \qquad (7)$$

In order to use efficiently the sum available, the manager tries to find a production plan **x** = $(x_{11}, x_{12},,,, x_{1n}, x_{21}, x_{22}, \dots, x_{2n})$ such that it will bring a maximum return, it will minimize the overcome of the waste levels and the financial risk and it will allow him to comply with environmental restrictions.

Therefore there are three objectives should be met. These three objectives can be expressed as follows.
Objective for maximum return

$$Max\left[\sum_{i=1}^{2}\sum_{j=1}^{n}(E[c_{ij}] - p_{ij})x_{ij}\right] \qquad (8)$$

Objective for waste level

$$Min\left(\sum_{i=1}^{2} b_{ij}x_i - d_{js}\right)\ s = 1,2 \quad j = 1,2,\dots,n \qquad (9)$$

Objective for financial risk related to the waste

$$Min\left(\sum_{i=1}^{2}\sum_{j=1}^{n} \sigma_{ij}x_i x_j\right) \qquad (10)$$

In this case we can consider the model as a portfolio investment model of Markowitz. Therefore we should be able to split the multi objective into two single objectives, such as, minimizing financial risk and maximizing return.

4. A MINIMUM FINANCIAL RISK MODEL

In the minimum financial risk problems the manager tries to minimize the financial risk taking into account the following restrictions:

a. The production plans satisfy the environmental and resource conditions (2) and (3), that is $\mathbf{x} \in E_1$.
b. The sum M invested in the fabrication plan is in the range $[M_1, M_2]$.
c. The expected return of the production plan is greater than a given value W.

(3

The model is the following:

$$(Q_1)\begin{cases} \min\left(\sum_{i=1}^{2}\sum_{j=1}^{n} \sigma_{ij}x_i x_j\right) \\ f_1(\mathbf{x}) \le v \\ \sum_{i=1}^{2}\sum_{j=1}^{n}(E[c_{ij}] - p_{ij})x_{ij} \ge W \\ M_1 \le \sum_{i=1}^{2}\sum_{j=1}^{n} p_{ij}x_{ij} \le M_2, \mathbf{x} \in E_1 \end{cases} \qquad (11)$$

Here W is the parameter that controls the expected return of the production plan and ν is the parameter that controls monetarily the penalties paid for pollution.

5. A MAXIMUM EXPECTED RETURN MODEL

In the maximum expected return problem the manager tries to maximize the expected net return taking into account the following restrictions:

a. The production plans satisfy the environmental and resource conditions (2) and (3), that is $\mathbf{x} \in E_1$.
b. The sum M invested in the production planning is in the range $[M_1, M_2]$.
c. The financial risk is smaller than a given value τ

$$(Q_2)\begin{cases} \max [\sum_{i=1}^{2}\sum_{j=1}^{n}(E[c_{ij}]-p_{ij})x_{ij} - f_1(\mathbf{x}) \\ \sum_{i=1}^{2}\sum_{j=1}^{n}\sigma_{ij}x_1x_j \le \tau \\ M_1 \le \sum_{i=1}^{n}P_{ij}x_{ij} \le M_2,\ \mathbf{x}\in E_1 \end{cases} \quad (12)$$

The problem (Q_1) and (Q_2) are single objective programming problems.

5.1 Stochastic Model

The parameters v and W in constraints problem Q_1 represent the uncertain parameter of our problem. If we ignore the uncertainty and replace these random quantities by representative values, such as their mean values, we can solve a deterministic problem (DP) to obtain a simple solution for this problem. This deterministic solution will be helpful as a benchmark.. There are two other ways to handle uncertainty that for this problem lead to the solution of a single deterministic problem DP: chance constrained programming and robust optimization. The solution of this CPO production planning problem through other methods of representing uncertainty, such as stochastic programming and markov-decision processes require more involved solution procedures and will not be explored in this paper.

