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Flexible Job Shop Scheduling Problems Dealing with Expiration Issues

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Abstract**: *Fast-food products consider product safety aspects, such as expiration date. The existence of a fish canning industry in a flexible job shop (FJS) system is a matter of uncertainty and is a short-term production in manufacture industry. Stochastic programs are applied to make optimal decisions. However, the FJS is really challenging and even more complex added by expired date requirements and lot sizes. In this paper, an expiration issue in FJS on fish canning industry with lot size requirements is presented. The goals are to minimize the overall total cost , such as, production cost, raw materials cost, inventory cost of raw materials and finished goods, unused raw material cost due to decay, and unused product cost due to expiration. The problem is then modeled as a mixed integer programming (MIP) problem. A direct search is addressed to solve the model.***

Keywords: Job-shop Scheduling Problem, Integer Programing, Fish Canning Industry, Expiration, Lot Size.

I. INTRODUCTION

In line with technological development, many benefits are provided by fast food products since it can ease humans' work in processing it. Recent evidence shows that the importance of this fast-food product becomes a very interesting topic in various research fields. Fast-food products consider product safety aspect, such as expiration. This research is focused on fish canning industry. However, the problem arises regarding to whether the product of canning process meets the basic feasibility requirements, and can the manufacturer guarantee and ensure the product safety aspect? Canned fish is a high technology product which have high resistance of decay because it is easy to evaporate. Meanwhile, raw materials are quickly damaged in decaying process.

This paper contributes to the management of easily damaged or expired products. Many literatures discuss the perishable goods in terms of costs, profits, and managing storage at the retail level. [1] state that papers discussing production scheduling with expiration requirements are relatively rare, and papers discussing the flexible lot size of JSS is even rarer. However, expiration, in some cases, is a very important issue regarding to technical and operational levels of production planning. The expired feature on canned fish is related to food safety which is information about the best and safest expiration/ utilization limit of the canned fish product can be stored.

Products expiration is closely related to shelf life. In the fish canning industry, it poses a significant problem in the production planning process. Products expiration is one of the biggest challenges and constraints on the food safety industry. (e.g. [2]) state that to anticipate potential hazards (risks), it is needed to improve systemic control efficiency of food safety procedures. (e.g. [3]), suggest that food manufacturer should strive to ship products to their customers by reducing product storage time to avoid expiration, decay, and avoid shipping of products at its expired date. As a result, manufacturer operates more frequently and it leads to an increasing the cost of machine setup. Moreover, it can also affect the quality of products. To anticipate the rising costs occurred and to save product storage time in order to avoid expired, it is better to have a planning mechanism at the production scheduling aspect.

Production scheduling related to short-run production problems may be considered as job shop scheduling (JSS). The main purpose of job shop scheduling (JSS) is to allocate resources so as to complete a set of work with certain purposes. These objectives are varied, such as minimize completion time , minimum total costs incurred, and other objectives. Practically, JSS is a pattern of a set of jobs on a dozen of machines. For instance, there are n jobs $(J_1, ..., J_n)$ with varying sizes such that each job is necessarily to be scheduled on each machine m $(m_1, ..., m_m)$. Each job is operated on each machine, which requires a certain period of time. Due to the problem structure, JSS is known as a problem with combinatorial nature, and various optimization methods have been discussed on literatures. Many papers discuss job shop scheduling, where an operation can be processed only on a particular machine. However, in real world situations, there are generally many machines that can process certain operations, with different processing times. Choosing which machine will perform the operation of the available tasks is also an important consideration.

The problem of flexible job shop scheduling (FJSS) is a generalization of classic job shop issues. Each operation can be processed on any machines selected from limited candidate of subset machines. This is to find allocations for each operation and to determine the order of operations on each machine such that to minimize the make span. In the real situation, the existence of fish canning industry is one of flexible system of job shop. The manufacturing process is flexible in responding to design changes and order quantities so it is classified into a flexible job shop scheduling (FJSS) issues. In general, these problems are complicated, even the task of scheduling on two parallel machines to minimize the completion time ([4], [5]). The FJSS problem reflects the possible flexibility of a production system where one operation can be executed on different machines or one machine can perform different operations by a fast setup ([6]). Flexible Job Shop Problem (FJSP) with more than three jobs and two machines is also NP-hard ([7]). [8] discuss two types of flexible job shop issues; at first, the job could have alternate sequence operations and some machines are capable to perform each operation. In second place, the work has a fixed operation sequence but there are still alternative machines for each operation.

