

AN ABSTRACT OF THE THESIS OF

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Abstract approved: _____
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Shrimp gradually has become a significant portion of seafood in Oregon during the last two decades. The attention is attracted to the economic, technology, and efficiency of resource management, harvesting, processing, and marketing.

This thesis is a study of the path of Pacific pink shrimp, *Pandalus Jordani*, from the ocean, through harvesting and processing, to the cold storage of seafood processing plants. Major concerns of this study are the costs and benefits of shrimp processing machinery, processing methods, and management of all resources related to the complete processing system. Cause-and-effect diagrams, economic analyses, unit-time process charts, control charts, and resource planning and management (RPM) models are illustrated.

Both major and auxiliary equipment are illustrated by pictures and evaluated by cost-benefit curves and tables. The economic effects are clearly defined by decision-table steps which show alternate break-even points dependent upon each processor's data base.

In addition to economic criteria concerning present operations, cause-and-effect diagrams with alternate resultant RPM models can be used for more effective long range decisions. Important pertinent details and their future profit and quality effects can be identified by predicted productivity differences from unit-time flow charts, quality control measures, training performances and the differentials between initial raw shrimp costs and the final shrimp meat product selling prices.

SHRIMP PROCESSING IN OREGON-
PLANNING, ANALYSIS AND CONTROL

by

CHI MING CHEUNG

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SHRIMP PROCESSING IN OREGON- PLANNING, ANALYSIS AND CONTROL

I. INTRODUCTION

Annual landing of shrimp, primarily *Pandalus*, in Oregon increased rapidly during the last ten years from 1.75 million pounds in 1965 to over 19 million pounds each year in the last three years. Oregon is the second highest shrimp landing state of the entire Pacific coast since 1966.^{1/} Annual landing record since 1957 is shown in Figure 1. In Figure 2, harvesting zones of shrimp fisheries is exhibited and the landing data is revealed in Table I. The 1974 commercial catch of fish and shellfish in Oregon weighed almost 96 million pounds, with a dockside value of about 34.4 million dollars. Shrimp constitutes 13% of the total value.^{2/} As shrimp becomes a more significant natural food resource, studies are made to learn its social and economic implications. This study concentrates in the processing section - in 1975 the processing of over 20 million pounds of shrimp. Economic analysis of equipment, facility layout, quality control, processing procedure, and processing cost are areas considered in this thesis.

The less that happens to a shrimp - from the time it is dropped on the trawler's deck to the moment it is ready to be tasted - the better it is likely to be delicious. Once a shrimp is caught out from the sea,

^{1/} Alaska always maintains the highest shrimp landing record. Over one hundred million pounds per year was recorded in 1973 and 1974.

^{2/} Information obtained from Marine Science Center exhibition in Newport.

it deteriorates rapidly. It has to be handled as little as possible, processed promptly, and kept at a constant low temperature during distribution. Time and temperature control are important factors as a shrimp is being harvested, processed, and distributed.

Pacific pink shrimp, *Pandalus Jordani*, is the major specie harvested along the Oregon coast. The trawler's facilities, the sizes of the trawler's hold, and the distance from port affect the methods of harvesting. Generally, trash fish and undesireable marine creatures are sorted out from the shrimp after the catch is laid on the deck. Then shrimp are iced in layers and stored in holds. When shrimp are delivered to a processing plant, they are washed and any remaining undesirables are removed. Then they are either reiced and stored or processed immediately. Most processing plants in Oregon cook and peel their shrimp. After inspection, cooked-peeled shrimp are generally packed in five-pound cans and frozen in cold storage. One plant peels its shrimp raw; then cooks them, cans them, and retorts them. The processing cost and quality very much depends on the procedure and equipment being used.

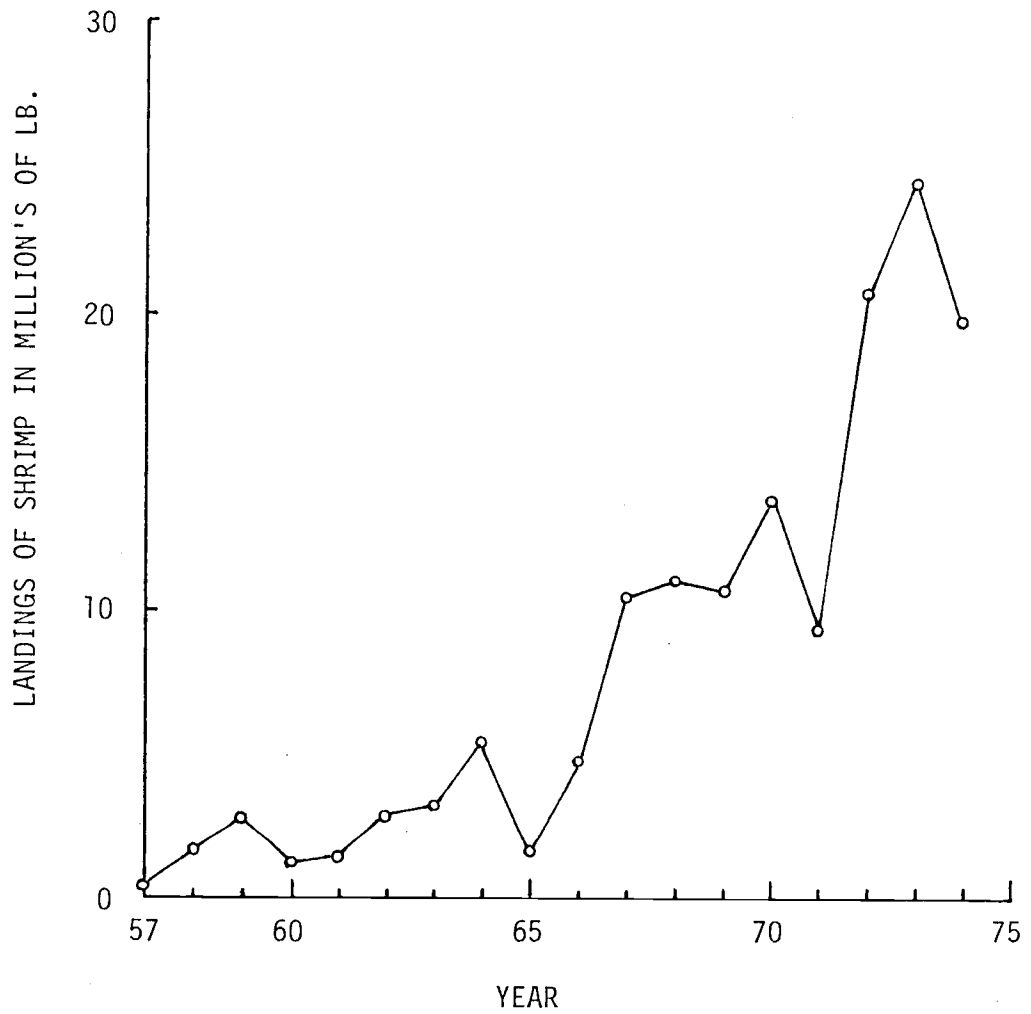


Figure 1. Annual landings of shrimp in Oregon, primarily *Pandalus* species, 1957-1974 (17).

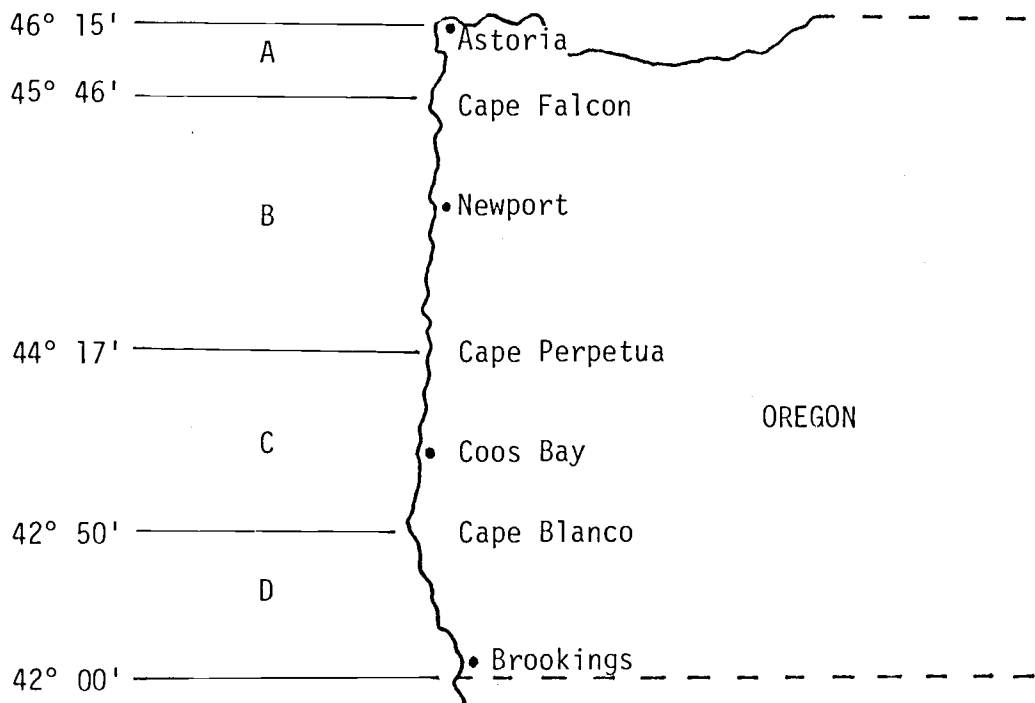


Figure 2. Harvesting zones of shrimp fishery in Oregon (17).

TABLE I. ANNUAL LANDING OF SHRIMP AT ZONES SHOWN IN FIGURE 2, 1965-1974 (17).

Ocean Shrimp (<i>Pandalus jordani</i>) Catch in 1,000's of lbs.				
Year	Area A	Area B	Area C	Area D
1965	11.6	83.4	921.6	722.7
1966	24.6	837.7	2766.6	1216.0
1967	1797.4	4299.7	2759.9	1482.2
1968	1771.7	2986.8	4301.6	1614.7
1969	1259.8	4090.4	3812.9	17.0
1970	669.7	5189.9	4889.8	1732.5
1971	430.2	5623.3	1534.4	1625.3
1972	14.1	9296.6	7011.3	2863.3
1973	105.9	8841.5	10757.4	3047.9
1974	682.9	5387.7	5661.5	1290.0

System Under Study

Consultation with Oregon seafood processors and their employees, equipment manufacturers, and Oregon State University sea grant researchers led to the conclusion of the system under study. The system and its interactions begins before the fisherman goes to sea and ends when the shrimp are eaten by the consumer. Major emphasis is placed upon the following:

1. Economic analysis of equipment
2. Direct labor time in processing
3. Statistical quality control in the system
4. Building mathematical models for the system
5. Training of workers

Steps in the process are treated as subsystems of the system under study. Reliable supply of good quality shrimp from fishermen, adequate facilities, skillful workers, and sound management are important to produce a low cost and good quality shrimp product. All these variables can be visualized as resources in the system. The system's environment which the decision maker of the system has indirect influence over the interacting elements is shown in Figure 3.

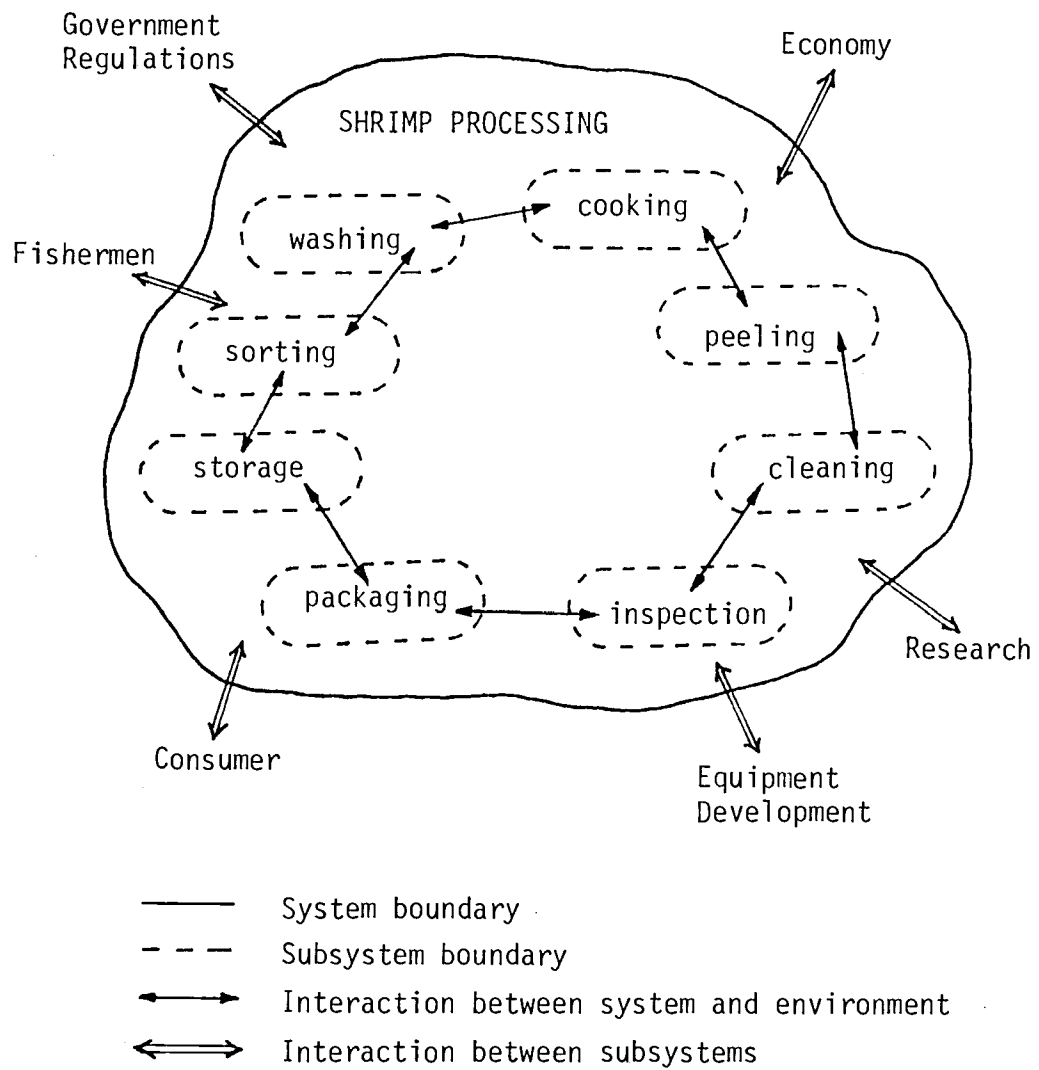


Figure 3. System, subsystems, and environment.

System Analysis

System analysis emphasizes the investigation of the whole system rather than the component systems and attempts to optimize the whole system's effectiveness instead of improving the efficiency of its subsystems. However, this study looks into both - the whole system and its subsystems. While increasing productivity, optimizing profit, and improving shrimp product quality are essential goals for the whole system, improved coordination and maximum effectiveness of subsystems are continuing goals. Quality control, processing cost, facilities layout, equipment, and processing procedures are considered when the whole system is being investigated. Deice washers, peelers, separators, washer-cleaners, air blowers, and shakers are analysed in the subsystems studies. Cause-and-effect diagrams are used to identify both cause and effects. Economic analyses are applied in the justification of equipment utilization. Processors can follow the technique to conduct their own analysis with their own data and goals. Unit time flow process charts can be developed to show direct labor costs of processing. It can be used to develop processing time standards to monitor the usage of direct labor time in the process. Resource planning and management models are employed to analyze the efficiency of the whole processing system. Rational and linear programming models are presented in this study.

General Goal of Study

Ten years ago the shrimp production in Oregon was small and had an uncertain profit position. The cost of processing was high. Mechanical equipment was unavailable and shrimp were picked manually. As a mechanical peeler and its accessory equipment were introduced and adopted by seafood processors, processing cost was reduced 37 cents per pound. Since the 1970 study, further reductions in cost were made (7). However, there are still problems in the shrimp processing industry:

1. Uncertainty of the supply of shrimp from week to week, year to year;
2. Only six and a half months production due to resource management policies of regulatory agencies (17);
3. Uncertain quality of raw shrimp from fishermen;
4. Quality control in processing;
5. Lack of information on factors affecting price of product;
6. Effects of new equipment on processing costs and quality;
7. Inadequate engineered standards for the evaluation of alternate methods of shrimp processing.

This study looks into all the above problems and tries to come up with feasible and practical solutions to improve the efficiency of the industry.

A specific product of this thesis is the presentation of cost-benefit curves and decision tables which will enable processors to evaluate more accurately the effects of increased mechanization.

Structure of Thesis

In this introduction chapter, subject under study, shrimp processing, is briefly described. The system, its subsystems, and its environment are defined. Scope and purpose of this study is mentioned. The plan of development is expressed in the following chapters.

Chapter II provides insights into the basic concepts of cause-and-effect diagrams, economic evaluations, unit time flow process charts, and the resource planning and management model.

In Chapter III, a detailed description of shrimp processing in Oregon before the introduction of mechanical peeler and other processing equipment.

In Chapter IV, a brief history of the research work done by Oregon State University Industrial Engineers is presented.

Chapter V is a detailed description of current practices in the shrimp processing industry. This chapter looks into the growth and changes which have occurred in the industry.

Chapter VI shows how economic evaluation of processing equipment is performed. Graphs and tables are used to illustrate important points.

Chapter VII deals with the macroscopic analysis of the system. Unit time flow process charts, statistical control charts, RPM models, and training methods are introduced in this chapter.

Chapter VIII is a summary of the analyses.

Chapter IX contains the conclusions of the study and recommendations for future research.

II. METHODOLOGY

Cause-And-Effect (C&E) Diagram

Most of the graphical tools for analyzing systems, such as flow process charts, Gantt charts, critical path scheduling charts, are time oriented and mathematical in nature. Cause-and-effect diagrams provide a more basic and flexible way to construct the causal relationship of factors inside a system. Ishikawa first used a cause analysis diagram in 1953. Riggs and Inoue developed and expanded the Ishikawa diagram into C&E diagram in 1970. The framework of a C&E diagram is shown in Figure 4. The problem definition or goal is written in a hexagonal box. Arrows at the left point towards the box representing principal causes and those at the right point away from the box representing main effects. Smaller arrows represent sub-factors of principal cause or main effect. Examples of C&E diagrams can be found in pages 67, 164, and 195.

In constructing a C&E diagram, principal causes and main effects are identified first. Subsequently, related factors or sub-factors are added until all causes and effects are considered. Cause-and-effect diagram is an excellent analysis and planning tool for identification of all variables in a system. It is a good communication tool and easy to construct.

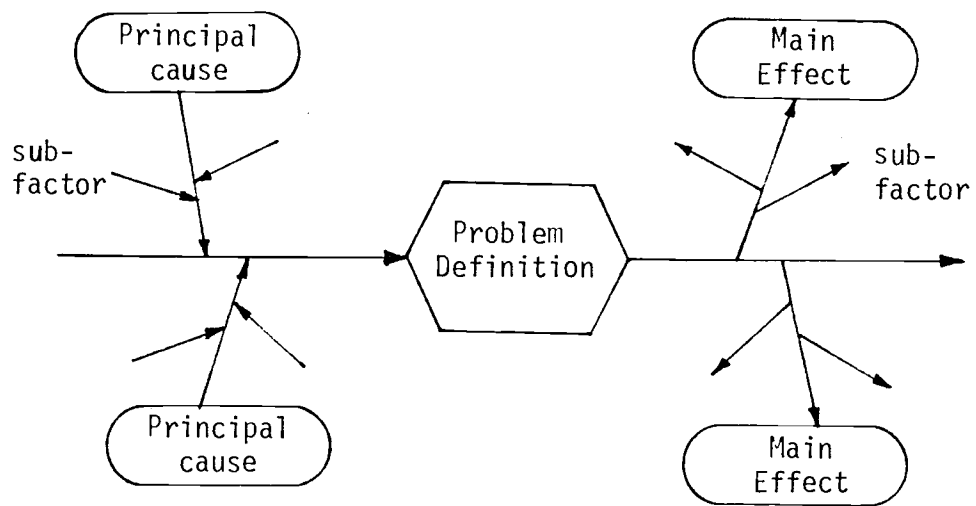


Figure 4. Cause-and-effect diagram format.

Unit Time Flow Process Chart

The process chart is a tool for recording an operation or process in the sequence in which it occurs. It presents the operation in a logical manner and condensed form. This arrangement allows the process to be analyzed systematically and critically. Symbols used in a process chart are shown in Figure 5 on the next page.

Unit time flow process chart ^{3/} is a modification of the conventional process chart. Unit direct labor time and/or unit direct machine time of a product can be easily calculated from the chart as shown in Figure 6. The definition of one unit of product have to be defined before the calculation. Then the total number of units going through each step can be calculated and put in column B in the chart. Actual time is the total time taken by the units in "B". Then unit time of direct labor and/or direct machine can be obtained by dividing actual time by total units of each step. The total unit time of the whole process is the sum of all unit times in each step.

The unit time obtained can be used for scheduling, production planning, and process evaluation purpose. Also, the unit time process chart can be modified to include distance travelled and space required.

^{3/} Developed by Professor W. F. Engesser of Industrial and General Engineering Department, Oregon State University.

<u>Symbol</u>	<u>Process</u>
○	Operation
➡	Transportation
□	Inspection
D	Delay
▽	Storage

Figure 5. Process chart symbols.

	(A)			(B)	$\frac{(B)}{(A)}$	
	Wt. in lb.	Pro- cess units	Process symbols	Act- ual time	Unit time	Description
1			○□➡D▽			
2			○□➡D▽			
3			○□➡D▽			
4			○□➡D▽			
5			○□➡D▽			

Figure 6. Unit time flow process chart.

Economic Evaluation

The most common bases for economic evaluation of an alternative or process are the present worth, the annual equivalent amount, the capitalized amount, the future worth, and the rate of return. Other bases are the payback period and the prospective value. Annual equivalent amount and payback period are the major decision criteria used in Chapter 6 for evaluation of equipments. Simple line diagram as shown in Figure 7 is used to illustrate the time, cost and tax benefit relationship of an equipment. An arrow points towards the year-line represents a cost and an arrow points away from the year-line represents a benefit in a specific year.

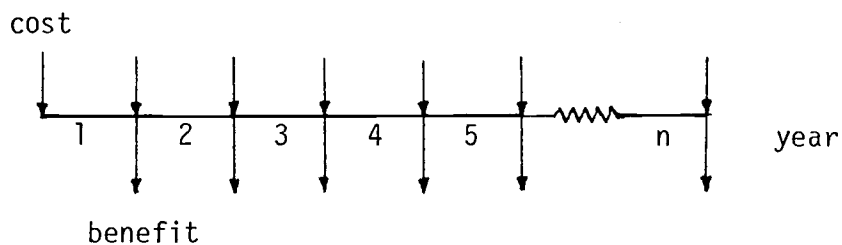


Figure 7. Time, cost and benefit line diagram.

The annual equivalent cost (AEC) for an interest rate i and a period of n years can be defined as:

$$\begin{aligned} \text{AEC}(i) &= \text{Present cost} \left[\frac{i(1+i)^n}{(1+i)^n - 1} \right] \\ &= \sum_{t=0}^n F_t (1+i)^{-t} \left[\frac{i(1+i)^n}{(1+i)^n - 1} \right] \end{aligned}$$

Where F_t = net cash flow at time t .

Tables of interest factors $(A/P, i, n)$, $(A/F, i, n)$ and others can be found in most of engineering economy and finance text books (20).

$(A/P, i, n)$ means to find A , given P

$(A/F, i, n)$ means to find A , given F

where A = annual equivalent cost

P = present worth

F = future worth

i = interest rate

n = number of years

The payback period is the number of years which elapse between the time an investment is made and the time the earnings or saving from the investment equal the investment with no interest. It can be defined as the value of n that satisfies the equation:

$$0 = F_0 + \sum_{t=1}^n F_t$$

where F_t = net cash flow at time t

It measures the speed with which invested funds are returned to the business. Because it is relatively simple to calculate and because managers instinctively like to recover their investment as rapidly as possible, the payback calculation, in the above or modified forms, is frequently used to evaluate investment proposals. When used in conjunction with other measures, such as AEC, payback period is useful in promoting wise investment decision-making. When used as the sole or principal criterion for investment decisions, payback period is dangerous because it ignores the time value of money and the consequences of the investment following the payback period including the magnitude and timing of the cash flows and the expected life of investment.

Control Charts

Control charts are graphical aids for detection of quality variations in output from a production process. There are four basic kinds of control charts.

1. \bar{X} chart - test the average measurement in the sample.
2. R chart - test the range of measurement in the sample.
3. p chart - test the percent defective in the sample.
4. c chart - test the number of defective in the sample.

Average, \bar{X} , and the range, R, charts are the best known control charts and their application on shrimp processing is discussed in Chapter 7. Usually, three standard deviations above and below the central line or expected value are set as the trial control limits. These limits are a means of comparing actual performance with a standard. If all data points fall within the control limits, it indicates that only chance variation is present. If any data points fall outside the control limits, it indicates assignable variation may be present in the process.

Formulas for the control limits on sample average (\bar{X} chart) are:

$$\text{Upper control limit} = \bar{\bar{X}} + A\bar{R}$$

$$\text{Center line} = \bar{\bar{X}}$$

$$\text{Lower control limit} = \bar{\bar{X}} - A\bar{R}$$

where $\bar{\bar{X}}$ = average of sample average

\bar{R} = average of sample ranges

A = factor based on the sample size and is used to estimate the 3-standard deviation boundaries around the center line.^{4/}

Formulas for control limits on sample range (R chart) are:

Upper control limit = $B\bar{R}$

Center line = \bar{R}

Lower control = $C\bar{R}$

where B and C are the function of sample size and set 3-standard deviation bounds around the center lines.^{5/}






An illustration of the application of \bar{X} and R charts is shown in Chapter 7, pages 175 to 178.

^{4/} Value of A is shown in Table 17 on page

^{5/} Value of B and C are shown in Table 17 on page

Resource Planning and Management (RPM) Model

Graphical aid or model has long been used as an aid to accelerate communication. RPM model, developed by Riggs and Inoue in 1972, is another efficient graphical tool for systems analysis. An RPM model consists of five basic symbols:

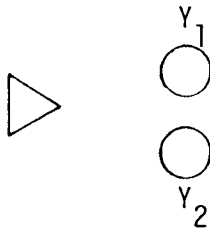
1.  Circle represents resource (noun).
2.  Rectangle represents process or activity (verb).
3.  Triangle represents boundary of system under study.
4.  Arrow represents flow of resource to process or vice versa.
5.  Dashed arrow represents flow from the environment to the system under study or vice versa.

These five symbols can be used to build precedence, rational, linear programming, and goal programming models, etc. to any degree of complexity. Detail explanation and application on RPM model can be found in references in the Bibliography (12) (16) (18). The following represents how to build an RPM model and how to interpret a linear programming model from the RPM model.

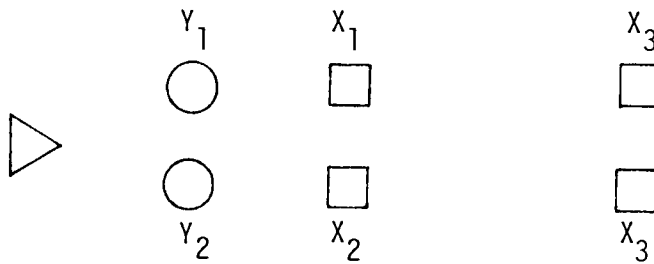
1. Start from the left with a triangle.



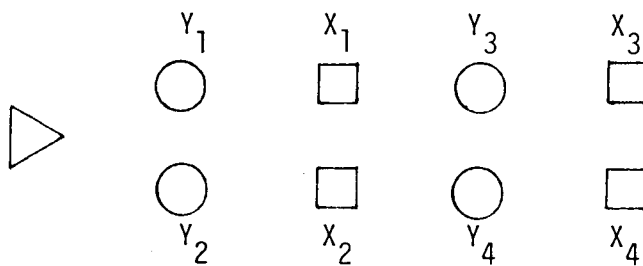
2. Put fundamental resources (raw resources) down.



3. Put all processes or activities down.

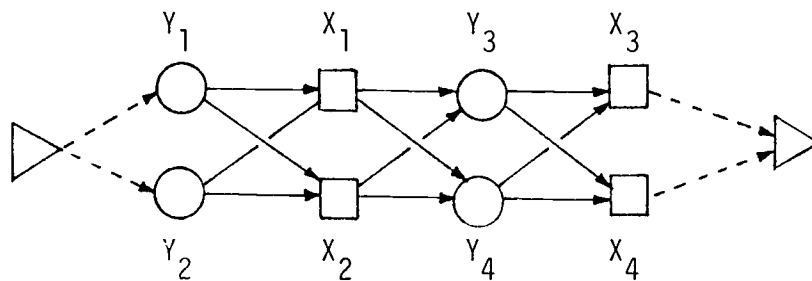


4. Put transitional resources (resources during processing) between process nodes.

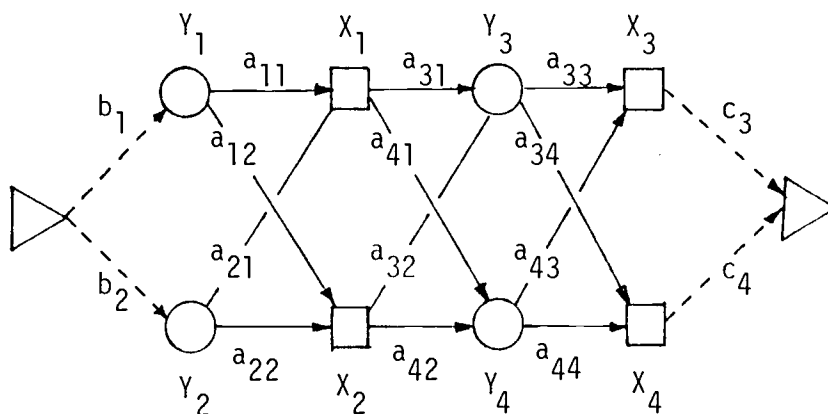


5. Use solid and dashed arrows to indicate the flow relationship in the RPM model.

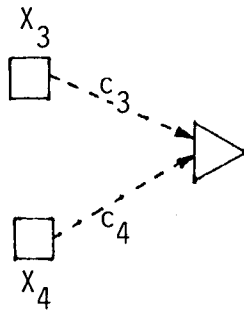
- i. Connect all fundamental resources to the left triangle and appropriate process nodes to the right triangle with dashed arrows.
- ii. Solid arrows are either from resource to process or vice versa.



6. Once a rational RPM model is built, numerical relationship among resources and processes can be added into the model and a linear programming model can be interpreted from the RPM model.

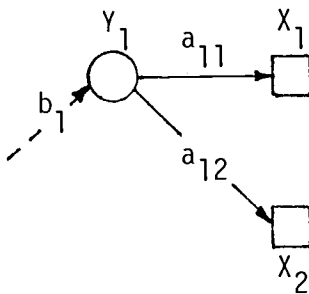


Objective function and constraints can be interpreted in the following manner.

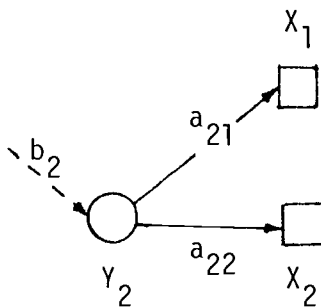


Objective function:

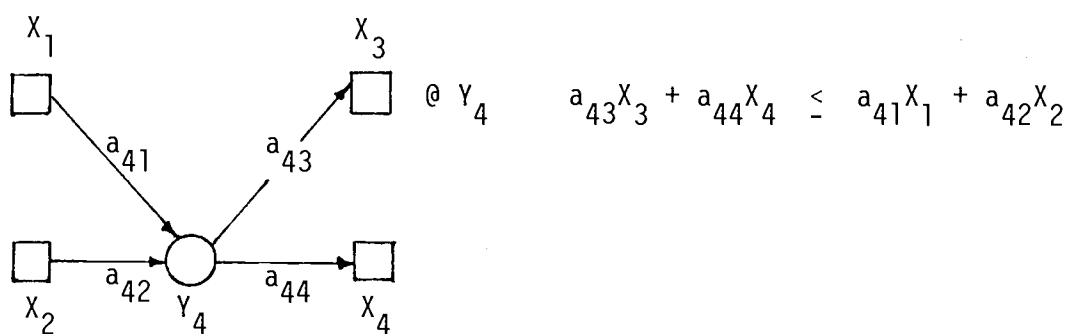
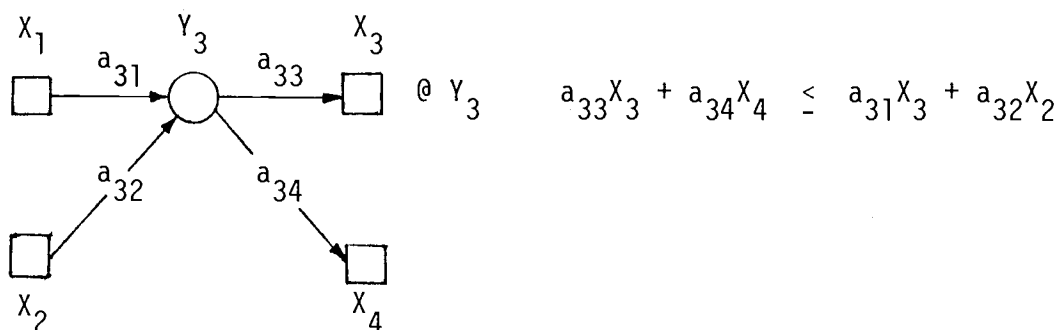
$$\text{Maximize } Z = c_3 X_3 + c_4 X_4$$



$$@ Y_1 \quad a_{11} X_1 + a_{12} X_2 \leq b_1$$



$$@ Y_2 \quad a_{21} X_1 + a_{22} X_2 \leq b_2$$



The complete linear programming model is:

$$\text{Maximize } Z = c_3x_3 + c_4x_4$$

subject to

$$@ Y_1 \quad a_{11}x_1 + a_{12}x_2 \leq b_1$$

$$@ Y_2 \quad a_{21}x_1 + a_{22}x_2 \leq b_2$$

$$@ Y_3 \quad a_{33}x_3 + a_{34}x_4 \leq a_{31}x_1 + a_{32}x_2$$

$$@ Y_4 \quad a_{43}x_3 + a_{44}x_4 \leq a_{41}x_1 + a_{42}x_2$$

$$x_1, x_2, x_3, x_4 \geq 0$$

One advantage of the RPM model is that computer input for *REX^{6/} can be directly read from the model without going through the development of equations. Input for *REX can be written in the following manner.

1. Put down the name of the objective function.

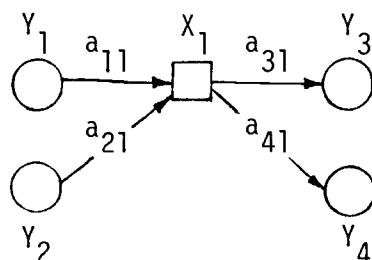
```
INPUT
ROWS
$Z
```

2. Put down all names of resources with proper sign after the the name of the objective function.

```
INPUT
ROWS
$Z Y1 Y2 Y3 Y4
```

3. Examine each process node and put down its relationship with resources. For example:

```
COLUMNS
X1 Y1 A11 Y2 A21 Y3 -A31 Y4 -A41
```



4. Put down the amount of each fundamental resource.

```
RESOURCE Y1 B1 Y2 B2
```

5. Put "EOF" on the lastline of the input.

^{6/} *REX was developed by H. Lynn Scheurman at Oregon State University.

The complete input is shown below.

```

INPUT
ROWS
$Z Y1 Y2 Y3 Y4
COLUMNS
X1 Y1 A11 Y2 A21 Y3 -A31 Y4 -A41
X2 Y1 A12 Y2 A22 Y3 -A32 Y4 -A42
X3 Y3 A33 Y4 A43 Z C3
X4 Y3 A34 Y4 A44 Z C4
RESOURCE Y1 B1 Y2 B2
EOF

```

After computer result of the linear programming is obtained, shadow price, residue of resource, opportunity cost, and amount processed can be put into the RPM model as shown below.

shadow price



residue

amount processed



opportunity cost

where shadow price = imputed value of the resource
 residue = surplus of the resource
 amount processed = amount produced in the process
 opportunity cost = loss incurred per unit of product
 produced in the process.

At optimal (shadow price) x (residue) = 0

(amount processed) x (opportunity cost) = 0

A rational RPM model and a linear programming RPM model is illustrating in Chapter 7.

III. SHRIMP PROCESSING BEFORE MECHANIZATION

Background and History

The factors causing the profitability problem facing Oregon processors ten years ago were many and varied but the most outstanding ones were the high cost of processing, a low market demand in the Pacific Northwest, an unstable supply of raw shrimp from the fishermen to the processors and hence from the processors to the distributors, the absence of production standards, and inability of processors to handle large quantities.

As demand and production increased during the years immediately following 1961, shrimp processors' profit positions remained uncertain. The desire of many processors to find some automated means of picking shrimp was hampered by their relatively small scale economic size and the high initial cost of automated equipment that was unproven on Oregon shrimp. The future was still uncertain for the shrimp processing industry and cooperation between processors was hindered by scattered physical plant locations.

