Seafood Production Planning Considering Perishable Inventory

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Abstract Perishable products, such as fish processed, provide extra challenges to the production planning due to their limited shelf-life. Fish and its processed products are the most affordable source of animal protein in the diet of most people in Indonesia. The goal in production planning is to meet customer demand over a fixed time horizon divided into planning periods by optimizing the trade-off between economic objectives such as production cost, waste processed cost, and customer satisfaction level. The major decisions are production and inventory levels for perishable products and the number of workforce in each planning period. In this paper we consider the management of traditional business at North Sumatera Province of Indonesia which performs processing fish into several local seafood products. We propose a mixed integer programming model for the production planning problem that handle the perishable issue at the inventory. We use feasible neighborhood search for solving the model. The results which show the amount of each fish processed product and the number of workforce needed in each horizon planning are presented.

Keywords— Mixed integer programming, production planning, perishable product, inventory control, feasible direct search

I. INTRODUCTION

Production planning can be viewed as planning of the acquisition of resources and raw materials, as well as planning of the production activities required to transform materials into finished products [17]. Furthermore, production planning is a hard optimization problem due to its combinatorial nature, and thus academically challenging.

The goal in production planning is to meet customer demand over a fixed time horizon divided into planning periods by optimizing the trade-off between economic objectives such as production cost and customer satisfaction level [14]. The major decisions are production and inventory levels for each product in each planning period. To address production planning problems, research efforts have tried to adapt solution methods that have been successful for other applications. For some problems, however, the proposed approaches are insufficient because short-term decisions need to be taken into account to obtain good solutions. This can be accomplished by integrating production planning with detailed scheduling models. However, this leads to large optimization problems that are intractable for practical applications.

In this paper we consider production planning problem which arises in marine fisheries industry in Indonesia. Marine fisheries play an important role in the economic development of Indonesia. This industry could also provide employment to people who live at coastal areas, to increase the financial gain of local government, and to conserve sustainability. Fisheries industrial sector can be classified into three different parts, i.e., open sea fishing, fish cultivation and processed fish. This paper is focusing on the latter sector.

The raw material of fish processed products are fish, which can be regarded as perishable materials. Perishability feature addressed here using the concept of shelf life, defined as the maximum length of time a material can be stored under specified conditions and remain suitable for use, consumption or for its intended function. Unlike other models of inventory control and production planning involving deteriorating inventory with loss of functionality depending on storage time, we consider raw materials fully functional until the end of its shelf-life. The perishable nature of products in the fresh food industry poses significant constraints on planning processes.

Regardless of the formulation technique, production planning models are applied to multiple types of manufacturing systems. Due to the formulation flexibility of these models, variables and constraints are adjusted to requirements and specifics of each problem. Specifically, industries such as food and chemicals have manufacturing systems involving products and raw materials that have the characteristic of being perishable, meaning that, once they are produced, after a certain time, due to its microbial property, expire, deteriorate or cease to be completely useful and should be discarded or diminish its commercial value.

Product shelf life is one of the greatest challenges and constraints in fresh food industries. Due to the perishable nature of these products, inventory levels across fresh food supply chains have to be very low in order to avoid waste due to product expiration and spoilage [13]. [9] analyzed lot sizing and its effect on inventory levels and lost sales. They found that holding inventory in order to satisfy most of the demand is not the optimal solution. This is particularly critical in perishable industries where shelf-life constrains the storage time. Many authors have elaborated on this issue suggesting optimal solution for managing perishable products’ supply chain, [6] developed a collaborative manufacturing, planning and scheduling system with integration of lean and agile production. This system is capable of adapting production
schedules based on real-time information and also to consider available resources and capacities of entire supply chain. [11] also investigated the production planning and scheduling process in perishable manufacturing industries. They suggested that food producers should strive to deliver fresher products to their customers but also to reduce inventory time and avoid subsequent deliveries of products with the same expiry date. This goal may lead to more frequent manufacturing which in turn increases machine setup costs, and may affect product quality issues [13]. [5] and [1] suggested that production scheduling optimization could be achieved through adjusting either cycle time or production rate, or both simultaneously. Decreasing batch size or more frequent production of a product may result in decreasing production lead time, thus making a manufacturer more responsive. Due to improved responsiveness, inventory levels could be kept lower which in turn provides fresher products and less waste costs.

This characteristic of perishable products can be reflected in other aspects even beyond the physical conditions of the product (deterioration or depletion). [12] considered the productive or marketable life of a product in a competitive emerging market as a form of perishability. In this sense, the concept of shelf-life can be defined as the time period during which a product can be stored without loss of function for which it was designed, or without loss of its usability. To present recent and relevant contributions in the area of production planning models considering this special feature of perishability or shelf-life, we can begin with [7], who made an overview of some of the most encountered production planning and scheduling problems in the chemical process industry and their specific characteristics. He took into account and distinguished three classes of production systems: continuous, batch and semi-batch production. Among the several aspects needed for undertaking such problems, Kallrath refers to the possible limitations on the shelf-life time of products.