Several optimization approaches for FJSS have been addressed, such as exact algorithms, heuristic algorithms, and metaheuristic algorithms using priority rules. Exact algorithms such as the branch-and bound method ([9]). [10] propose Integer Programming (IP) to minimize the makespan as its objective function in solving FJSS. This study includes selection of alternative processes in determining the sequence of processes. IP formulation is also performed by ([11]) by comparing Branch and Bound, Simulated Annealing method, and Tabu search. However, an exact approach can not optimally solve large-scale problems.

As the FJSS problem belongs to NP-hard, it is not surprising that metaheuristic approaches are also used. For example, genetic algorithm (GA) ([12]-[16]), tabu search (TS) ([17]-[20], [21]), Particle Swarm Optimization (PSO) ([22]-[23]). Although metaheuristic algorithms can solve large-scale problems in a reasonable time, performance solutions worsen as the dimension of the problems growth.

In addition, heuristic approaches have been done, with neighboring search methods proposed by ([18], [24]-[26]). Optimization of ant colonies (ACOs) is used by ([27]-[28]). Although, in general, it has a strong advantage in terms of time calculation, the quality of the solution is not high.

In spite of the expiration products issue which is the biggest challenges and constraints for the fish canning industry, order quantity and the quantity ordered of an item need to be considered in order to fulfill the customer demand. [29] state that company must be able to meet customer demand in a minimum cost. Order quantity Determination and the quantity ordered of an item related to lot size and this is also a flexible job shop scheduling (FJSS) issue. Integrating lot size and scheduling is very important for many companies ([30]). [31] suggests that there are three important aspects that will determine the fulfilment of FJSS objectives, namely lot-size determination, sequencing and determining the required production capacity. In this paper, the issue of expiration dealing with FJS issues in the fish canning industry with lot size consideration is explained.

II. SHELF-LIFE

The duration of the accumulation of reactions resulting in the quality of food no longer acceptable is called as shelf -life. (e.g. [32]) reveal that shelf life is the duration required by food products, in storage conditions, to reach a certain level or level of quality degradation. The food product will be called damaged if the product has exceeded its optimum shelf life and in general the food decreases its nutritional quality even though its appearance is still good.

According to the Institute of Food Technologist, shelf life is the time interval between the time of production to the time of consumption where the product is in a satisfactory condition in terms of appearance, taste, aroma, texture, and nutritional value. The National Food Processor Association defines the shelf life as follows: a product is in its shelf life range if the product quality is generally acceptable for the purpose as desired by the consumer and as long as the packaging material still has integrity and protects the packaging contents. Determination of shelf life is done by observing the changes that occur in the product during a certain time. The shelf life duration should be designed to provide reasonably useful information to determine the shelf-life expectations of the product, when it is stored in the conditions set on the label. Product stabilization should, at least, extend shelf life of product types or beyond the cancellation specification limits, although it is shorter ([33]).

III.MATHEMATICAL MODEL WITH EXPIRATION CONSIDERATIONS

Some products can be produced gradually and produce at every stage which involves a parallel machine that has the same characteristics, speed and settings. All machines can produce any product and it is assumed that each machine can be used on a possible i, k operation at a time. The capacity of each available machine is limited and could be varied between periods and stages. Each period is represented for one week from the planning horizon. A period is divided into several sub periods as a variable size.

Demand for goods depends on the production of the next stage. The products can be produced in various sizes on one of the parallel machines at each stage. Production rates may vary between product and machine, but are constant throughout the planning horizon. Setting required between time periods is called as set up. A switch from one product to another requires a setup time when the machine is not productive. The cost and set up time depend on the order and can vary between machines. Set up is done when no product is being processed (setup carryover). At the beginning of the planning horizon, each machine is prepared for a particular product where the specification is selected certain products must be processed instantly at the time the order is assigned so that customer demand is fulfilled.