The following figures show the old practice of shrimp processing prior to the mechanization stage. A process chart in Figure 8 and a layout model in Figure 9 are constructed to facilitate the understanding of the old processing method. Although harvesting is not included in the system of processing, it is also mentioned in order to show a continuous picture of how shrimp from sea may be delivered to processing plants.

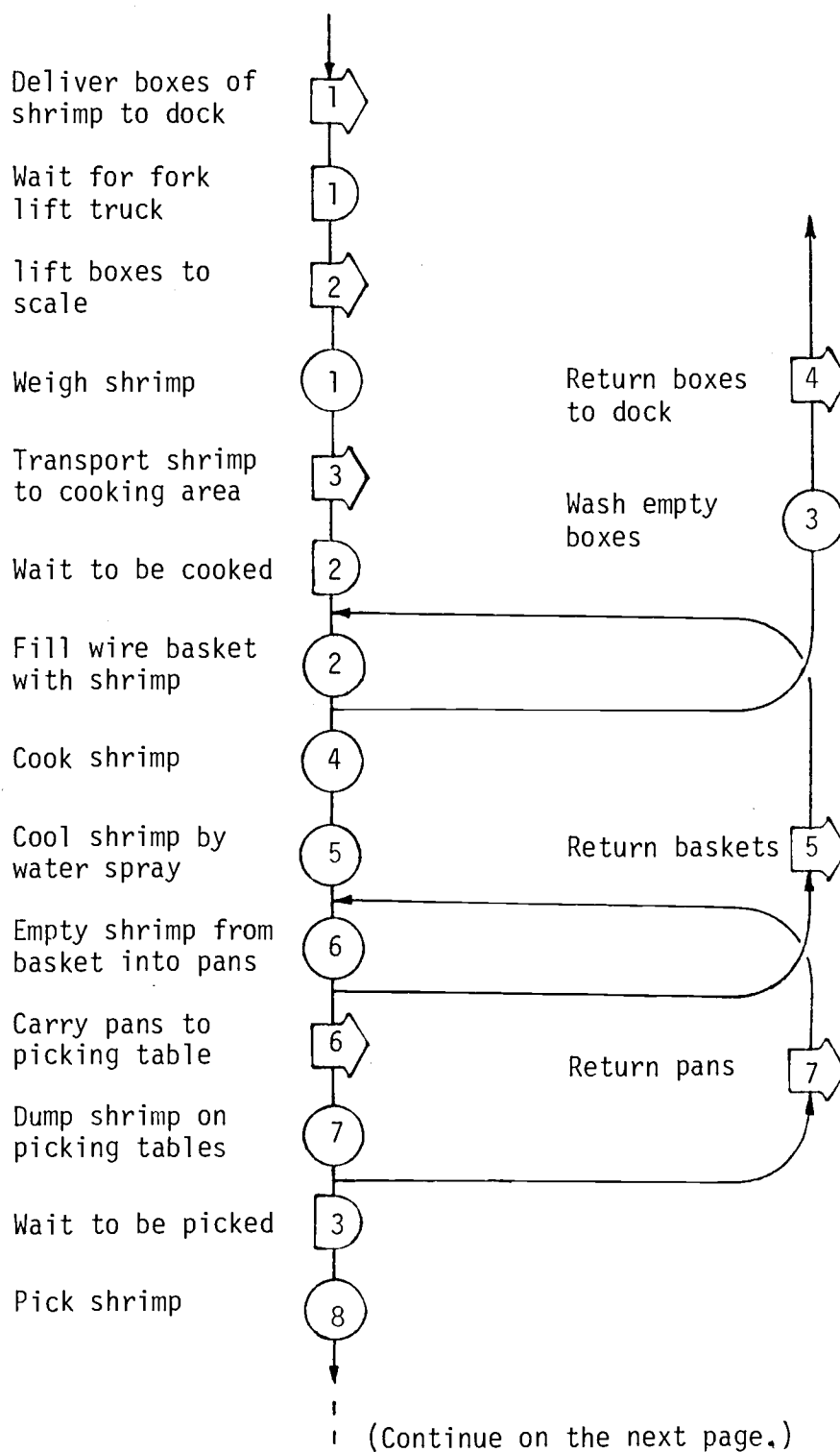


Figure 8. Process chart of shrimp processing before mechanization.

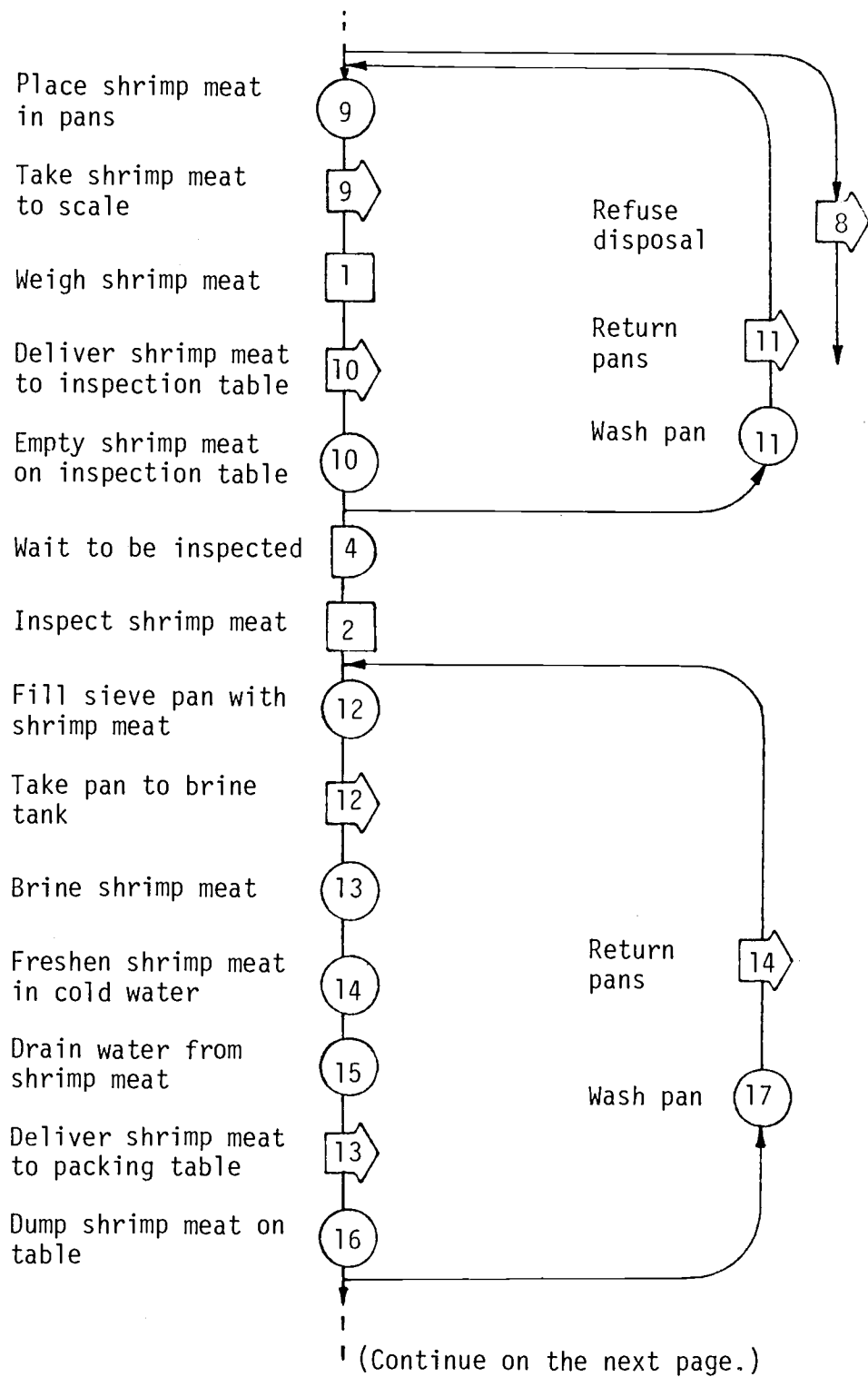


Figure 8. Continued.

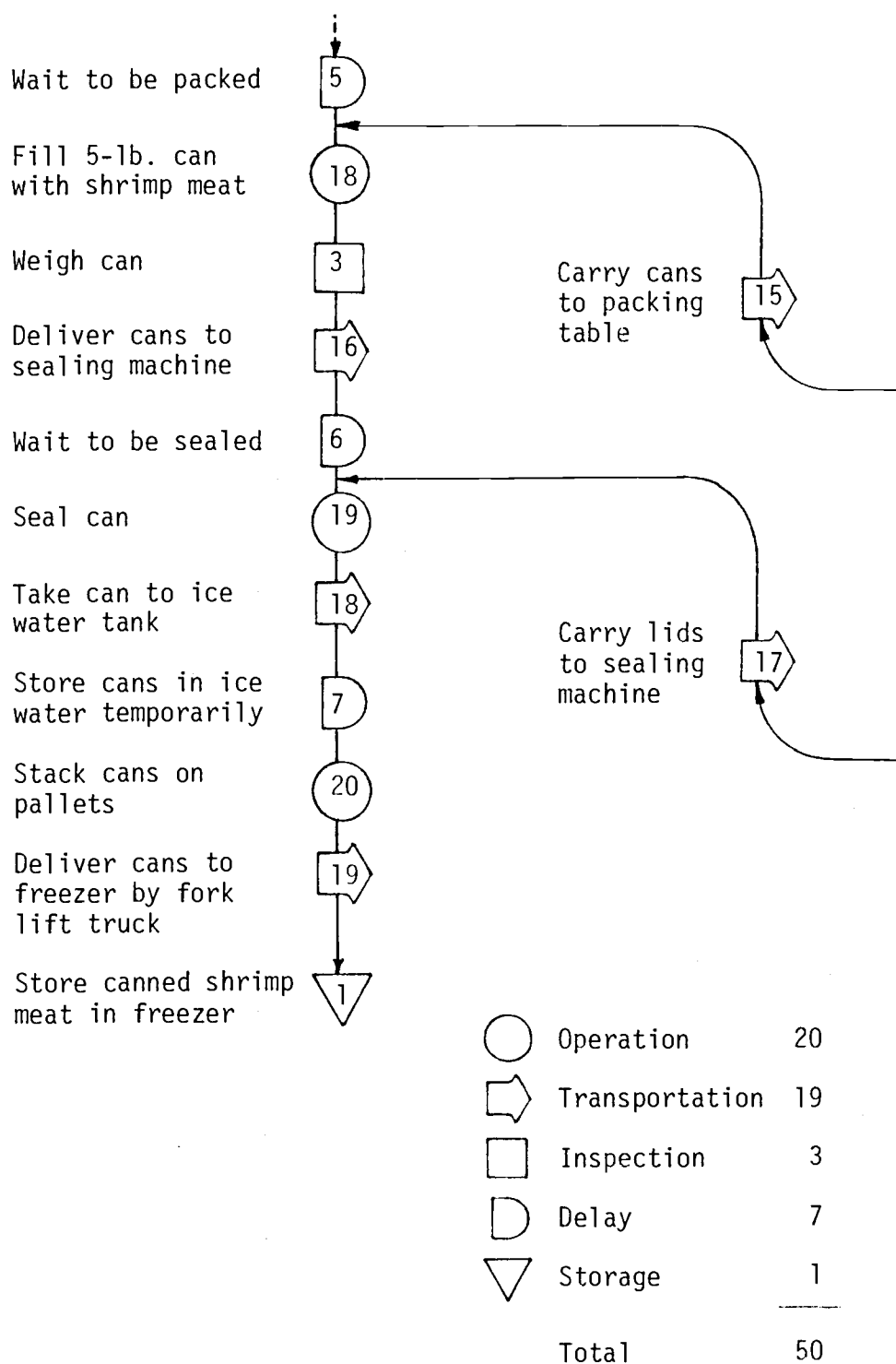


Figure 8. Continued.

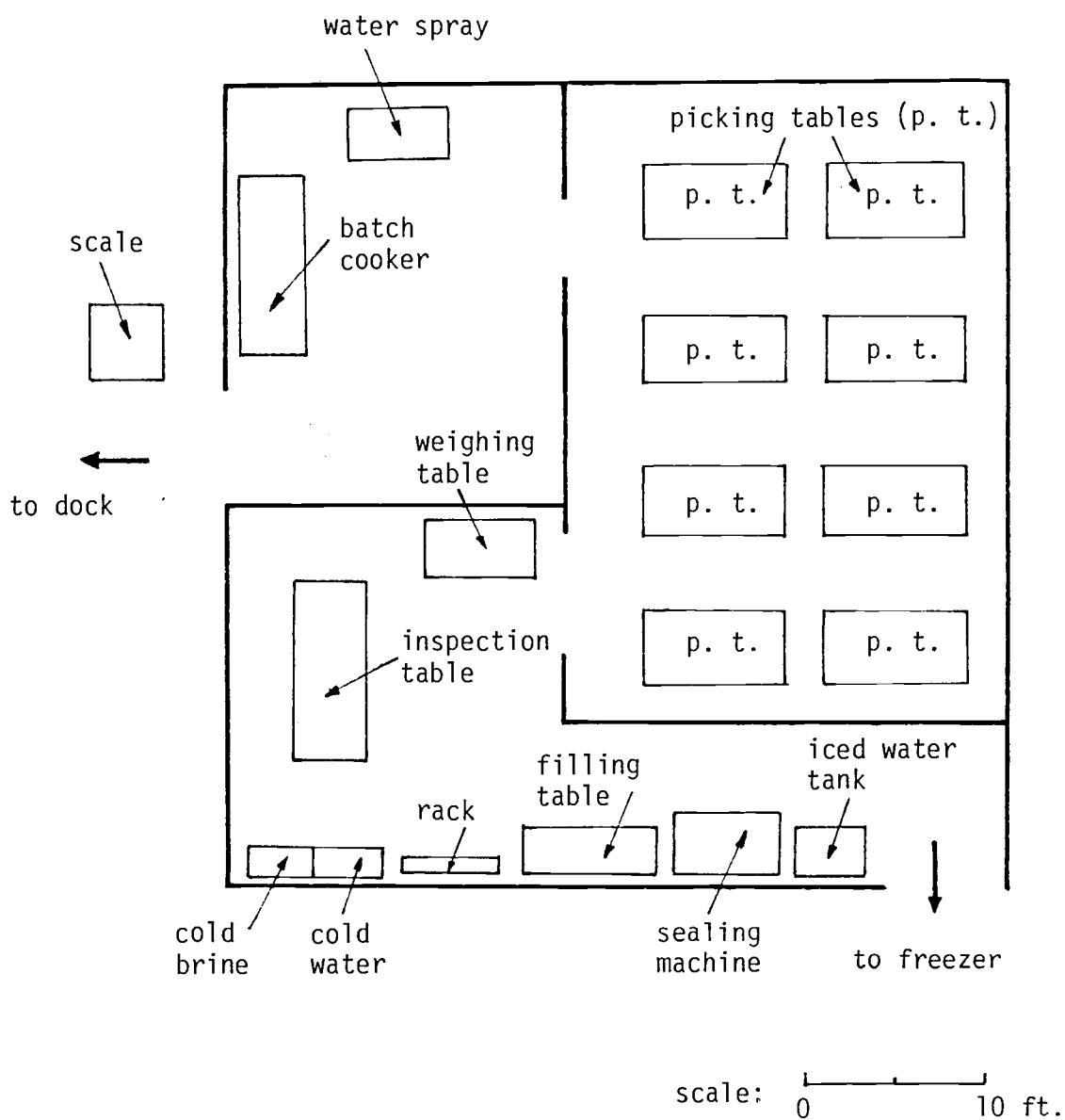


Figure 9. A typical layout model of shrimp processing before mechanization.

Harvesting and Holding

After a catch of shrimp was decked on a trawler, trash fish were sorted. Trash fish and small pinhead shrimp (shrimp too small to be processed) were two of the prime problems of the fishermen. Sorting trash fish cost fishermen time and money. The price of the catch would be lowered if pinhead shrimp remained in the catch. Another problem facing the fishermen was net drag. This reduced his ability to fish and also increases his fuel cost. The fishermen commonly had a winch system to pull in the net once it was full. However, the early winch designs did not perform efficiently. After the sorting operation the remaining shrimp were shoveled into the hold of the trawler. In the hold they were kept cool in alternate layers of ice until the port was reached.

Receiving and Unloading

Generally, processing plants were located at the water fronts. As a trawler reached a plant, shrimp were shoveled from the hold into wooden tote boxes. Once filled the box was lifted by crane to the dock and stacked on a pallet where it waited to be weighed. The fisherman was either paid by the weight of his raw shrimp or by the recovery of shrimpmeat. Usually one man shovelled shrimp into tote boxes and the second man operated the cranes. After a pallet was filled a fork lift truck transported the shrimp to a scale and then to the cooking area where they awaited cooking. If the shrimp were allowed to sit in the boxes for extended periods of time, either at dockside or in the cooking area, the ice melted, the shrimp decayed and bacteria counts increased. To prevent this, many plants in Oregon reiced the shrimp after they were unloaded.

Cooking and Cooling

The typical shrimp processing plant used a batch cooker. Shrimp were taken from the wooden tote boxes and dumped into a wire mesh basket for cooking. The basket was submerged into the cooking water where it stayed for approximately three minutes. One drawback to this type of cooking was that the shrimp in the middle of the basket were not cooked as well as the ones near the edge resulting in an uneven cook. Another problem observed was that baskets varied in size while cooking time did not vary with cooking volume.

Upon being taken from the cooking bath and placed on a drying rack the shrimp were immediately cooled by a cold water spray. Again the shrimp closest to the outside of the basket received the greatest cooling effect and the ones in the middle received very little benefit. In a few plants the baskets were dipped in a cold water bath after cooking but the result of uneven cooling was still the same. After colling the shrimp were dumped into small wooden boxes and taken to the picking area. Pictures of batch cooker and cold water spray are shown on the next page.

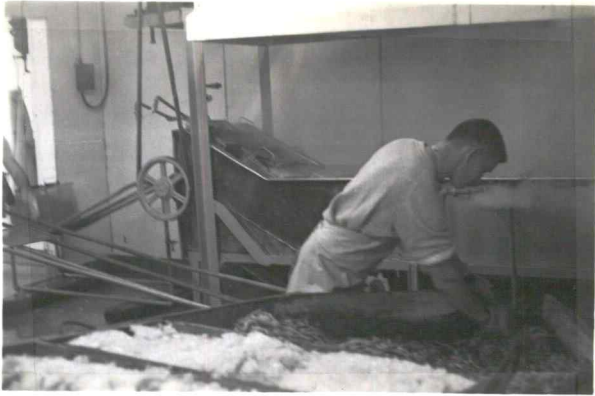


Figure 10.
Batch cooker.



Figure 11.
Cold water spray.

Picking

Figure 12 shows lines of women employed for picking shrimp. Each woman used her own individual picking style because there was no standard method of picking at this time. The picking rate changed from four and one half pounds per hour to seven pounds per hour. The difference in picking rates were due to natural ability, the degree of effort, rhythm, and speed. The ability of some of these women to earn a maximum wage was seriously impaired by inefficient hand motions.

After a picker had picked enough shrimp to fill her plastic tray she transported it to a weighing station where her output was measured and recorded. The method of recording was marking a card which was attached to the picker's apron or recording on a card from the operator's disc.

After weighing her shrimp the picker would get a new tray and return to her picking station to resume picking.



Figure 12.
Shrimp pickers.

Inspection

After the shrimp meat was weighed the weigher took it to an inspection table. There they were dumped onto the table and inspectors fingered their way through the shrimp meat picking out pieces of shell, antenna and broken bodies. This inspection process was time consuming, and allowed the bacteria count to mount as a result of hand contact and delays during the inspection.



Figure 13.
Inspection table (back-ground) and cold water bath (foreground).

Brining, Freshening, and De-watering

After inspection the shrimp meat was loaded into pans with tiny holes on the bottom. Pans of shrimp meat were immersed into cold brine solution and then freshened by dunking the pans into a cold water bath. The pans were then placed on dry racks to allow the containers to drain and to await packing and storage.

Packing

Pans of shrimp meat was taken from the drying rack and the shrimp meat was dumped on a table. Then workers at the table filled the shrimp meat into cans to the specified weight, five pounds, by hand as the cans were on top of scales. This task was costly and bacteria count was increased due to repeated human handling and exposure of shrimp meat to the air. After a can was filled to the proper weight it was transferred to a sealer where an operator sealed it and placed it in a cold water bath where it stayed until it was taken to cold storage.



Figure 14.
Shrimp meat was filled
into cans.

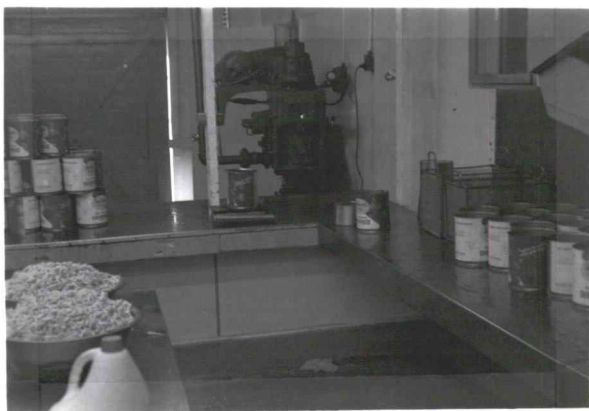


Figure 15.
Semiautomatic sealing
device (background).

Storage

As previously stated, cans were held in a cold bath after sealing until enough were available for a forklift truck to transport them to cold storage. Once in cold storage the cans of shrimp meat were stacked on shelves and exposed to below freezing temperatures. The cans remained in cold storage until they were ready to be delivered by refrigerated truck to some point of further storage or consumption.

IV. RESEARCH AND RESULTING SYSTEM DESIGNS BY OREGON STATE UNIVERSITY INDUSTRIAL ENGINEERS

Beginning Sea Grant Research on Shrimp Processing

In 1968, shrimp processing studies were initiated under the Oregon State University Sea Grant Program. The initial studies were directed toward improving the manual hand-motion used to process shrimp. Improved work design enabled 1) workers to pick more shrimp per hour (4) and thus increase their earnings and 2) processors to lower their cost per pound and increase their production rate. However, within two years of the initiation of shrimp studies many of the plants had acquired automatic shrimp picking machines that were processing as many shrimp as thirty to eighty women had been doing in previous years. Four years after the studies began nineteen mechanical pickers had been installed in nine processing plants in Oregon and the shrimp processors enjoyed a more desirable profit position.

One of the first investigators on the industrial engineering team in 1968 was Abe Ghaffari, a graduate student. Under industrial engineering guidance he analyzed processing activities, for the purpose of interacting with processors to exchange information and ideas, and worked on the theoretical design of new equipment for improving shrimp processing. His work in the above areas led him to form a flow chart, Figure 16, of the original shrimp processing method and to develop theoretical processing systems of hand picked and machine picked shrimp. In his development of the proposed systems he estimated costs and savings of each system. His system of mechanically, picked shrimp was

based on a typical plant production of 450,000 pounds of picked shrimp and thus the estimated savings were impossible to validate because at that time no one processed that much. The savings of his proposed mechanical peeling system were based on the above mentioned volume and a feasible savings of two-third of the potential savings which is equivalent to thirty-three cents per pound of picked shrimp.

Man Type Flow Process Chart

SUMMARY		HO.	TIME	DIST.	SPACE	FLOW PROCESS CHART Page 1 of 2		
UNITS			Sec.	Ft.		PRESENT	DATE	ANALYST
○		12	4021			<input type="checkbox"/> PROPOSED	12-5-68	Abe Chaffari
□		1	5			SUBJECT & QUANTITY Shrimp processing "man" chart with direct labor time adjusted ¹ to correspond to 5 pounds of picked shrimp or 25 pounds of raw shrimp.		
◇		8	30	2.46				
▽		1	12					
TOTALS		22	4068	2.16				
WHY? IS IT REALLY NECESSARY?						POSSIBLE ACTION		
WHAT? WHEN? WHERE? WHO? HOW?						ELIMINATE		
						COMBINE		
						SCUPE		
						PLACE		
						PERSON		
						IMPROVE		
STEP	SYMBOL	TIME	DIST.	SPACE	PROCESS STEPS	ELIMINATE	COMBINE	SCUPE
1	○□◇▽	2.5*	133*		Lift truck five shrimp boxes to cooking area.			
2	①□◇▽	4.4			Two workers dump shrimp box in chute.			X
3	②□◇▽	6.0			Pull (by hand) shrimp into cooking basket.	X		
4	○□◇▽	1.4	7*		Place basket by cooking pot			X
5	③□◇▽	2.6			Place basket inside cooking pot		X	combine with #4
6	④□◇▽	28.4			Cook shrimp (4 baskets at a time)			
7	⑤□◇▽	2.8			Pull basket of shrimp out of pot			X
8	⑥□◇▽	2.3			Sprinkle water on shrimp basket for cooling.			X
9	○□◇▽	2.0	10*		Carry basket to cooling platform and set it there.	X		
10	⑦□◇▽	5.2			Dump cooked and cooled shrimp from basket into rectangular dit. pans.	X		
11	⑧□◇▽	1.7			Level shrimp in each pan.	X		
12	○□◇▽	2.3	37*		Roll hand truck to women's work table.			X
13	○□◇▽	8.5	17*		Carry shrimp from truck to work table.			X
14	⑨□◇▽	9.2			Dump shrimp on work table and put the rectangular pan away.			X
15	⑩□◇▽	39.50			Pick shrimp and place in pan. (Five pounds)			X
16	○□◇▽	12.5			Picker wait for weighing.	X		
17	○□◇▽	6.4	17*		Carry filled pan to scales for weighing.	X		
18	○□◇▽	5.3			Weigh pan.	X		
19	⑪□◇▽	5.6			Dump shrimp into a rectangular pan and give the (round) pan back to picker.	X		
20	⑫□◇▽	2.5			Wash pan and apron.			X
21	○□◇▽	6.4	17*		Walk back to work table.	X		
22	○□◇▽	.8	8*		Carry filled rectangular pan to wash ladder.	X		

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* Estimated time (all other times from micromotion study).

Figure 16. Flow process chart of shrimp processing (old method).

SUMMARY		UNITS	NO.	TIME Sec.	DIST. ft.	SPACE	FLOW PROCESS CHART Page 2 of 2		
○			13	115.7			<input type="checkbox"/> PRESENT	DATE 12-5-68	ANALYST Abe Chaffari
□			2	56.8			SUBJECT & QUANTITY		
◇			6	11.5	67		Shrimp Processing (5 pounds picked shrimp)		
▽									
TOTALS			21	184.0	67				
WHY? IS IT REALLY NECESSARY? WHAT? WHEN? WHERE? WHO? HOW?							STEPS		PERSONS & DEPT. CONTACTED
									POSSIBLE ACTION
STEP	SYMBOL	TIME	DIST.	SPACE	PROCESS STEPS				
23	○□◇▽	1.4			Dump shrimp on wash ladder.				
24	○□◇▽	1.3	13*		Place a rectangular pan at the end of wash ladder.				
25	○□◇▽	11.0			Wash shrimp down the ladder into the pan.				
26	○□◇▽	.8	8*		Carry filled pan to rinse sink.				
27	○□◇▽	2.0			Dump shrimp in salt brine solution for rinsing and put pan away.				
28	○□◇▽	2.0			Rinse shrimp in solution by hand.				
29	○□◇▽	1.0			Fill a pan with rinsed shrimp.				
30	○□◇▽	.5			Dump shrimp from pan into a sieve pan.				
31	○□◇▽	1.5			Rinse filled sieve pan in fresh water and drain the water.				
32	○□◇▽	1.3	13*		Carry sieve pan to storage rack for temporary storage.				
33	○□◇▽	.8	8*		Carry pan of shrimp from rack to work table.				
34	○□◇▽	1.8			Dump shrimp on work table and put empty pan away.				
35	○□◇▽	45.8			Sort and inspect shrimp.				
36	○□◇▽	41.1			Fill a can and put it aside.				
37	○□◇▽	2.3	8*		Carry the can to table nearby scales.				
38	○□◇▽	5.8			Place can by scales.				
39	○□◇▽	11.0			Weigh can.				
40	○□◇▽	7.8			Place lid on can and put it away.				
41	○□◇▽	5.0	17*		Move a can to sealing machine.				
42	○□◇▽	5.8			Place can into the machine.				
43	○□◇▽	34.0			Seal can and put it away.				

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Labor time used in processing 5 pounds of picked shrimp = 4253

Adjusted labor cycle time = $1.20 \times (4252 \text{ sec.}) = 5104 \text{ sec.} = 85 \text{ min.}$
allowance factor

Figure 16. Continued.

The First Publication Concerning Shrimp-System Recommendations

The results of the first feasible system studies were presented in early 1970 by Engesser and Evans (6). The shrimp cost-benefit table shown on Table II identified the areas of immediate savings to Oregon processors. The recommendations of this first system were oriented toward improving both manual picking systems and mechanical picking systems.

TABLE II. SHRIMP COST-BENEFIT TABLE (6)

Equipment and Operating Changes	Hand Picked Estimated Cost	Potential Benefits	
		Economic	Quality and Sanitation
1. Shaker separator of pinhead shrimp	\$2800	\$6250 ^a	Less handling and contamination exposure
2. Picker tables with drop delivery design	2000		Less handling and elimination of floor contamination
3. Motion-picture training	1000	6250	Greater awareness of safe practices
4. Trash tub containers (over \$600 for conveyors)	600±	600 ^b	Cleaner working condition, less contamination exposure
5. Shrimp antenna remover	1400	(250 hr.) ^c 500	Cleaner working condition, less contamination exposure
Safety Margin	1200		
Hand-picked sub-totals	\$9000	\$13,600	

a. Based on a one pound per hour rate increase.

b. Should pay for itself.

c. Hours in parenthesis show annual estimated man hour savings.

TABLE II. Continued.

Equipment and Operating Changes	Machine Picked Estimated Cost	<u>Potential Benefits</u>	
		Economic	Quality and Sanitation
6. Vibrating-inspection table with screen sort before inspection	\$2600	(3000 hr.) ^d \$6000	Cleaner working condition, less contamination exposure
7. Brine table with pump, conveyor and tank	2000	(500 hr.) ^d 1000	Cleaner working condition, less contamination exposure
8. Scale table with scale	2000	(500 hr.) ^d 1000	Cleaner working condition, less contamination exposure
Safety Margin	1400		
Summary			
Hand-picked	9000	13,600	
Mechanical-picked	8000	8,000	
Grand Totals	\$17,000	\$21,600	

c. Hours in parenthesis show annual estimated man hour savings.

d. Assuming 100% disposition of savings.

Continuing Sea Grant Research

Viravat Cholvanich continued the study of the operations of a "typical" processing plant in 1970. Perhaps the most significant result of his work was his conversion of Ghaffari's process chart symbol times into unit times. By exactly defining each symbol he was able to convert the flow process chart on Figures 16A and 16B into a mathematical model.

To develop his mathematical model Cholvanich took actual times for each activity from the flow process chart and adjusted the time to correspond to a unit of product which in this case was five pounds of picked shrimp. After obtaining the adjusted time in terms of a unit of product he then applied the standard time study allowance factor to arrive at a total labor processing time. Part of his conversion table is shown in Table III.

Cholvanich's subdivision of the processing system into subsystems lead David Slack in 1970, to develop a process time comparison bar chart shown in Figure 17. This chart allowed comparison between processors in the area of cooking, brining, freshening, inspecting, can filling, can weighing, can sealing and total processing times. This knowledge would give individual processors an incentive for seeking improvement in areas where they were slow and this in turn would lead to more standard methods - one of the major aims of the research project.

TABLE III. CONVERSION OF PROCESS CHART SYMBOL TIMES INTO UNIT TIMES.

Activity	Actual time (sec.)	Multiplication factor for adjusting the time to correspond to unit of product	Adjusted time corresponding to unit of product	Allowance multiplication factor	Total time per unit of product
1. Dump shrimp on conveyor	12.80	$\frac{25\#}{80\#} = 0.3125$	4.04	1.2	4.85
2. Shrimp transported to cooker	40.00	$\frac{25\#}{25\#} = 1.00$	40.00	1.2	48.00
3. Cook shrimp in continuous cooker	180.00	$\frac{25\#}{160\#} = 0.153$	28.40	1.2	34.08

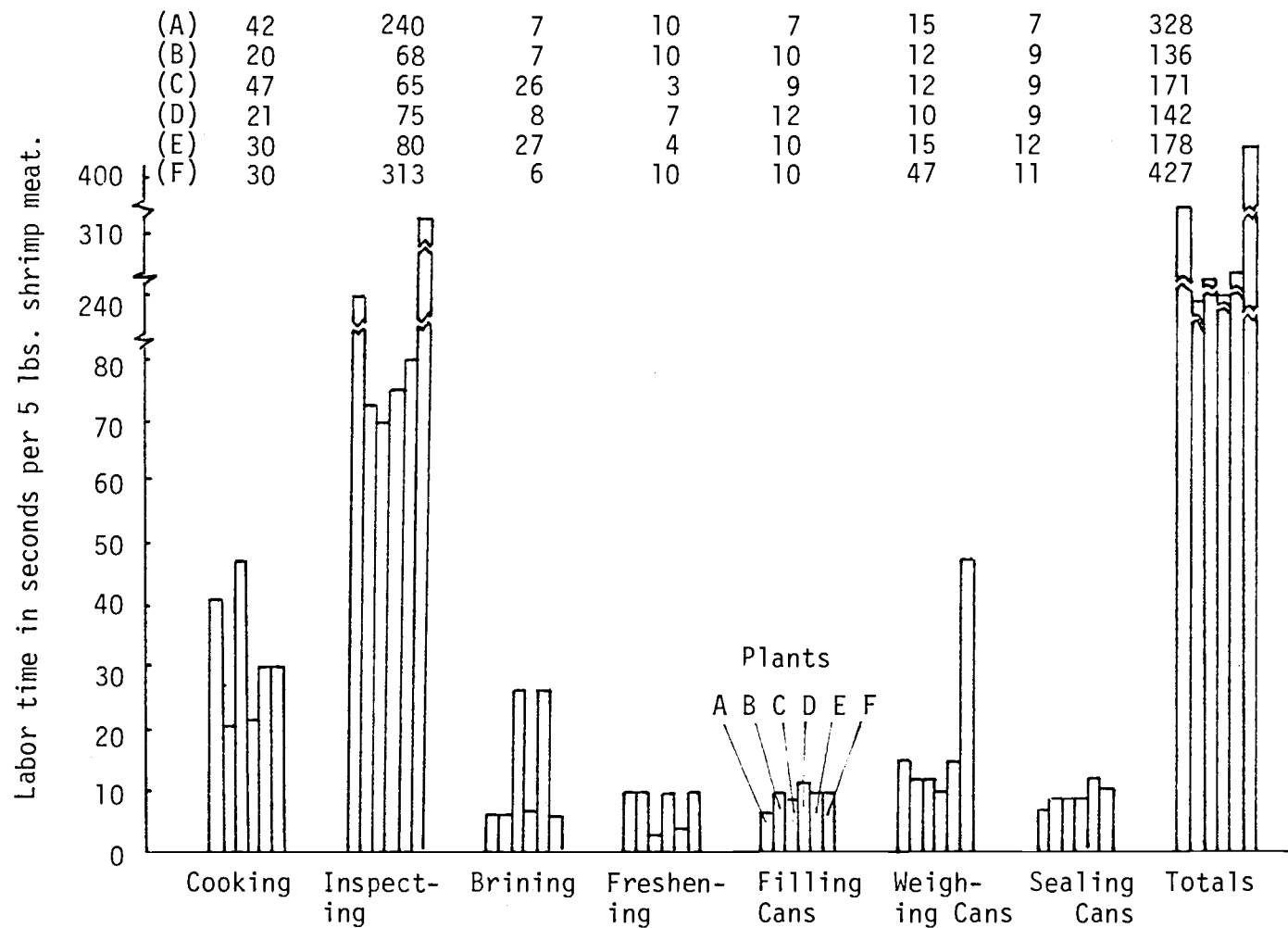


Figure 17. Process time comparison bar chart.

The Second System Recommendations

The second feasible system recommendations were presented by Engesser in 1970 (5). A cost-benefit table of the system is shown in Table IV. Improved motion pattern and work place layout were developed. Illustrations of these two improvements are shown in Figures 18 and 19. In addition to manual picking, harvesting practices and mechanical picking costs were further investigated. This system listed six immediate actions that would promote sanitation and improve processing standards. The following are these six actions:

1. Eliminate pinhead shrimp
2. Improve workplace design
3. Use training movies
4. Use beltless conveyors
5. Use brine pump and sprays
6. Improve can filling and weighing

In addition to the immediate actions the second system identified a number of long-range objectives of the National Marine Fisheries (5). They were:

1. Net escapement of trash fish and immature shrimp
2. On deck sorting of shrimp and unwanted fish
3. Determination of verticle movement of shrimp for improved harvesting procedure.

TABLE IV. SHRIMP COST-BENEFIT TABLE (5).

