Decision Model for Planning and Scheduling of Seafood Product Considering Traceability

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Abstract. Due to the global challenges, it is necessary for an industrial company to integrate production scheduling and distribution planning, in order to be more efficient and to get more economics advantages. This paper presents seafood production planning and scheduling of a seafood manufacture company which produces simultaneously multi kind of seafood products, located at Aceh Province, Indonesia. The perishability nature of fish highly restricts its storage duration and delivery conditions. Traceability is a tracking requirement to check whether the quality of the product is satisfied. The production and distribution planning problem aims to meet customer demand subject to traceability of the seafood product and other restrictions. The problem is modeled as a mixed integer linear program, and then it is solved using neighborhood search approach.

Keywords: Optimization, modeling, production planning, traceability, neighborhood search.

1. Introduction
Indonesia’s coastal fisheries can be regarded as an essential source of food, income and cultural heritage to its people. Sixty percent of Indonesian fishers, or 1.6 million, are small-scale fishers, and 85% of their catch is used for human consumption. Additionally, Indonesia has the second longest coastline in the world, and 40% of the population (roughly 100 million people) lives near the coast. Coastal fisheries therefore play an essential role in national food security and nutritional health in Indonesia. 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.

Naturally the fish industry in Indonesia can be found at the coastal area. There are a lot of varieties of fish processed can be produced, depending on the region. Due to the nature conditions, the management of fish industry is still dominated by the local small traditional business, using conventional management strategy. Consequently, they do not have enough knowledge about production and distribution planning and in particular supply chain.

The seafood production is a semi-continuous process and subject to individual characteristics. Seafood is a notably perishable product within the category of food industry. The perishability highly restricts its storage duration and delivery conditions. In order to maintain the quality of the seafood beside perishability, it is necessary to have traceability of the product.
In terms of definition, Hobbs et al. [1] pointed out that there is no agreement on the definition of traceability. However they simply define traceability as the ability to follow the movement of food through specified stages of production, processing, and distribution. In our case we define that traceability is the action to trace and follow the food raw material and finished product through stages of production, inventory and distribution.

Successful traceability processes generally incorporate a carefully devised planning stage to determine when, how, where, and why each traceability link will be created [2]. By aligning traceability tasks with project and organizational goals, and capturing these planning decisions in a trace strategy graph, project stakeholders can ensure that their traceability effort provides effective support for critical software engineering tasks. In prior work, several researchers have proposed the use of strategic traceability graphs [2], [3] to define the traceability goals of a project. In its simplest form, such a graph defines a set of traceable artifacts, the traceability links between them, and the purpose of each of these links. However, such graphs fall short of providing the level of support needed to fully automate the traceability process, especially when artifacts are stored in heterogeneous formats.

The optimal performance of the operations in production-distribution planning is to optimize total cost due to converting the raw fish into final seafood product, keep the products in the inventory and then deliver them to distribution centers. In more detail, [4] described the modelling of a more complete integrated supply chain system which composed of raw material suppliers, primary and secondary plants (each one with inventories of raw materials and finished products), distribution centers, warehouses and customer areas. In a situation where uncertainties occur, Bakhrankova et al., [5] used stochastic programming for production planning of fisheries. In the integrated stochastic model, they incorporate both upstream (raw fish quantities) and downstream (price of the finished product) uncertainties, while accounting for fish quality and shelf life requirements.

From the structure of the planning and scheduling of manufacturing problem, it is reasonable that mixed integer linear programming (MILP) models could provide mathematical optimization frameworks to represent the main characteristics of problems. [6] addressed an MILP model, which integrate production, distribution and marketing and involved plants and sales points. Their paper intends to cover the relevant features required for the complete supply chain management with a multi-site production network. The MILP is an extensively accepted tool in the dairy industry for well-defined problems (e.g., [7]; [8], [9]). Bilgen and Celebi [10] present a MILP model addressing the production scheduling and distribution planning problem in a yoghurt production line of multi-product dairy plants. [11] develop a MILP global supply chain model for determining product – plant and customer – distribution center assignments, number of supply chain echelons, and number and locations of distribution centers. [12] formulate a two-stage supply chain model that determines the optimal quantities of products to be produced at each plant, transported from each plant to each distribution center. However, even though they solve a large scale problem, there is no perishability condition involved. [13] present mixed integer linear programming models and computational strategies for the problem of multi-echelon supply chains with inventory under uncertainty. [14] consider a multi-period production system which integrate load distribution and production planning. They use three-phase heuristic approach and Tabu Search for solving the integrated model. Camacho-Vallejo [15] use bilevel mathematical programming model for solving a supply chain’s production-distribution planning. An interesting extensive review of the integrated system can be found in ( [16], [17], [18]).