The important part of this research is production which has expired or shelf-life products. Shelf-life is defined as the maximum length of time when the raw material can be stored under certain conditions and can still be processed. In this research, the expired product is used as information which states that the best/ safest utilization time limit (food safety) of canned fish products can be stored under certain conditions. Therefore, inventory control or storage control is required in handling the order so that no unused materials exist, and safe products can be stored and still can be used or consumed. To know which inventory component is returned when it has expired, it should be noted the time period of the component received. If the component reaches the end of the shelf-life and expiration period, the component is returned. The component supply drawn is a supply that can not be used again after the expiration date. (e.g. [34]) describes most of data dealing with supply, for problems involving shelf-life, should be multiplied by adding a shelf-life index. In addition, the amount of deposits serves as reserves, we also need to know when the components should be ordered or received. Thus, the mathematical formulation model incorporating the expiration factor is by adding the index variables and the expired constraints in the model. Moreover, cost of withdrawal per unit of the returned component is also added. As the result, there will be additional costs not only for the component being withdrawn or returned but also for the holding fee.

Before the model formulation is made, it is necessary to make a model notation first. The model notation designs as follows:

A. *Nomenclature*

1) *Indices:*

r	The number of items ordered
j	Raw materials unit
i	Unit, product (state, item), $i \in I = \{1, 2, ... NI\}$
k	Unit, $k \in K = \{1, 2, ... NK\}$
l	Machine
t	Time period
s	Sub period

2) *Parameters*

I_{i0}	Initial Resulted Product Supply
v_{i0}	Initial Raw Material Supply
q_{jt}	Ordering Raw Materials j at time t
d_{it}	Demand on product i at time t
$b_{j,i}$	The number of raw material units j required for production process i
a_j	*Shelf-life* of raw materials j
a_i	*Shelf-life* product i
S_j	Size of ordering of raw material unit j
l_j	Grace period of ordering of raw material unit j
$x_{l,i,s}$	Time for production of product i on machine l in sub period s
$t'_{t,i,k}$	Time for setup change over of product i to product k at time t
f'_i	Cost of returning of product i /can

f_j Cost of disposal of the raw material unit j

c_j Cost of raw materials for j

p_i Production cost for product i

h_i Cost of storing production supplies for product i

m_j Storage cost of raw material unit j

A_i Fixed cost of production process for product i

g_j Fixed cost of ordering raw material unit j

$\delta_{i,k}$ Cost for set changeover from product i to product k

K_i Production capacity for product i

L_i Ordering capacity for product i

$K'_{l,t}$ Capacity of machine l in period t

$M_{l,i,t}$ Upper bound $x_{l,i,s}$ or upper bond or production time limit of product i on machine l in sub period s

$\pi_{j,t}$ Possible unit of raw material j at production time interval t

3) Variables

$x_{i,t}$ The number of units i produced at time t

$I_{i,t}$ Production inventory for product i at time t

$Q_{j,t}$ Ordering unit of raw material j at time t

$V_{j,t,r}$ Stock for raw material unit j at time t based on quantity of goods ordered

$C_{j,r,t}$ The use of raw material unit j based on quantity of goods ordered at time t

Y_i The number of returned product of type i

Z_j The number of disposal of raw material unit j

$y_{i,t}$ Binary variable of ordering product type i at time t

$w_{j,t}$ Binary variable of ordering schedule of raw material unit j at time t

$W_{j,t}$ Binary variable of fixed ordering of raw material unit j at time t

$\alpha_{l,i,k,s}$ Binary variables in case of change over product type i to product type k on machine l in sub period s

$\beta_{l,i,s}$ Binary variables in case of setting up machine l for product type i in sub period s

Subsequently, a formulation model to present the FJSS problem by considering the lot-size is developed based on the classical lot size problem developed by ([35]-[36]). In addition, the expiration issues are also considered besides the lot-size issues.