Equipment, motion-pattern design and procedure changes	Estimated ^a short-range economic potential		Estimated short-range benefits in -- quality sanitation and environment (physical & mental)
	Costs	Savings	
Hand-picked shrimp	Drop-delivery chute and better work design	\$2000 \$3125 ^b	Elimination of floor contamination and reduction of exposure time
	Motion-picture training in hand picking	1000 3125 ^b	Increase in understanding and desire to meet recommended standards

Hand- and machine-picked shrimp	Motion-picture training in proposed standards	(1000) (Included below)	Increase in understanding and desire to fulfill items 4-7
	Pin-head shrimp separators	2800 6250 ^b	A reduction of material-handling and bacteria-exposure time
	Inspection table with size-screen sort	2600 (3000) ^c 6000	Reduction of in-process storages, manual sorting and bacteria exposure
	Brine table with pump conveyor and tank	2000 (500) ^c 1000	Reduction of manual material-handl- ing and sorting activities
	Semiautomated filler and weigher	2000 (500) ^c 1000	A reduction of material-handling and bacteria-exposure time

TABLE IV. Continued

Equipment, motion-pattern design and procedure changes	Estimated ^a short-range economic potential	
	Costs	Savings
Hand- and machine-picked shrimp	Total per plant -- hand-picked	\$15,000 ^d \$20,500
	Total per plant -- machine-picked	\$12,000 ^d \$14,250
Assumptions and restrictions		
a. Estimates based on simulation and limited mock runs (further testing needed).		
b. Based on a five cents per pound savings and an annual volume of 125,000 pounds of picked shrimp meat.		
c. Hours in parenthesis show annual estimated man-hour savings, assuming 100 percent disposition.		
d. Includes a safety margin of \$1800.		

Left Hand	Time	Right Hand
		(Each unit 18 frames)
		Pull tail shell
	13	& drop on floor
shrimp	16	3 Move to meat
ze meat out		Grasp & remove
ad shell		6 meat
shell on	2	2 Palm shrimp
to next	4	
p		
ion & grasp		7 Palm shrimp
shrimp	5	
to RH	3	5 Wait for LH
36		36 (frames)

Task	Time (frames)	Task	Time (frames)
als two frames. one second)		Pull tail shell & drop into chute	6
Hold shrimp	9	Move to meat	3
Squeeze meat out of head shell	5	Get and Remove meat from head shell	5
Drop shell	2		
Move to next shrimp	3		
Position & grasp shrimp	2	Drop shrimp meat	7
Move to RH	3	Move to LH	3
24		24 (frames)	

73

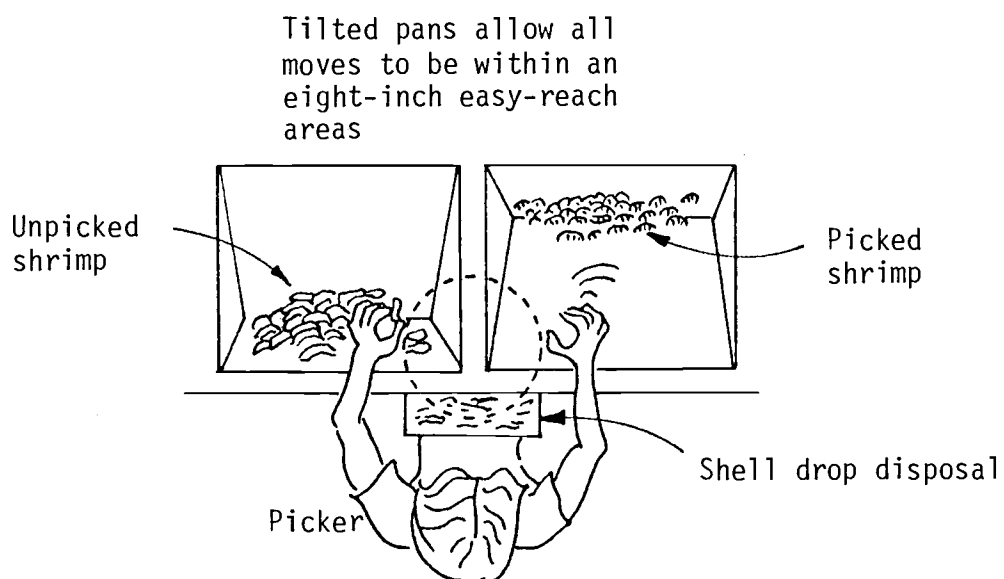


Figure 19. Improved workplace layout -- drop-delivery picking chute.

Other Studies and Findings

A study of a "typical plant" by Ellis had shown that mechanical peelers had substantially reduced cost by implementing part of the equipment originally recommended by Ghaffari. The work of Ellis was based on limited models which did not cover some real world considerations. From his study Ellis estimated that the costs associated with automatically picking shrimp amount to 11.8 cents per pound.

In an effort to confirm the estimates of Ellis a case study of the mechanical picking costs of a cooperating plant were studied by Walls. Walls' estimated costs as shown in Figure 20 was 15.8 cents per pound.

Another study done by IIT^{7/} Research Institute compared the costs of mechanical peeling on a Laitram Corporation machine and a Mathiesen machine (4). The Laitram machine costs were reported to be 12.5 cents per pound of peeled shrimp. A comparison of different estimated shrimp processing costs using the Laitram machines and derived by IITRI, Ellis and Walls are shown in Table V. These figures did vary from each other to some extent but it should be remembered that the IITRI studies took place in Alaska where costs were subjected to considerable fluctuation because of the variation in volume, shrimp size, separator practices, and labor cost.

^{7/} Illinois Institute of Technology

Table VI shows a comparison of costs between manual picking systems and automatic systems. The automatic costs were the Walls figures shown in Figure 6 and were from actual plant data. The first manual costs were historical production data from the plant Walls studied and were taken before the installation of automatic peelers. The second manual cost column contains values calculated from the process comparison chart in Figure 17. These figures were based on the mean of each processing subsystem and estimated figures for indicated costs. Table VI readily shows a substantial savings available to a processor by changing his manual picking system to a mechanical peeling system.

Direct Labor Costs:	cents/lb.*	cents/lb.*
1. Machine operator	0.658	
2. Machine cleaner	0.230	
3. Tray cleaner	0.461	
4. Fork lift operator	0.329	
5. Cooking & transferring	1.908	
6. Inspection, filling, storage	<u>4.587</u>	
		8.173
Equipment Costs:		
1. Shipping and handling	0.312	
2. Installation	0.369	
3. License	0.426	
4. Lease - peelers	3.915	
5. Lease - separator	0.511	
6. Fork lift	<u>0.083</u>	
		5.616
Overhead Costs:		
1. Water	0.440	
2. Electricity	0.071	
3. Meter cost	1.316	
4. Unemployment insurance	<u>0.221</u>	
		2.048
TOTAL COSTS		<u><u>15.837</u></u>

* Picked shrimp.

Assumptions:

1. A production of over 275,000 lbs. of picked shrimp per year.
2. A production rate in accordance with manufacturers specifications.
3. Labor costs - assumed area rates.
4. An assumed loss due to shrimp breakage of 10%.

Figure 20. Automatic shrimp picking costs.

TABLE V. PROCESSING COSTS USING LAITRAM PRECOOK MODEL A (PCA) PEELERS.

Study	Cost
IITRI	17.1 cents/lb. peeled shrimp
Ellis	11.4 cents/lb. peeled shrimp
Walls	15.8 cents/lb. peeled shrimp

TABLE VI. SHRIMP PICKING COST COMPARISON - AUTOMATIC VS MANUAL

	Automatic	(Walls) Manual	(Slack) Manual
Direct labor costs (cents/lb.):			
1. Preparing, picking	3.586	42.321	42.321
2. Inspection, filling, storage	4.587	4.578	3.800
Indirect labor costs:		4.995	4.495
Equipment costs:	5.616	0.064	0.064
Overhead costs:	2.048	0.069	0.069
Total Processing Costs:	15.837*	52.036*	50.739*
Savings of automatic over manual:		?	?
		36.029	34.912

* Cents per pound peeled shrimp.

All cost figures are based on over 275,000 pounds picked shrimp and one hundred eight-hour working days per year.

V. CURRENT SHRIMP PROCESSING PRACTICES IN OREGON

Summary of Survey

For a better understanding of the shrimp processing industry in Oregon, a survey^{8/} conducted among Oregon seafood processors and equipment manufacturers shows the following:

1. Most processors get their shrimp supply from independent fishermen. Some processors make contracts with fishermen for their annual shrimp supply. The shrimp availability depends heavily on the length of the harvesting season, weather, the egg-laying period, the abundance of shrimp in the sea, and the facilities of fishermen. Generally, the shrimp supply has been reliable.
2. Price of raw shrimp fluctuates over the harvesting season. The fluctuation is caused by the availability of shrimp, the physical condition, demand (wholesale prices) and size of shrimp. Some processors are willing to pay higher price (one to four cents more per pound) for better quality shrimp (better handling, cleaning, and storage of shrimp on boat). Figure 21 shows how much one of the processors paid for his shrimp in 1974 and 1975. Most processors pay their shrimp for the gross weight of shrimp they bought. Others pay theirs on recovery basis (i.e. They pay according to the weight of shrimp meat extracted from their shrimp).

^{8/} Copy of the questionnaire is shown in Appendix A.

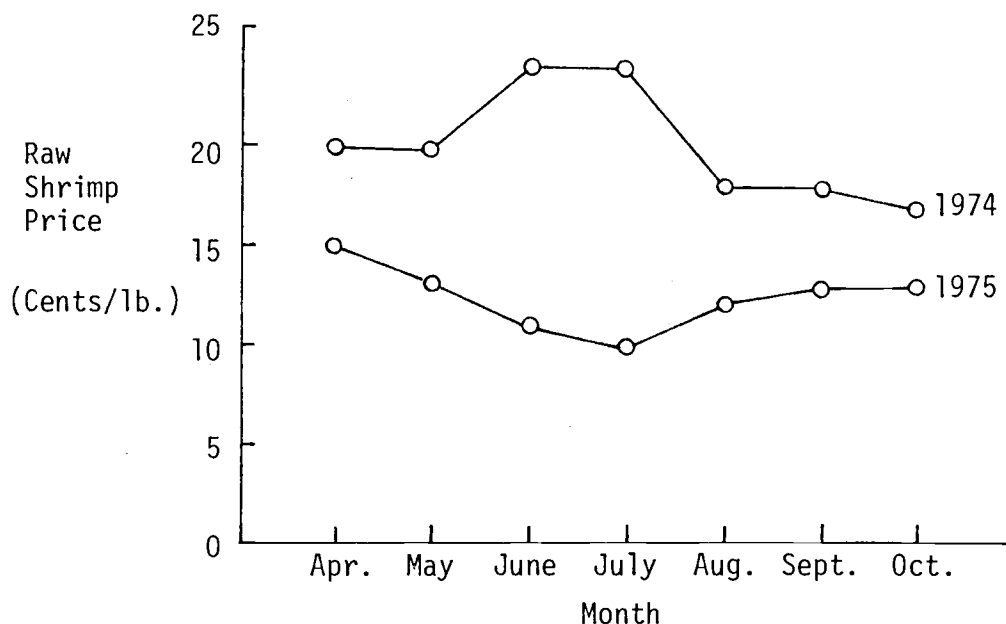


Figure 21. Price of raw shrimp paid by one processor.

3. Other factors affecting the price of raw shrimp are:
 - a. recovery rate of shrimp meat from shrimp;
 - b. percentage of broken shrimp, percentage of shrimp bearing eggs, freshness and cleanliness of shrimp.
4. The shrimp processing season is the same as shrimp harvesting season. Processors in Oregon are prohibited to process shrimp from other states. Table VII shows the shrimp harvesting season of Oregon (17).
5. Experience of shrimp processing (with mechanical peelers) among plants ranges from two to eight years. Most plants did manual shrimp picking before the mechanical peeler was introduced.

TABLE VII. OREGON SHRIMP HARVESTING SEASON (17).

Year	Season
1971 and before	Year-round, before 1964. Now March 1 to October 31, except catches south of California-Oregon border may not be landed October 1 to May 1.
1972	March 1 to October 31, except catches south of California-Oregon border may not be landed November 1 to May 1.
1973	April 1 to October 15, except catches south of California-Oregon border may not be landed October 16 to April 16.
1974	Same as 1973.
1975	Same as 1973, except the end of the season was extended to October 31.

6. Shrimp processing is the only business of two of the 20 plants. Others process bottom fish and/or crab also. Generally, most plants process as much shrimp as they can and in addition, they process crab and bottom fish.
7. Volume of shrimp processed for each plant in the last five years average ranges from 750,000 pounds to 1.5 million pounds annually.
8. Plants producing frozen shrimp meat pack their shrimp meat into traditional five-pound cans. Two of them also have one-pound cans or one-pound bags. Frozen shrimp meat are kept frozen until they are sold to wholesalers. Two plants can their shrimp meat in 4.5-ounce cans and retort them.
9. Wholesale price of shrimp meat fluctuates as the price of raw shrimp. It ranges from \$1.25 to \$2.00 per pound. Some plants price their shrimp meat a bit higher than the others.
10. Customers of the processors are wholesalers, brokers, institutions, chain stores, and retailers. Next year, one processor plans to sell directly to the consumer.
11. Factors affecting price of shrimp meat are:
 - a. market condition - supply and demand;
 - b. availability of raw shrimp;
 - c. cost of processing;
 - d. price of other meat.
12. Shrimp meat is viewed as a kind of luxury food item which is very much affected by the shape of the national economy.

13. Basically all processors appear to be satisfied with thir own operation.
14. Most processors have an interest in further reduction of processing cost, better utilization of labor and equipment, and more and steady supply of raw shrimp.
15. Peelers and separators are common to most plants, but there is considerable variation in auxiliary equipment^{9/} and operating practices.
16. Progressive processors are enthusiastic about future improvement in shrimp packaging and marketing.

^{9/} A summary of equipment used among plants is shown in Table VIII on the following page.

TABLE VIII. SUMMARY OF EQUIPMENT^{10/} USED AMONG PLANTS IN OREGON

Plant	From boat to dock	Deice- washer	Ground to peeler	Number of PCA peeler	Number of washer- cleaner	Peeler or cleaner to separator
A	H.	No	H.	2	1	G.F.
B	H.	No	H.	1	1	G.F.
C	H.	Yes	P.	5	3	G.F.
D	H.	Yes	H.	1	1	G.F.
E	H.	No	H.	2	0	G.F.
F	H.	No	H.	1	0	G.F.
G	H.	No	H.	2	0	G.F.
H	P.	Yes	H.	4	0	G.F.
I	H.	Yes	H.	1	1	G.F.
J	H.	Yes	H.	2	2	G.F.
K	H.	No	H.	2	1	G.F.
L	H.	Yes	H.	2	2	G.F.
M	H.	Yes	H.	4	0	C.F.
N	H.	No	H.	1	1	C.F.
O	H.	No	H.	1	1	C.F.
P	H.	No	H.	1	1	G.F.
Q	H.	Yes	P.	2	0	W.P.
R	H.	Yes	H.	3	0	G.F.
S	H.	Yes	H.	2*	2	G.F.---
				1*	1	C.F.---
T	H.	No	H.	3	0	G.F.

H. = Hoisted

P. = Pumped

G.F. = Gravity Feed
(with water flume)

C.F. = Conveyor Feed

W.P. = Water Pump

* = Model A (no precook)

^{10/} Equipment pictures appear on the following pages.

TABLE VIII. Continued.

Plant	Number of separators	Number of air-blowers	Number of de-water shakers	Inspect- ion channel	Refrig- erated brine
A	2	0	0	T.	A.
B	1	0	0	T.	A.
C	3	1	1	C.	A.
D	1	0	0	T.	A.
E	1	1	0	C.	A.
F	1	0	0	C.	A.
G	1	0	0	C.	A.
H	2	0	0	T.	A.
I	1	0	0	C.	A.
J	2	0	0	T.	A.
K	1	0	0	T.	A.
L	2	0	0	T.	A.
M	2	0	0	T.	A.
N	1	0	0	T.	A.
O	1	0	0	T.	A.
P	1	0	0	T.	A.
Q	1	1	2	C.	A.
R	2	0	1	C.	A.**
S	$\begin{array}{l} \text{---} 2 \\ \text{---} 2 \end{array} > 1$	0	0	C.	A.**
T	2	0	0	T.	A.

T. = Inspection Table
 C. = Conveyor Belt
 A. = Brined After Inspection
 ** = Automatic Brining

Cause-And-Effect Diagram of Shrimp Processing

A cause-and-effect diagram, Figure 22, was constructed after plant visitings, discussion with processors, equipment manufacturers, and sea-grant researchers. Eight major causes are 1) shrimp supply, 2) plant facilities, 3) management, 4) workers, 5) receiving shrimp from fishermen, 6) peeling and cooking, 7) inspection, and 8) packing. The main effects are product and profit.

Causes

Processors are concerned about a reliable and steady supply of shrimp. Some trawlers can bring back as much as twenty thousand pounds of shrimp. The major species in the catches is pacific pink shrimp (*Pandalus Jordani*). Size of shrimp range from 50 shrimp per pound (about nine gram per shrimp) to over 150 shrimp per pound (less than three gram per shrimp). The handling and storage of shrimp on a trawler is important to both fishermen and processors. Fishermen can get a better price for his shrimp if he can keep his shrimp clean (no mud, trash fish and undesirable foreign matter), more uniform in size, and iced properly. Generally shrimp, after being caught, stay on the trawler from one to three days before they are brought back to port and sold to processors.

Facilities of a processing plant are important to the cost of processing, production rate, and quality of shrimp meat. Equipment in plants range from the least mechanized, with mechanical peeler and separator, to the more mechanized, with deice-washer, shrimp grader,

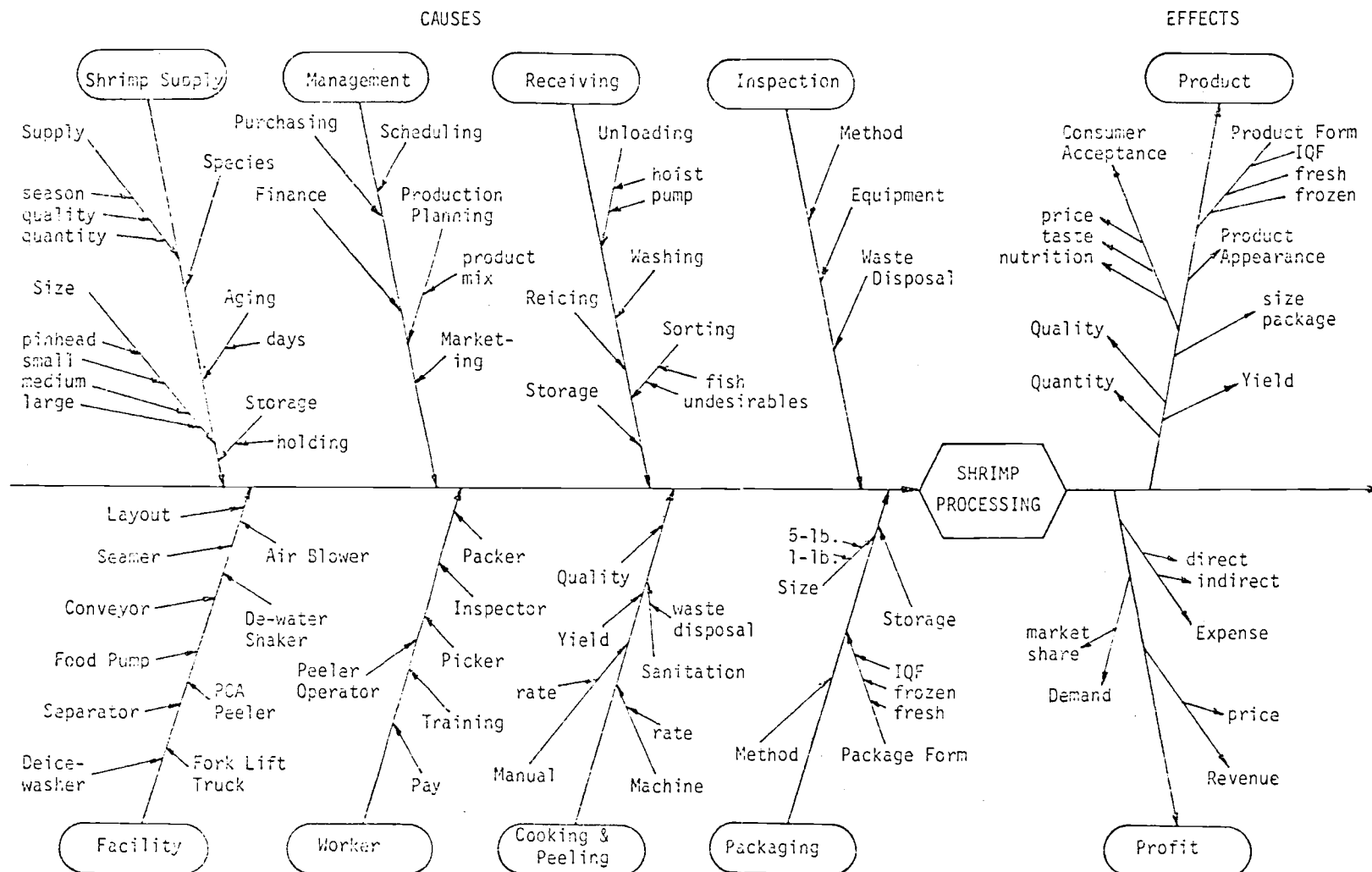


Figure 22. Cause-and-effect diagram of shrimp processing.

sump pump, mechanical peeler, washer-cleaner, separator, air blower, de-water shaker, inspection conveyor, and automatic can sealer.

Equipment will be described in detail in the later part of this chapter.

The role of management is extremely important for the optimization of profit. Purchasing, production planning, scheduling, marketing and financing are management's major responsibility. Most processing plants in Oregon are small independent operations. Only a few are branches of large corporations. For the small plants, the number of staff in the management team is small (in some cases, the owner is the manager) and each staff has to get involved in all the management functions. Communication between processors and the market (both raw shrimp and shrimp meat markets) is another important area. Processors have to be alert and skillful at all times in order to maintain their profit and competitive position.^{11/}

Generally workers working on the shrimp processing line are women - except those taking care of the mechanical peelers. Since the jobs, inspection and packaging, are more or less similar to an assembly line, monetary return (wages and other benefits) and personal relationship are important to maintain the efficiency of the operation. The floor-lady has the responsibility not only to keep the processing line going but also to keep the whole work team together. Most processors try to

^{11/} A detailed description of improved management-decision methodology occurs when the data-base information is transferred from the cause-and-effect diagram to a resource-planning-management (RPM) model which is described on pages 181 to 193.

make their workers proud of the quality of their product - shrimp meat. Since shrimp processing in Oregon is not a year round operation, it is the processors' desire to train their workers to shake crab and fillet bottomfish so that the workers can extend their work on crab or bottomfish after the shrimp processing season is over. This enables processors to maintain higher skill levels, to keep a constant skillful work force, to minimize hiring and training cost, and to reduce unemployment compensation payments.

Receiving of shrimp includes unloading of shrimp from a trawler to dock, deicing, washing, and reicing. Most plants do not grade their shrimp. If the shrimp are mixed with trash fish, the fish will be picked out before the shrimp are reiced. Once the shrimp are reiced, they will be processed on the same day or kept for one to three days. However, the quality of shrimp deteriorate very rapidly especially after they had been caught for more than three days.

Cooking and peeling are done simultaneously. All plants but one in Oregon use Laitram precook model A peelers to cook and peel their shrimp. Besides the sizes, physical condition, and length of aging of shrimp, recovery of shrimp meat also depends on the adjustment of peeler, cooking time, peeling rate, and the use of mechanical cleaning devices. One plant uses Laitram model A peelers to peel its shrimp raw, then cooks the shrimp meat, and retorts them after canning. Shrimp shell is becoming an area processors care about because the shells have to be disposed of in a proper manner. Most plants collect their shells and bring them to landfill sites. Research is going on to find ways of

utilizing shrimp shells (e.g. animal feed and fish feed).^{12/}

Ever since manual picking of shrimp has been replaced by mechanical peeling, inspection of shrimp meat has become the most labor consuming activity. Four to seven female inspectors stand beside a conveyor belt or a table to pick out pieces of shell, antenna, and foreign matter from shrimp meat coming out from one mechanical peeler. However, this activity also allows the shrimp meat to be exposed to air and human hands. A reduction of exposure time and bacteria growth is discussed on pages 109 and 110.

Effects

Shrimp meat is generally packed in five-pound cans and kept frozen. Two plants also pack one-pound packed shrimp meat. Two other plants can their shrimp meat in 4.5-ounce size and retort them. Recently, two plants installed an individual quick freeze (IQF) system. The system is for freezing shrimp meat individually. One plant did not use its facilities this year. The other plant has tested a few hundred pounds of shrimp meat on its system and plans to expand its IQF shrimp meat market in the next processing season. Product form and product appearance are important factors in marketing of shrimp meat.

Shrimp meat comes out of processing plants in the form as it is packed. However, the plants are recognized by big buyers only, not individual consumers in the supermarkets. It is because the five

^{12/} Personal interview with Dr. D. L. Crawford, Department of Food Science and Technology, Oregon State University Seafoods Laboratory, Astoria.

pound can of shrimp is thawed and repacked into smaller packages which do not identify the processor. Due to the small size of Oregon shrimp, frozen shrimp meat in cocktail form is the only form that bears the processor's label. Larger shrimp from the Gulf of Mexico can be breaded or sold with the shell on.

Profit is the ultimate goal of processing. A plant can keep operating only if it can earn a fair profit from its operation. Cost saving, improved shrimp quality, further mechanization, better resource planning and utilization, and better marketing are major ways to increase profit.

Harvesting and Holding

Shrimp fishing off the Oregon coast remains basically the same as it was several years ago when studies were begun. The fishermen still use the same net design and gear to fish shrimp, except for two limited experiments.^{13/} Separation of trash fish from shrimp is still done manually. Funds for studies on improved net design to allow escapement of pinhead shrimp and small fish have been cut and little progress of the program has been made.

After shrimp are washed and sorted, they are shovelled into the holding compartment of the trawler and then a layer of ice is laid on top of them. This is the same practice that was being used several years ago. This method requires a lot of labor and quality losses due to shovelling and improper icing can be large. The following are detailed descriptions of each activity along the processing line. A process chart and a layout of the current general practice are shown in Figures 23 and 24. Although harvesting and holding of shrimp is not the processor's job, they are relevant to the processor's operation and the quality of his product - shrimp meat.

^{13/} Test runs conducted at sea under the direction of Marine Advisory Extension agents during the summer of 1975.

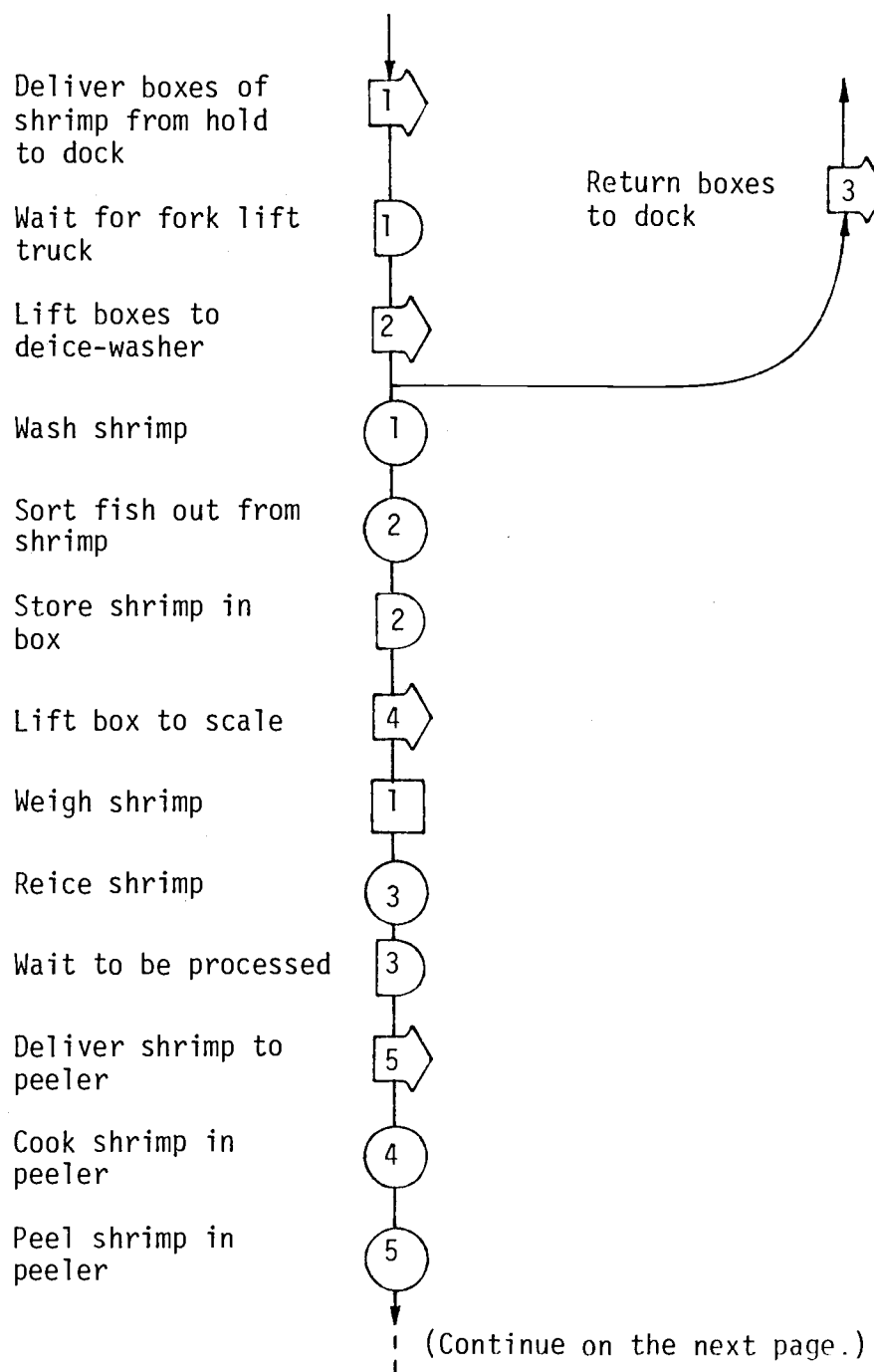


Figure 23. Process chart of shrimp processing - current general practice.

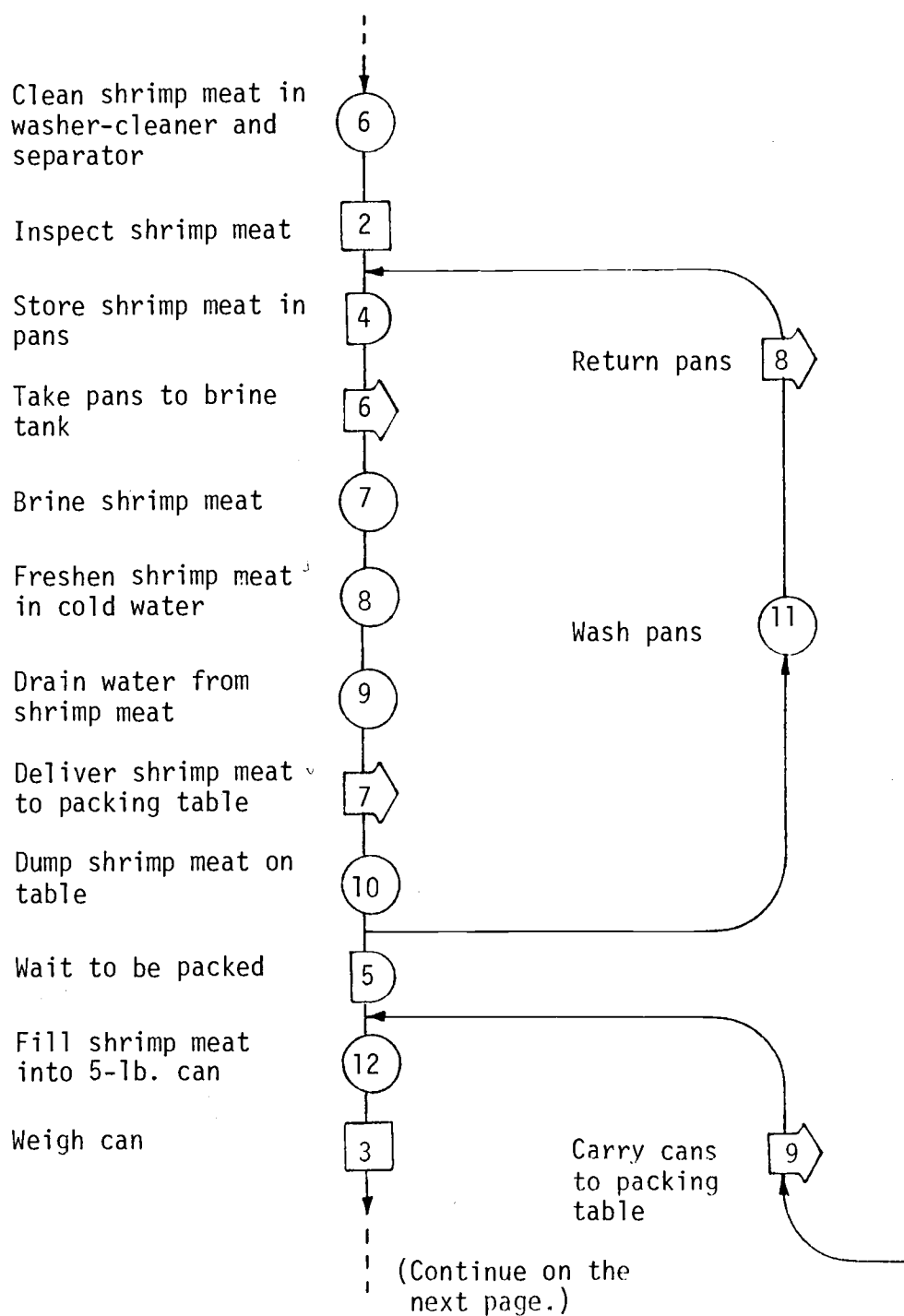
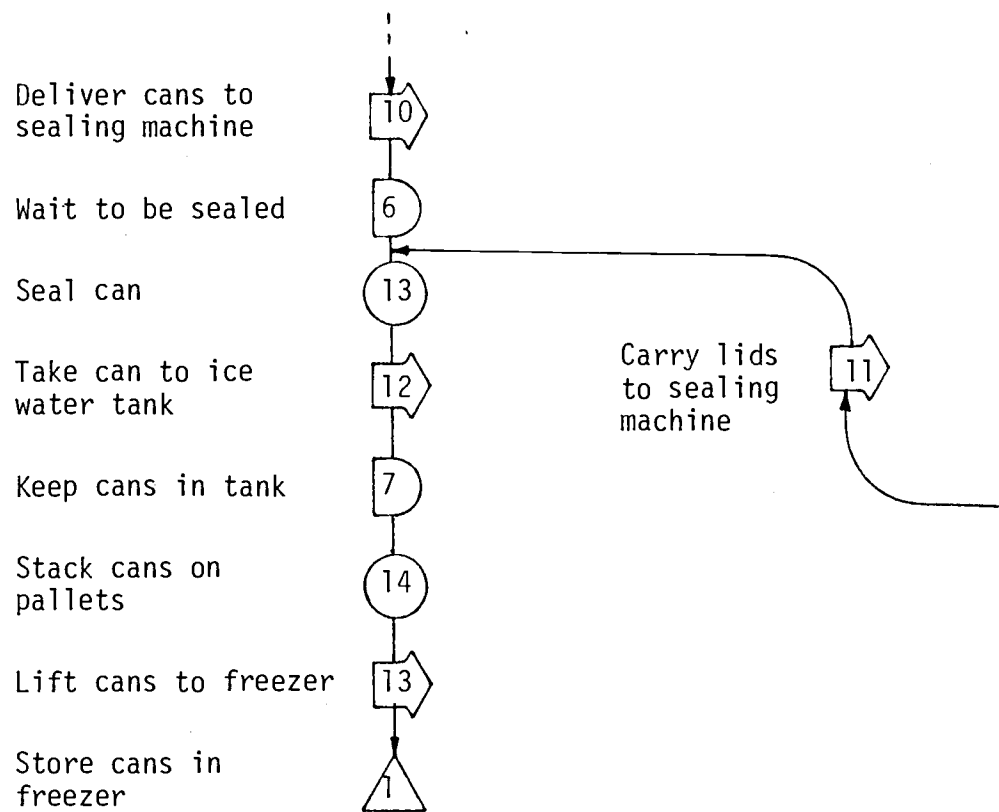


Figure 23. Continued.



○	Operation	14
➡	Transportation	13
□	Inspection	3
⊖	Delay	7
▽	Storage	1
Total		<hr/> 38

Figure 23. Continued.