It should be noted that all papers that have been mentioned do not consider tracing processes in the production planning. This paper considers a production scheduling and distribution planning problem using tracing process which arises in fisheries industry in Indonesia. The location under investigation for this paper is located at Aceh Province, Indonesia. Marine fisheries play an important role in the economic development of Indonesia, particularly in Aceh province. The main points of this industry are to provide employment to people who live at coastal areas, to increase the financial gain of local government, and to conserve sustainability.
Perishable products and tracing processes, such as fish processed, would impose additional difficulties to the supply chain management due to their limited shelf-life and deterioration of fish quality. These difficulties include the duration of storing the products due to the expired date. Hence, quantities delivered to distribution centers are limited by the shelf-life of goods as well as the distribution center's holding capacity. [19] consider the modelling of the integrated production-distribution planning model for perishable products. The supply chain network considered consists of production facility and multiple distribution centers. [20] discussed an integrated production-distribution planning with scheduling for food catering service industry. Their paper is to find a scheduled production-distribution planning in such a way that the customers service level is satisfied and the total cost is minimized.

The challenge for companies in managing the supply chain of perishable foods is that the value of the product deteriorates significantly over time at rates that are highly dependent on the environment [21]. According to these authors, temperature and humidity are key factors in this process. An additional concern about food production and distribution systems around the world is that they must to be more reliable than manufactory traditional systems. Supply chain of perishables is more susceptible to economic shocks, environmental changes, or even to management errors supported by lack of knowledge [22]. The literature had indicated that in the future food system will have to joint four major characteristics: resilience, sustainability, competitiveness, and ability to manage and meet customer expectations [23]. Due to diseases related to food ingestion and food production globalization [24], customers had become more conscious of origin and nutritional contents of their own foods. As a consequence of that, an increase of interest on traceability, freshness, and high quality patterns of food is demanded. At the same time, producers have expanded products choice in order to attend customers' wishes.

This paper concerns with the modeling the integrated production scheduling and distribution planning for several seafood products. There are several plants are setup to produce these seafood products. Due to the shelf life of raw fish and production capacity it is necessarily to conduct traceability and then to schedule to which plant a kind of seafood to be produced. Inventories of raw fish are available at each plant with limited capacity and limited time. The finished qualified seafood products will be delivered to a set of distribution centers, which has limited cooled store rooms. The problem is formulated as a mixed integer linear programming (MILP) model. A direct neighborhood search approach is developed for solving the model.

2. Problem Formulation

This problem is motivated by a fish industry located at the Aceh Province of Indonesia. The industry plans to produce N kinds of local traditional seafood products from J plants. These plants are dispersed in several cities. The finished products will be packed in packaging container and then distributed to a set of L distribution centers. Due to the perishability issue of the raw fish material and the seafood finished products it is necessarily to schedule the storage during the production and distribution operations, and then to conduct traceability for the quality of the products.

The fish industry wishes to plan the production and distribution system with a proper scheduling for the N kind of seafood products within period of time \( t = 1, \ldots, T \), in order to fulfill the market demand. There are J plants available. In order to maintain the freshness of fish raw material, each plant has a limited capacity cooled store room with unit holding cost of \( \rho_{nt}^j, n \in N, j \in J, t \in T \). These raw material have a shelf-life \( \tau_r \). If the stored raw materials are not fully used after their shelf-life, they would be discarded. Also there would be tracing processes for the raw fish, these raw fish should be discarded if they do not pass the quality standard. Therefore the level of inventory of raw material at plant \( j \) of \( n \) kind of fish product before their shelf-life would be denoted as \( I_{n,t,<\tau_r}^j \).
There is a set of L distribution centers located around Aceh Province close enough to each plant. Each distribution center \( l \) (k = 1, 2, …, L) has a nonnegative and deterministic demand \( D^l_t \) of \( n \) kind fish product in planning period \( t \) of the planning horizon. A limited amount of inventory can be stored in cooled room of distribution center \( l \) with unit holding cost of \( \rho^l_{nt} \) in each planning period \( t \). Note that each finished product has shelf-life \( \tau_f \).

We assume that the demand for each kind of seafood in the scheduled time period at each distribution center is known. The demands have certain due dates. Unmet demand for a period is not allowed to be transferred to the next period. The unmet demand would be discarded at costs.

The problem for the fish company is to schedule production and distribution, in such a way that will minimize the total cost occurred in the production operations and inventory at each plant and at each distribution center.

For the mathematical description of the model, the following notations are defined.