B. Function Goals

Minimize

$$\sum_{j=1}^{J}\sum_{t=1}^{T} g_j W_{j,t} + \sum_{j=1}^{J}\sum_{t=1}^{T} g_j w_{j,t} + \sum_{j=1}^{J}\sum_{t=1}^{T} \pi_{j,t} \left[\sum_{j=1}^{J}\sum_{t=1}^{T} c_j Q_{j,t} + \sum_{j=1}^{J}\sum_{t=1}^{T}\sum_{r=0}^{R} m_j V_{j,t,r} + \sum_{j=1}^{J} f_j z_j \right] \quad (1.\ A)$$

Minimize

$$\sum_{i=1}^{N}\sum_{t=1}^{T} p_i x_{i,t} + \sum_{i=1}^{N}\sum_{t=1}^{T} A_i y_{i,t} + \sum_{l=1}^{L}\sum_{i=1}^{N}\sum_{k=1}^{N}\sum_{s=1}^{S} \delta_{i,k}\alpha_{l,i,k,s} \tag{1. B}$$

Minimize

$$\sum_{i=1}^{N} f_i Y_i + \sum_{i=1}^{N}\sum_{t=1}^{T} \pi^*_{i,t}\left[\sum_{i=1}^{N}\sum_{t=1}^{T} h_i I_{i,t} + \sum_{i=1}^{N}\sum_{t=1}^{T} K_i I_{i,t}\right] \tag{1. C}$$

Constraints

$$I_{i,t} = I_{i,t-1} - X_{i,t} - d^{\sigma}_{i,t},\ \forall i \in N,\ \forall t \in T,\ \forall \sigma \in \Omega. \tag{2}$$

$$\sum_{r=0}^{t} V_{j,t,r} = v_{i,0} + S_j q_{j,t} - \sum_{i=1}^{N} b_{j,i} X_{i,t},\ \forall j \in J$$

$$\forall t \in T,\ \forall r \in T,\ t = 1 \tag{3}$$

$$\sum_{r=0}^{t} V_{j,t,r} = \sum_{r=0}^{t-1} V_{j,t-1,r} + S_j q_{j,t} - \sum_{i=1}^{N} b_{j,i} X_{i,t},$$

$$\forall j \in J,\ \forall t \in T, 1 < t < a_j, t \le l_j \tag{4}$$

$$\sum_{r=t+1-a_j}^{t} V_{j,t,r} = \sum_{r=t+1-a_j}^{t-1} V_{j,t-1,r} + S_j q_{j,t} - \sum_{i=1}^{N} b_{j,i} X_{i,t},$$

$$\forall j, t \in T, T \ge a_j, t \le l_j \tag{5}$$

$$\sum_{r=0}^{t} V_{j,t,r} = \sum_{r=0}^{t-1} V_{j,t-1,r} + S_j Q_{j,t-l_j} - \sum_{i=1}^{N} b_{j,i} X_{i,t},$$

$$\forall j, t \in T, 1 < t < a_j,\ t > l_j \tag{6}$$

$$\sum_{r=t+1-a_j}^{t} V_{j,t,r} = \sum_{r=t+1-a_j}^{t-1} V_{j,t-1,r} + S_j Q_{j,t-l_j} - \sum_{i=1}^{N} b_{j,i} X_{i,t},$$

$$\forall j, t \in T, T \ge a_j, t > l_j \tag{7}$$

$$\sum_{i=1}^{N} b_{j,i} X_{i,t} = \sum_{r=0}^{t} e_{j,r,t},\quad \forall j \in J,\ \forall t \in T,\ t < a_j. \tag{8}$$

Next, the constraint occurs in maintaining the availability of existing raw materials.

$$V_{j,t,r} = S_j q_{j,t} - e_{j,r,t},\qquad \forall j \in J,\ \forall t \in T,\ \forall r \in T,\ r = t,\ t \le l_j \tag{9}$$

$$V_{j,t,r} = S_j Q_{j,t-l_j} - e_{j,r,t},\qquad \forall j \in J,\ \forall t \in T,\ \forall r \in T,\ r = t,\ t \le l_j \tag{10}$$

$$V_{j,t,r} = V_{j,t-1,r} - e_{j,r,t},\qquad \forall j, t, r, t - r < a_j, 1 \le j \le J, 1 \le r \le T \tag{11}$$

A constraint of raw materials disposal due to the shelf-life exceeded.