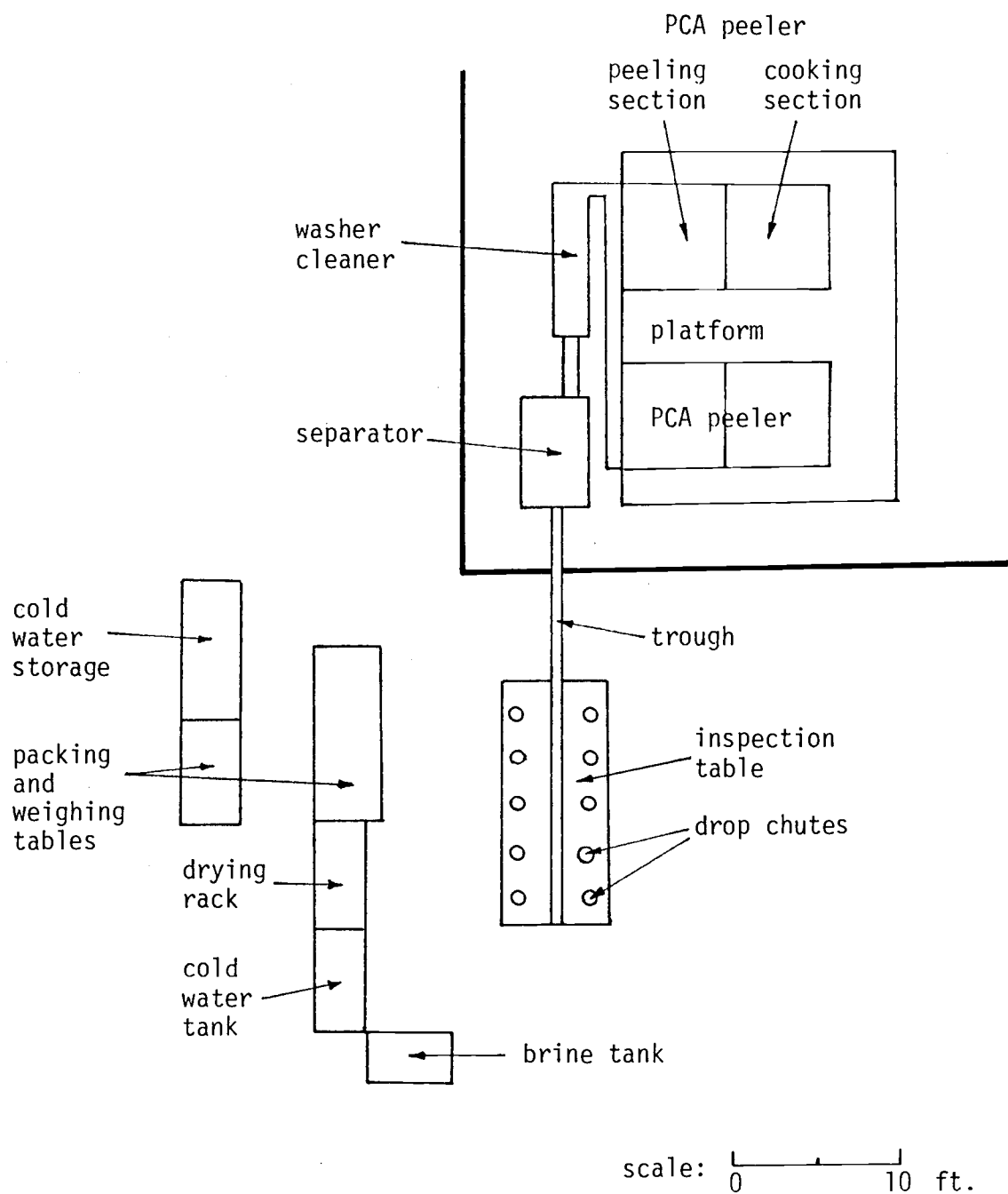


Figure 24. A typical layout of shrimp processing - current general practice.

Unloading

After a trawler has brought its' shrimp catches to a processing plant, the shrimp are usually shovelled into boxes and hoisted to the dock from the holding compartment as shown in Figure 25.

One plant uses a pneumatic vacuum pump to bring the shrimp from the holding compartment to the dock. This method shortens the unloading time but allegedly increases the percentage of broken shrimp. After boxes of shrimp (between 80 and 300 pounds per box) have arrived on the dock, they are delivered by a fork lift truck to a deice-washer where shrimp are washed. Some plants do not have such a device and omit the washing procedure. These processors claim that the shrimp fishermen can do a better washing job at sea. A picture of a deice-washer is shown in Figure 45. From the washer tank, shrimp are carried by a conveyor belt to a box. Trash fish and unwanted objects are sorted out as the shrimp travel on the conveyor. Figure 26 shows how the sorting is done. Then the boxes of shrimp are delivered by a fork lift truck to a scale to be weighed. Most fishermen are paid by the gross weight of shrimp they brought to the plant. However, there is a growing tendency to pay fishermen on a "yield" basis.



Figure 25.
Shrimp from trawler to dock.



Figure 26.
Sorting of trash fish and unwanted
objects from shrimp.

Grading of Shrimp Size

Only one plant grades its shrimp into two sizes before the shrimp are delivered to be cooked and peeled. The grading process is done by a mechanical grader which vibrates as the shrimp are moving through it. Smaller shrimp drop through smaller channels into a tote box and larger shrimp move on and drop into another tote box. A picture of the shrimp grader being used by the plant is shown in Figure 46. The purpose of grading is to obtain a more uniform size of shrimp before they are cooked and peeled in a PCA peeler. This will allow the peeler peel more efficiently and therefore better recovery of shrimp meat can be obtained. Other plants process their shrimp in mixed size.

Reicing

If the shrimp are not processed immediately, they will be reiced. For a small tote box containing less than a hundred pounds of shrimp, a layer of ice is laid on top of shrimp. For a large tote box containing about 200 to 500 pounds of shrimp, alternate layers of ice are used to keep the shrimp cool and prevent rapid growth of bacteria.

Aging

Aging of shrimp refers to the storage period of shrimp after harvesting and before peeling. Table IX shows the differences in shrimp quality, peeling, and recovery between different aging of shrimp.

The less the storage time before the shrimp are cooked and peeled, the better the quality of the shrimp meat will be. Shrimp aged one day are good in quality but comparatively difficult to be peeled because the fresh shrimp meat is not loosen enough from the shell. Thus recovery of one day old shrimp is not optimal in productivity rates and yields. Two days old shrimp are easier to be peeled and the recovery is relatively good. Both quality and recovery go down gradually as the aging period increases.

TABLE IX. AGING EFFECTS ON SHRIMP

Aging	Quality	Peeling	Recovery
1 day	Good	Difficult	Fair
2 days	Fairly Good	Easy	Good
3 days	Fair	Easy	Fairly Good
More than 3 days	Bad	Very Easy	Bad

Cooking and Peeling

In Oregon, all processing plants but one use the Laitram PCA peeler. Although other kinds of peelers are available, processors in Oregon tend to use the Laitram PCA because it has been tested successfully and is suitable to Oregon shrimp. Laitram PCA peeler is composed by two parts, a cooking tank and a peeling section. Most plants elevate boxes of shrimp and dump them into the cooking tank. One plant uses a sump pump instead. Cooking time depends on the temperature of cooking water, size of shrimp, and procedure of processing. The average time is three minutes. After being cooked, shrimp are conveyed into the peeling section. Cold water is used to cool the shrimp and flume them along the peeling rolls. As the shrimp are flumed along the peeling rolls, shrimp shells are broken by pressure fingers and shells are carried away by roller-edge nip points. A picture of a peeling section is shown in Figure 5-6. Pictures of PCA peelers in action are shown in Figures 36, 37, 48, and 49. Then the shrimp meat is flumed to a washer-cleaner or separator. According to processors and the equipment manufacturer, normal peeling rate of a Laitram PCA peeler is as shown in Table X. } Shrimp size of between 90 to 120 raw shrimp per pound is ideal for the peeler. Over 150 raw shrimp per pound, shrimp yields decrease, especially when the peelers are not adjusted to handle smaller sizes.

Only one plant in Oregon uses Laitram model A peeler which is similar to the PCA peeler. Shrimp are peeled raw by model A peeler and cooked after the shrimp meat are cleaned by washer-cleaner and separator. This plant does not freeze its shrimp. It cans them into 4.5 ounce size

and retorts them. Recovery from using model A peeler is larger than recovery from using PCA peeler. However, shrimp peeled by PCA peeler appear better in color and shape.

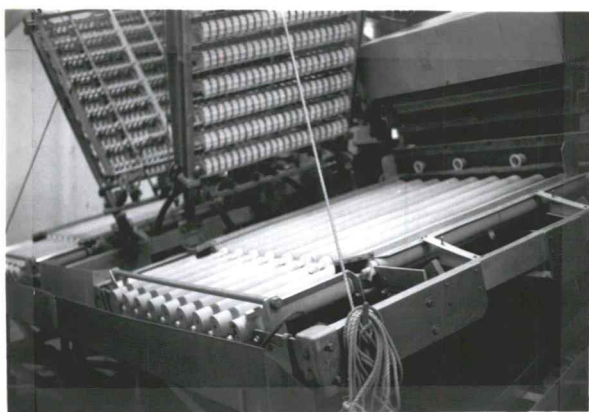


Figure 27.
Peeling rolls (foreground)
and pressure fingers (lifted
up) of Laitram PCA peeler.

TABLE X. NORMAL PEELING RATE OF A LAITRAM PCA PEELER

Age Period	Normal Peeling Rate lbs. of raw shrimp per hour per peeler
one day	350 to 500
two days	500 to 700
three days	700 to 900
more than three days	over 1000

Cleaning

After shrimp have gone through the peeler, they are either flumed down or delivered by a conveyor to cleaning devices. Some plants use both washer-cleaners and separators while others use separators only to remove shells, antenna, and eyes adhered on the shrimp meat. Pictures of a washer-cleaner and a separator are shown in Figures 28 and 29. The function of the washer-cleaner is to loosen any unpeeled shells. The function of the separator is to detach any remaining shells, take away the antenna, and eyes.

Before the shrimp meat is delivered to the inspection station, it will pass through an air blower (or air cleaner) if the plant has one. The air blower is used to blow away any tiny pieces of shell, antenna, and eyes to further reduce the inspection effort. A picture of an air blower is shown in Figure 53.

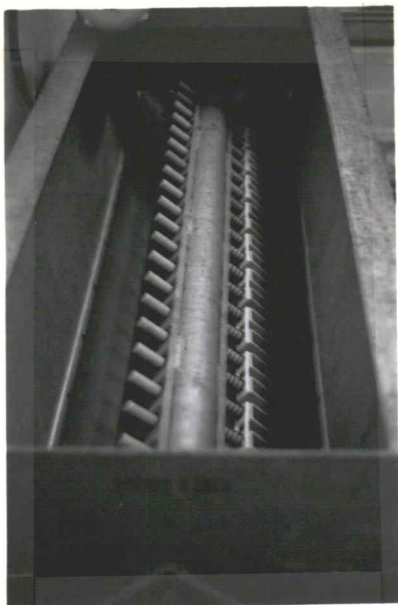


Figure 28.
Washer-cleaner.



Figure 29.
Separator.

Inspection

As manual shrimp picking is replaced by mechanical peeling, inspection of shrimp meat becomes the most labor consuming activity in the entire processing line. An inspection table, as shown in Figure 30, a shaker-table, as shown in Figure 41, or a conveyor, as shown in Figure 54, is used as an inspection platform. The inspection table has a drop chute for shrimp meat and a water flume to dispose waste material. The shaker-table and the conveyor allow inspection with minimum human handling of shrimp meat. Several plants use de-water shaker, as shown in Figure 52, to reduce water on shrimp meat before inspection. Some plants use conveyor belts and/or shaker-tables to move shrimp past the inspectors, as shown in Figure 41. Shaker-table users claim that the manual handling is minimized and the water exposure is eliminated. Generally, four to six inspectors are needed to inspect shrimp meat coming out from two peelers.^{make up this number} The duty of the inspectors is to make sure the shrimp meat is free from unwanted objects. After inspection, shrimp meat are accumulated in a pan temporarily or delivered into a brine tank.



Figure 30.
Inspection table.

Brining and Freshening

Generally shrimp meat in a sieve pan or sieve basket are immersed into a cold brine solution and then freshened in a cold water tank. Then they are placed on a rack to allow water to drain from shrimp meat. All these can be seen in Figure 31. Some plants use brine spray and water spray to perform the brining and freshening and de-water shakers are used to drain the water.

Packing

Almost all plants who process frozen shrimp meat pack their products into five-pound cans. Two plants also have one-pound cans or one-pound bags. In one plant, retorted shrimp meat are canned in 4.5-ounce size. Figure 32 shows examples of different kinds of packaging. Packaging of five-pound cans is done manually as shown in Figure 31, Operators fill the can and adjust the weight to a specific requirement - five pounds. Then the operator seals the can with a can seamer. Two plants in Oregon own an individual quick freeze (IQF) system. However, no mass production of IQF shrimp meat was done this year due to adverse marketing conditions. One plant did not process IQF shrimp in the 1975 season. The other one is still testing its' system. Further discussion of the IQF system is in the next chapter. For retorted shrimp meat, can filling, weight adjustment, brine filling, and can sealing are performed automatically by machine.



Figure 31.
Inspection, brining and
freshening.



Figure 32.
Five-pound can, one-pound
can, one-pound bag, and
4.5-ounce can.

Storage and Freezing

After the shrimp meat are canned and placed in a cold water bath temporarily they are transported to the freezer compartment and held there until they are shipped to customers. This method is practiced in Oregon almost exclusively and has been done this way for many years.

Pictorial Examples Show Sequence of Shrimp Processing in Two Plants

Plant T (Plant T has a minimum of auxiliary equipment.)



Figure 33.
Shrimp are hoisted up to
the platform.



Figure 34.
Shrimp are hoisted toward a
cooker.



Figure 35.
Shrimp are dumped into a
cooker.



Figure 36.
Shrimp are cooked.

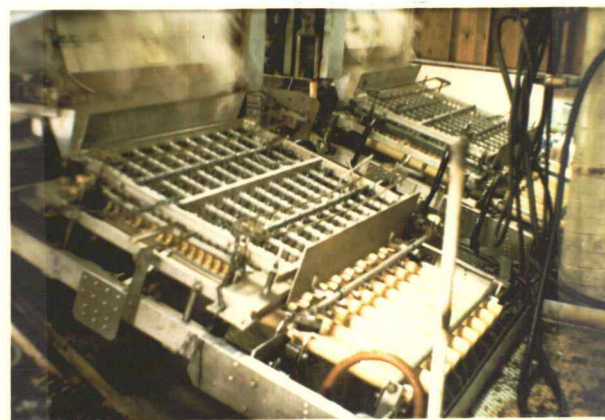


Figure 37.
Shrimp are peeled.

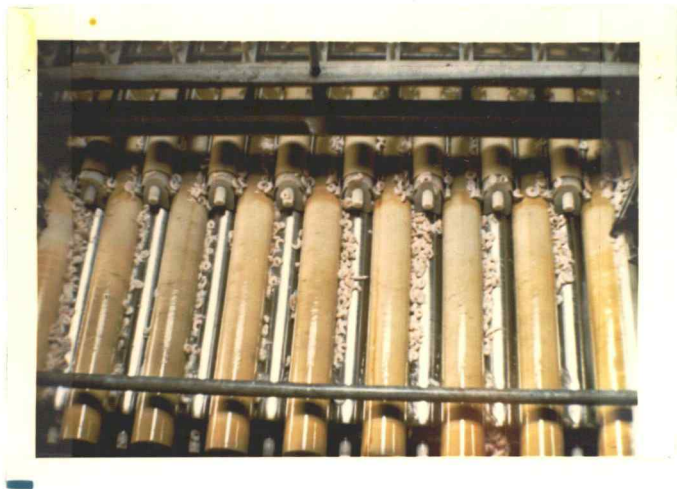


Figure 38.
Shrimp are peeled (close up).

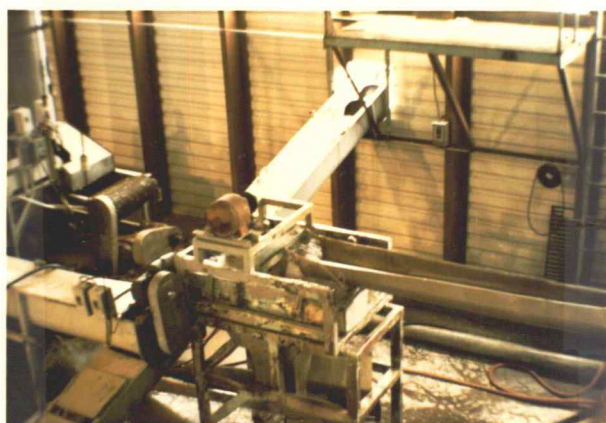


Figure 39.
Shrimp shell are discarded.

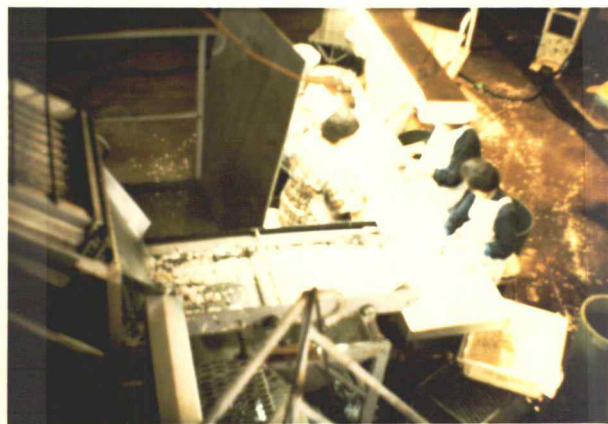


Figure 40.
Shrimp meat is dropped to a
shaker table from separator.



Figure 41.
Shrimp meat is inspected on
a shaker table.



Figure 42.
Shrimp meat is inspected
and packed in five-pound
cans.



Figure 43.
Cans are sealed by a can
seamer.



Figure 44.
Cans of shrimp meat are delivered to cold storage.

Plant Q (Plant Q has above-average equipment accessories.)

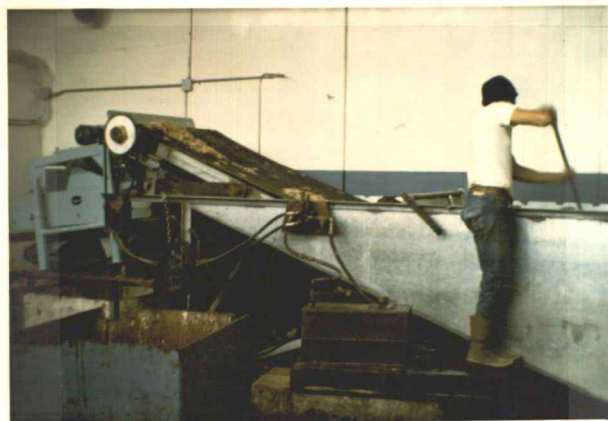


Figure 45.
Shrimp are washed in a
wash-tank.



Figure 46.
Shrimp are sorted by size.



Figure 47.
Shrimp are dumped into a
food pump.

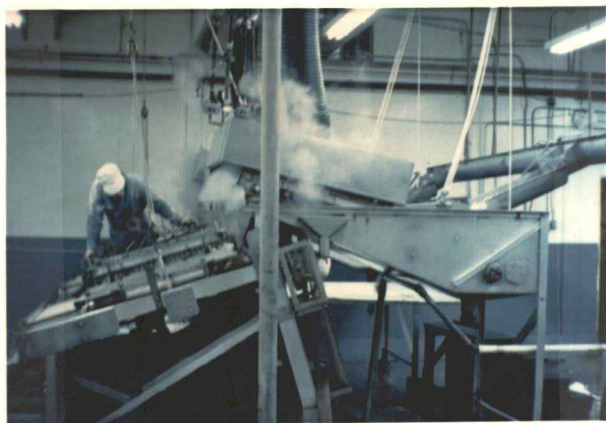


Figure 48.
Laitram PCA peeler.

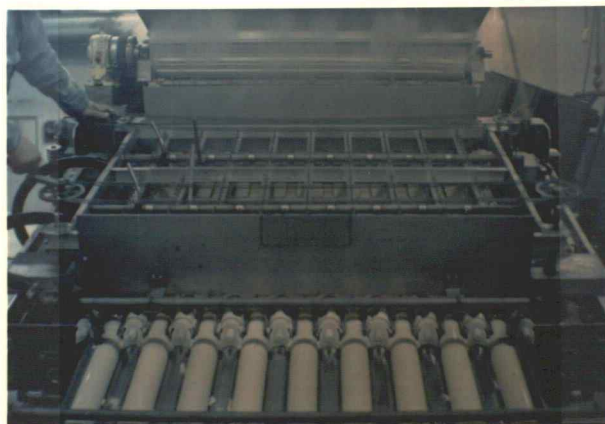


Figure 49.
Shrimp are peeled.



Figure 50.
Shrimp meat is flumed into a
sump pump.



Figure 51.
Shrimp meat is cleaned in a
separator.



Figure 52.
Shrimp meat is flumed into a
de-water shaker.



Figure 53.
Shrimp meat is cleaned by
an air-blower.



Figure 54.
Shrimp meat is inspected on
a conveyor belt.



Figure 55.
Shrimp meat is brined,
de-watered and packed.

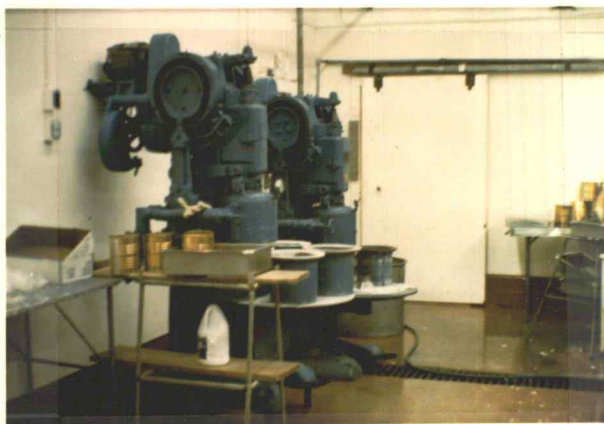


Figure 56.
Cans are sealed by a can
seamer.

VI. ECONOMIC ANALYSIS OF SHRIMP PROCESSING MACHINERY

Harvesting and Holding

Better cleaning and sorting can benefit both the fishermen and processors. Until new net design (5) allowing escapement of pinhead shrimp, fishermen can seek benefits by on board cleaning and sorting.

Fishermen can seek three benefits.

1. Upgrade shrimp quality by lessening fish oil coating.
2. Delay bacterial growth by removing unwanted fish which deteriorate faster than shrimp.
3. Allow more holding space for shrimp due to the elimination of undesirables.

Processors can seek two benefits.

1. Increase shrimp meat recovery due to the fact that shrimp without fish oil coating, trash fish, and foreign matter can be peeled more efficiently.
2. Reduce inplant labor because shrimp have been cleaned at sea.

However, a thorough cleaning process is very inefficient if the fishermen have to do it manually. Their time may be too precious to be used for cleaning shrimp. They may benefit by spending their time to catch more shrimp unless they can get a higher price for cleaned shrimp.

Barry Fisher, a former associate professor of fisheries at Oregon State University has been working on the development of a shrimp-trash sorting machine. In "test runs at sea", a marine advisory team has

successfully separated trash fish from shrimp. As yet, the final design specifications are not available. However, recently, an equipment manufacturer^{13/} has introduced a separator for on board vessel cleaning and sorting process. Following is a description of how the machine works. After shrimp and fish are caught, they are dumped on deck and hosed into a shrimp washer sump. Then the shrimp and fish are metered on a wash belt and onto a separator. Then fish are rejected back into the sea and shrimp are blown into the holding compartment ready to be iced. An illustration of the machine is shown in Figure 57. Below is an economic analysis of the machine^{14/}.

Separator cost = \$5500

Installation = \$1000

Annual maintenance cost = \$ 100

Salvage value = \$ 500

Life of machine = 10 years

Assume: Income tax rate = 40%

Minimum attractiv rate of return (MARR) = 10%

Straight line depreciation is adopted

Annual harvesting volume = 200,000 pounds

^{13/} Key Equipment Company, Milton-Freewater, Oregon.

^{14/} Cost of the machine depends on the specification of each customer. Figures presented in the analysis are approximations.

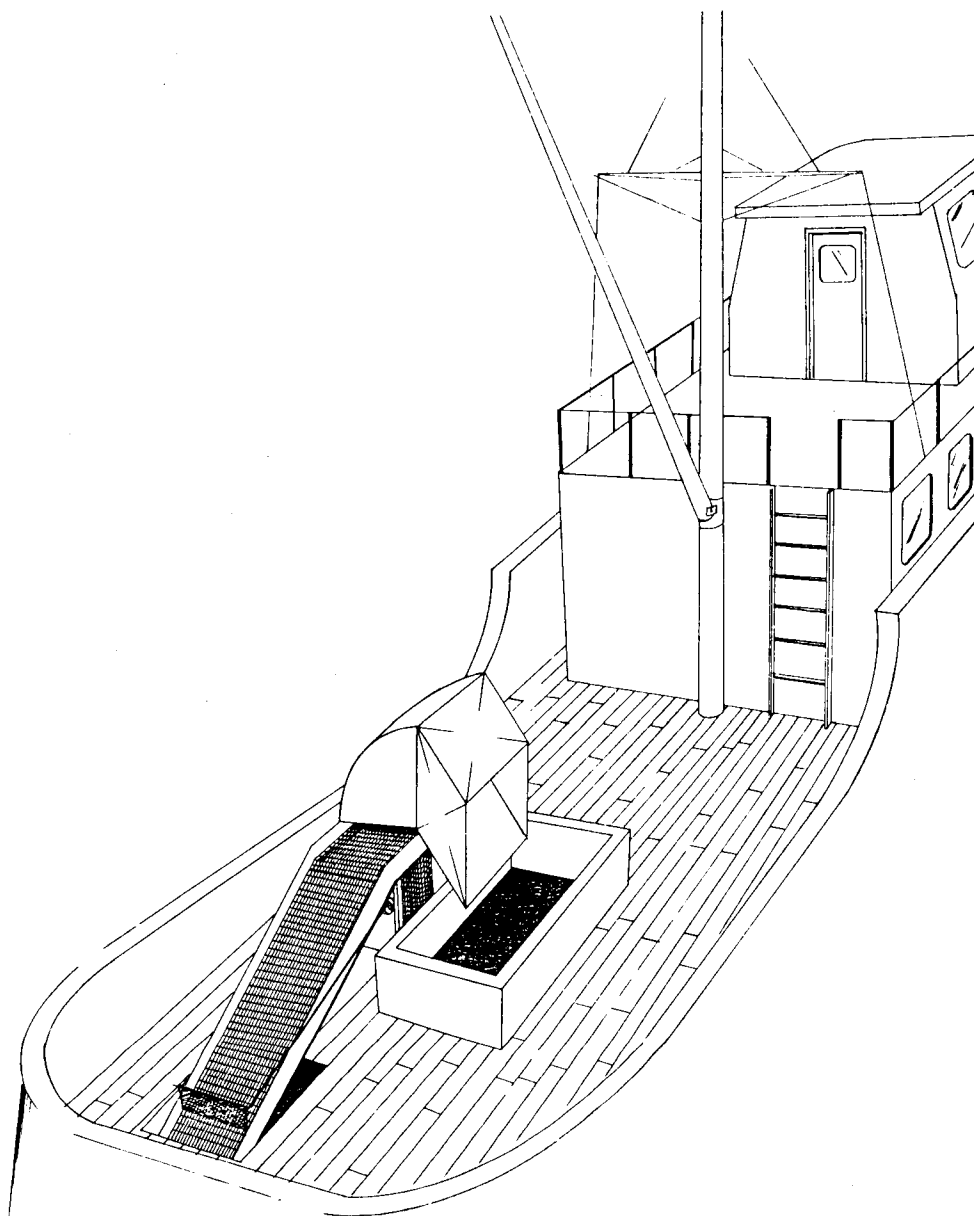


Figure 57. Shrimp from fish separator by Key Equipment Company.

Tax effect on:

$$\text{Installation} = \$1000 \times 0.4 = \$400 \text{ (reduction)}$$

$$\text{Annual maintenance cost} = \$100 \times 0.4 = \$40 \text{ (reduction)}$$

$$\begin{aligned} \text{Annual depreciation} &= \$(5500 - 500)/10 \times 0.4 \\ &= \$200 \text{ (reduction)} \end{aligned}$$

The cost pattern can be expressed in Figure 58.

Annual equivalent cost (AEC)

$$\begin{aligned} &= \$6500(A/P, 10, 10) + 100 - 240 - 600(P/F, 10, 1)(A/P, 10, 10) \\ &\quad - 500(A/F, 10, 10) \\ &= \$6500(0.1628) - 140 - 600(0.9091)(0.1628) - 500(0.0628) \\ &= \$1058.2 - 140 - 88.8 - 31.4 \\ &= \$798 \end{aligned}$$

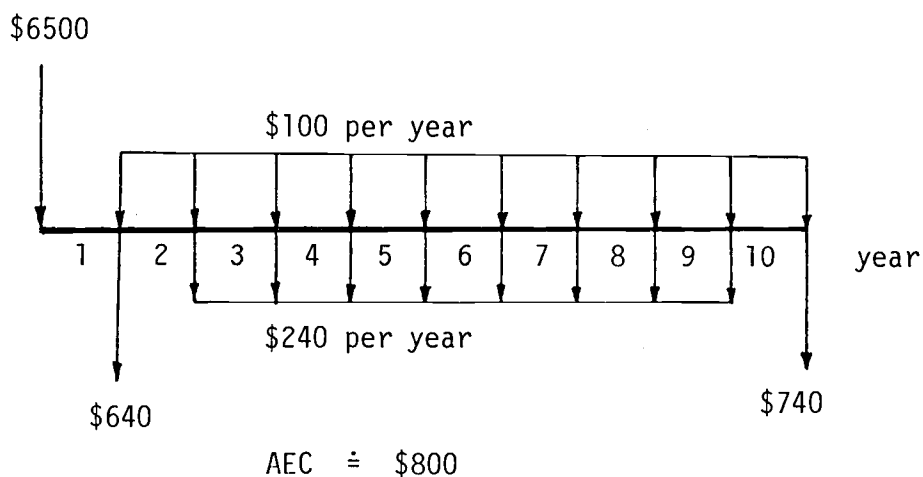


Figure 58. Cost pattern of shrimp from fish separator.

Assume the capacity of harvesting will be increase by X% due to the installation of the separator. Figure 59 shows the relationship between cost and benefit. Market price 24 cents per pound, 18 cents per pound, and 12 cents per pound are assumed to be the optimistic, most likely and pessimistic price respectively. After tax, the income will be 14.4 cents per pound, 10.8 cents per pound, and 7.2 cents per pound respectively.

Y, Annual benefit after tax.

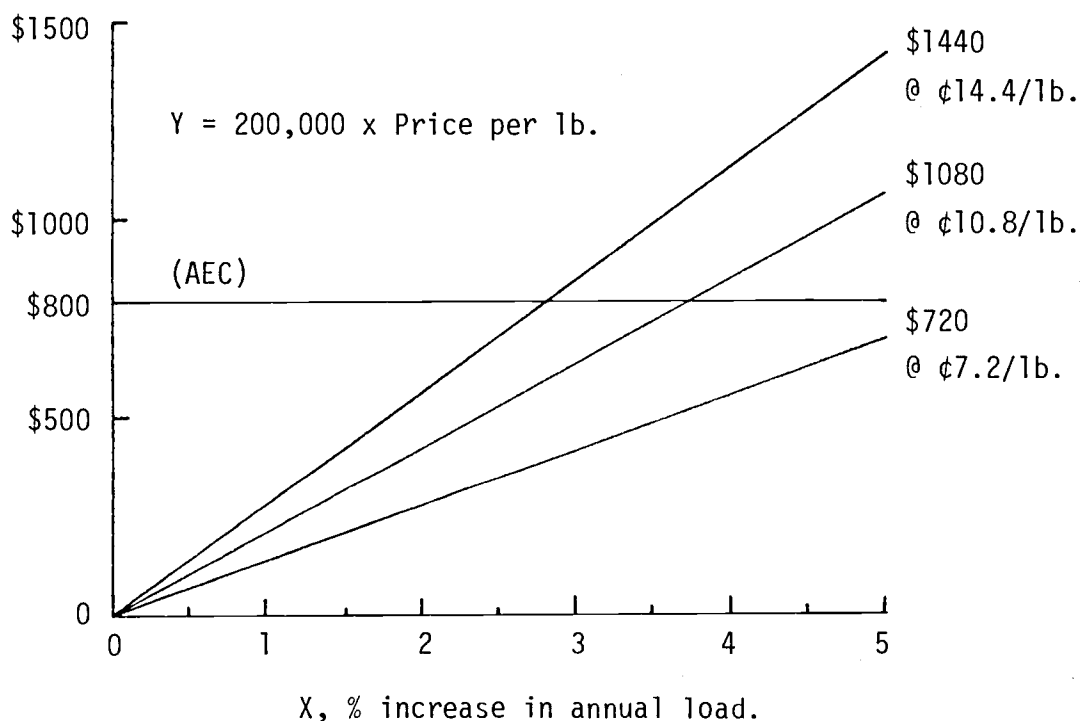


Figure 59. Annual benefit due to load increase.

Assume the fishermen will obtain higher price per pound for cleaned shrimp. Figure 60 shows the annual benefit of price increase together with harvested volume increase at a base price of 18 cents per pound (10.8 cents per pound of income after tax).

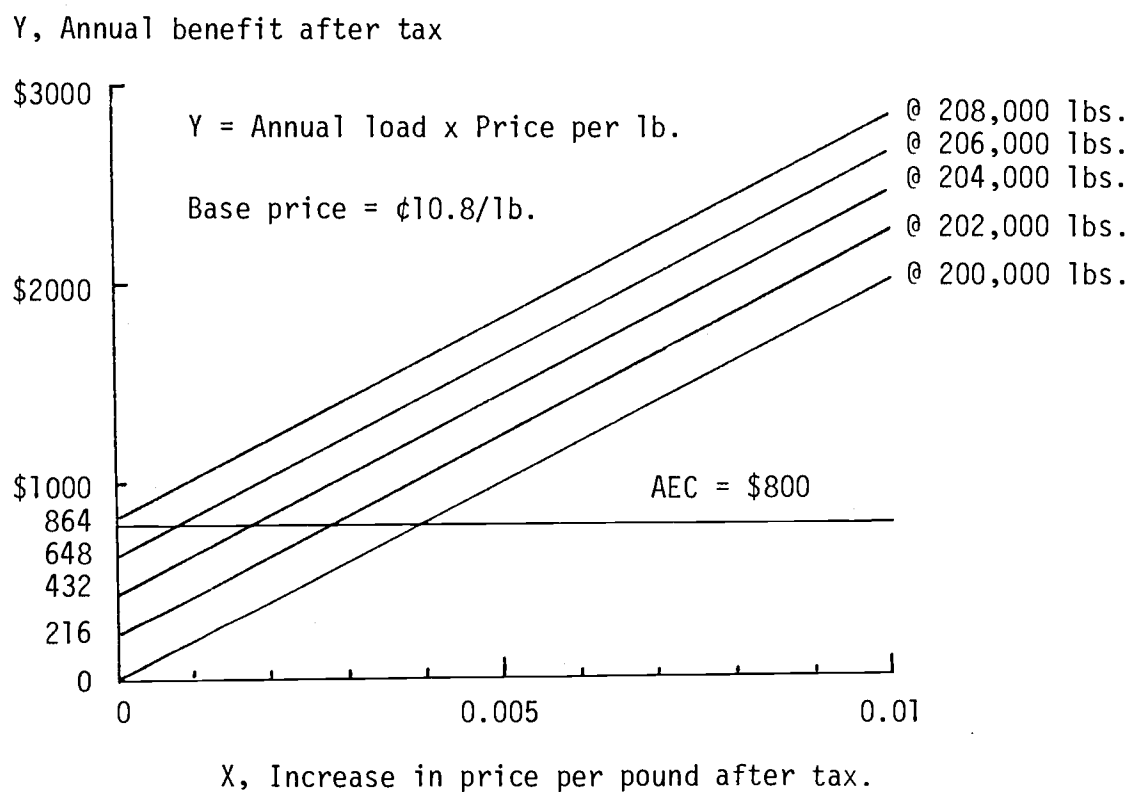


Figure 60. Annual benefit due to price increase.

Fishermen can be profited by the separator only if the annual benefit is larger than the annual equivalent cost and the payback period is within a desirable range. Figure 61 shows the relationship between payback period and annual benefit of the fish from shrimp separator.

Y, Payback period (years).

