

System Analysis of a Prawn Freezing Plant - I.

Analysis of Raw Prawn Preparation and Freezing Operations

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A system analysis approach has been taken to study and analyse various operations of a hypothetical prawn freezing plant. Results of analysis for processing three different products showed that the data on rate of prawn handling by a number of workers can be fitted to linear relations, and optimum operating conditions can be arrived at with minimum freezer idle time and maximum number of loads per freezer. It has been further found that scheduling of prawn preparation time is very crucial during the early stage of processing.

Prawn is a high value sea food product in terms of export earnings in many tropical countries of the world. Among them India has become the leading exporter of frozen prawn as a result of a regular increasing trend of prawn landings and subsequent increase in the number of freezing units to process the prawns. However, most of the freezing units are faced with problem of running at much below the installed capacity, because of fluctuations in the supply. The aquaculture farm produce from coastal areas is also not sufficient to augment the production. On the other hand, when there is a bumper catch in peak seasons there may arise problems of freezing the requisite stock due to non-availability of number of freezers, labour, and space in the cold store. Moreover, there may be fluctuations in demand of a particular product by the importers.

For a rational approach to these problems, system analysis of prawn freezing units is imperative. The objectives would be to study and analyse the various operations of the process flow in a freezing plant, to maximise the raw prawn procurement and to optimise resource utilisation. The plant may procure raw prawn from the marine fisheries and/or aquaculture

farm and process them into one or more products following the operations - heading and/or peeling, cleaning, grading and packing in the preparation line, and finally freezing and storing in the cold storage till shipment. The present report incorporates the results of analysis of a hypothetical freezing plant with respect to these operations and suggest suitable measures for better utilisation of available resources.

A Hypothetical Prawn Freezing Plant

The freezing plant processes three different varieties of prawn (P₁, P₂ and P₃) for three frozen products: one headless shell-on (HL) and two peeled and undeveined (PUD₁ and PUD₂) respectively. The operations involved for the three products are shown in Fig.1. It is assumed that the raw prawns for PUD products are received sometimes in quantities more than the capacities of the freezers and, therefore, frozen directly after heading and then stored for future use. This frozen stock is processed along with fresh P₂ and P₃ when they are received in less quantities. This operation is referred to as "double processing."

The plant operates with two plate freezers of 440 kg/load each. Prawns are

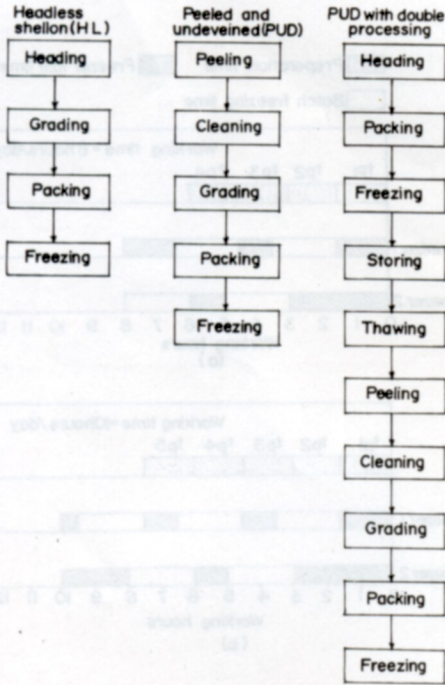


Fig. 1. Process flow of the products in the hypothetical freezing plant.

packed as 2.2 kg slabs and frozen in about 120 min time. In a particular batch operation the whole time of processing is divided into time of preparation and freezing time, and it is likely that 220 slabs for one load may not be prepared within the time of freezing of the previous load. This will, then, lead to idle time for the freezer and for the workers also. If, on the other hand, the supply of raw prawns is more than the capacity of the workers, the raw prawn may be held up in the preparation stage. Idle time for workers leads to loss in man- hour, i.e. less utilisation of resource. Therefore estimation of idle time both for the freezers and workers should be made in order to find out the best operating conditions. For this purpose a two step procedure would be useful: (a) analysis of data of various operations, and (b) estimation of idle time.