[11] introduced a Mixed Integer Nonlinear Programming model for an Advanced Planning System (APS) in the context of batch production for process industries. The model is reduced to a Mixed Binary Linear Program of moderate size, and includes constraints referring to perishability of products, where production tasks are assigned to consuming tasks so that no perishable product is kept in stock at any time, i.e. the amount produced by a batch must equal the amount consumed in following tasks without delay. The proposed model was applied for a chemical industry production plant and solved by a branch-and-bound algorithm.

[4] developed three Mixed Integer Linear Programming (MILP) models that incorporate shelf-life limitations for final products in planning and scheduling for an industrial case study of stirred yoghurt production. The models presented focus on the flavoring and packaging steps of the yoghurt production process. Considering a shelf-life-dependent pricing component. [4] included the shelf-life aspect in their models’ objective function, which aims at maximizing the contribution margin. Numerical investigation was carried out to assess the suitability of the models for specific planning problems.

[8] presented a compilation of Mixed Integer Optimization (including MILP) for solving planning and design problems. One of the special features in planning in the process industry where Kallrath’s work delves more specifically in the case of shelf-life for products. According to Kallrath, in these cases, such limitations on the shelf-life require controlled records to trace time stamps of products. For this, a variable disposal cost is associated with products that have exceeded its shelf-life, are no longer useful and need to be discarded. From the above, inventory balance equations are presented and show how to add the shelf-life aspect for products. [3] proposed two MILP models to solve production, working hours and holiday weeks for human resources in a multi-product process with perishable products. Both models have the same objective function: maximizing the profit (income minus costs due to production, product elimination, lost demand, and inventory, among others), introducing a unit cost of eliminating product that has reached its shelf-life and must be discarded.

[16] presented a binary integer programming model for operations planning involving product traceability, production batch size, inventory levels, product shelf-life, and other aspects in perishable food production. They modeled two different scenarios: one with two-level bill of materials (raw materials and finished products), and one with three-level bill of materials (adding components). Shelf-life is considered to be the period between manufacture and retail purchase of a product during which the product is of satisfactory quality or saleable condition, and it is calculated by deducting the product storage time from the product life. To incorporate the shelf-life factor, a temporary price discount is applied quantifying product deterioration cost. [16] note that the model is applicable not only in perishable food manufacturing contexts, but in a wider area of batch production and assembly processing. [2] proposed an optimization model for joint replenishment and delivery for perishable products. [15] proposed an integer programming model which integrates production, inventory and routing plan of perishable products.

II. PROBLEM BACKGROUND

Fish and its processed products are the most affordable source of animal protein in the diet of most people. In Indonesia, most of the fish processed industries are found at the coastal area. In these industries fish are processed traditionally. There are eight kinds of fish product to be produced by the community, namely, , dried fish, salted fish, BBQ fish, pindang fish, smoked fish, fish preserved, pressed fish, and fish bowl.
The fish processed industry under investigation is located at the eastern coastal area of North Sumatra province of Indonesia. The industry run by the community of that area has to make a production plan for these eight fish processed products to fulfill market demand over each period of time \( t, t = 1, \ldots, T \). In this case each period equals to three months. Therefore there will be four periods in a year.

A. Shelf-Life Consideration

The core aspect of the problem under study is the perishability condition of the components considered as raw materials for production. These components are those that, for various reasons, will expire after certain date, or can only be used for a determined period of time. The term “shelf-life” refers to the maximum length of time a component can be stored under specified conditions and remain suitable for use, consumption or for its intended function.

The relevance of the above lies in the need to track the age of components with specific time-stamps for each of them. Individual inventory control is required to properly handle the ordering/receiving of materials, their remaining shelf-life, their consumption and the subsequent disposal. As described by [8], most of the data associated with inventories have to be duplicated for problems involving shelf-life, regarding additional shelf-life index. Besides the amount of inventory kept in stock, we also need to know when the material has been ordered or received. In order to track the inventory of components that must be discarded when they expire, it is required to keep specific records of the period in which the components were received. Thus, they are later totalized as inventory to be unsuitable for use after expiration date. If a component reaches the end of its shelf-life and expires, it will have to be discarded. This will cause additional costs: besides the cost of acquiring the component and holding. Hence, we present a mathematical model formulation that takes this factor into account by adding variables, indexes and constraints for these individual time-stamps. Also, a disposal cost per unit of discarded component is applied.