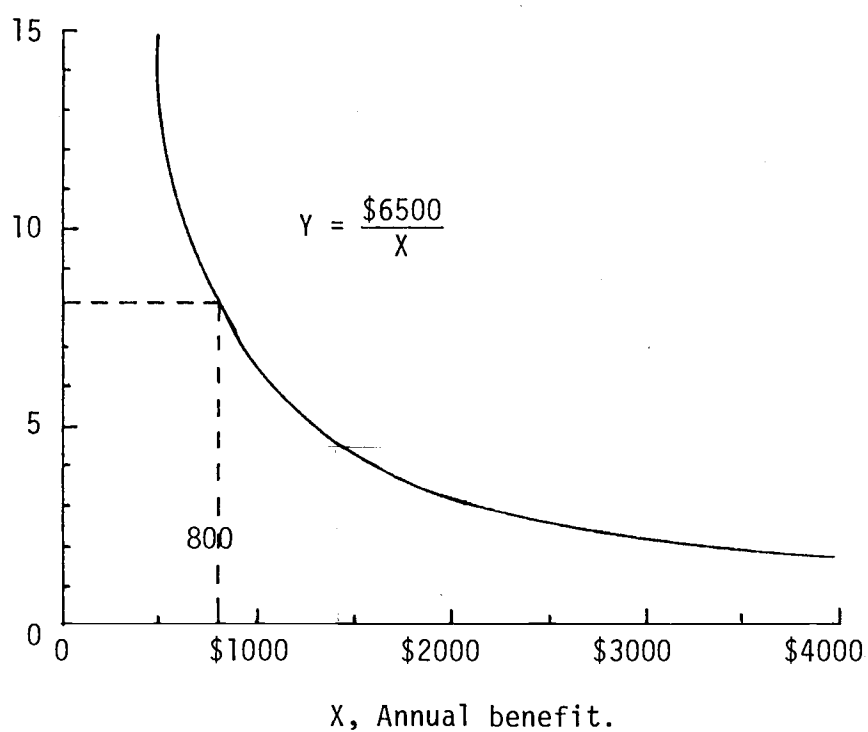


Figure 61. Relationship between payback period and annual benefit of fish from shrimp separator.

The benefit of the machine depends on:

1. Increase in annual harvested load.
2. Price of raw shrimp.
3. Price increase due to thorough cleaning of shrimp.
4. Payback period.

From the above analysis, if:

1. Harvested load increased by three percent.
2. Income after tax of raw shrimp (no cleaning) = $\phi 10.8/\text{lb.}$
3. Income after tax due to price increase for cleaning
= $\phi 0.004/\text{lb.}$

The annual benefit will be \$1472 (\$674 over annual equivalent cost) with a payback period of 4.4 years. The fishermen should buy the separator if the 4.4 years payback period is not undesirable.

Figures 59 and 60 can be combined and represented in Table XI. An aspiration level can be chosen according to a desirable payback period. For example, from Figure 61, a payback period of eight years indicates an expected annual benefit of \$800 is necessary. The dashed line in the table describes the values below \$800. If the annual volume increases 4.5 percent and price after tax increases three cents, the expected annual benefit will be \$1599. Under these assumptions, separator should be bought.

The above analysis is very general because the figures are approximations and the assumptions may not suit a fisherman's own need. To be specific, a fisherman should acquire his own data and experience to construct his own graphs and conduct his own analysis in order to reach

TABLE XI. COMBINED EFFECT OF VOLUME INCREASE AND PRICE INCREASE DUE TO ON-BOARD CLEANING AND SORTING. ?

Percent Volume Increase*	Price Increase Per Pound After Tax (Cent)					
	0	0.001	0.002	0.003	0.004	0.005
0	\$ 0	\$ 200	\$ 400	\$ 600	\$ 800	\$1000
0.5	108	309	510	711	912	1113
1	216	418	620	822	1024	1226
1.5	324	527	730	933	1136	1339
2	432	636	840	1044	1248	1452
2.5	540	745	950	1155	1360	1565
3	648	854	1060	1266	1472	1678
3.5	756	936	1170	1377	1584	1791
4	864	1072	1280	1488	1696	1904
4.5	972	1181	1390	1599	1808	2017
5	1080	1290	1500	1710	1920	2130

* Based on an annual volume of 200,000 lbs. at \$10.8/lb. after tax.

his own conclusion. Besides the possible economic benefit, a good cleaning process can extend the quality, yield, and storage life of raw shrimp.

The shrimp storage and the sanitation condition of the holding compartment are also essential factors for the extension of shrimp life. A microbiological study of iced shrimp was made by Carroll, Reese, and Ward (2). They found that the population growth of bacteria in shrimp slowed down when shrimp were properly preserved with ice. Some kinds of bacteria cannot live under low temperature and the salt-dependent bacteria diminish in number as the melting ice washes the salt away. They recommended the following for the prolongation of grade of shrimp.

1. Clean the boat and equipment with 200 p.p.m. chlorine solution before sailing.
2. Brush the hold and equipment with a scrub brush and rinse the surface with 200 p.p.m. chlorine solution.
3. Construct a false bottom in holds to allow passage of melt water so that shrimp on bottom of hold will not be immersed in the contaminated melt water from above.
4. Coat the hold with plastic which can prevent the penetration of molds and bacteria into the surface of hold.
5. Keep the shrimp shaded.
6. Sort, wash, and ice shrimp promptly.
7. Mix shrimp with ice in an one to two ratio rather than layer the shrimp and ice.
8. Use enough ice to prevent shrimp from contact with anything

but ice.

9. Maintain a temperature slightly higher than 0°C (32°F) to allow ice melting.
10. Wash shrimp again at dock.

Although each individual action may only help to extend a few hours storage life of shrimp, the cumulative effect could well be several days.

Unloading

Although sump pump has been introduced for faster and less labor unloading of shrimp from trawler to dock, most processors still use shovels, totes, and hoists. Some processors claim that the present design of sump pump tend to break some of the shrimp when used and therefore decrease the recovery of shrimp meat. Figure 62 illustrates the cost of shrimp breakage due to loss in recovery of shrimp meat. Total volume of shrimp processed per year is assumed to be 1.5 million pounds. Market prices \$1.8 per pound, \$1.5 per pound, and \$1.2 per pound are assumed to be the optimistic, most likely, and pessimistic price respectively. After 40 percent tax, the income will be \$1.08 per pound, \$0.90 per pound, and \$0.72 per pound respectively. Figure 62 can be represented by Table XII.

For an average of 1.5 million pounds of raw shrimp per year and an unloading speed of 10,000 pounds per hour when two workers are required and shovels and hoist are used, annual cost of unloading is:

Labor cost	=	$\frac{1,500,000}{10,000}$	x 2 worker x \$2.5/worker	=	\$750
Material (shovels) cost ^{15/}				=	\$ 50
Total				=	\$800
Tax-effect	=	\$800 x 0.4		=	\$320
After tax cost				=	<u>\$480</u>

^{15/} Hoist is provided by fishermen.

Even if the \$480 can be completely saved by the adoption of a sump pump, a shrimp meat recovery loss of more than 0.02^{16/} percent at a price of \$1.5 per pound will lead to a loss and the loss could be huge. In fact the sump pump may only reduce three-fourth of the labor cost and the pump costs about \$1500. Therefore, at current shrimp prices and with relatively low volumes in Oregon, it appears that sump pump is not economical beneficial as far as the whole processing system is concerned.

A conveyor belt should be considered for delivering shrimp from hold to dock and the conveyor could be connected to a deice-washer thus the handling of shrimp from dock to deice-washer could be eliminated. Better design of sump pump to eliminate the breaking effect is another alternative. Any investment on new equipment for unloading purpose should be justified by its economic, yield, and quality effects, not just the speed alone.

^{16/} $480 / (1,500,000 \times 1.5) \times 100\% = 0.02\%$

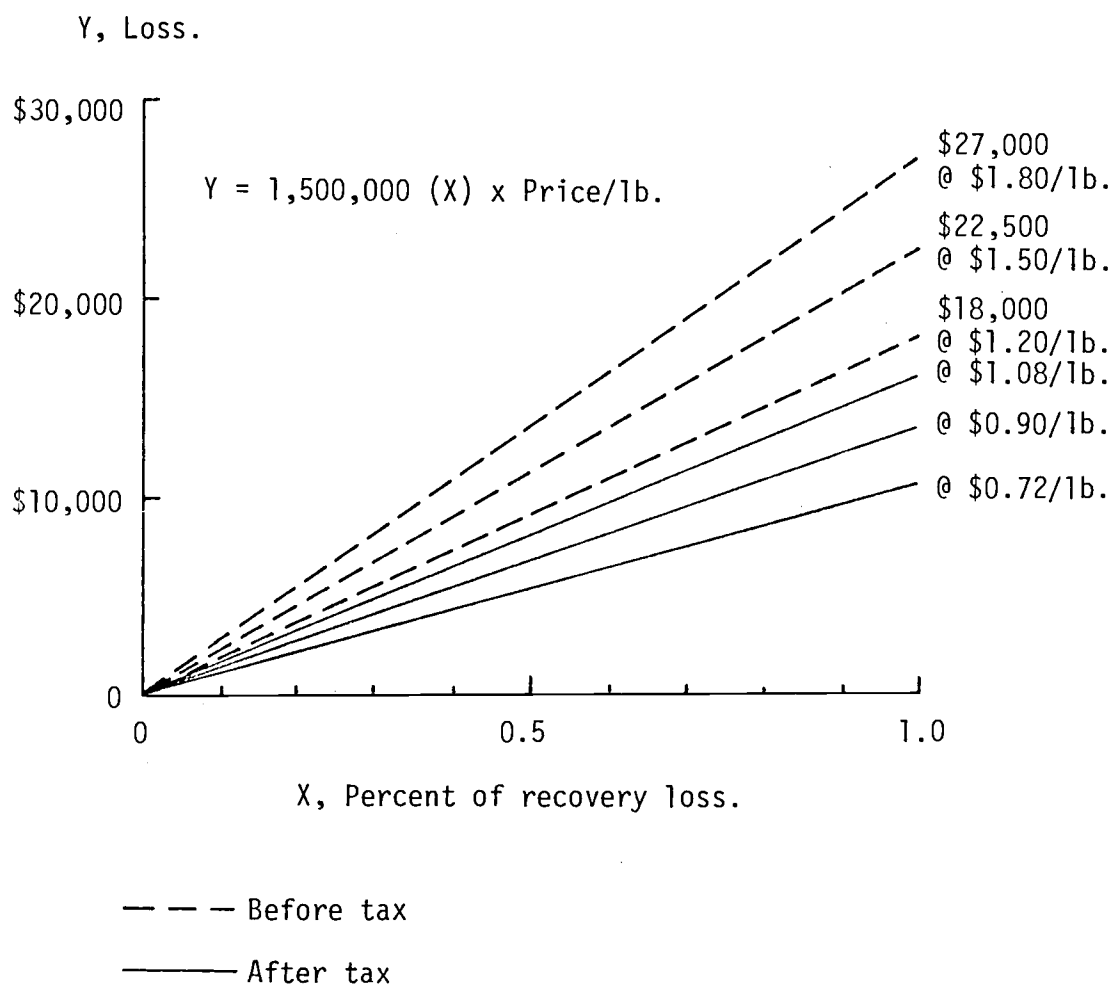


Figure 62. Cost of shrimp breakage.

TABLE XII. COST OF SHRIMP BREAKAGE AT DIFFERENT PRICES

		Price of Shrimp Meat Per Pound (After Tax)		
		\$1.08	\$0.90	\$0.72
	0.1	\$1620	\$1350	\$1080
	0.2	3240	2700	2160
	0.3	4860	4050	3240
% Recovery Loss* Due to Shrimp Breakage	0.4	6480	5400	4320
	0.5	8100	6750	5400
	0.6	9720	8100	6480
	0.7	11340	9450	7560
	0.8	12960	10800	8640
	0.9	14580	12150	9720
	1.0	16200	13500	10800

* Based on an annual processing volume of 1.5 million pounds.

** If the expected cost is below \$5000, the buying decision is supported when machine benefits exceed \$5000 annually.

Washing

As mentioned in the "Harvesting and Holding" section if shrimp are cleaned well at sea, they may not need washing at the dock. However, washing after unloading is especially important if there are mud and trash fish among the shrimp. Besides the sanitation reason, dock washing may assure the processor that he pays for shrimp only. Some plants have deice-washers^{17/} to perform the washing process. A picture of the deice-washer is shown in Figure 45. After unloading, shrimp are dumped into the deice-washer where ice is melted and shrimp are washed. Then washed shrimp are delivered out from the deice-washer by a conveyor for further processing or weighing. Plants which do not have such a machine skip the washing. These plants estimate the net weight of their shrimp by measuring the results in a few samples of their incoming shrimp. However, most plants do not use formal analysis in their sampling. Following is an economic analysis of a deice-washer^{18/}.

Deice-washer cost	= \$8000
Installation	= \$1000
Annual maintenance cost	= \$ 100
Salvage value	= \$ 800
Life of machine	= 10 years
Processing rate	= 8000 lbs./hr.

^{17/} Key Equipment Company, Milton-Freewater, Oregon.

^{18/} Actual cost depends on specification of customer.

Assume: Income tax rate = 40%

Minimum attractive rate of return = 10%

Straight line depreciation is adopted

Average volume of annual incoming shrimp = 1,500,000 lbs.

One worker is required to run the machine.

Pay rate of the worker = \$2.50 per hour

Utility cost = \$0.50 per hour

Price of shrimp meat = \$1.50 per pound

$$\begin{aligned}\text{Annual operating cost is} &= \frac{1,500,000}{8,000} \times (\$2.50 + \$0.50) \\ &= \$562.5\end{aligned}$$

Tax effect on:

$$\text{Installation} = \$1000 \times 0.4 = \$400 \text{ (reduction)}$$

$$\text{Annual maintenance cost} = \$100 \times 0.4 = \$40 \text{ (reduction)}$$

$$\text{Annual operating cost} = \$562.5 \times 0.4 = \$225 \text{ (reduction)}$$

$$\begin{aligned}\text{Annual depreciation} &= \$(8000 - 800)/10 \times 0.4 \\ &= \$288 \text{ (reduction)}\end{aligned}$$

The cost pattern can be expressed in Figure 63.

Annual equivalent cost (AEC)

$$\begin{aligned}&= \$9000(A/P, 10, 10) + 662.5 - 400(F/P, 10, 10)(A/P, 10, 10) \\ &\quad - 553 - 800(A/F, 10, 10) \\ &= \$9000(0.1628) + 109.5 - 400(0.0901)(0.1628) - 800(0.0628) \\ &= \$1465.2 + 109.5 - 59.2 - 50.24 \\ &= \$1465.26\end{aligned}$$

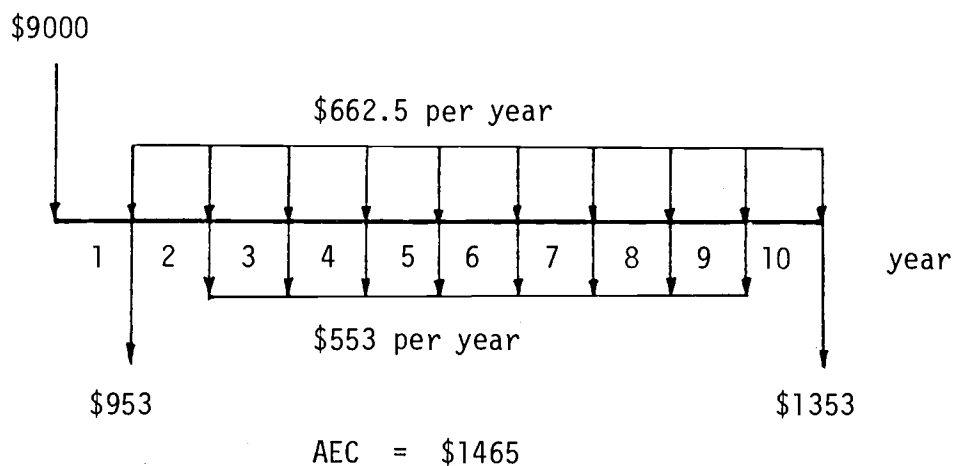


Figure 63. Cost pattern of a deice-washer.

Assume the positive error of net weight of shrimp due to the lack of a deice-washer is X percent. Figure 64 shows the cost of error. Market prices 12 cents per pound, 18 cents per pound, and 24 cents per pound are assumed to be the optimistic, most likely, and pessimistic price respectively. After tax, the costs become 7.2 cents per pound, 10.8 cents per pound, and 14.4 cents per pound respectively.

Assume the loss in shrimp meat recovery due to lack of washing is X percent. Figure 65 illustrates the possible loss. Most likely market price is assumed to be \$1.5 per pound. Income after tax will be \$0.90 per pound. Figure 66 shows the relationship between payback period and annual benefits (cost savings).

Y, Annual cost.

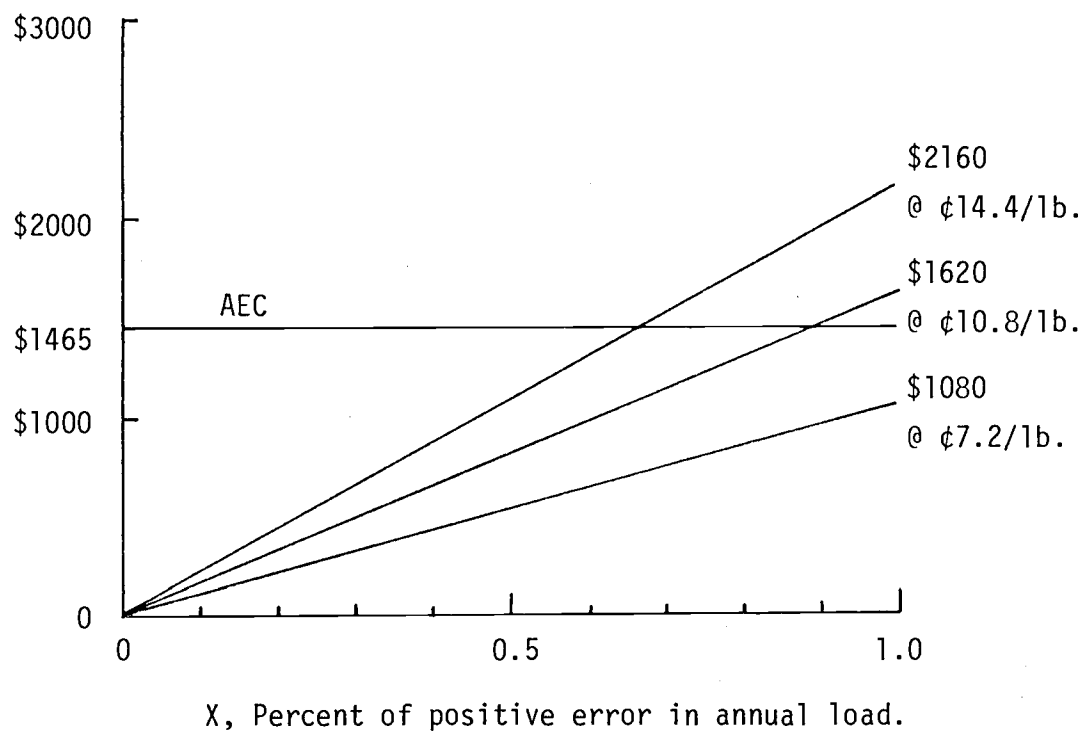


Figure 64. Annual cost due to positive error in weighing.

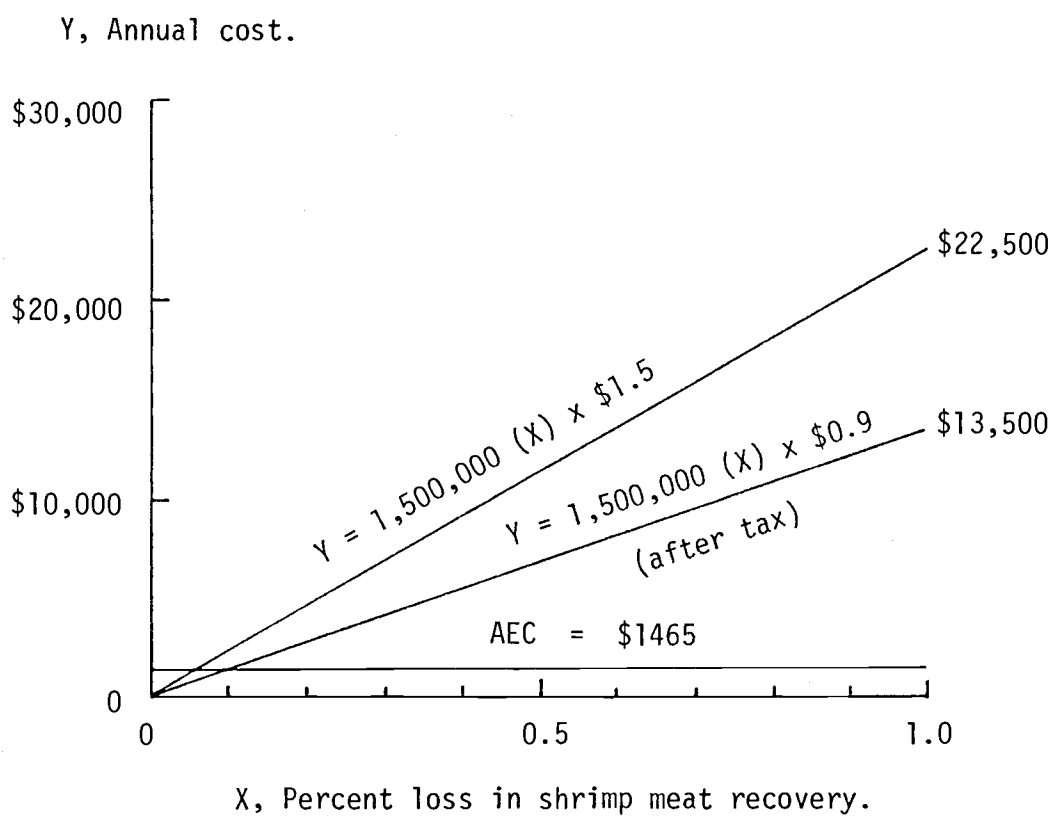


Figure 65. Annual cost of recovery loss due to inefficient washing.

Y, Payback period (years).

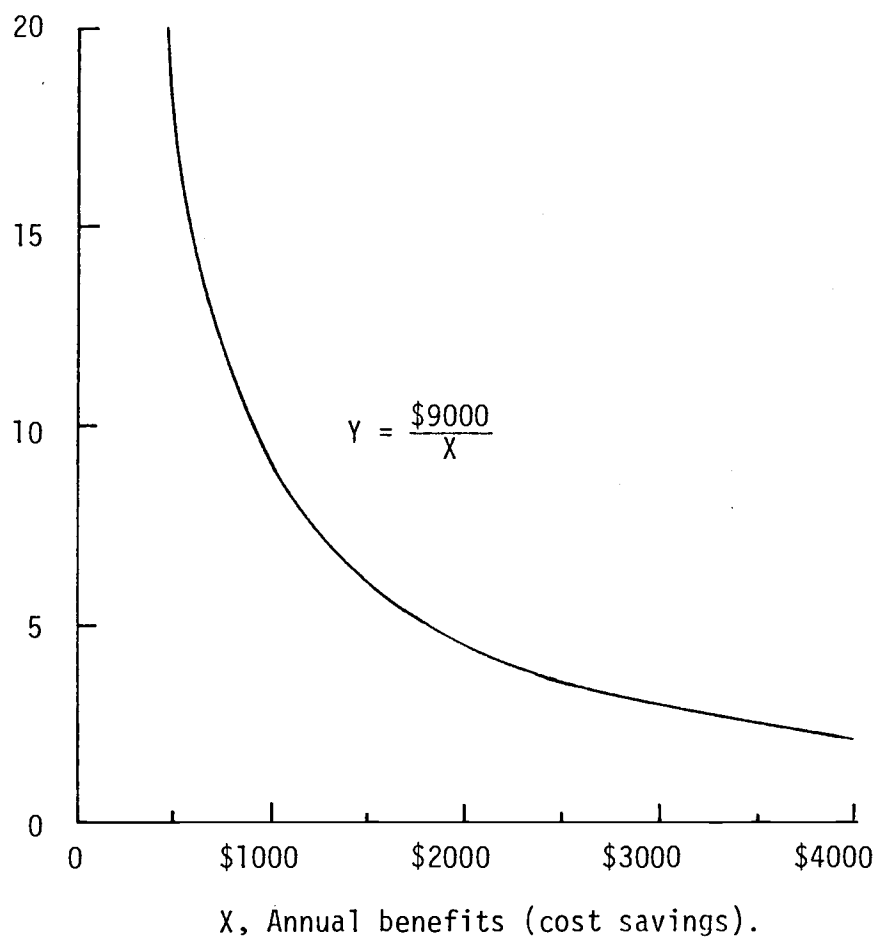


Figure 66. Relationship between payback period and annual benefits (cost savings) of deice-washer.

From the analysis, annual cost is very sensitive to recovery losses. A loss of 0.11^{19/} percent recovery costs \$1465.25. A positive error of one percent costs over a thousand dollars per year. The cumulative effect of both types of losses could be very large.

If a deice-washer can help reducing a positive error of 0.5 percent at 10.8 cents per pound and a recovery loss of 0.15 percent, the total annual cost savings will be:

$$= 1,500,000 \left(\frac{0.5}{100} \times 0.108 + \frac{0.15}{100} \times 0.9 \right) = \$2835$$

The payback period will be

$$= 9000/2835 = 3.2 \text{ years}$$

The analysis shows it will be beneficial for the processor to have a deice-washer. The combined cost of positive weighing error and recovery loss is shown in Table XIII.

^{19/} $1465.25 / (1,500,000 \times 0.9) \times 100\% = 0.1085\%$

TABLE XIII. COMBINED COST OF POSITIVE WEIGHING ERROR AND RECOVERY LOSS.

		% of Positive Error in Weighing* of Raw Shrimp (at \$0.108/lb. After Tax).									
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
% Recovery Loss* of Shrimp Meat (at \$0.9/lb. After Tax).	0.1	\$1512	\$1674	\$1836	\$1998	\$2160	\$2322	\$2484	\$2646	\$2808	\$2970
	0.2	2862	3024	3186	3348	3510	3672	3834	3996	4158	4320
	0.3	4212	4374	4536	4698	4860	5022	5184	5346	5508	5670
	0.4	5562	5724	5886	6048	6210	6372	6534	6696	6858	7020
	0.5	6912	7074	7236	7398	7560	7722	7884	8046	8208	8370
	0.6	8262	8424	8586	8748	8910	9072	9234	9396	9558	9720
	0.7	9612	9774	9936	10098	10260	10422	10584	10746	10908	11070
	0.8	10962	11124	11286	11448	11610	11772	11934	12096	12258	12420
	0.9	12312	12474	12636	12798	12960	13122	13284	13446	13608	13770
	1.0	13662	13824	13986	14148	14310	14472	14634	14796	14958	15120

* Based on an annual processing volume of 1.5 million pounds.

** Even if the annual equivalent cost of the deice-washer were three times as great, \$4400, as in the analysis, a saving of 0.4 percent recovery loss will favor the decision to buy the machine.

Sizing

After washing, generally shrimp will be weighed and iced again. If the shrimp are not processed on the day of receiving, they should be kept in cold storage until processing. However, shrimp continue to deteriorate as the population of bacteria in shrimp increases. The general practice is to keep the shrimp no more than three days.

When a mechanical peeler is used to peel shrimp, an uniform size of shrimp will allow maximum efficiency of the peeler since the peeler can only be adjusted to one size range at a time. Also, the recovery of shrimp meat will be higher if shrimp size is uniform. A large variation in shrimp size will hinder the performance of the peeler because shrimp too large will be broken and shrimp too small will remain unpeeled or will be lost with other shrimp shells. Most plants do not separate their shrimp according to their sizes. Recently, an equipment manufacturer^{20/} introduces a shrimp grader to size shrimp into different grades. The capacity of the grader can be up to 16,000 pounds per hour. Following is an economic analysis of the shrimp grader^{21/}.

^{20/} Allen Machinery, Newberg, Oregon.

^{21/} Actual cost depends on specification of customer.

Shrimp grader cost = \$14,000
 Installation = \$ 500
 Annual maintenance cost = \$ 50
 Salvage value = \$ 1,400
 Life of machine = 5 years
 Processing rate = 16,000 lbs./hr.

Assume: Income tax rate = 40%

Minimum attractive rate of return (MARR) = 10%

Straight line depreciation is adopted.

Average volume of shrimp processed annually

= 1,500,000 lbs.

No additional labor is required for the grader.

Utility cost = \$0.5 per hour

Annual utility cost = $\$(1,500,000/16,000) \times 0.5$
 = \$46.88

Tax effect on:

Installation = $\$500 \times 0.4 = \200.00 (reduction)

Annual maintenance cost = $\$50 \times 0.4 = \20 (reduction)

Annual utility cost = $\$46.88 \times 0.4 = \18.75 (reduction)

Annual depreciation = $\$(14,000 - 1,400)/5 \times 0.4$
 = \$1,008 (reduction)

The cost pattern of the shrimp grader is illustrated in Figure 67.

Annual equivalent cost (AEC)

$$\begin{aligned}
 &= \$14,500(A/P, 10, 5) + 96.88 - 200(P/F, 10, 1)(A/P, 10, 5) \\
 &\quad - 1046.75 - 1400(A/F, 10, 5) \\
 &= 14,500(0.2638) + 96.88 - 200(0.9091)(0.2638) - 1046.75 \\
 &\quad - 1400(0.1638) \\
 &= \$2597.95
 \end{aligned}$$

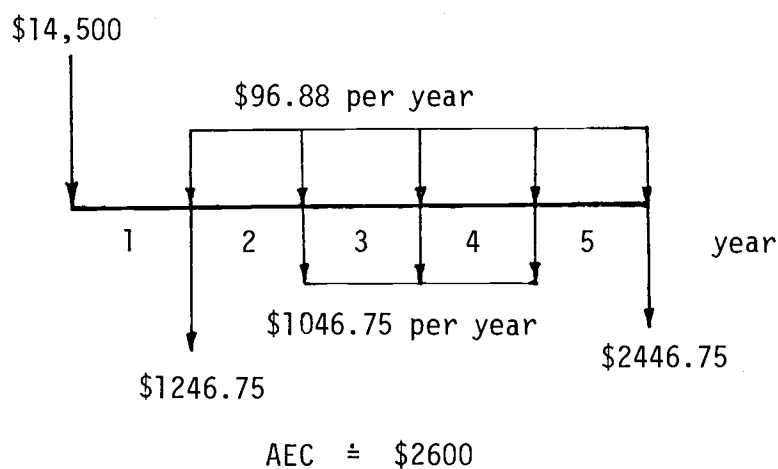


Figure 67. Cost pattern of a shrimp grader.

Assume shrimp meat recovery will increase X percent due to the differentiation of sizes. Figure 68 shows the benefit due to recovery increase. Market prices \$1.8 per pound, \$1.5 per pound, and \$1.2 per pound are assumed to be the optimistic, most likely, and pessimistic price respectively. Income after 40 percent tax will be \$1.08 per pound, \$0.9 per pound, and \$0.72 per pound respectively. Payback period and annual benefit relationship is shown in Figure 69.

From Figure 68, it shows that the potential benefit is so large that even one percent increase in recovery will increase income after tax by more than \$10,000. Under these conditions, the annual equivalent cost appears negligible in comparison with the potential benefit. Figure 68 can also be interpreted in a tabular form as shown in Table XIV.

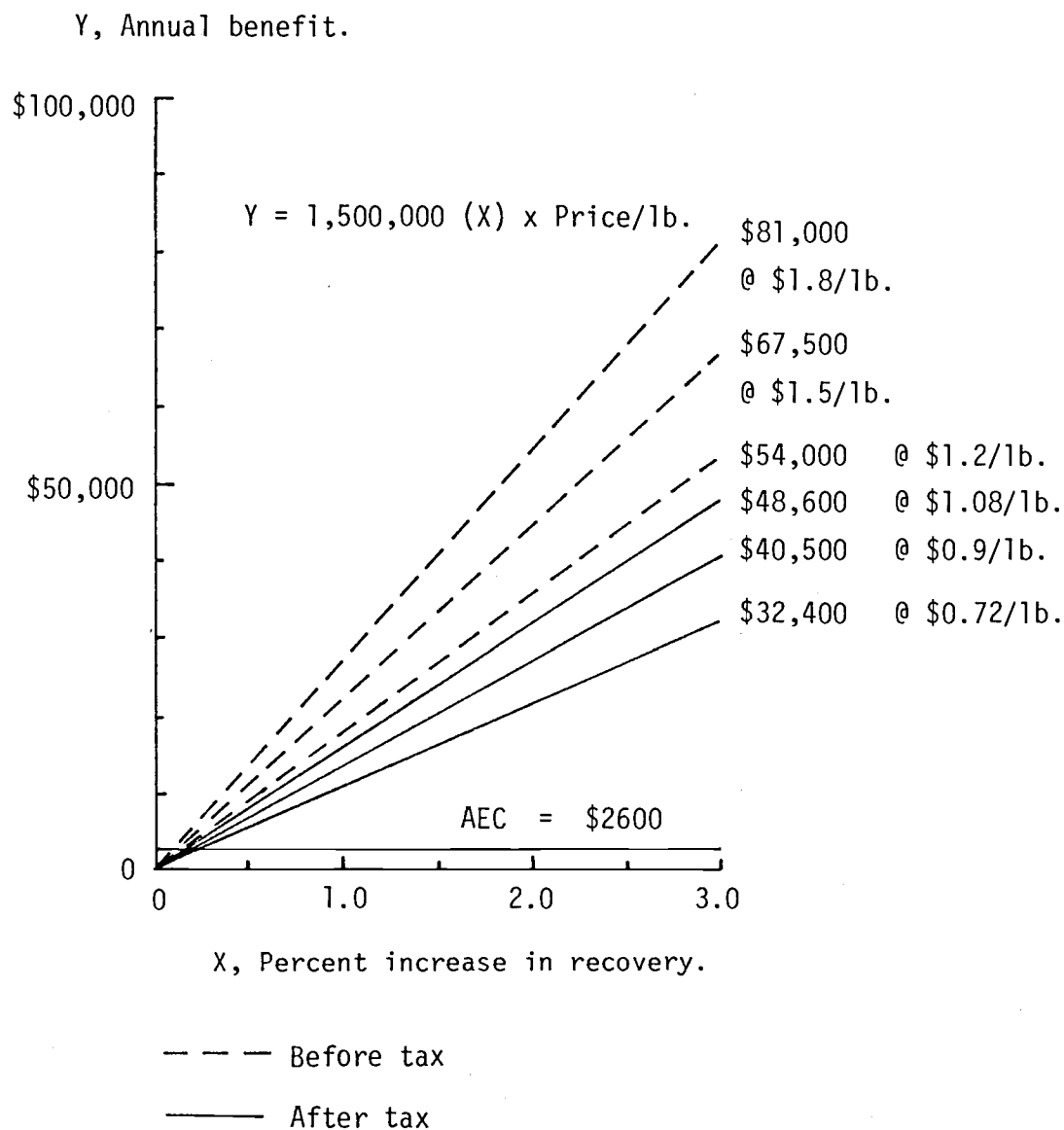


Figure 68. Annual benefit of recovery increase due to sizing.

Y, Payback period (years).

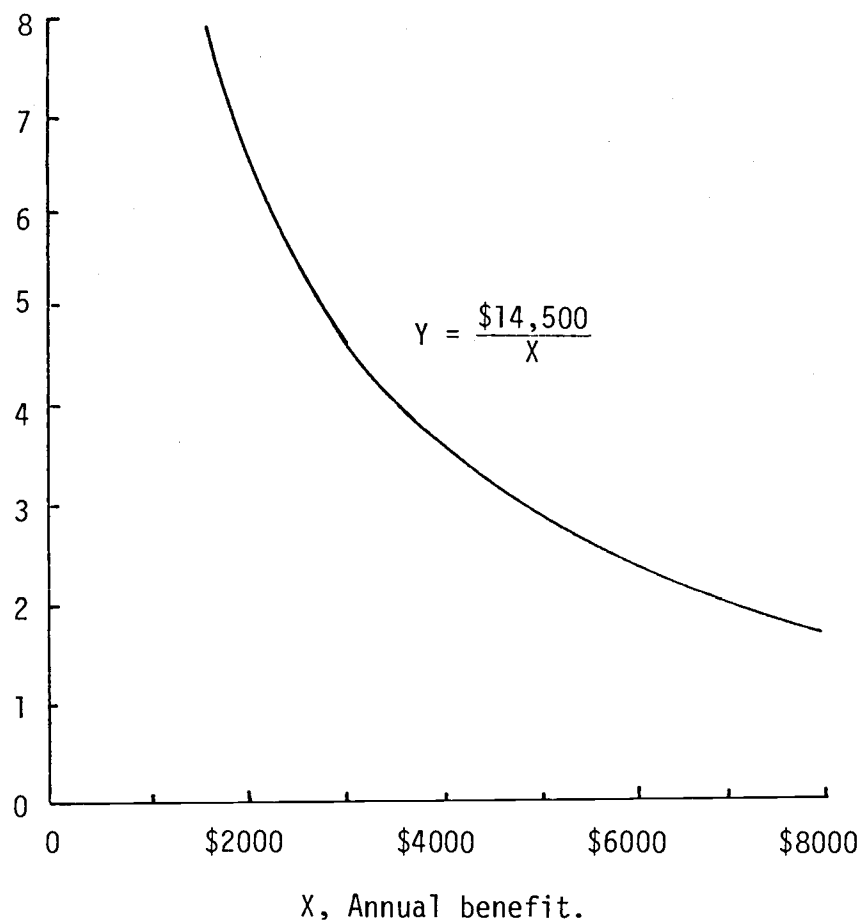


Figure 69. Payback period and annual benefit relationship of a shrimp grader.