Analysis of data of Various Operations

Let us suppose that the data are available for each operation as rates of raw prawn

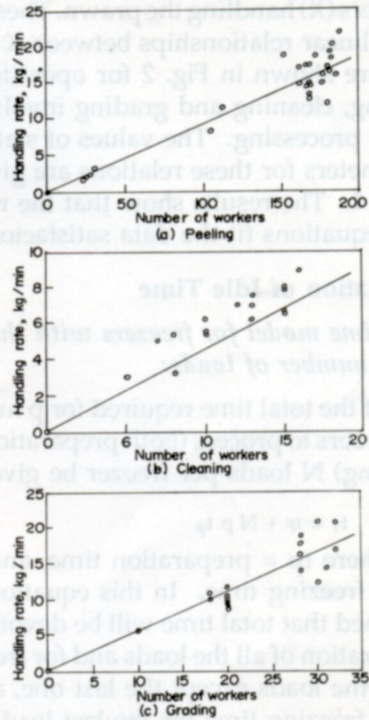


Fig. 2. Linear relationship between prawn handling rate and number of workers during peeling, cleaning and grading of PUD prawn

Table 1. Empirical relations and estimates of statistical parameters.

Operations	Empirical relations	Standard error of estimate	Prediction interval at 10% significant level	Correlation coefficient
PUD ₁				
Peeling	$Y = 0.095 X$	2.08	$Y \pm 3.54$	0.950
Cleaning	$Y = 0.470 X$	1.07	$Y \pm 1.88$	0.994
Grading	$Y = 0.578 X$	2.75	$Y \pm 4.73$	0.894
PUD ₂				
Peeling	$Y = 0.067 X$	0.39	$Y \pm 0.68$	0.995
Cleaning	$Y = 0.435 X$	1.23	$Y \pm 2.20$	0.886
Grading	$Y = 0.452 X$	1.74	$Y \pm 3.02$	0.910
HL				
Heading	$Y = 0.410 X$	0.989	$Y \pm 1.70$	0.999
Grading*	mean = 8.576	S.D. = 3.146		

*The number of graders remaining constant, only mean is calculated.

handled (Y kg/min) and the number of workers (X) handling the prawn. These data yield linear relationships between X and Y and are shown in Fig. 2 for operations of peeling, cleaning and grading involved in PUD₁ processing. The values of statistical parameters for these relations are given in Table 1. The results show that the regression equations fit the data satisfactorily.

Estimation of Idle Time

Idle time model for freezers with the same number of loads:

Let the total time required for p number of freezers to process (both preparation and freezing) N loads per freezer be given by

$$t_T = t_F + N p t_p$$

Where t_p = preparation time, and t_F = batch freezing time. In this equation it is assumed that total time will be devoted for preparation of all the loads and for freezing of all the loads except the last one, and t_F is the freezing time for the last load.

The total idle time (t_i) during processing of n th freezer in N number of loads is composed of two components:

(a) Initial idle time (I_i) - the idle time before the first load for each freezer,

$$\text{i.e. } I_i = n t_p \quad \dots(2)$$

where $n = 1, 2, 3, \dots$ the sequence number of freezers.

(b) Intermediate idle time (I_m) - it is the difference between the freezing time and preparation time of one load for p number of freezers, i.e.

$$I_m = (N-1) (p t_p - t_F) \quad \dots(3)$$

Assuming that the freezers are loaded one by one according to their sequence numbers, the total idle time for n th freezer in N loads is given by

$$(t_i)_n = n t_p + (N-1) (p t_p - t_F) \quad \dots(4)$$

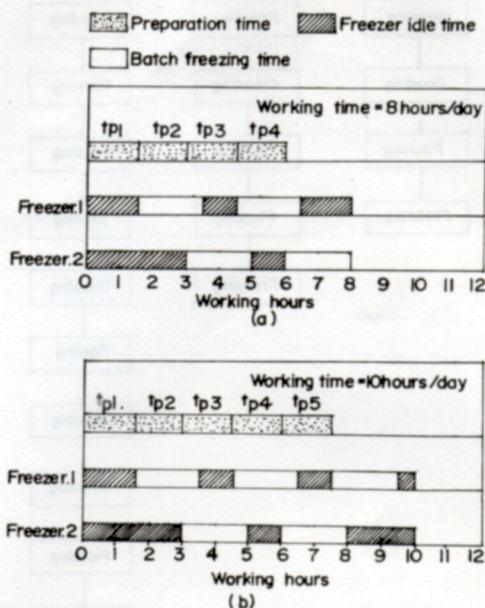


Fig. 3. Plant operation showing freezer idle time

The total idle time during processing for p number of freezers is given by

$$t_i = p (p + 1)/2 \cdot t_p + p (N-1) (p t_p - t_F) \quad \dots(5)$$

If the total working hours in a day is considered, the total freezer idle time (t_o) is