$$Z_j = \sum_{t=a_j}^{T} V_{j,t,t+1-a_j},\qquad \forall j \in J \tag{12}$$

For the production capacity of processed fish can be written as

$$Y_i = \sum_{t=a_i}^{T} I_{i,t,t+1-a_i}, \qquad \forall i \in I \tag{13}$$

$$X_{i,t} \le K_i, \qquad \forall i \in N, \forall t \in T \tag{14}$$

$$\sum_{i=1}^{N}\sum_{s\in S_t} x_{lis} + \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{s\in S_t} st_{ik}\alpha_{lijs} \le K'_{lt} .$$

$$\forall t = 1,\dots,T;\ l = 1,\dots,L \tag{15}$$

$$x_{lis} \le M_{lit}\beta_{lis} \qquad \forall l = 1,\dots,L;\ i = 1,\dots,N;\ t = 1,\dots,T;\ s \in S_t \tag{16}$$

Constraints of ordering capacity can be written as

$$Q_{j,t} \le L_j, \qquad \forall j \in J, \forall t \in T \tag{17}$$

Constraints toward binary variables of preparing and ordering costs can be written as

$$X_{i,t} \le M_{yi,t}, \qquad \forall i \in N, \forall t \in T \tag{18}$$

$$Q_{j,t} \le MW_{j,t}, \qquad \forall j \in J, \forall t \in T \tag{19}$$

$$q_{i,t} \le Mw_{j,t}, \qquad \forall j \in J, \forall t \in T . \tag{20}$$

Constraints of negativity and binary can be written as

$$X_{i,t}, I_{i,t}, Q_{j,t}, V_{j,t,r}, C_{j,r,t}, Z_j \ge 0, \forall i, j, r \tag{21}$$

$$y_{i,t}, W_{j,t}, w_{j,t} = 0 \tag{22}$$

$$M_{lit} = Min\{K'_{lt}, maks_{k:p_{ki}\neq 0} \frac{\sum_{h=t}^{T} d_{kh}}{p_{ki}};$$

$$\forall l = 1,\dots,L;\ i = 1,\dots,N;\ t = 1,\dots,T \tag{23}$$

Constraints (23), (24), and (25) the correlation between setup of two successive sub-periods determines the turn of changeovers and maintains the setup.

$$\sum_{i=1}^{N} \alpha_{liks} \le \beta_{lis}$$

$$\forall l = 1,\dots,L;\ k = 1,\dots,N;\ s = 1,\dots,S \tag{24}$$

$$\beta_{li(s-1)} = \sum_{j=1}^{N} \alpha_{liks}$$

$$\forall l = 1,\dots,L;\ i = 1,\dots,N;\ s = 1,\dots,S \tag{25}$$

$$\sum_{j=1}^{N} \alpha_{liks} = \beta_{lis}$$

$$\forall l = 1,\dots,L;\ i = 1,\dots,N;\ s = 1,\dots,S \tag{26}$$

IV. THE PROPOSED ALGORITHM

Stage 1. Solve the problems of Eq. (1) to Eq. (26) by relaxing the integer requirement. If the continuous optimal solution is satisfied the integer requirement. Stop. The optimal integer feasible solution is obtained. Otherwise, Go To Step1.

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

(This choice is motivated by the desire for minimal deterioration in the objective function, and clearly corresponds to the integer basic with smallest integer infeasibility).

Step 2. Do a pricing operation

$$v_{i*}^T = e_{i*}^T B^{-1}$$

Step 3. Calculate $\sigma_{ij} = v_{i*}^T \alpha_j$

With corresponds to

$$\min_j \left\{ \left| \frac{d_j}{\alpha_{ij}} \right| \right\}$$

Calculate the maximum movement of nonbasic *j* at lower bound and upper bound. Otherwise go to next non-integer nonbasic or superbasic *j* (if available). Eventually the column *j** is to be increased form LB or decreased from UB. If none go to next *i**.

Step 4. Solve $B\alpha_{j*} = \alpha_{j*}$ for α_{j*}

Step 5. Do ratio test for the basic variables in order to stay feasible due to the releasing of nonbasic *j** from its bounds.

Step 6. Exchange basis

Step 7. If row $i* = \{\varnothing\}$ go to Stage 2, otherwise Repeat from step 1.

Stage 2. Pass1 : move integer infeasible superbasics by fractional steps to reach complete integer feasibility. Pass2 : adjust integer feasible superbasics. The objective of this phase is to conduct a highly localized neighbourhood search to verify local optimality.

V. CONCLUSION

This paper presents a mathematical model of FJSS dealing with expiration issues and considering the lot-size in fish canning industry. The model is a large scale mixed integer program. The concept of superbasic variables is exploited for solving the model.

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