TABLE XIV. BENEFIT OF SIZING AT DIFFERENT PRICE OF SHRIMP MEAT

		Price of Shrimp Meat Per Pound (After Tax)		
		\$1.08	\$0.90	\$0.72
% Recovery Increase* Due to Sizing	0.5	\$ 8100	\$ 6750	\$ 5400
	1.0	16200	13500	10800
	1.5	24300	20250	16200
	2.0	32400	27000	21600
	2.5	40500	33750	27000
	3.0	48600	40500	32400
	3.5	56700	47250	37800
	4.0	64800	54000	43200
	4.5	72900	60750	48600
	5.0	81000	67500	54000

* Based on an annual processing volume of 1.5 million pounds.

** Even if the annual equivalent cost of the shrimp grader were five times as high, almost \$13,000, an increase of 1.5 percent in recovery will favor the decision to buy the machine.

Although the shrimp grader has great promise, it creates a problem - all small size shrimp meat will be canned together and customers may not be willing to pay the same price as they pay for the large size shrimp meat. Traditionally and currently, shrimp meat are mixed in sizes. There are two ways to look at the problem.

First, if the large size shrimp meat cannot be sold at a higher price while the small size shrimp meat has to be sold at a lower price, it will be profited to do so as long as the benefit due to recovery increase is larger than the loss in selling the small size shrimp meat. Both Figures 70A and 70B help illustrating the point. Assume size distribution of shrimp meat obeys the normal distribution as shown in Figure 70A. Assume annual benefit after tax of sizing is \$10,000, \$20,000, or \$30,000. The break even price of small shrimp meat will be \$1.46 per pound, \$1.41 per pound, and \$1.37 per pound respectively as shown in Figure 70B. The three break even prices show a 2.7 percent, 6.1 percent, and 8.7 percent decrease from the price \$1.5 per pound respectively.

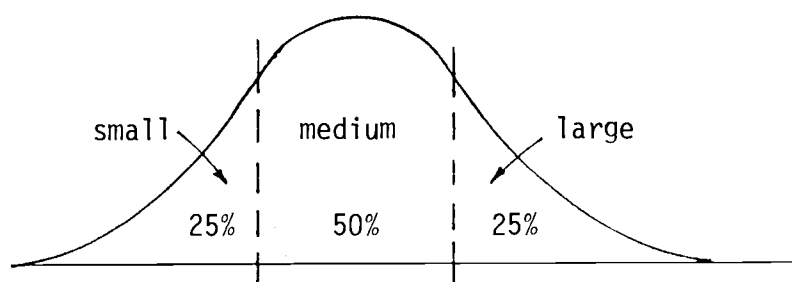


Figure 70A. Size distribution of shrimp meat.

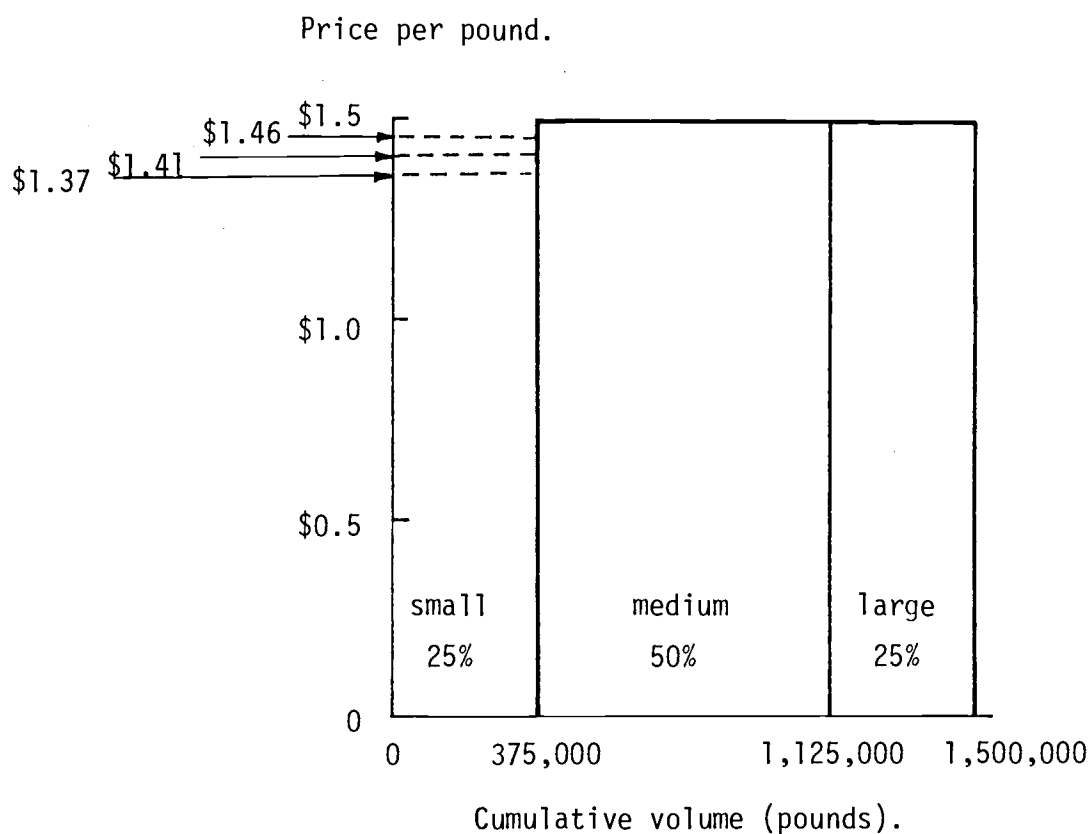


Figure 70B. Break even prices of small shrimp meat.

Second, if the large size shrimp meat can be sold at a higher price and the small size shrimp meat has to be sold at a lower price, the sizing procedure will not cause any loss as long as the additional revenue from large size shrimp meat covers the decrease in income of the small size shrimp meat. In Figure 71, if "A" is greater than "B", there will be not loss due to size differentiation. Besides the contribution of recovery increase, the shrimp grader provides a way for the processor to find out exactly what sizes of shrimp they are buying.

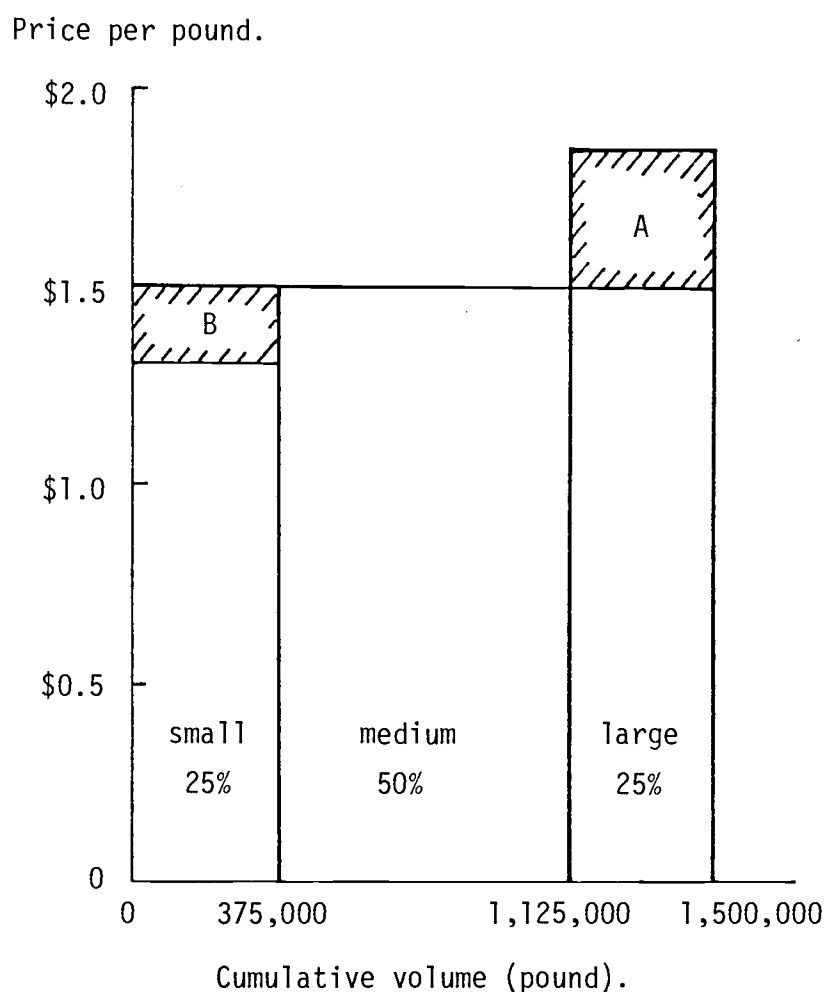


Figure 71. Pricing relationship between large and small size shrimp meat.

Experiments had been conducted by Babbit, Law, and Crawford to mix small and broken shrimp with minced fish and form a fish-shrimp patty. The patty was breaded. A 50:50 fish-shrimp proportion was found to be highly desirable by flavor panels. A cooperative processor indicated that the fish-shrimp portion is a very acceptable consumer item (21).

Cooking and Peeling

Manual shrimp picking was phased out gradually as mechanical peelers were adopted by processors. Different types of mechanical peeler, Mathiesen and Laitram, are available in the market. However, only Laitram peeler are being used in Oregon. Laitram peeler has two models, model A and precook model A (PCA). Model A is used for peeling raw shrimp. Only one plant in Oregon uses model A peelers. In this plant, shrimp are peeled raw, then cooked, inspected, and retorted. It does not produce frozen shrimp meat. The other plants use PCA peelers, and all but one plant produce frozen shrimp meat. The exception one produce retorted canned shrimp meat. According to the experience of the processors, model A provides a better recovery than PCA while PCA allows the shrimp meat to come out in better color and shape. Only two plants own their mechanical peelers. The others lease theirs from the Laitram Corporation. Their reason for not buying their peelers is because the payback period of the machine is too long. Generally, they expect a payback period of no more than four years. Following is a evaluation of the buy or lease alternatives^{22/}. The utility and operating costs of the two alternatives are the same. Their differences are the first cost and the annual maintenance cost.

^{22/} Actual cost depends on specification of customer.

Cost of a PCA peeler = \$30,000

Installation = \$ 1,500

Annual maintenance cost = \$ 200

Annual lease (Installation and maintenance included)

= \$ 8,000 (payable in advance)

Assume: Income tax rate = 40%

Minimum attractive rate of return (MARR) = 10%

Salvage value of peeler = \$3000

Life of machine = 10 years

Straight line depreciation is adopted.

Tax effect on:

Installation = \$1500 x 0.4 = \$600 (reduction)

Annual maintenance cost = \$200 x 0.4 = \$80 (reduction)

Annual depreciation = $\$(30,000 - 3000)/10 \times 0.4$
= \$1080 (reduction)

Annual lease = \$8000 x 0.4 = \$3200 (reduction)

Figure 72 shows the cost patterns of the two alternatives.

Annual equivalent cost (AEC)

For "buy" alternative:

$$\begin{aligned}
 &= \$31,500(A/P, 10, 10) + 200 - 600(P/F, 10, 1)(A/P, 10, 10) \\
 &\quad - 1160 - 3000(A/F, 10, 10) \\
 &= \$31,500(0.1628) + 200 - 600(0.9091)(0.1628) - 1160 \\
 &\quad - 3000(0.0628) \\
 &= \$5128.2 + 200 - 88.8 - 1160 - 188.4 \\
 &= \$3771
 \end{aligned}$$

For "lease" alternative:

$$= \$8000(F/P, 10, 1) - 3200$$

$$= \$8000(1.1) - 3200$$

$$= \$5600$$

The relationship between payback period and annual benefit is shown in Figure 73.

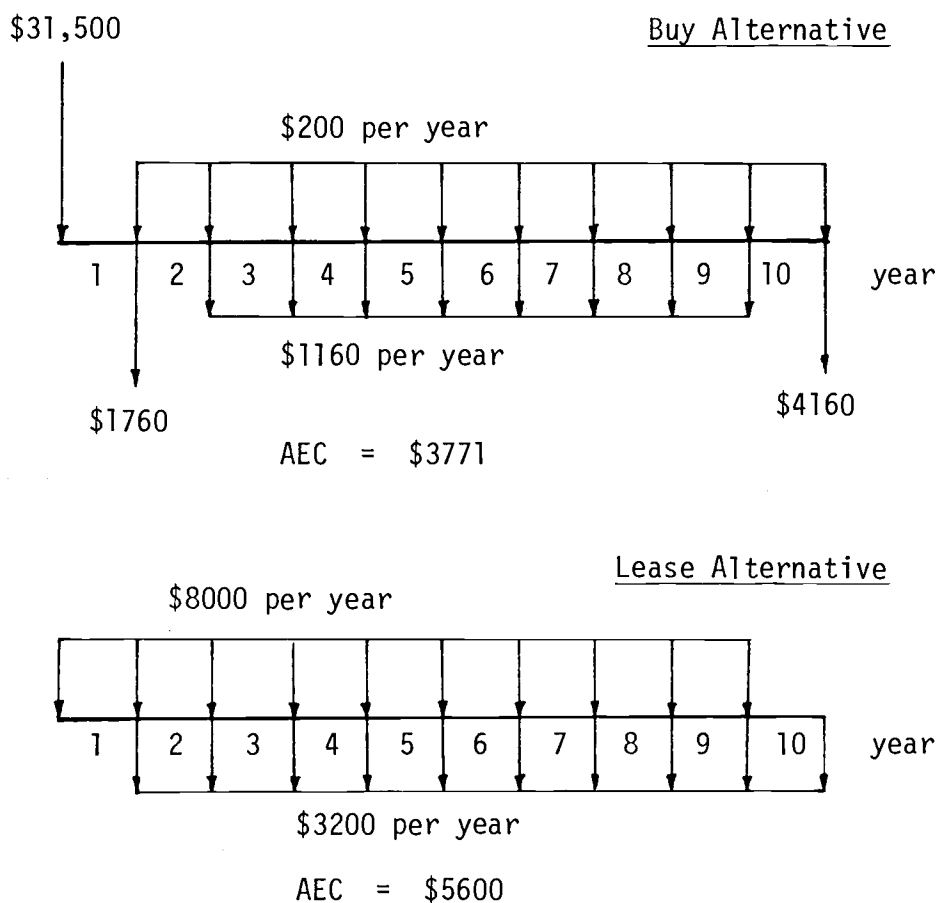


Figure 72. Cost patterns of buy and lease alternatives of PCA peeler.

The annual equivalent cost of the buy alternative is \$1829^{23/} less than the lease alternative or the buy alternative is about 30 percent less expensive as shown in the above analysis. However, the \$1829 benefit has a very long payback period of almost eighteen years. Theoretically, it is much cheaper to buy the peeler than lease it. In reality, technological changes of machine and uncertainty of supply and demand of shrimp in such a long period cast hesitation on processors' minds. Even though the lease alternative appears to be more expensive, it assumes no long term risk.

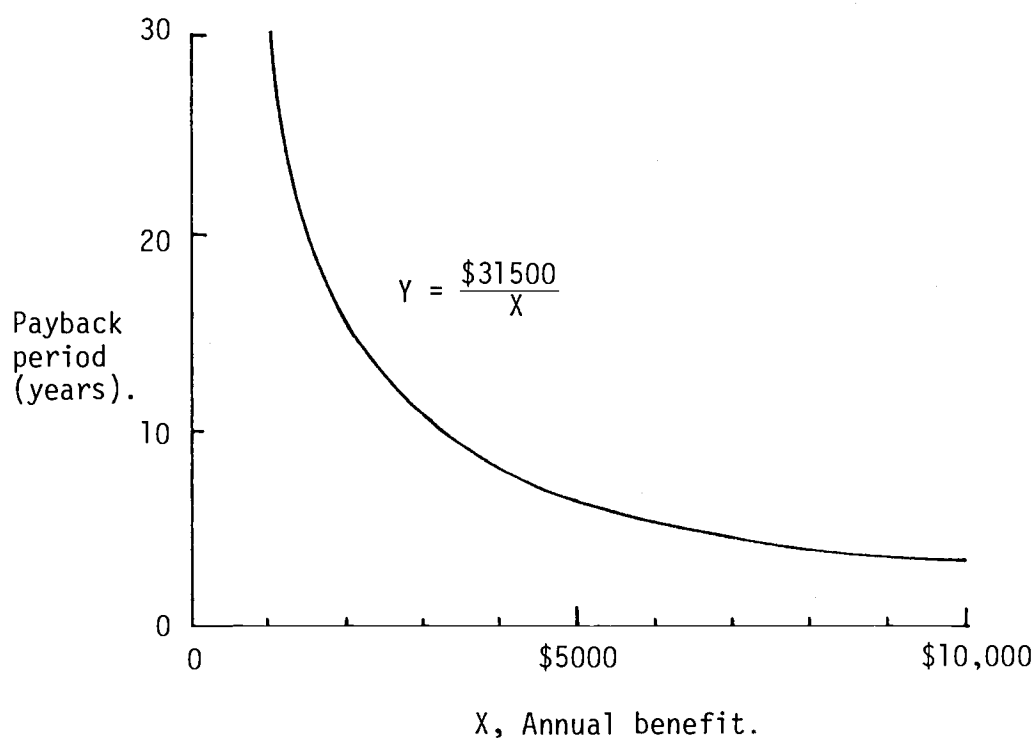


Figure 73. Relationship between payback period and annual benefit of mechanical peeler.

^{23/} \$5600 - \$3771 = \$1829

Cleaning

After shrimp are peeled, they are either flumed or conveyed to mechanical devices for cleaning before inspection. The cleaning process is designed to eliminate the shell, antenna, legs, and eyes which adhere on shrimp meat. The cleaning can reduce inspection effort especially when the size variation of raw shrimp is large and peeling cannot be efficiently done. Basically, a washer-cleaner and a separator are involved in the cleaning process. As shown in Table VIII, all plants equip with separators and twelve plants out of twenty have washer-cleaners. Processors agree that the separator does good job. The performance of the washer-cleaner is more or less controversial. Some processors say it helps cleaning and some say it breaks some of the shrimp meat. This area has not been closely looked into due to the time and shrimp harvesting season limitation. It will be interesting to find out the actual performance of the washer-cleaner. Following is an economic analysis of a washer-cleaner and a separator.

Annual lease^{24/} of a washer-cleaner = \$ 700 (payable in advance)

Annual lease^{24/} of a separator = \$1200 (payable in advance)

For a 40 percent income tax rate, the tax effect will be:

Washer-cleaner \$700 x 0.4 = \$280 (reduction)

Separator \$1200 x 0.4 = \$480 (reduction)

^{24/} Currently Laitram washer-cleaner and separator are for lease only. Lease cost depends on the condition of the processor.

Cost patterns of a washer-cleaner and a separator are shown in Figure 74.

Annual equivalent cost (AEC) -- (Assume MARR = 10%)

For a washer-cleaner

$$= \$700 - \$280(P/F, 10, 1)$$

$$= \$700 - \$280(0.9091)$$

$$= \$445.45$$

For a separator

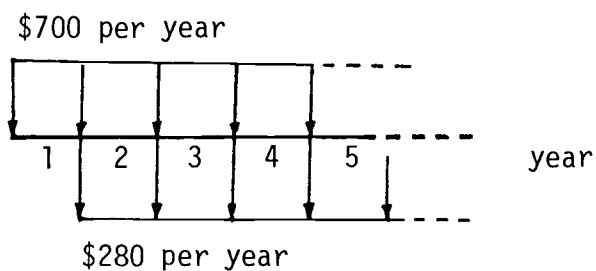
$$= \$1200 - \$480(P/F, 10, 1)$$

$$= \$1200 - \$480(0.9091)$$

$$= \$763.63$$

Washer-cleaner

$$AEC = \$445.45$$



Separator

$$AEC = \$763.63$$

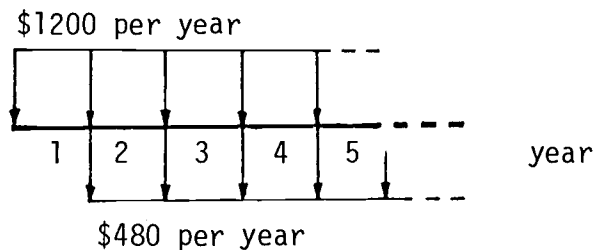


Figure 74. Cost patterns of a washer-cleaner and a separator.

Assume: Raw shrimp processed per year = 1,500,000 lbs.

Processing rate = 700 lbs. raw shrimp per hour

Hourly pay per worker = \$2.50

Total processing time = $1,500,000/700$ hours

= 2142.86 hours

After 40% tax, effective hourly cost per worker

= $\$2.50(1 - 0.4)$

= \$1.50

Figure 75 shows the cost and benefit relationship of a washer-cleaner and a separator. Let X be the number of worker reduced due to the cleaning effort of the machines.

From the analysis, the two machines are beneficial if together they can reduce more than 0.387 workers (i.e. 829.3 worker-hours) per year. However, if the washer-cleaner does break shrimp meat and reduce recovery, it will become disadvantageous because the cost of recovery loss is large as shown in Figure 68.

Y, After tax cost.

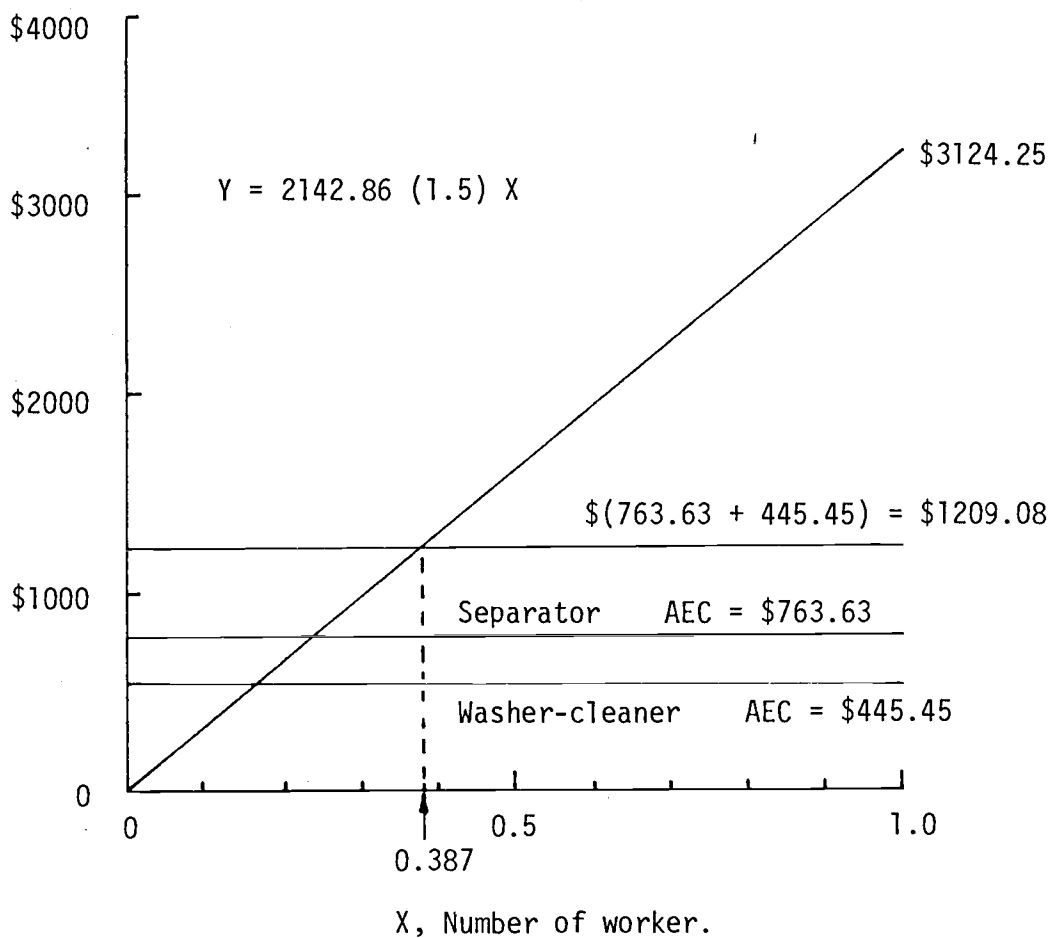


Figure 75. Cost and benefit of a washer-cleaner and a separator.

Another cleaning device, an air blower, is currently available^{25/} and shows promise to reduce inspection effort further without affecting the recovery of shrimp meat. Function of the air blower is to blow away tiny pieces of waste which are left on the shrimp meat after being gone through the washer-cleaner and separator. The air blower can reduce a great deal of inspection effort due to the fact that small pieces of waste are much more difficult to be detected by human eyes. Two plants have the air blower. Both praise its efficiency. Following is an economic analysis of the air blower.

Air blower cost ^{26/}	= \$4000
Installation	= \$ 400
Annual maintenance cost	= \$ 50
Salvage value	= \$ 400
Life of machine	= 10 years
Annual utility cost	= \$ 50
Assume: Income tax rate	= 40%

Minimum attractive rate of return (MARR) = 10%

Straight line depreciation is adopted.

Annual processing volume of raw shrimp = 1,500,000 lbs.

^{25/} Key Equipment Company, Milton-Freewater, Oregon.
Steve Pool Service, Aberdeen, Washington.

^{26/} Actual cost depends on specification of customer.

Tax effect on:

$$\text{Installation} = \$400 \times 0.4 = \$160 \text{ (reduction)}$$

$$\text{Annual maintenance cost} = \$50 \times 0.4 = \$20 \text{ (reduction)}$$

$$\text{Annual utility cost} = \$50 \times 0.4 = \$20 \text{ (reduction)}$$

$$\begin{aligned} \text{Annual depreciation} &= \$ (4000 - 400) / 10 \times 0.4 \\ &= \$144 \text{ (reduction)} \end{aligned}$$

Cost pattern of an air blower is shown in Figure 76.

Annual equivalent cost (AEC)

$$\begin{aligned} &= \$4400(A/P, 10, 10) + 100 - 160(P/F, 10, 1)(A/P, 10, 10) \\ &\quad - 184 - 400(A/F, 10, 10) \\ &= \$4400(0.1628) + 100 - 160(0.9091)(0.1628) - 184 \\ &\quad - 400(0.0628) \\ &= \$583.52 \end{aligned}$$

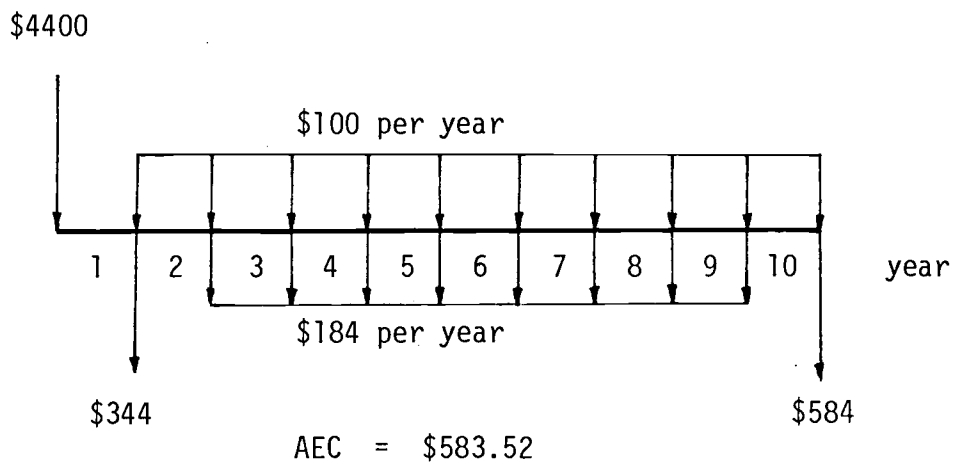


Figure 76. Cost pattern of an air blower.

Following the same reasoning as in Figure 75, a similar graph is constructed and shown in Figure 77. The air blower is beneficial if it can reduce more than 0.18 worker (i.e. 386 worker-hours) per year. If the machine can reduce one worker, its payback period will be about two years. The relationship between payback period and annual benefit is shown in Figure 78. Other than its economic benefit, the air blower also enhances product quality, appearance, and consumer acceptance.

Y, After tax cost.

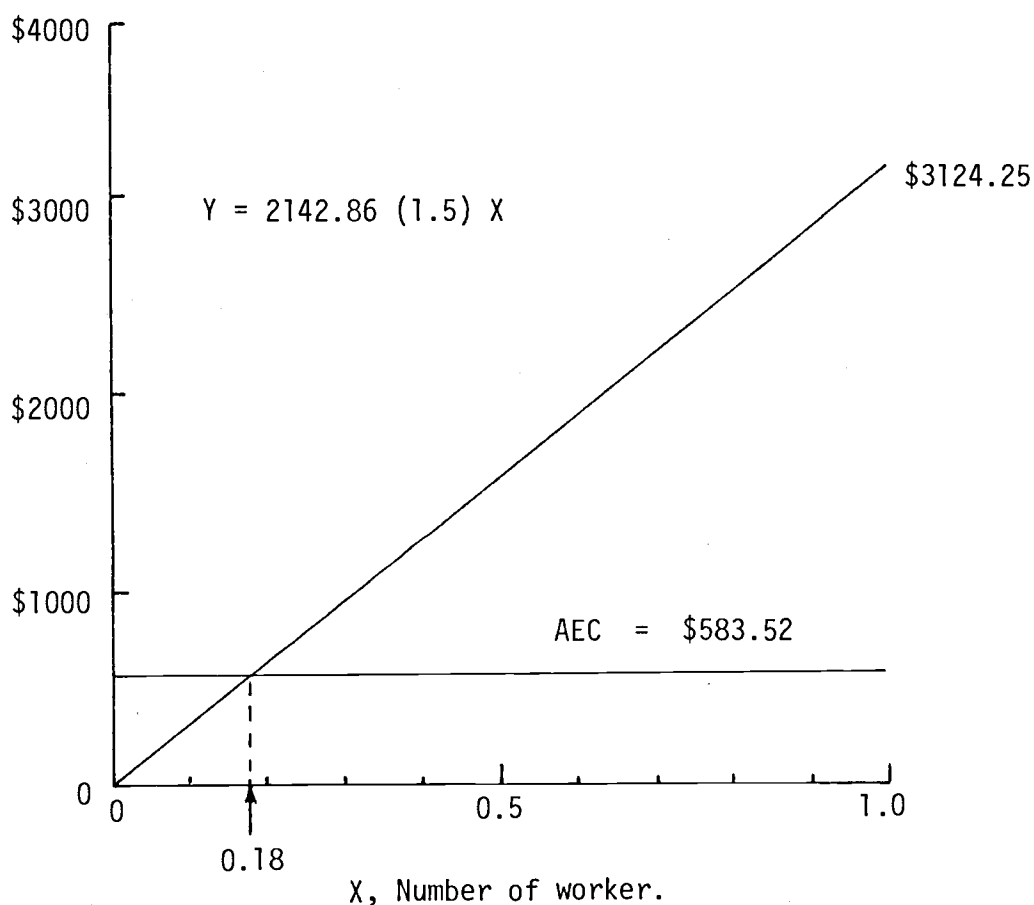


Figure 77. Cost and benefit of an air blower.

Y, Payback period (years).

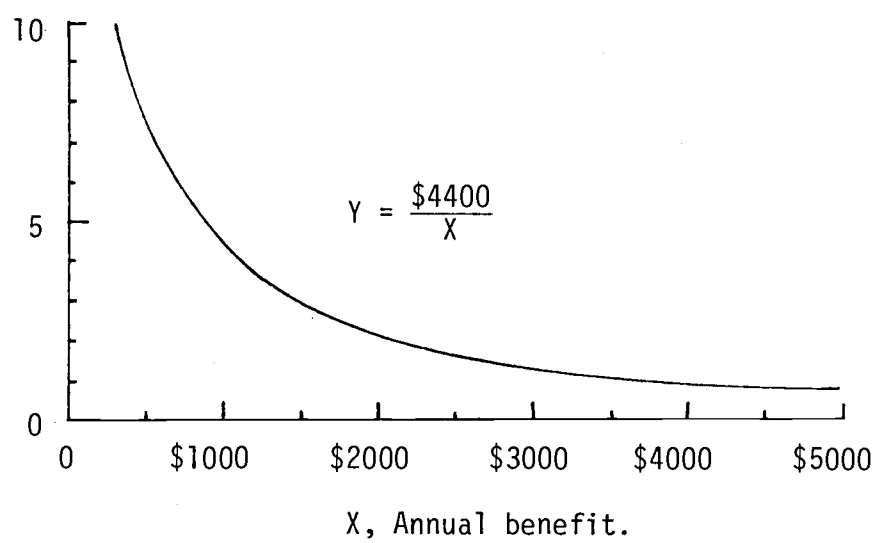


Figure 78. Relationship between payback period and annual benefit of air blower.

Inspection

As unloading, washing, grading, cooking, peeling, and cleaning become more and more mechanized, inspection remains as it was. It may be because no machine can ever be built to replace the coordination of human eyes and hands in getting rid of tiny pieces of waste among the shrimp meat or because it is too expensive to build such a machine for inspecting shrimp meat. Inspection is the most labor consuming activity in shrimp processing. Four to six inspectors are needed to do a decent job for the shrimp meat coming out of one peeler and still maintain a smooth workflow. Although no inspection machine is available, inspection work area is improved from time to time to allow maximum efficiency of motion pattern of the inspectors. Three kinds of inspection work layout are being used in Oregon processing plants - inspection table, conveyor belt, and shaker table.

Inspection table (picture shown in Figure 30) - After shrimp meat have gone through the cleaning equipment, they are flumed to the trough at the middle of the inspection table. Each inspector takes a portion of the shrimp meat to her work area and picks out any unwanted objects from the shrimp meat. The waste are discarded into a trough besides the table and the shrimp meat are delivered through a drop chute and flumed into a pan for further processing. This kind of set up allows inspectors to examine the shrimp meat in detail and make sure no foreign object is left after the inspection. However, it has the drawback of too much human handling and too much water on the shrimp meat.

Conveyor belt (picture shown in Figure 54) - Shrimp meat is dropped on a conveyor belt after going through the cleaning devices. Inspectors line on two sides of the conveyor and pick up waste as the shrimp meat passes before them. This kind of set up allows minimum human handling on the shrimp meat because inspectors only touch the unwanted objects. However, only one side of the shrimp meat is seen on the conveyor. If the conveyor goes too fast, inspectors may not be able to catch up with the speed. Also, one piece of shrimp meat may be examined and examined by several inspectors and uneven workload among inspectors may be resulted. There are two basic kinds of conveyor belt, flat belt and intralox belt. The intralox belt is the better kind because it allows drainage of water and easy to be cleaned.

Shaker table (picture shown in Figure 41) - The shaker table works similarly as a conveyor belt except that the shrimp meat is transported by vibrating motion along the slightly inclined stainless steel table. The vibration also keeps the shrimp meat turn over therefore both sides of the shrimp meat can be inspected. However, the vibrating motion may disturb the vision of the inspectors and reduce their efficiency.

So far, there is no perfect layout for inspection. The shaker table appears to be the best. For 1.5 million pounds of raw shrimp per year with a processing rate of 700 pounds per hour, labor cost of inspection is shown in Figure 79. A \$2.5 per hour per worker pay rate and a 40 percent income tax rate are assumed.

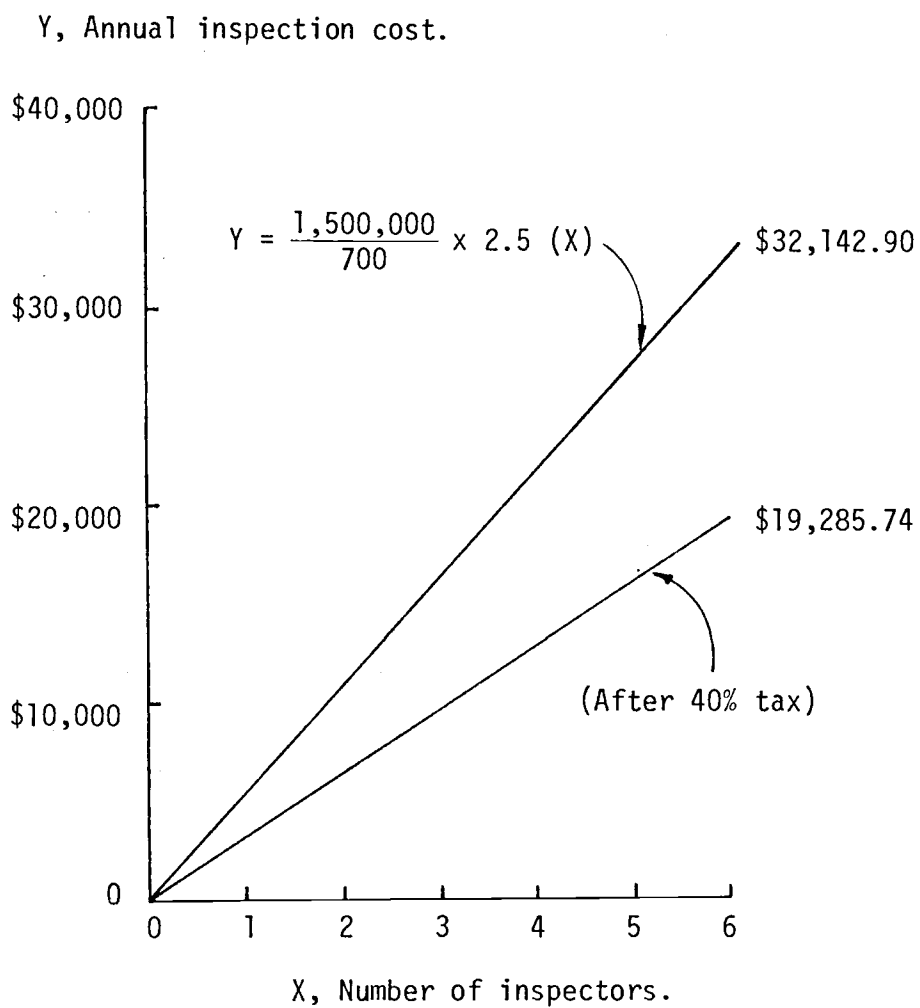


Figure 79. Annual inspection cost.