In chance constrained programming (CCP) we assume that the parameters *v and W* are unknown at the time of planning but follow some known probability distributions. We assume they are uniformly and independently distributed. We let α_D and α_T represent the confidence level of the chance constraints defining the unmet waste. Thus, the constraints with stochastic parameters must hold with these given probabilities. For a given distribution on *v and W* we can rewrite the constraints in the chance constrained fashion with levels α_p and α_r as follows:

$$P[f_1(x) \le v] \ge 1-\alpha_p \quad (13)$$

$$P[\sum_{i=1}^{n}(E[c_i]-p_i)x_i \ge W] \ge 1-\alpha_r \quad (14)$$

5.2 Chance-Constrained Programming

A generic chance-constrained optimization problem can be formulated as

$$\min_{x\in X} f(x) \text{ subject to } \Pr\{G(x,\xi) \le 0\} \ge 1-\varepsilon \quad (15)$$

where $X \in R^n$ represents a deterministic feasible region, $f\colon \mathbb{R}^n \to \mathbb{R}$ represents the objective to be minimized, ξ is a random vector whose probability distribution is supported on set $\Xi \subset \mathbb{R}^n$, $G\colon \mathbb{R}^n \times \mathbb{R}^d \to \mathbb{R}^m$ is a constraint mapping, 0 is an m-dimensional vector of zeroes, and $\varepsilon \in (0, 1)$ is a given risk parameter (significance level). Formulation (14) seeks a decision vector x from the feasible set X that minimizes the function $f(x)$ while satisfying the chance constraint $G(x, \xi) \le 0$ with probability at least $1 - \varepsilon$. It is assumed that the probability distribution of ξ is known.

By way of illustration, consider the following simple facility sizing example. We need to decide capacities of n facilities servicing uncertain customer demand. The cost-per-unit capacity installed for each facility is given, as is the joint demand distribution. The goal is to determine the cheapest capacity configuration so as to guarantee that the installed capacity exceeds demand with probability $1 - \varepsilon$. This chance-constrained problem can be formulated as follows.

$$\min_{x\ge 0}\sum_{i=1}^{n}c_ix_i \text{ subject to } \Pr\{\xi_i - x_i \le 0, i = 1,\dots,n\} \ge 1-\varepsilon \quad (16)$$

Here x_i, c_i and ξ_i denote the capacity, cost, and random demand for facility i, respectively. It is assumed that the (joint) probability distribution of the random vector $\xi = (\xi_1, \dots, \xi_n)$ is known (otherwise the probabilistic constraint in (16) is not defined). Note that the probabilistic (chance) constraint of (16) can be considerably weaker than trying to satisfy the demand for all possible realizations of ξ. Note also that (16) is an example of (15) with $G(x, \xi) = \xi - x$.

In this example, we require that the reliability requirement be applied to all facilities jointly. One could also consider the individual chance constraints $\Pr\{\xi_i \le x_i\} \ge 1-\varepsilon_i$, $i = 1, \dots, n$, applied to each facility separately. This leads to a much simpler problem, since $\Pr\{\xi_i \le x_i\} \ge 1-\varepsilon_i$ is equivalent to $F_i^{-1}(x_i) \ge 1-\varepsilon_i$, where F_i is the cumulative distribution function (cdf) of ξ_i. Note, however, that in order to ensure the joint chance constraint by enforcing the individual chance constraints, the corresponding risk parameters ε_i should be considerably smaller than especially when n is large.

The approach for solving the problems in which it is assumed that the distribution of ξ is such that checking feasibility is easy, and the resulting feasible region is convex. A classical example of this case is when $G(x,\xi) = v - \xi^T x$ and ξ has a multivariate normal distribution with mean μ and covariance matrix Σ. Then for $\varepsilon \in (0, 0.5)$,

$$\{x \in \mathbb{R}^n : \Pr\{\ \xi^T x \ge v\} \ge 1-\epsilon\} = \{x \in \mathbb{R}^n : v - \mu^T x + z_\delta\sqrt{x^T \textstyle\sum x \le 0}\} \quad (17)$$

where $z_\varepsilon = \Phi^{-1}(1 - \varepsilon)$ is the $(1 - \varepsilon)$-quantile of the standard normal distribution. In this case, under convexity of X, the chance-constrained problem reduces to a deterministic convex optimization problem.

6. CONCLUSION AND DISCUSSION

Managing business environmental risk in agro-industry consists of making the production process more efficient in such a way as to limit its environmental consequences while increasing profitability.

In this paper we present a multi-objective programming model for managing business environmental risk in a crude palm oil manufacture. We split the multi objective into two single objective. Due to the uncertainty in level of waste, we address a chance constrained programming model, which consists of making the production process more efficient in such a way to limit the impact of environmental consequences and to meet the investment risk. We use covariance approach to transform the stochastic model into deterministic optimization problem.

From the model we could get that if we increase the production plan of crude palm oil (CPO) and Palm Kernel (PK), then we will get higher return. However, the investment cost and waste discharge are getting higher. Furthermore the probability that the financial risk less than τ is getting lower. Therefore we should have a trade off between economic factor, the environmental factor, and financial risk

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