B. Assumptions and Notation

To structure the problem and the mathematical formulation, we make use of the following assumptions and notation:

- Demand is deterministic with no back-orders
- Production is instantaneous and immediate
- Fish as resources are always available
- Shelf-life is known for each product

In this production planning problem we will decide:

- The quantity of each fish processed product to be produced in each period
- The additional resource to be used
- The number of regular additional and laying-off workers in each period

Model parameter and decision variables used throughout this paper are defined as follows.

Sets

- \( T = \) number of periods
- \( N = \) set of products
- \( M = \) set of resources

Variables

- \( X_{jt} \): Quantity of product \( j \in N \) in period \( t \in T \) (ton)
- \( u_{it} \): Additional amount of resource \( i \in M \) to purchase in \( t \in T \) (unit)
- \( k_t \): Number of workers required in period \( t \in T \) (man-period)
- \( k^+_{jt} \): Number of workers laid-off in period \( t \in T \) (man-period)
- \( k^-_{jt} \): Number of additional workers in period \( t \in T \) (man-period)
- \( I^r_{jt} \): Quantity of product \( j \in N \) to be stored in period \( t \in T \) (units) with \( I^r < SL \)
- \( I^l_{jt} \): Quantity of product \( j \in N \) to be stored in period \( t \in T \) (units) with \( I^l > SL \)
- \( B_{jt} \): Under-fulfillment of product \( j \in N \) in period \( t \in T \) (units)

Parameters

- \( \alpha, \beta, \gamma, \delta, \mu, \rho, \lambda, \tau \) are all costs
- \( D_{jt} \): Demand for product \( j \in N \) in period \( t \in T \) (units)
- \( U_{it} \): Upper bound on \( u_{it} \)
- \( r_{ij} \): Amount of resource \( i \in M \) needed to produce one unit of product \( j \in N \)
- \( f_{ij} \): Amount of resource \( i \in M \) available at time \( t \in T \) (units)
- \( a_j \): Number of worker needed to produce one unit of product \( j \in N \)
- \( SL \): Shelf-life of product
- \( C_{jt} \): Production capacity of product \( j \in N \) in period \( t \in T \) (units)

C. Model formulation

The mixed integer programming model for the problem is formulated as follows.
Minimize
\[ \sum_{t \in T} \sum_{j \in J} \alpha_j x_{jt} + \sum_{i \in I} \sum_{t \in T} \beta_{ij} u_{it} + \sum_{i \in I} \mu_i k_i + \sum_{i \in I} \gamma_i k_i^+ + \sum_{i \in I} \delta i k_i^- + \sum_{j \in J} \sum_{t \in T} \tau_j I_{jt} + \sum_{j \in J} \sum_{t \in T} \lambda_j B_{jt} \]

Subject to
\[ \sum_{j \in J} r_{jt} x_{jt} \leq f_{it} + u_{it}, \quad \forall i \in M, \forall t \in T \]
\[ u_{it} \leq U_{it}, \quad \forall i \in M, \forall t \in T \]
\[ \sum_{j \in J} a_j x_{jt} \leq k_i, \quad \forall t \in T \]
\[ k_i = k_{i-1} + k_i^+ - k_i^- \quad t = 2, \ldots, T \]
\[ x_{jt} + B_{jt-1} + I_{jt+1}^r - B_{jt} = D_{jt}, \quad \forall j \in N, \forall t \in T \]
\[ I_{jt} = I_{jt}^r + x_{jt} - D_{jt}, \quad \forall j \in N, \forall t \in T \]
\[ X_{jt} \leq C_{jt}, \quad \forall j \in N, \forall t \in T \]
\[ x_{jt}, u_{it}, k_i, k_i^+, k_i^- \] are all integers

The objective expressed in (1) is to minimize the related production costs, work force costs, and inventory costs. Constraint (2) expresses that the amount of resource \( i \in M \) needed to produce product \( j \in N \) at least should have the same amount of resources available at time \( t \in T \) together with the additional resource needed. However, the additional resource needs to have an upper bound (expression (3)). In constraint (4), we have the number of workers needed to produce one unit product \( j \in N \). Constraint (5) ensures that the available workers in any period equal the number of worker from the previous period plus any change in the number of worker level during the current period. The change in the number of worker level may be due to either adding extra workers or laying off redundant workers. Constraint (6) determines either the quantity of product to be stored in inventory or to purchase from outside to fulfill the shortfall in meeting market demand. The inventory involved in this constraint only inventory of fish processed product before the expired date. Constraint (7) expresses the amount of inventory of products after shelf-life. The level of production should have capacity, this kind of condition is presented in constraint (8). The non-negativity conditions are expressed in (9). Expression (10) is to make sure that the amount of workers are integer.

III. The Algorithm

Cycle 1. After solving the relaxed problem, the procedure for searching a suboptimal but integer-feasible solution from an optimal continuous solution can be described as follows: Let
\[ x = \lfloor x \rfloor + f, \quad 0 \leq f \leq 1 \]
be the (continuous) solution of the relaxed problem, \( \lfloor x \rfloor \) is the integer component of non-integer variable \( x \) and \( f \) is the fractional component.