$$t_o = p (t_T - N t_F) \quad \dots(6)$$

The validity of Eqs. (1) - (6) can be tested by taking examples and depicting the freezing plant operations as in Fig 3(a):

Example 1. With $p = 2$, $t_T = 8$ h, $t_p = 1.5$ h and batch freezing time = 2 h,

$N = 2$, $t_i = 6.5$ h and $t_o = 12$ h

Example 2. With $t_T = 10$ h,

$N = 2.67 \approx 2$, $t_i = 6.5$ h and $t_o = 12$ h

The fractional value of N has been neglected and only the integer has been considered, since it is not possible to run the freezer for a fraction of its stipulated freezing time.

Since the freezer idle time for the working hours are considerably high and uneconomical, the following idle time model for freezers with different number of loads have been suggested.

Idle time model for freezers with different number of loads

Let the freezer No. 1 be loaded first. Eq. (4) is then modified for freezer No.1 by putting $n = 1$, $p = 2$ and $N = N_1$ as

$$(t_i)_1 = t_p + (N_1 - 1) (2t_p - t_f) \quad \dots(7)$$

For freezer No.2, by putting $n = 2$, $p = 2$ and $N = N_2$,

$$(t_i)_2 = 2t_p + (N_2 - 1) (2t_p - t_f) \quad \dots(8)$$

where $N_1 + N_2 = N_T$, total number of loads, and $N_1 = N_2 = N_T/2$ or $N_1 = N_T/2 + 0.5$ for $N_T =$ even or odd number respectively. If the freezer No.2 is loaded first, the same models will be valid with subscripts N_1 and N_2 interchanged. Application of Eqs. (7) and (8) has been illustrated in example 3 and Fig.3(b) as follows:

Example 3. With $t_T = 10$ h, $t_f = 2$ h and $t_p = 1.5$ h,
 $N_T = (10 - 2)/1.5 = 5.33 \approx 5$

Assuming that Freezer No.1 is loaded first,

$$N_1 = 3, N_2 = 2, (t_i)_1 = 3.5 \text{ h}, (t_i)_2 = 4.0 \text{ h}$$

$$\text{Total idle time} = 7.5 \text{ h and } t_0 = 10 \text{ h.}$$

This calculation can be repeated for various working hours per day and for various preparation times to get the values of t_i , t_0 and N_T . The results of one set of such calculation for 20 h working day performed with the help of a computer programme are given in Fig.4.

It is observed from Fig.4a that from 60 min to 100 min preparation time, number of freezer loads changes rapidly with the change of preparation time. From 100 min onwards the slope of the curve decreases and become almost constant from about 200 - 300 min. Since usually processors will try to have maximum number of freezer loads, it is better to have 60 min preparation

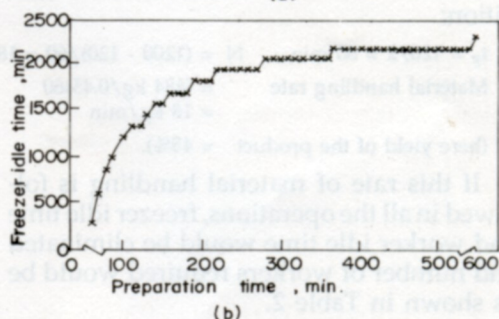
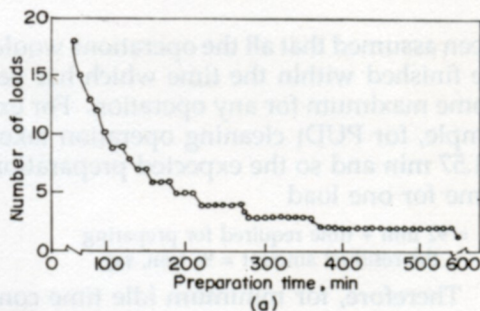