**Sets and indices**

- \( T \) : Set of time period with index \( t \)
- \( P \) : Set of fish processed products with index \( p \)
- \( J \) : Set of plants with index \( j \)
- \( M \) : Set of raw fish resources with index \( m \)
- \( L \) : Set of distribution centers with index \( l \)

**Variables**

- \( x^t_{pj} \) : Quantity of product \( p \) produced to be traced in time period \( t \) from plant \( j \) (ton)
- \( z^t_{plj} \) : Quantity of qualified product \( p \) delivered to distribution center \( l \) from plant \( j \) in time period \( t \) (ton)
- \( u^t_{ij} \) : Additional amount of raw fish \( m \) to purchase in time \( t \) for plant \( j \) (unit)
- \( k^t_j \) : Number of workers required in time period \( t \) at plant \( j \) (man-period)
- \( k^{t-}_j \) : Number of workers laid-off in time period \( t \) at plant \( j \) (man-period)
- \( k^{t+}_j \) : Number of additional workers in time period \( t \) at plant \( j \) (man-period)
- \( I^t_{mj} \) : Inventory level of raw fish \( m \) at plant \( j \) in time period \( t \) considering shelf-life \( \tau_r \) (units)
- \( I^t_{pl} \) : Quantity of product \( p \) to be stored in distribution center \( l \) in time period \( t \) considering shelf-life \( \tau_f \) (units)
- \( B^t_{pj} \) : Under-fulfillment of product \( p \) in period \( t \) at plant \( j \) (units)
- \( Q^t_{pl} \) : Unmet demand of product \( p \) in time period \( t \) at distribution center \( l \) (units)
- \( y^t_{pj} \) : Binary variable to state whether a kind of seafood product is set up to be traced at plant \( j \) in time period \( t \)
- \( v^t_{pj} \) : Quantity of product \( p \) to be rejected at plant \( j \) in time period \( t \)
Parameters

- $c_{pj}^t$: Cost associated with producing $p$ fish products at plant $j$ in time period $t$ (Rp.)
- $c_{mj}^t$: Cost to buy additional raw fish for plant $j$ in time period $t$ (Rp.)
- $c_{w_r}^t$: Cost associated with regular worker at plant $j$ in time period $t$ (Rp.)
- $c_{w_a}^t$: Cost associated with additional worker at plant $j$ in time period $t$ (Rp.)
- $c_{w_l}^t$: Cost associated with laid-off worker at plant $j$ in time period $t$ (Rp.)
- $c_{ir}^t$: Inventory cost of raw fish $m$ at plant $j$ in time period $t$ (Rp.)
- $c_{uf}^t$: Cost associated with under fulfillment of fish product $p$ at plant $j$ in time period $t$ (Rp.)
- $c_{ct}^t$: Transportation cost to deliver fish product $p$ from plant $j$ to DC $l$ in time period $t$ (Rp.)
- $c_{id}^t$: Inventory cost of fish product $p$ at DC $l$ in time period $t$ considering shelf-life $\tau_f$ (Rp.)
- $c_{dp}^t$: Cost associated with discarding unmet quality of fish product $p$ at DC $l$ in time period $t$ (Rp.)
- $c_{tf}^t$: Cost associated with tracing process of fish product $p$ at plant $j$ in time period $t$ (Rp.)
- $c_{rf}^t$: Cost associated with dumping the rejected fish product $p$ at plant $j$ in time period $t$ (Rp.)
- $p_d^t$: Demand for product $p$ in period $t$ from plant $j$ (units)
- $u_i^t$: Upper bound on additional resources at plant $j$ (units)
- $s_{ipj}^t$: Amount of resource $i$ needed to produce one unit of product $p$ at plant $j$
- $s_a^t$: Amount of resource $i$ available at time $t$ at plant $j$ (units)
- $a_p$: Number of worker needed to produce one unit of product $p$ (man)
- $U_{ij}^{t<\tau_f}$: Upper bound on inventory of product $p$ at the plant $j$ in period $t$ before shelf-life (units)
- $U_{pl}^{t<\tau_f}$: Upper bound on inventory of product $p$ at the distribution center $l$ in period $t$ before shelf-life (units)