Step 1. Get row \( i^* \) the smallest integer infeasibility, such that
\[ \delta_{i^*} = \min \{ f_i, 1 - f_i \} \]

Step 2. Calculate
\[ v = \ell_p B^{-1} \]
this is a pricing operation

Step 3. Calculate
\[ \sigma_{ij} = \frac{d_j}{\sigma_{ij}} \]

With \( j \) corresponds to \( \min \{ f_i, 1 - f_i \} \)

1. For nonbasic \( j \) at lower bound
If \( \sigma_{ij} < 0 \) and \( \delta_{i^*} = f_i \) calculate
\[ \Delta = \frac{1 - \delta_{i^*}}{-\sigma_{ij}} \]
If \( \sigma_{ij} > 0 \) and \( \delta_{i^*} = f_i \) calculate
\[ \Delta = \frac{1 - \delta_{i^*}}{\sigma_{ij}} \]
If \( \sigma_{ij} < 0 \) and \( \delta_{i^*} = 1 - f_i \) calculate
\[ \Delta = \frac{\delta_{i^*}}{-\sigma_{ij}} \]
If \( \sigma_{ij} > 0 \) and \( \delta_{i^*} = 1 - f_i \) calculate
\[ \Delta = \frac{\delta_{i^*}}{\sigma_{ij}} \]

II. For nonbasic \( j \) at upper bound
If \( \sigma_{ij} < 0 \) and \( \delta_{i^*} = 1 - f_i \) calculate
\[ \Delta = \frac{1 - \delta_{i^*}}{-\sigma_{ij}} \]
If \( \sigma_{ij} > 0 \) and \( \delta_{i^*} = f_i \) calculate
\[ \Delta = \frac{1 - \delta_{i^*}}{\sigma_{ij}} \]
If \( \sigma_{ij} > 0 \) and \( \delta_{i^*} = 1 - f_i \) calculate
\[ \Delta = \frac{\delta_{i^*}}{-\sigma_{ij}} \]
We solve a problem faced by the fish industry located at the coastal area of North Sumatera Province in Indonesia. The data of the problem can be found in [10].

TABLE I. THE NUMBER OF EACH PRODUCT TO BE PRODUCED (TON).

<table>
<thead>
<tr>
<th>Product</th>
<th>Period 1</th>
<th>Period 2</th>
<th>Period 3</th>
<th>Period 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>250</td>
<td>250</td>
<td>250</td>
<td>300</td>
</tr>
<tr>
<td>2</td>
<td>900</td>
<td>900</td>
<td>900</td>
<td>950</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>200</td>
<td>200</td>
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<tr>
<td>4</td>
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<td>5</td>
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<td>6</td>
<td>200</td>
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<td>200</td>
<td>300</td>
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<tr>
<td>7</td>
<td>200</td>
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<td>200</td>
<td>300</td>
</tr>
<tr>
<td>8</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>300</td>
</tr>
</tbody>
</table>

TABLE II. ADDITIONAL RESOURCES TO BE USED (TON).

<table>
<thead>
<tr>
<th>Resources</th>
<th>Period 1</th>
<th>Period 2</th>
<th>Period 3</th>
<th>Period 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine 1</td>
<td>12.20</td>
<td>12.20</td>
<td>12.20</td>
<td>16.95</td>
</tr>
<tr>
<td>Machine 2</td>
<td>9.80</td>
<td>9.80</td>
<td>9.70</td>
<td>13.80</td>
</tr>
<tr>
<td>Machine 3</td>
<td>8.65</td>
<td>8.75</td>
<td>8.65</td>
<td>12.55</td>
</tr>
</tbody>
</table>

TABLE III. WORKFORCE PLAN

<table>
<thead>
<tr>
<th>Policy</th>
<th>Period 1</th>
<th>Period 2</th>
<th>Period 3</th>
<th>Period 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reg. workforce</td>
<td>38</td>
<td>35</td>
<td>35</td>
<td>47</td>
</tr>
<tr>
<td>Add. workforce</td>
<td>35</td>
<td>0</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Lay off</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

IV. COMPUTATIONAL RESULTS

The computational results, presented in Table 1, Table 2, and Table 3, respectively, describes the quantity of each product to be produced, additional resources needed, and the plan for workforce.

V. CONCLUSIONS

In this paper, we develop a deterministic model for production planning problem of a fish processed industry at coastal area with perishability condition. The model is adequate for solving the planning problem faced by the management of the industry. The model includes the computation of worker which is very useful for the industry in...
order they will be able to schedule a number of local people, and to conserve sustainability. We also propose an algorithm for solving the mixed integer programming problem.

REFERENCES