Fig. 4. Number of loads and freezer idle time as function of preparation time.

time for that purpose. Further much attention should be taken in maintaining the preparation time within 60 - 100 min, because even 5 - 10 min increase in preparation time leads to reduction of number of freezer loads. The plot of total idle time v. preparation time during total working hour of a day (Fig.4b) follows the same pattern of change with the preparation time but with an increasing trend, which is quite obvious.

Estimation of operating conditions Based on Minimum Idle Time

For minimum idle time during processing the intermediate idle time should be zero, i.e.

$$\begin{aligned} p(n-1)(p t_p - t_f) &= 0 \\ \text{i.e., either } p &= 0, N = 1 \text{ OR } p t_p - t_f = 0 \\ \text{ie, } t_p &= t_f/p \end{aligned} \quad \dots(9)$$

For the hypothetical plant under study running for 20 h/day and engaging the required number of workers, preparation time, number of loads and total idle time have been calculated for each product and tabulated in Table 2. In each case it has

been assumed that all the operations would be finished within the time which has become maximum for any operation. For example, for PUD₁ cleaning operation takes 91.57 min and so the expected preparation time for one load

$$= 92 \text{ min} + \text{time required for preparing the residual amount} = 95 \text{ min, say.}$$

Therefore, for minimum idle time condition:

$$t_p = 120/2 = 60 \text{ min, } N = (1200 - 120)/60 = 18$$

$$\text{Material handling rate} = (484 \text{ kg}/0.45)/60 = 18 \text{ kg/min}$$

$$(\text{here yield of the product} = 45\%).$$

If this rate of material handling is followed in all the operations, freezer idle time and worker idle time would be eliminated and number of workers required would be as shown in Table 2.

Table 2. Comparison of processes for the three products

Operations	No. of workers	Rate of handling, kg/min	With Idle Time			Total idle time, min	With minimum Idle Time				
			Required time, min	Prepn. time, min	No. of loads		Required rate of handling, kg/min	No. of workers	Prepn. time, min	No. of loads	Total idle time, min
PUD ₁ (Quantity = 1076 kg, yield = 0.45)											
Peeling	150	14.25	75.5						190		
Cleaning	25	11.75	91.57						38		
Grading	30	17.34	62.05						31		
Packing	6	19.56	55	95	11	1080	18.0	6	60	18	180
PUD ₂ (Quantity = 1274 kg, yield = 0.38)											
Peeling	150	10.05	127						317		
Cleaning	25	10.88	117						49		
Grading	30	3.56	94						47		
Packing	6	19.56	55	135	8	1440	21.23	6	60	18	180
HL (Quantity = 706 kg, yield = 0.67)											
Heading	40	16.40	43						29		
Grading	20	8.58	82.3						23		
Packing	15	16.05	44	85	12	960	11.77	11	60	18	180

If a prawn freezing plant processes only a particular variety of prawn, then the processor has to employ workers corresponding to the variety of prawn as shown in Table 2 under minimum idle condition. This situation may occur if prawns are received from aquaculture farms where usually a particular size and variety of prawns will be cultured and harvested. In

capture fishery-based plants, if the processor is able to change the number of workers according to the variety available in a particular day, he can also follow the same schedule of work and engage workers for each variety as given in Table 2. But in marine catch, particular size and variety of prawns are not available daily. The catch fluctuates seasonally and daily. So for plants based on marine catch it is suggested to employ workers as per the variety which consumes maximum preparation time. Under the present case it is the PUD₂ variety on the basis of which number of workers can be engaged.

From the results of analysis of various operations involved in processing of three different products in a hypothetical freezing plant it has been found that the data can be analysed with the help of a data fitting

technique and number of workers for each operation can be suggested to arrive at minimum freezer idle time and maximum number of loads per freezer. Results further showed that scheduling of preparation time is very crucial during the early stage of processing, because slight changes of preparation time leads to fall in the daily capacity of the plant.