3. Mathematical Formulation

The objective of the problem is to minimize the total cost, mathematically can be written as follows.
Minimize 

\[ z = \sum_{p \in P} \sum_{j \in J} c_{pj}^t x_{pj}^t + \sum_{m \in M} \sum_{j \in J} c_{mj}^t u_{mj}^t + \sum_{j \in J} c_{wr}^t k_{j}^t + \sum_{j \in J} c_{wa}^t k_{j}^t + \]

\[ \sum_{j \in J} c_{wl}^t k_{j}^t - \sum_{m \in M} \sum_{j \in J} c_{ir}^t x_{mj}^t l_{mj}^t + \sum_{p \in P} \sum_{j \in J} c_{tf}^t p_{pj}^t B_{pj}^t + \]

\[ \sum_{p \in P} \sum_{j \in J} \sum_{i \in I} c_{f}^t i_{pj}^t x_{pj}^t + \sum_{p \in P} \sum_{j \in J} \sum_{i \in I} c_{r}^t i_{pj}^t y_{pj}^t + \]

\[ \sum_{p \in P} \sum_{j \in J} \sum_{l \in L} c_{t}^t i_{pj}^t z_{pj}^t + \sum_{p \in P} \sum_{j \in J} \sum_{i \in I} c_{d}^t i_{pj}^t l_{mj}^t + \sum_{p \in P} \sum_{j \in J} \sum_{i \in I} c_{q}^t i_{pj}^t Q_{pj}^t \]

\[ \sum_{p \in P} \sum_{j \in J} \sum_{i \in I} c_{t}^t i_{pj}^t x_{pj}^t + \sum_{p \in P} \sum_{j \in J} \sum_{i \in I} c_{r}^t i_{pj}^t y_{pj}^t + \]

(1)

Constraints to be met are as follows.

\[ \sum_{p \in P} r_{pj}^t x_{pj}^t \leq f_{ij}^t + u_{ij}^t \quad \forall j \in J, \forall t \in T, t < t_r, \forall j \in J \]

(2)

Constraint (2) presents the amount of fish resources needed to produce fish product \( p \) which should have the same amount of available raw fish resources at time \( t \), together with the additional raw resources needed. Note that the raw fish resources are within their shelf life \( t \), and have passed the tracing processes.

\[ x_{pj}^t \leq C_{pj}^t \quad \forall p \in P, j \in J, t \in T \]

(3)

Constraint (3) is to make sure that the production of all kind of fish products occur at the scheduled plant.

\[ u_{ij}^t \leq U_{ij}^t \quad \forall i \in M, \forall t \in T, \forall j \in J \]

(4)

Constraint (4) states that the additional raw resources have upper bound.

\[ \sum_{p \in P} a_{pj}^t x_{pj}^t \leq k_{j}^t \quad \forall j \in J \]

(5)

The number of regular workers needed is expressed in Constraint (5).

\[ I_{pj}^t = I_{pj}^{t-1} + \sum_{l \in L} Z_{pj}^t - D_{pj}^t \quad \forall p \in P, t \in T, l \in L, t < t_r \]

(6)

\[ I_{pj}^{tcr} \leq U_{pj}^{tcr} \quad \forall p \in P, t \in T, j \in J \]

(7)

\[ I_{pl}^{tcr} \leq U_{pl}^{tcr} \quad \forall p \in P, l \in L, t \in T \]

(8)

Constraints (6) to (8) present the inventories at the plant and distribution center. The shelf life are associated in those expressions.

\[ k_{j}^t = k_{j-1}^t + k_{j}^{j+} - k_{j}^{j-} \quad t = 2, \ldots, T, \forall j \in J \]

(9)

Constraints (9) describe that the available workers in any time period equal to the number of the previous period plus any change in the number of worker type during the current period.

\[ x_{pj}^t + B_{pj}^{t-1} + I_{pj}^t - B_{pj}^t = D_{pj}^t \quad \forall p \in P, \forall t \in T, \forall j \in J \]

(10)
Constraints (10) determine either the produced quantity to be stored in the inventory of the plant or to purchase from other company in order to fulfill the shortfall of meeting the demand.

$$\sum_{p \in P} Z_{pjl}^t \leq \sum_{p \in P} U_l^t \quad \forall j \in J, t \in T$$

Constraints (11) ensure that the amount of all kind seafood product from all plant can be stored in the distribution center inventories.

$$Z_{pjl}^t + Q_{pjl}^t \geq D_{pjl}^t \quad \forall p \in P, l \in L, j \in J, t \in T$$

Constraints (12) states that the amount of delivery from each plant plus the unmet demand should be at least the same amount of market demand.

$$Z_{pjl}^t + Q_{pjl}^t \geq D_{pjl}^t \quad \forall p \in P, l \in L, j \in J, t \in T$$

Constraints (13) – (15) express the nature of the variables used in the model.

### 4. Conclusions
In this paper, we develop a large scale mixed integer linear programming model for the integrated of production scheduling and distribution planning problem of fish industry at Aceh Province, Indonesia with deterministic demand with considering traceability of the products. 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 the quality of seafood.

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