Packaging

Generally, plants use one to two workers to fill shrimp meat into cans and seal cans with a semi-automatic seamer. The amount of labor in this area will be difficult to be reduced even if further mechanization of the activity is implemented. The area deserves more attention is the weighing of shrimp meat. Even minor errors happen in the weighing process can be very costly in the long run. Weight less than specification could lead to legal trouble and weight over specification results loss in revenue. Statistical control should be used in this area. Further discussion on statistical control is in Chapter 7.

The size of a package is another important area that should be looked into. The traditional five-pound can does not provide the convenience for individual consumer because shrimp meat is frozen into a solid block that has to be thawed even only a small portion of the block is needed. Other smaller sizes of package should be seriously considered.

The individual quick freeze (IQF) system successfully being used in vegetable and fruits solves the "thaw the whole block of shrimp meat every time" problem. Inspected shrimp meat is delivered to a freezing tunnel where it is individually quick frozen. A picture of the freezing tunnel is shown in Figure 80. IQF shrimp meat provides consumers the convenience of using a portion of the package and leaving the rest of the shrimp meat frozen for future use. The advantage of IQF shrimp meat brings about a ten cents increase in price per pound. An economic analysis of an IQF system is shown in the following pages.

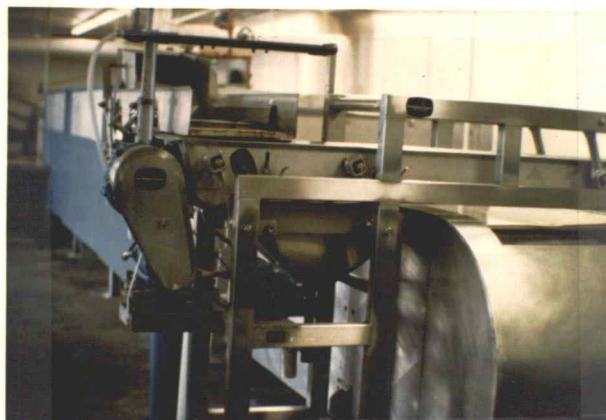


Figure 80.
Freezing tunnel.

IQF system cost^{27/} = \$100,000

Installation = \$ 10,000

Annual maintenance cost = \$ 500

Salvage value = \$ 10,000

Life of the system = 10 years

Annual utility cost = \$ 500

Assume: Income tax rate = 40%

Minimum attractive rate of return = 10%

Straight line depreciation is adopted.

^{27/} Cost figures are estimations.

Tax effect on:

$$\text{Installation} = \$10,000 \times 0.4 = \$4000 \text{ (reduction)}$$

$$\text{Annual maintenance cost} = \$500 \times 0.4 = \$200 \text{ (reduction)}$$

$$\text{Annual utility cost} = \$500 \times 0.4 = \$200 \text{ (reduction)}$$

$$\begin{aligned} \text{Annual depreciation} &= \$ (100,000 - 10,000) / 10 \times 0.4 \\ &= \$3600 \text{ (reduction)} \end{aligned}$$

The cost pattern of an IQF system is expressed in Figure 81.

Annual Equivalent cost (AEC)

$$\begin{aligned} &= \$110,000(A/P, 10, 10) + \$1000 - \$4000(P/F, 10, 1)(A/P, 10, 10) \\ &\quad - \$4000 - \$10,000(A/F, 10, 10) \\ &= \$110,000(0.1628) + 1000 - 4000(0.9091)(0.1628) - 4000 \\ &\quad - 10,000(0.0628) \\ &= \$13,687.99 \end{aligned}$$

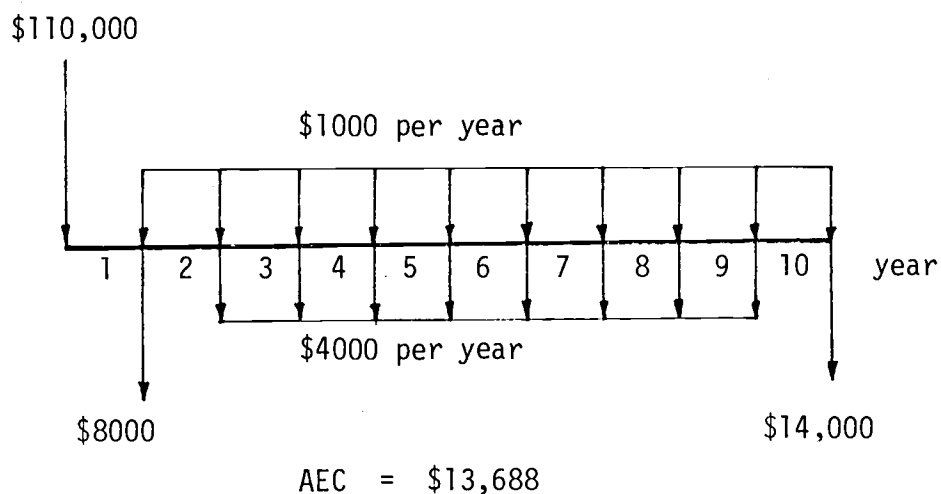


Figure 81. Cost pattern of an IQF system.

Assume 1.5 million pounds of raw shrimp are processed annually and the average recovery of shrimp meat is 25 percent. Figure 82 shows the increase in revenue if price goes up due to consumers' preference for IQF shrimp meat.

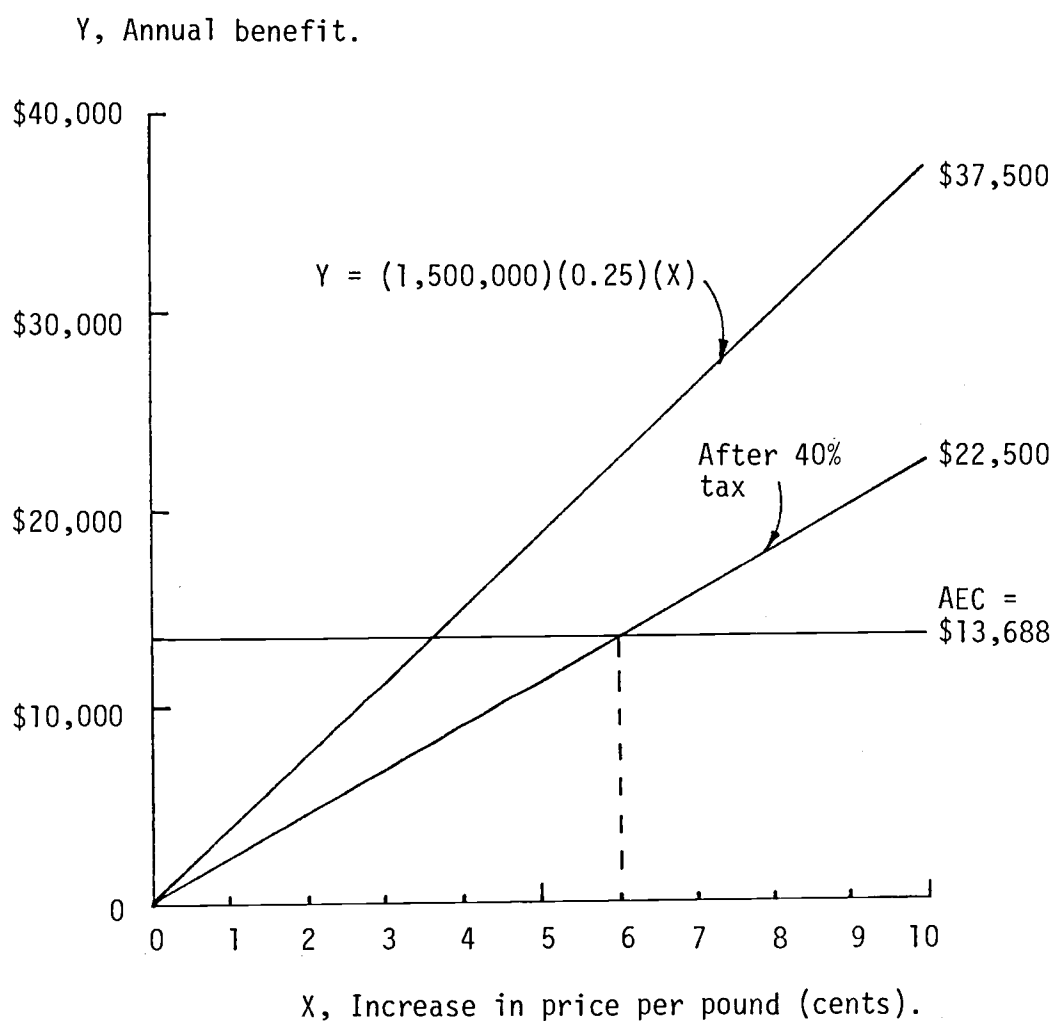


Figure 82. Annual benefit of an IQF system due to price increase.

From the graph in Figure 82, it indicates the break even point is when price per pound of shrimp meat increase equals to six cents. For a ten cents price increase per pound, the annual net benefit after tax will be $\$(22,500 - 13,688) = \$8,812$. The relationship between annual benefit and payback period is shown in Figure 83.

Y, Payback period (years).

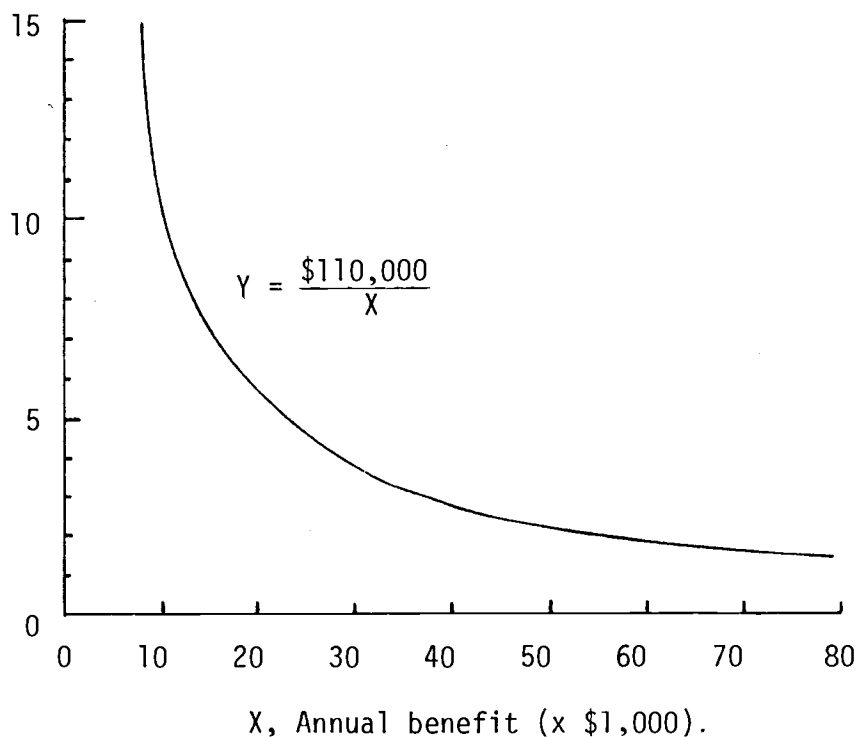


Figure 83. Annual benefit and payback relationship of an IQF system.

From the analysis, for a ten cents increase per pound, after tax annual benefit will be \$22,500 and the payback period will be 4.9 years. It appears that it will be beneficial to have an IQF system if the payback period seems right to the processor. The IQF system can also be used to pack bottomfish and crab meat when it is not working on shrimp meat. The alleged ten cents per pound uncrease is questioned by many (both processors and fish brokers). In evaluating IQF benefits, the drip losses of bottom fish and crab meat should also be considered as an IQF benefit. If a processor wishes to evaluate his payback with alternate price increase values, a range of benefits appears in Table XV, page 159.

Sensitivity Analysis

Basically, the analyses performed in this chapter are sensitivity analyses. Curves and tables are developed to show the cost and benefit relationship of the equipment. In the previous analyses, minimum attractive rate of return, life of machine, and annual processing volume are fixed. However, these parameters can be varied to see how their variation affects the result of the analyses.

The IQF system is chosen to illustrate the suggestion. Figures 84, 85, and 86 show how annual equivalent cost changes as the life of the system changes. The rate of annual equivalent cost increase accelerates as the life decreases. Figure 87 shows how annual equivalent cost increases as minimum attractive rate of return increases. Figure 88 shows how the changes in annual processing volume affect the annual benefit at different prices increase. Table XV is an interpretation of Figure 88.

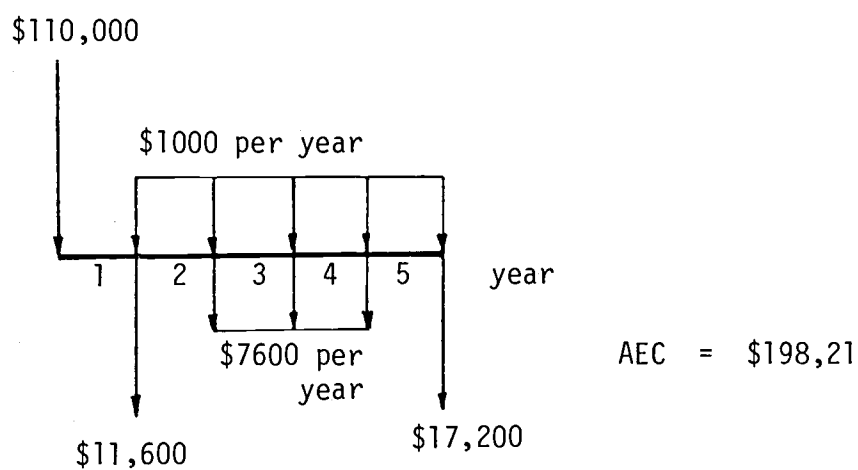


Figure 84. Cost pattern of an IQF system (life = 5 years).

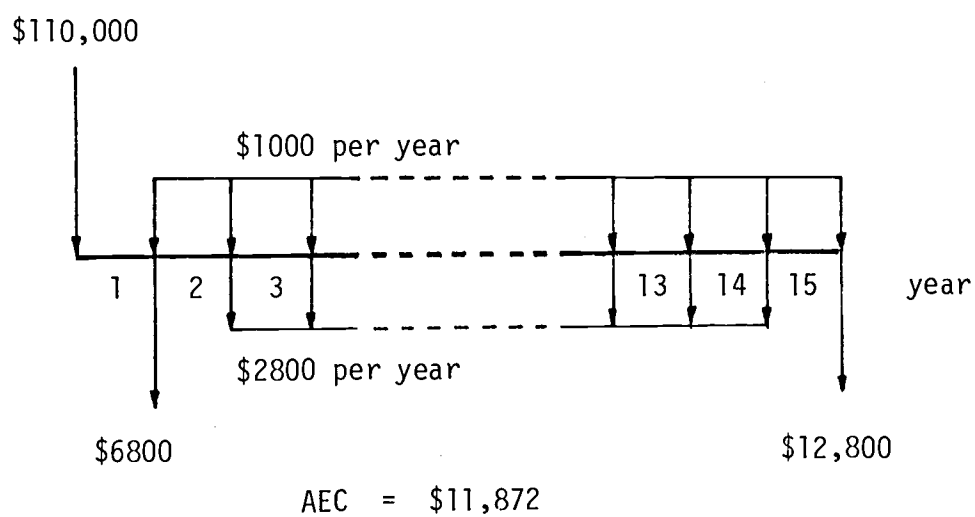


Figure 85. Cost pattern of an IQF system (life = 15 years).

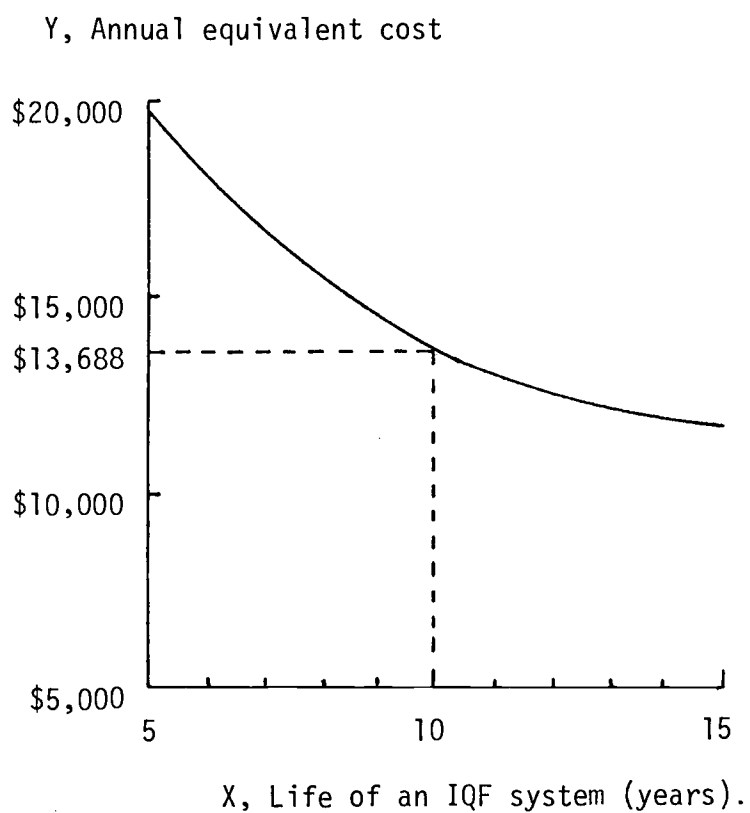
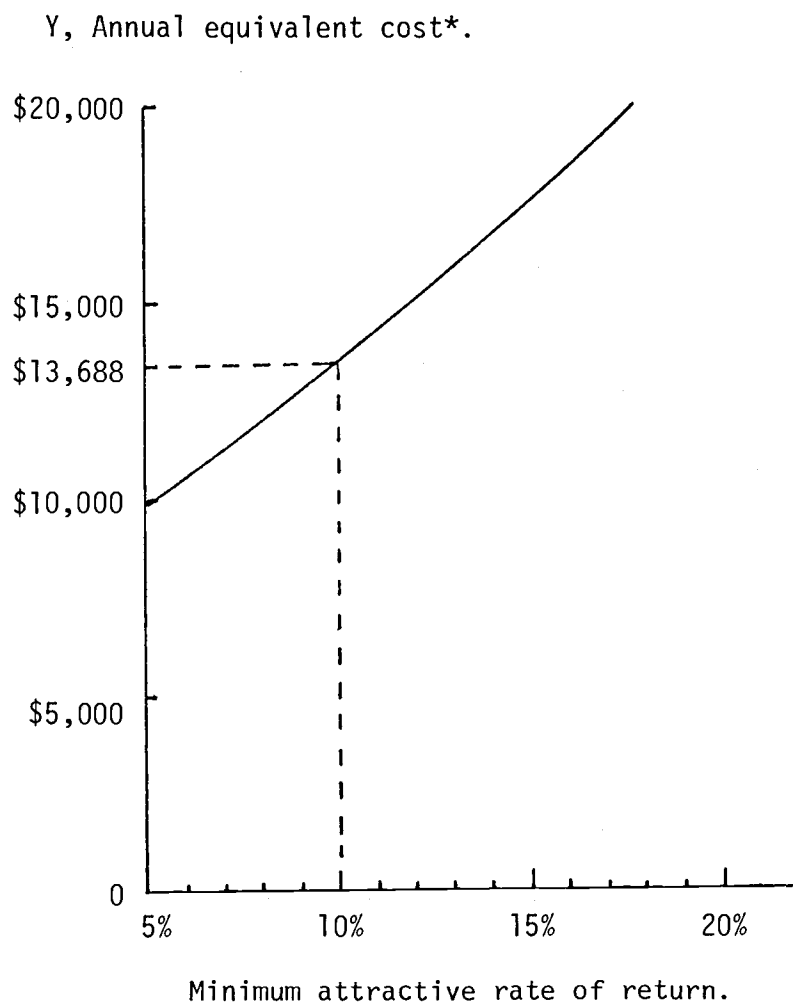


Figure 86. Annual equivalent cost of an IQF system with a life from five years to fifteen years.



* Based on a period of 10 years.

Figure 87. Annual equivalent cost of an IQF system at five percent to twenty percent minimum attractive rate of return.

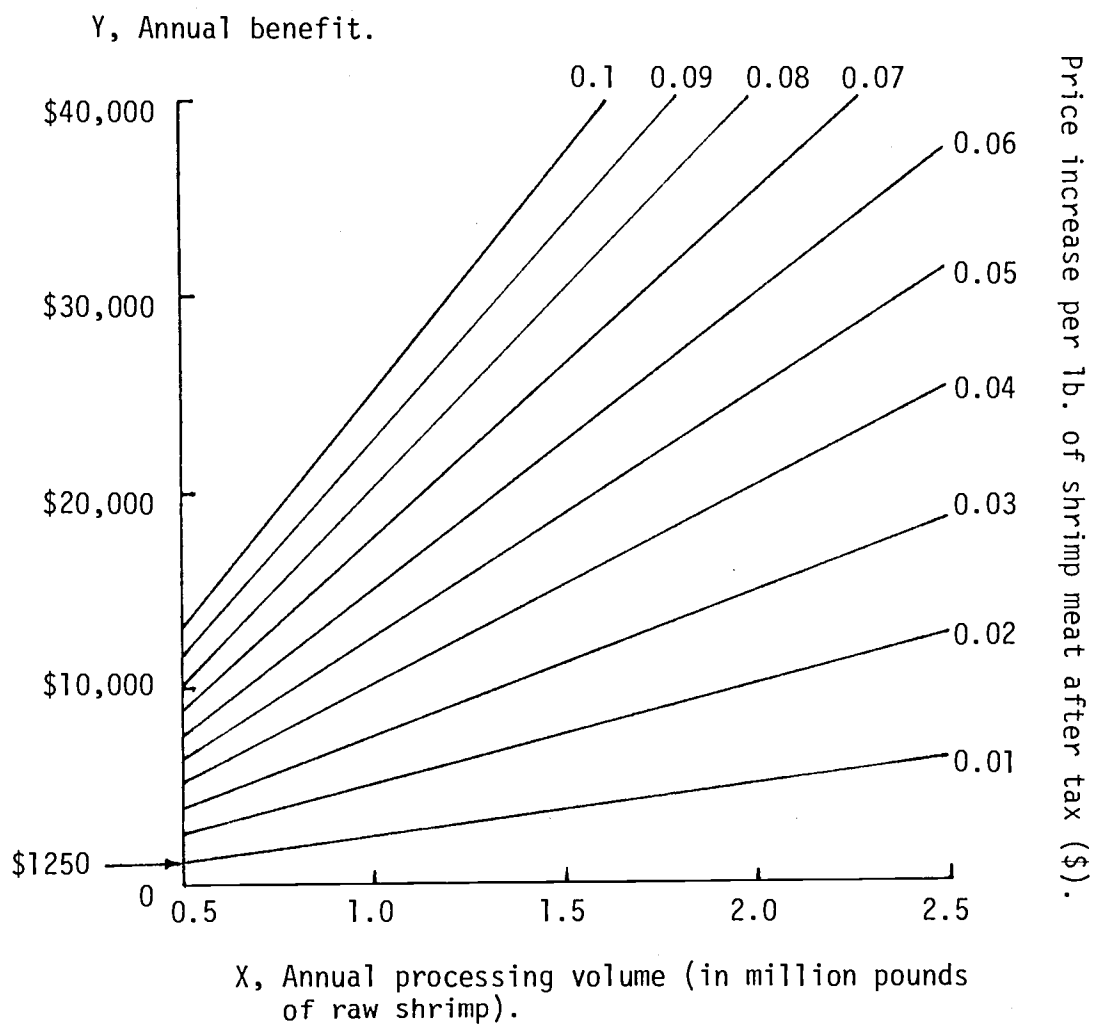


Figure 88. Annual benefit of an IQF system at different annual processing volume and different price increases.

TABLE XV. BENEFIT OF PRICE INCREASE DUE TO AN IQF SYSTEM AT DIFFERENT PROCESSING VOLUME.

		Price Increase Per Pound of Shrimp Meat (After Tax).									
		\$0.01	\$0.02	\$0.03	\$0.04	\$0.05	\$0.06	\$0.07	\$0.08	\$0.09	\$0.10
Annual Processing Volume in Million Pounds	0.5	\$1250	\$2500	\$3750	\$5000	\$6250	\$7500	\$8750	\$10000	\$11250	\$12500**
	1.0	2500	5000	7500	10000	12500	15000	17500	20000	22500	25000
	1.5	3750	7500	11250	15000	18750	22500	26250	30000	33750	37500
	2.0	5000	10000	15000	20000	25000	30000	35000	40000	45000	50000
	2.5	6250	12500	18750	25000	31250	37500	43750	50000	56250	62500

** The IQF system has an annual equivalent cost of almost \$13,700. Any expected benefit on the right side of the dashed line supports the buy decision.

Consideration of Intangibles

Besides the analyses of monetary costs and benefits of equipment, certain factors that can hardly be expressed in terms of money have to be considered also. Decision makers ignore intangibles may face serious and costly consequences. Major intangible factors of shrimp processing are described in the following.

1. Safety - Any change of the work layout or equipment should not increase the health hazard of workers.
2. Workers' skill - High cost and low recovery may be the result of low skill of workers.
3. Work environment - A pleasant work environment provides comfort to the workers and reduces their fatigue.
4. Worker satisfaction - A satisfied worker can contribute a lot to productivity increase.
5. Consumer satisfaction - A good quality (taste, color, shape, size, and sanitation) product satisfies customers and therefore help keeping a stable demand and increasing the processor's goodwill.

VII. MACROSCOPIC ANALYSIS OF THE SYSTEM

Processing Time Standard of Direct Labor

It is beneficial for a plant to have production time standards. The standard can provide grounds for planning, control, and improvement. As shrimp processing is gradually mechanized, direct labor cost is still the major cost of processing. Figure 87 illustrates how a process chart is used to calculate direct labor time used for one unit of production output, five pounds of shrimp meat, at plant T. Only activities where labor is involved are timed. Unit time is obtained by dividing total time by total units processed. From the results shown in the unit time column, 180 seconds are required to inspect five pounds of shrimp meat. Thus inspection time accounts for more than 50% of the total direct labor time, 344.67 seconds. The next most labor consuming activity is packing. One hundred and forty-four seconds of 42% of total direct labor time are required to pack five pounds of shrimp meat. It is obvious that inspection and packaging are the areas deserving more attention if improvements or changes are ever considered. The result of the process chart can also be used as a base to evaluate future processing performance.

	(A)		Process symbols	(B)	B	Description
	Wt. in lbs.	Process unit		Act-ual time sec.	Unit time sec.	
1	700	35	□□□□▽			(a) Shrimp are stored in tote boxes.
2	700	35	□□□□▽	48.5	1.39	One tote box is delivered by fork lift truck and elevated up to the platform.
3	700	35	□□□□▽			(a) Tote box is on the platform.
4	700	35	□□□□▽	24.3	0.69	(b) Tote box is pulled on a cart along rails to mechanical peelers.
5	700	35	□□□□▽	10.6	0.30	(b) Tote box is connected to a hoist.
6	700	35	□□□□▽	19.5	0.56	(b) Tote box is lifted to the mechanical peeler.
7	700	35	□□□□▽	22.2	0.63	(b) Shrimp are dumped into the peeler.
8	175	35	□□□□▽			(a) Shrimp are cooked and peeled in the peeler.
9	175	35	□□□□▽	6300	180	(c) Shrimp meat is inspected on a shaker table.
10	175	35	□□□□▽			Shrimp meat is stored in pans.
11	175	35	□□□□▽	70	2	Shrimp meat is taken into the packing room.
12	175	35	□□□□▽	35	1	Shrimp meat is dumped into a stainless steel pan.
13	175	35	□□□□▽	140	4	Shrimp meat is rinsed in ice water.
14	175	35	□□□□▽	140	4	Shrimp meat is rinsed in ice brine.
15	175	35	□□□□▽	17.5	0.5	Shrimp meat is brought to the packing table.
16	175	35	□□□□▽	50	0.7	Shrimp meat is dumped on the packing table.
17	175	35	□□□□▽	5040	141	(d) Shrimp meat is inspected, filled into cans, and weighed.
18	175	35	□□□□▽	94.5	2.7	Cans are fed into a sealing machine.
19	175	35	□□□□▽			(a) Cans are sealed mechanically.
20	175	35	□□□□▽	77	2.2	Cans are put on pallet and ready for storage.

(a) No direct labor time.

(b) One box of shrimp is fed into three PCA peelers.

(c) Five inspectors inspect shrimp meat at 500 lbs./hour.

(d) Four workers fill shrimp meat into cans at 500 lbs./hour.

1 unit = 20 lbs. raw shrimp or
5 lbs. shrimp meat.

Total direct labor time for
processing 5 lbs. shrimp meat

= 314.67 seconds

= 5.74 minutes

Figure 89. Unit time flow process chart used to calculate unit direct labor time.

Statistical Control

Good quality shrimp meat begins with good quality raw shrimp. The term "quality" implies the size, freshness, color, shape, texture, taste, and bacteria count. After the shrimp have been caught each step of handling and processing affects the quality of the final product - shrimp meat. In Figure 90, a C&E diagram pinpoints the sources of causes and the main effects.

Although processors have no direct control over the fishermen's harvesting and handling of raw shrimp, their method of receiving and paying for raw shrimp do influence the fishermen. Currently two different ways of paying for raw shrimp are practiced by processors. They are described in the following.

Pay by poundage - Most processors pay the fishermen according to the weight of raw shrimp the fishermen bring in. For those processors who have a deice-washer, they let the incoming raw shrimp go through the washer so that only raw shrimp (no ice included) are weighed. For those who do not have such a machine, they take a certain sample of raw shrimp among the incoming shipment and drain the ice and water of the samples. Then the percentage of ice by weight in the sample is determined. The percentage of ice in the sample will be used to calculate the net weight of raw shrimp in the shipment. Generally, the price per pound of raw shrimp is agreed between processor and fisherman before the fisherman go out to fish.

Pay by recovery - Processors pay the fishermen according to the

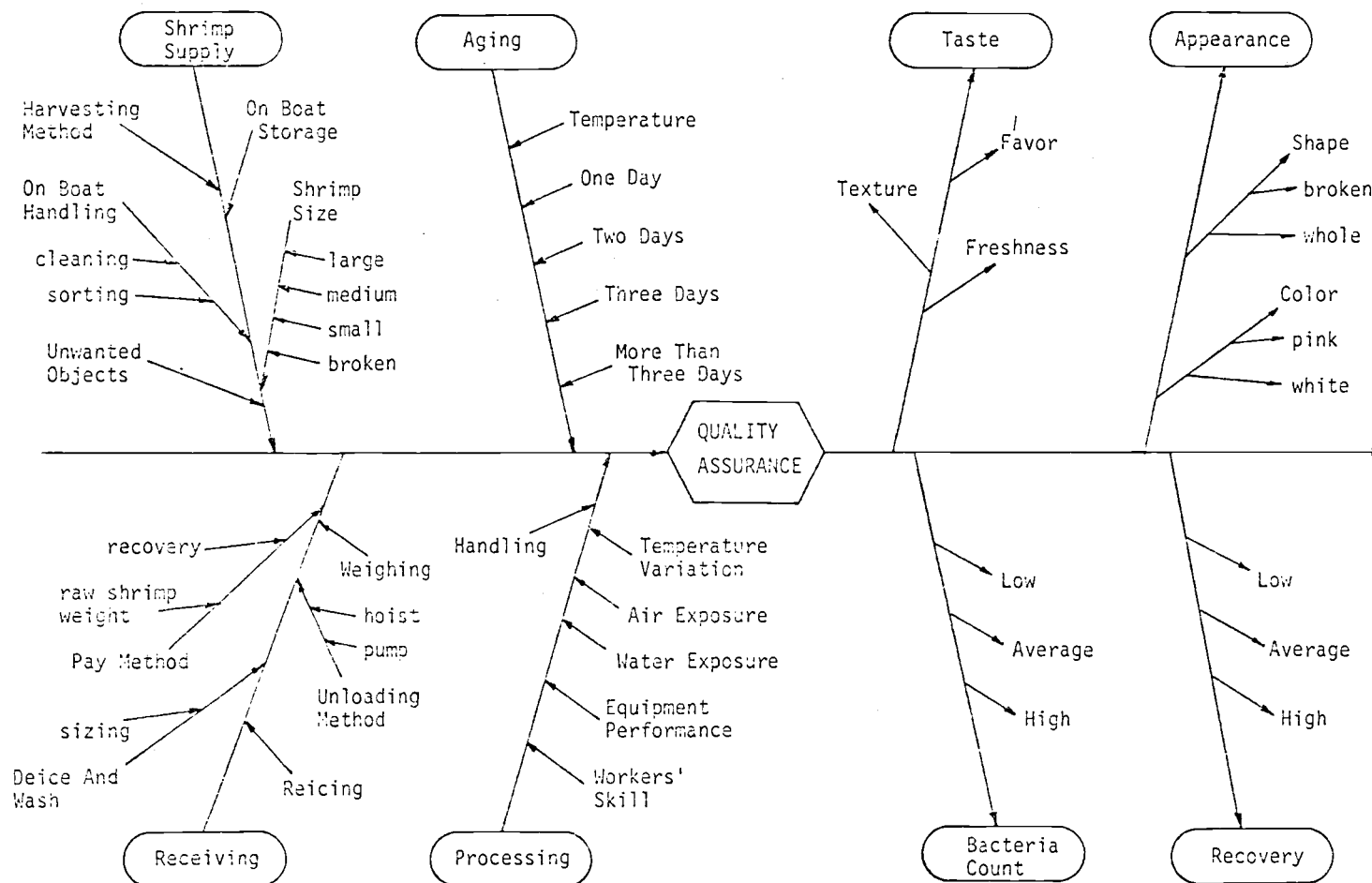


Figure 90. Cause-and-effect diagram of quality assurance of shrimp processing.

weight of the shrimp meat from the raw shrimp the fishermen bring in. In this case, the processor records the net weight of raw shrimp from a fisherman. After the shipment of raw shrimp is processed, the processor then knows the percentage of recovery and pays the fisherman accordingly.

The "pay by poundage" method looks easy to administrate and convenient to carry out. However, the size distribution of raw shrimp and conditions of raw shrimp are not accounted in this method. Both the fishermen and processors may not be happy with the recovery and quality of a particular shipment of shrimp because there could be a large percentage of small shrimp, broken shrimp, and deteriorated shrimp. Processors may think they pay more for their shrimp. Fishermen many think very much differently. They may think they brought in good quality raw shrimp for the processors and the result of low recovery is due to processors' mishandling and inefficient processing methods. The fishermen may even feel they get less than what they deserved. Although this method is used widely between processors and fishermen, both are not too happy with the method. They use this method simply because they perceive no better alternative.

The "Pay by recovery" method is very unpopular among the fishermen probably because they feel they take the risk to go out to fish then the processors should take their responsibility of the recovery of shrimp meat. Under this method, fishermen feel they also bear the risk of inefficient processing methods, mishandling, and bookkeeping errors. This method sounds ideal if and only if the fishermen and processors

can really trust each other and the processors do a perfect job on their part. As long as there are conflicts of interest between processors and fishermen - both try to maximize their profit - this plan probably will not work out smoothly in the long run. Processors may let fishermen examine the processing line from time to time but fishermen may not have the knowledge to know how to say anything or they may interfere too much about how the processors should run their business.

The two methods above are not satisfactory to both the fishermen and processors. Due to the time constraint on this project actual case studies are deferred. The following recommended procedures may hopefully bring the fishermen and processors closer together on a common statistical ground as far as the size distribution and paying method of raw shrimp is concerned. Most processors keep a record of the number of raw shrimp per pound and categorize them into large, medium, and small. Generally they only take a few pounds to come up with the results. No statistical test is performed. The number of samples is unlikely to be adequate and the validity of the results is questionable.

An ideal sampling method should have the following characteristics.

1. Knowledge of the size distribution of incoming raw shrimp.
2. Knowledge of the bacteria count of the incoming raw shrimp.
3. Knowledge of the percentage of broken shrimp.
4. Ease of use and administration.
5. Agreement by both processors and fishermen.

Although it is desirable to know the weight of each raw shrimp, it is tedious if not impractical to weigh each shrimp even if statistical sampling is applied. Fortunately, a study on the relationship between width and weight of pink shrimp (*Pandalus Jordani*) was made by Langmo and Rudkin (14). A regression equation was developed.

$$\begin{array}{l} \text{Width of shrimp at} \\ \text{widest point in} \\ \text{centimeter} \end{array} = 0.6310 + 0.0818 (\text{Weight in grams})$$

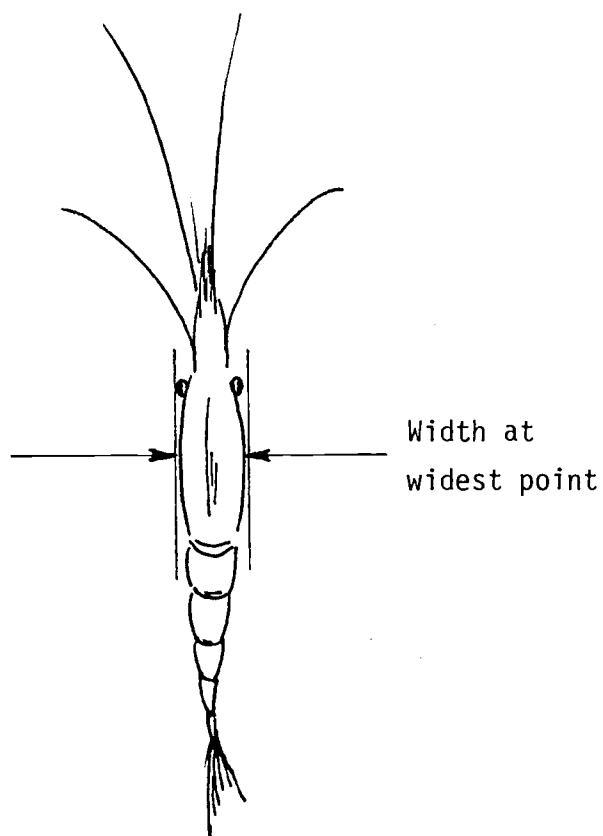
$$R^2 = 0.766$$

Width of shrimp at widest point is shown in Figure 91. Weight of shrimp can be expressed as the dependent variable in the above equation and the equation becomes:

$$\begin{array}{l} \text{Weight of shrimp} \\ \text{in grams} \end{array} = \frac{\begin{array}{l} \text{Width of shrimp at} \\ \text{widest point in} \\ \text{centimeter} \end{array} - 0.613}{0.0818}$$

From the transformed equation, Table XVI is constructed to show the numerical value of width, weight, and number of shrimp per pound.

Shrimp over 150 per pound are too small to be peeled efficiently by mechanical peeler and too expensive to be picked by hand. According to equipment manufacturers, 90 to 120 shrimp per pound are the sizes suitable for the mechanical peeler. The relationship between width, weight, and number of shrimp per pound is known. This information may help develop a practical and reliable sampling method. Also, this information can help in the designing of a shrimp grader. An ideal



(Posterior view of a shrimp)

Figure 91. Width of shrimp at widest point.

TABLE XVI. WIDTH, WEIGHT, AND NUMBER OF SHRIMP PER POUND.

1 lb. = 454 grams

$$L = 0.631 + 0.0818W$$

$$W = \frac{L - 0.631}{0.0818}$$

L cm.	W gm.	Number of shrimp per pound
0.70	0.8435	538
0.75	1.4548	312
0.80	2.0660	220
0.85	2.6773	170
0.90	3.2885	138
0.95	3.8998	116
1.00	4.5110	101
1.05	5.1222	89
1.10	5.7335	79
1.15	6.3447	72
1.20	6.9560	65
1.25	7.5672	60
1.30	8.1785	56
1.35	8.7897	52
1.40	9.4010	48
1.45	10.0122	45
1.50	10.6235	43
1.55	11.2347	40
1.60	11.8460	38

sampling method is not available. However, one way to find out the size distribution of shrimp is to let the whole population of shrimp go through a mechanical size grader. On machine^{28/} can size 16,000 pounds of raw shrimp into three grades - large, medium, and small - in one hour. This means the grading process will take 1.25 hours for a shipment of 20,000 pounds of shrimp. The grading process can be done concurrently with the unloading of shrimp from boat to dock. Once the shrimp are graded, the total price of the shipment can be paid according to the following manner.

$$\begin{aligned} \text{Total value of} \\ \text{shrimp} \end{aligned} &= X_1 (\text{Weight of large shrimp}) \\ &+ X_2 (\text{Weight of medium shrimp}) \\ &+ X_3 (\text{Weight of small shrimp})$$

where X_1 , X_2 , and X_3 are price per pound of large, medium, and small shrimp respectively.

The relationship among X_1 , X_2 , and X_3 can be corresponded to the relationship between size and recovery, processing cost, and shrimp meat price. A regression equation should be able to be developed as shown in Figure 92. Again, the regression analysis is recommended for further study.

As mentioned in Chapter Six, weighing of shrimp meat is another important area. Weight less than specification may cause customer dissatisfaction and even legal trouble. Weight more than specification

^{28/} Allen shrimp grader by Allen Machinery, Newberg, Oregon.

reduces revenue. Control charts are recommended to be used to monitor the variation in weight of shrimp meat in packing. Following are the procedure to develop control charts.

1. Take random samples and make precise weight measurement.
2. Calculate process average \bar{X} and range R .
3. Calculate average of \bar{X} and R .
4. Find the control limits of \bar{X} and R charts.
5. Plot data, \bar{X} and R , on control charts.
6. Examine pattern of data and draw conclusion.

The following is a format of the steps.

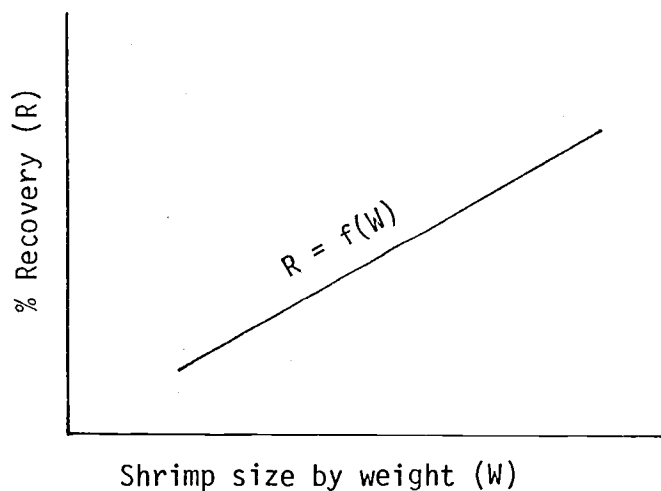


Figure 92. Relationship between size and recovery of raw shrimp.

Weight Measurement

Sample	1	2	3	...	n	Sum	\bar{X}	R
1	a_{11}	a_{12}	a_{13}	...	a_{1n}	Σa_{1j}	$\Sigma a_{1j}/n$	R_1
2	a_{21}	a_{22}	a_{23}	...	a_{2n}	Σa_{2j}	$\Sigma a_{2j}/n$	R_2
3	a_{31}	a_{32}	a_{33}	...	a_{3n}	Σa_{3j}	$\Sigma a_{3j}/n$	R_3
.
.
m	a_{m1}	a_{m2}	a_{m3}	...	a_{mn}	Σa_{mj}	$\Sigma a_{mj}/n$	R_m
Total							$\frac{mn}{\Sigma \Sigma_{ij}} a_{ij}/n$	$\frac{m}{\Sigma_i} R_i$

$$\bar{\bar{X}} = \frac{\Sigma \bar{X}}{m} \quad \bar{R} = \frac{\Sigma R}{m}$$

For \bar{X} control chart:

$$\text{Upper control limit (UCL)} = \bar{\bar{X}} + A\bar{R}$$

$$\text{Lower control limit (LCL)} = \bar{\bar{X}} - A\bar{R}$$

For R control chart:

$$\text{Upper control limit (UCL)} = B\bar{R}$$

$$\text{Lower control limit (LCL)} = C\bar{R}$$

"A" is control factor for \bar{X} chart, and "B" and "C" are control factors for R chart. These factors are a function of sample size and set three standard deviation bounds. Control factors, A, B, and C, are shown in Table XVII.

After all the calculations are done, \bar{X} control chart and R control chart can be construct as shown in Figure 93.

TABLE XVII. CONTROL FACTORS, A, B, AND C (19).

Control Limit Factor For \bar{X} chart, A.		Control Limit Factors For R chart, B and C.		
n	A	n	B	C
2	1.880	2	3.268	0.000
3	1.023	3	2.574	0.000
4	0.729	4	2.282	0.000
5	0.577	5	2.114	0.000
6	0.483	6	2.004	0.000
7	0.419	7	1.924	0.076
8	0.373	8	1.864	0.136
9	0.337	9	1.816	0.184
10	0.308	10	1.777	0.223

Then the data \bar{X} and R are plotted on the charts. If all data points fall within the control limits, the weighing process is under control and the variation between the samples, \bar{X} , and within the sample, R, can be explained by random influences. If there are samples outside the control limits, these points should be investigated to find out whether there is an assignable cause for deviation. An example on control charts is shown in the following pages.

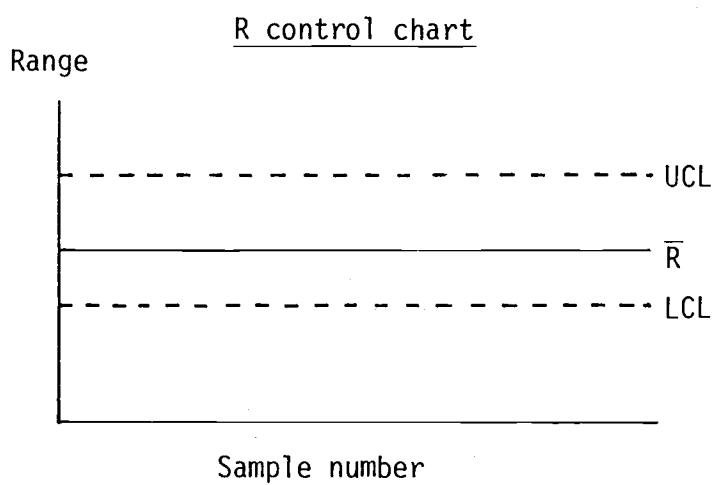
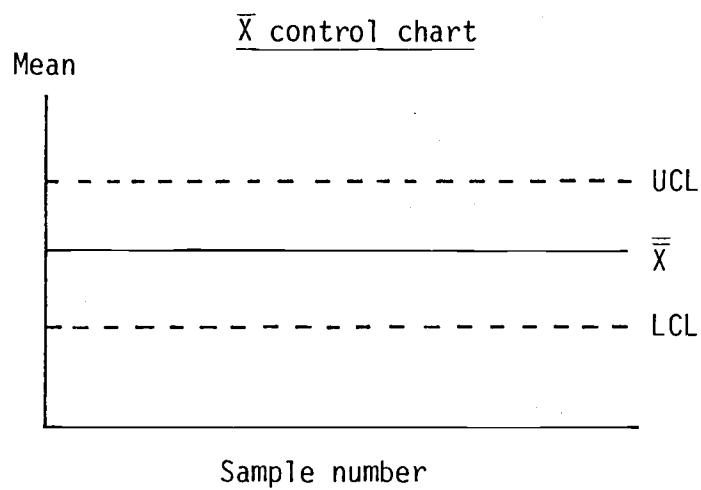


Figure 93. \bar{X} chart and R chart.

The results of weighing ten samples of five five-pound containers of shrimp meat are shown below. Two samples were taken each day by a random selection of containers packed during the day and stored in the cold room.

Sample	Weight Measurements (pounds)					Sum	\bar{X}	R
1	5.03	5.02	4.99	5.01	5.01	25.06	5.012	0.04
2	5.01	4.98	4.97	5.00	5.03	24.99	4.998	0.06
3	5.00	5.08	5.00	5.02	5.01	25.11	5.022	0.08
4	4.97	4.98	5.03	4.97	4.99	24.94	4.988	0.06
5	4.98	5.04	4.99	5.01	5.03	25.05	5.010	0.06
6	5.01	4.96	5.05	5.01	4.96	24.99	4.998	0.09
7	4.99	5.00	5.02	5.01	5.02	25.04	5.008	0.03
8	4.98	5.03	5.01	5.03	5.10	25.15	5.030	0.12
9	5.02	5.05	5.00	5.01	4.95	25.03	5.006	0.10
10	5.01	4.99	5.01	4.98	5.03	25.02	5.004	0.05
						Total	50.076	0.69

$$\bar{\bar{X}} = \frac{\sum \bar{X}}{N} = \frac{50.076}{10} = 5.0076$$

$$\bar{R} = \frac{\sum R}{N} = \frac{0.69}{10} = 0.069$$

For \bar{X} control chart:

$$\begin{aligned} \text{Upper control limit (UCL)} &= \bar{\bar{X}} + AR \\ &= 5.0076 + 0.577(0.069) \\ &= 5.047 \end{aligned}$$

$$\begin{aligned}
 \text{Lower control limit (LCL)} &= \bar{X} - AR \\
 &= 5.0076 - 0.577(0.069) \\
 &= 4.968
 \end{aligned}$$

where "A" for $n = 5$ is 0.577

For R control chart:

$$\begin{aligned}
 \text{Upper control limit (UCL)} &= B\bar{R} \\
 &= 2.114(0.069) \\
 &= 0.1459 \\
 \text{Lower control limit (LCL)} &= 0.0(0.069) \\
 &= 0.0
 \end{aligned}$$

where "B" for $n = 5$ is 2.114

"C" for $n = 5$ is 0.0

Data points, \bar{X} and R, are plotted on graphs as shown in Figures 94 and 95.

In the control charts, the plot of individual sample means and ranges indicates the weighing operation is under control. That is, the variation between the sample, \bar{X} , and within the samples, R, can be explained by random influences. Continued sampling may reveal a sample reading outside the control limits. Such a plot should be investigated to confirm whether there is an assignable cause for the deviation.

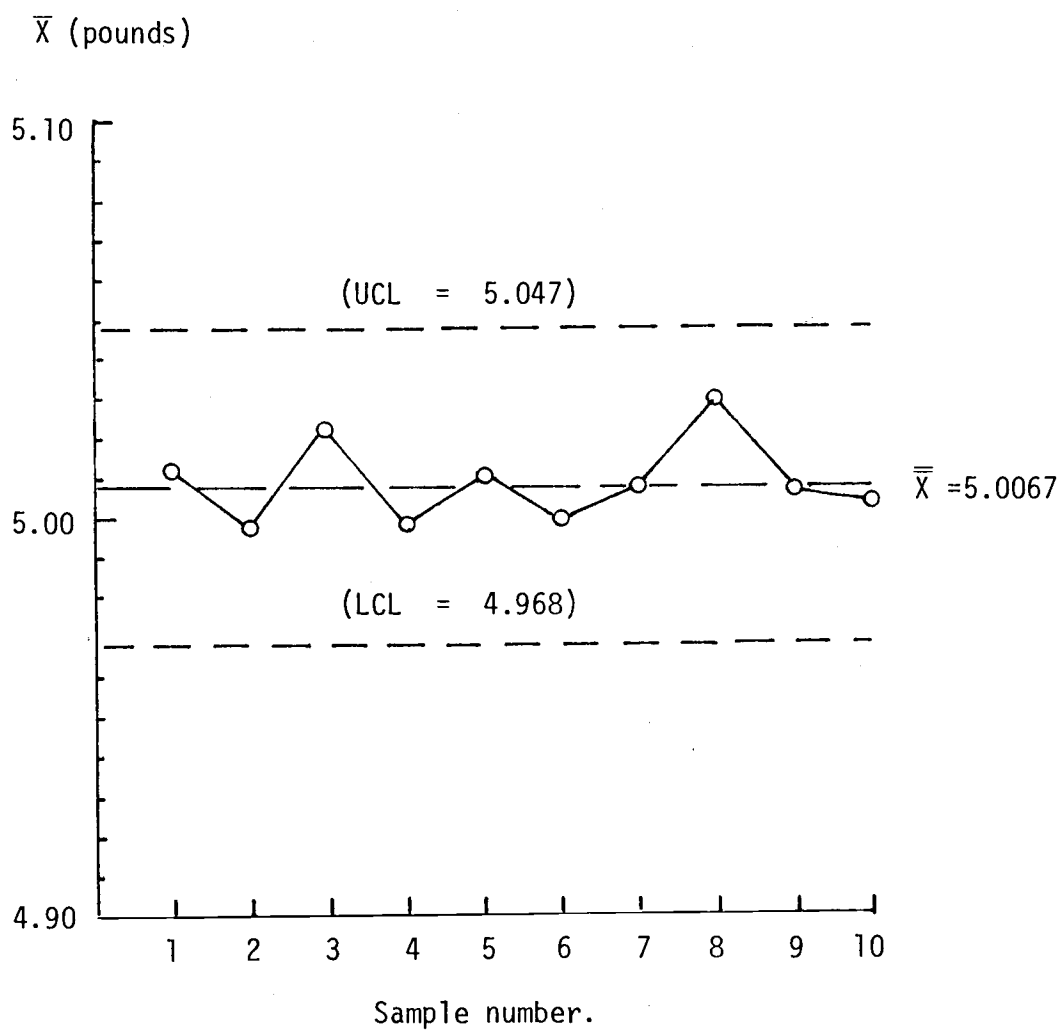


Figure 94. \bar{X} control chart with data points.

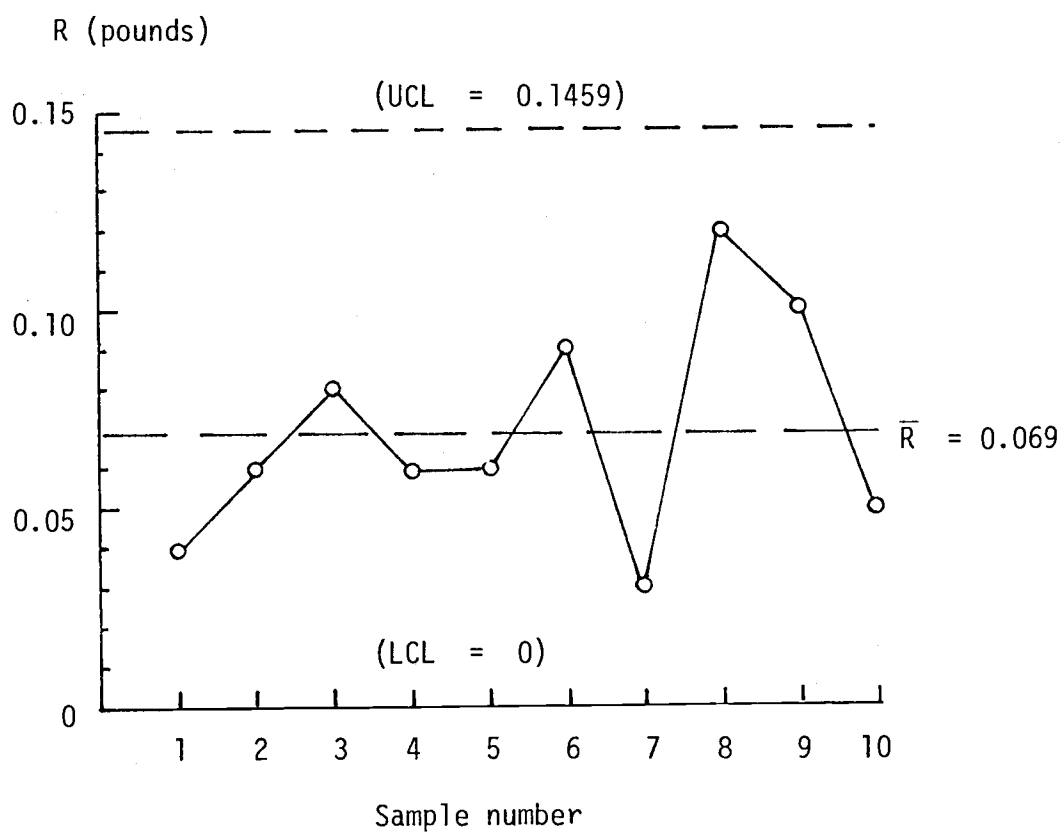


Figure 95. R control chart with data points.

A Rational Resource Management and Planning (RPM) Model

After the construction of the cause-and-effect diagram, with the help of processors, a rational RPM model is built to illustrate the system under study. In Figure 96, resources - demand, raw shrimp supply, capital, management, worker, and equipment - are represented by circles and operations - buy shrimp, process shrimp, and sell shrimp meat - are represented by squares. Relationships between resources and operations are indicated by arrows.

The RPM model is a simplified one. The operation "process shrimp" stands for all activities along the processing line. Only the major resources and operations are included. In the model, the amount of shrimp bought by processor is limited by the supply sources and his capital. Receiving, cooking, peeling, inspecting, and packaging are governed by capital, management, workers, and equipment. Marketing of shrimp meat is affected by demand and marketing effort of management.

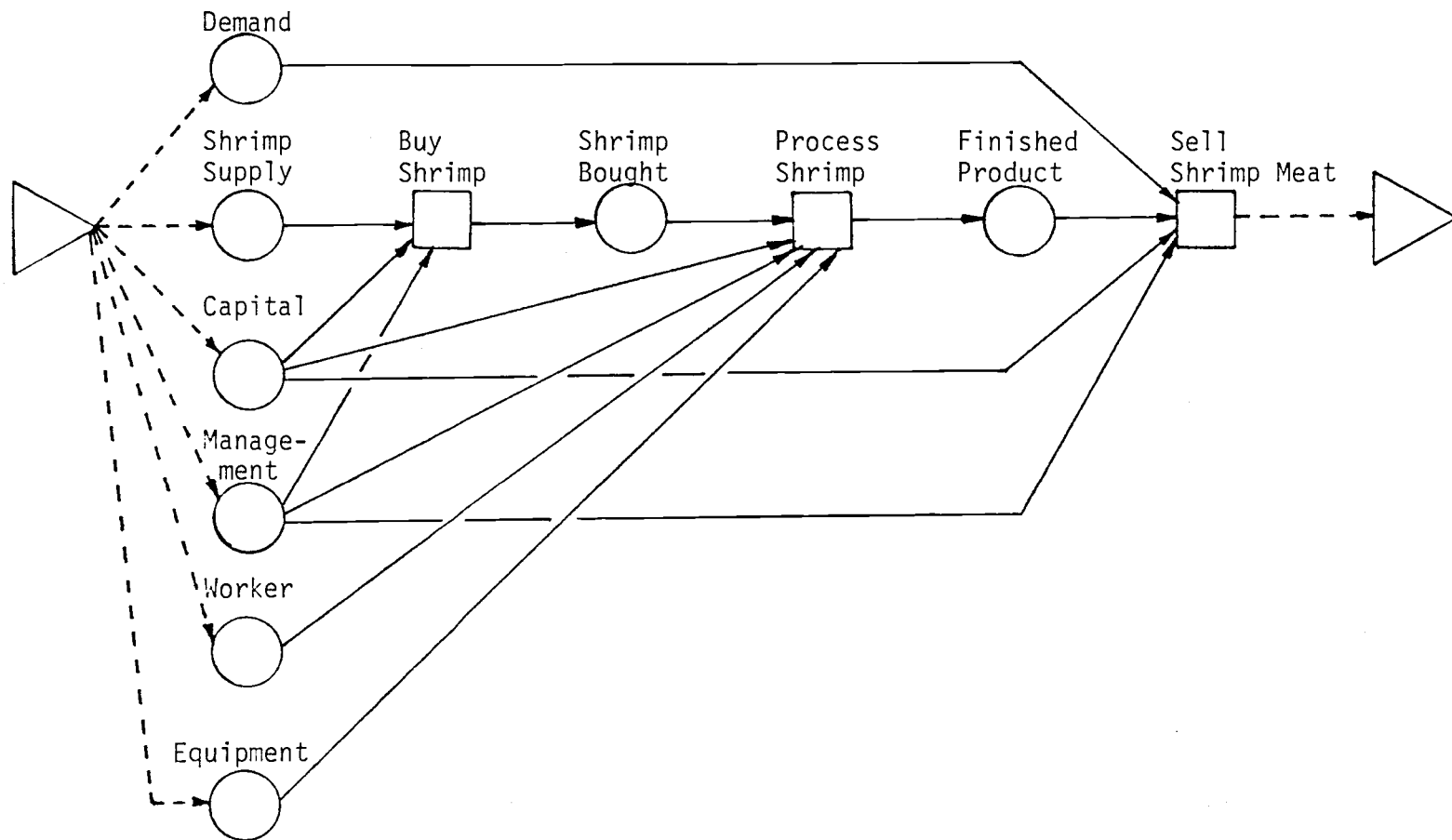


Figure 96. A rational RPM model of the shrimp processing system.

A Mathematical Resource Planning and Management (RPM) Model

RPM model has been successfully applied in linear programming and goal programming for product mix planning and optimization strategy (12) (16). RPM model is recommended here to be used as a control tool to monitor resource, output, cost and profit. The "easy to build" and "graphical" features of RPM can also facilitate the communication among management staff and workers. Thus RPM can help improve work methods and output indirectly. Following is the procedure to construct an RPM model.

1. Define all resources.
2. Define all processors.
3. Put the relationship between resources and processes in graphical form (use circles, squares, arrows, and triangles).
4. Fill numerical relationship of resources and processes in the graphical model if necessary or desired.
5. Develop linear programming model from RPM model if applicable.
6. Calculate amount produced in each process, opportunity cost, residue in each resource, shadow price and total profit.

A general RPM model for shrimp processing is shown in Figure 98. A portion of the model is extracted and shown in Figure 97 in order to show the reasoning behind the RPM model.

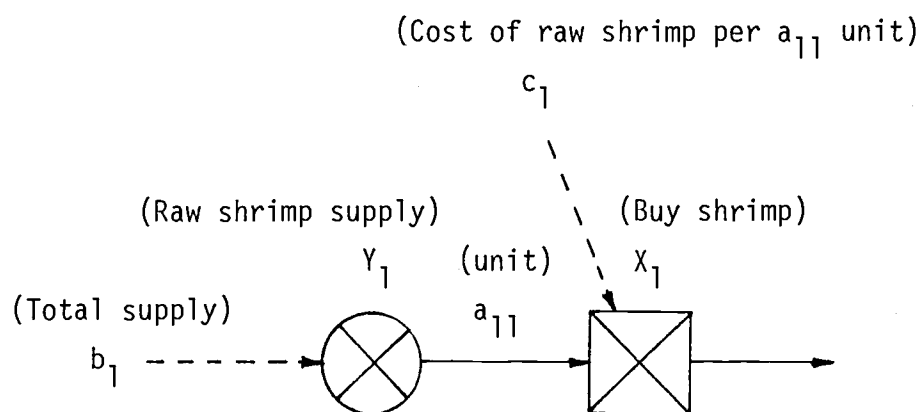


Figure 97. Extracted portion of the RPM model.

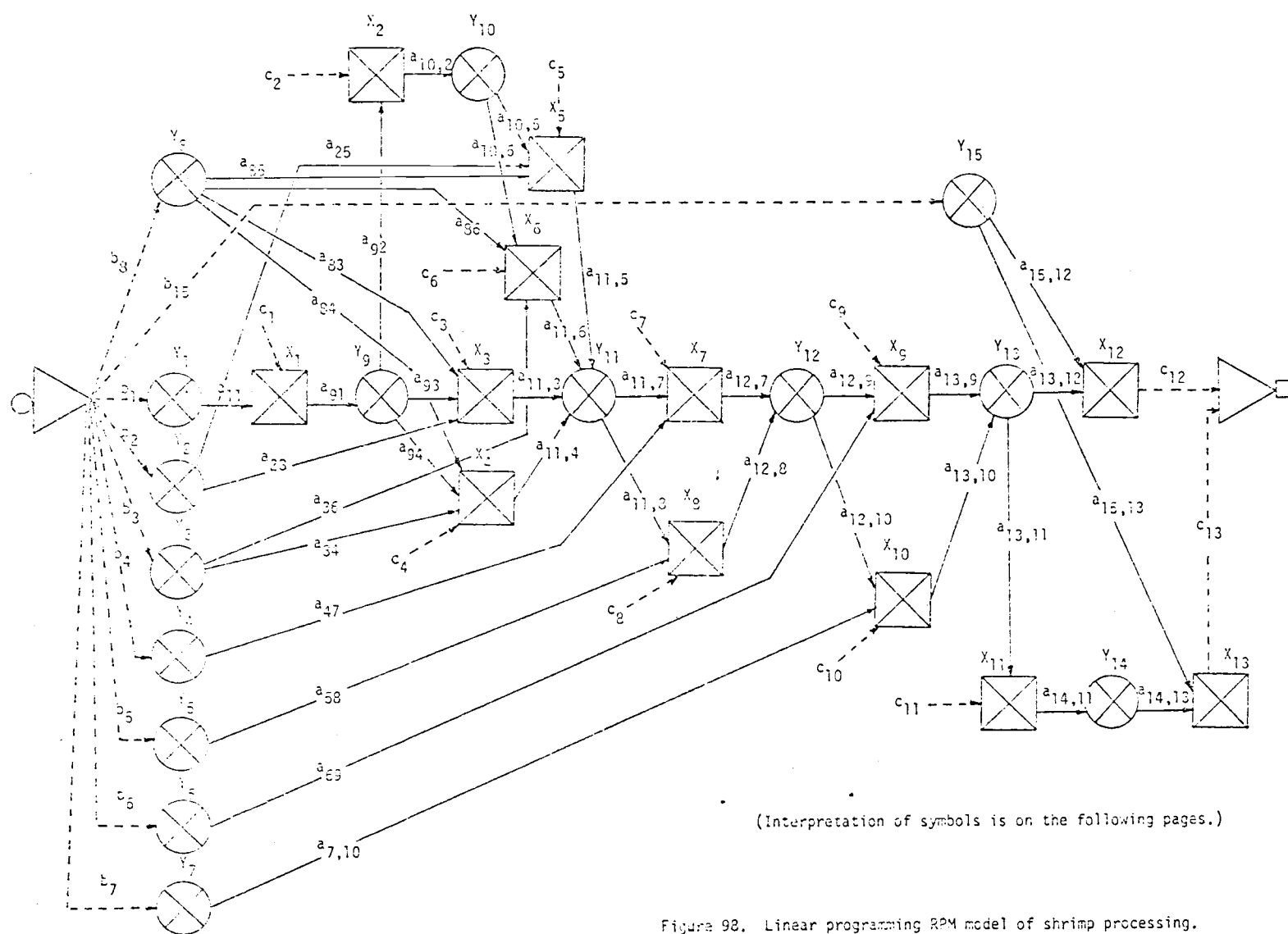


Figure 98. Linear programming RPM model of shrimp processing.

Interpretation of the variables in the linear programming RPM

model:

 Y_1 = Raw shrimp supply Y_2 = Machine operator time Y_3 = Machine operator overtime Y_4 = Inspector time Y_5 = Inspector overtime Y_6 = Packer time Y_7 = Packer overtime Y_8 = Machine time Y_9 = Raw shrimp bought Y_{10} = Raw shrimp after storage Y_{11} = Shrimp meat after cooking, peeling, and cleaning Y_{12} = Shrimp meat after inspection Y_{13} = Shrimp meat after canning Y_{14} = Five-pound can after storage Y_{15} = Demand of five-pound can shrimp meat X_1 = Buy shrimp X_2 = Store raw shrimp X_3 = Cook, peel, and clean shrimp at normal time X_4 = Cook, peel, and clean shrimp at overtime X_5 = Cook, peel, and clean shrimp at normal time after storage X_6 = Cook, peel, and clean shrimp at overtime after storage

X_7 = Inspect shrimp meat at normal time

X_8 = Inspect shrimp meat at overtime

X_9 = Pack shrimp meat into five-pound cans at normal time

X_{10} = Pack shrimp meat into five-pound cans at overtime

X_{11} = Store five-pound cans

X_{12} = Sell five-pound cans

X_{13} = Sell five-pound cans after storage

Interpretation of b_i , c_i , and a_{ij} are shown in pages 187 to 189.

In Figure 98, the amount of raw shrimp the processor can buy is limited by the total supply. The relationship can be expressed by the inequation below.

$$\text{at } Y_1 \quad a_{11}X_1 \leq b_1$$

In reality, the amount of raw shrimp the processor can buy is also limited by his capital. In this model, capital is assumed not to be a constraint. This assumption is not unreasonable because processors always try to buy all the shrimp available. Following is a complete linear programming model for the RPM model.

$$\begin{aligned} \text{Maximize: } Z = & -c_1X_1 - c_2X_2 - c_3X_3 - c_4X_4 - c_5X_5 - c_6X_6 - c_7X_7 \\ & - c_8X_8 - c_9X_9 - c_{10}X_{10} - c_{11}X_{11} + c_{12}X_{12} + c_{13}X_{13} \end{aligned}$$

Subject to:

$$\begin{aligned} @ Y_1 \quad & a_{11}X_1 & \leq & b_1 \\ @ Y_2 \quad & a_{23}X_3 + a_{25}X_5 & \leq & b_2 \\ @ Y_3 \quad & a_{34}X_4 + a_{36}X_6 & \leq & b_3 \\ @ Y_4 \quad & a_{47}X_7 & \leq & b_4 \\ @ Y_5 \quad & a_{58}X_8 & \leq & b_5 \\ @ Y_6 \quad & a_{69}X_9 & \leq & b_6 \\ @ Y_7 \quad & a_{7,10}X_{10} & \leq & b_7 \\ @ Y_8 \quad & a_{83}X_3 + a_{84}X_4 + a_{85}X_5 + a_{86}X_6 & \leq & b_8 \\ @ Y_9 \quad & a_{9,12}X_{12} + a_{9,13}X_{13} & \leq & b_9 \\ @ Y_{10} \quad & a_{10,2}X_2 + a_{10,3}X_3 + a_{10,4}X_4 & \leq & a_{10,1}X_1 \\ @ Y_{11} \quad & a_{11,5}X_5 + a_{11,6}X_6 & \leq & a_{11,2}X_2 \\ @ Y_{12} \quad & a_{12,7}X_7 + a_{12,8}X_8 & \leq & a_{12,3}X_3 + a_{12,4}X_4 \\ & & & + a_{12,5}X_5 + a_{12,6}X_6 \\ @ Y_{13} \quad & a_{13,9}X_9 + a_{13,10}X_{10} & \leq & a_{13,7}X_7 + a_{13,8}X_8 \\ @ Y_{14} \quad & a_{14,11}X_{11} + a_{14,12}X_{12} & \leq & a_{14,9}X_9 + a_{14,10}X_{10} \\ @ Y_{15} \quad & a_{15,13}X_{13} & \leq & a_{15,11}X_{11} \\ & X_i \geq 0 \quad (i = 1, 2, 3, \dots, 13) \end{aligned}$$

Following is the annual data of a shrimp processing plant.

b_1	(Raw shrimp supply)	=	1,500,000 pounds
b_2	(PCA operator time)	=	1,792 hours
b_3	(PCA operator overtime)	=	448 hours
b_4	(Inspector time)	=	10,752 hours
b_5	(Inspector overtime)	=	2,688 hours
b_6	(Packer time)	=	3,584 hours
b_7	(Packer overtime)	=	896 hours
b_8	(Machine time)	=	4,200 hours
b_{15}	(Demand of shrimp meat)	=	80,000 five-pound cans

c_1	(Fix cost + Unloading cost + Shrimp cost)	=	\$147.3 / 1000 lbs.
c_2	(Storage cost)	=	\$0.4 / 1000 lbs.
c_3	(One PCA operator at \$4/hr.)	=	\$4.0 / hour
c_4	(One PCA operator at \$6/hr. overtime)	=	\$6.0 / hour
c_5	(One PCA operator at \$4/hr.)	=	\$4.0 / hour
c_6	(One PCA operator at \$6/hr. overtime)	=	\$6.0 / hour
c_7	(Six inspectors at \$2.5/hr./inspector)	=	\$15.0 / hour
c_8	(Six inspectors at \$3/hr./inspector)	=	\$18.0 / hour
c_9	(Two packers at \$3/hr./packer)	=	\$6.0 / hour
c_{10}	(Two packers at \$3.5/hr./packer)	=	\$7.0 / hour
c_{11}	(Average storage cost per 50 five-pound can)	=	\$0.5
c_{12}	(Revenue per five-pound can at \$1.5/lb.)	=	\$7.5
c_{13}	(Revenue per five-pound can at \$1.5/lb.)	=	\$7.5

a_{11}	(Raw shrimp unit)	= 1000 lbs./unit
a_{91}	(Raw shrimp unit)	= 1000 lbs./unit
a_{92}	(Raw shrimp unit)	= 1000 lbs./unit
$a_{10,2}$	(Raw shrimp unit)	= 1000 lbs./unit
a_{93}	(Raw shrimp unit)	= 1000 lbs./unit
a_{23}	(Operator hour per unit)	= 1 hr./unit
a_{83}	(Machine hour per unit)	= 1 hr./unit
$a_{11,3}$	(Shrimp meat from each unit of raw shrimp)	= 200 lbs./unit
a_{94}	(Raw shrimp unit)	= 1000 lbs./unit
a_{34}	(Overtime operator hour per unit)	= 1 hr./unit
a_{84}	(Machine hour per unit)	= 1 hr./unit
$a_{11,4}$	(Shrimp meat from each unit of raw shrimp)	= 200 lbs./unit
$a_{10,5}$	(Raw shrimp unit)	= 1000 lbs./unit
a_{25}	(Operator hour per unit)	= 1 hr./unit
a_{85}	(Machine hour per unit)	= 1 hr./unit
$a_{11,5}$	(Shrimp meat from each unit of raw shrimp after storage)	= 250 lbs./unit
$a_{10,6}$	(Raw shrimp unit)	= 1000 lbs./unit
a_{36}	(Overtime operator hour per unit)	= 1 hr./unit
a_{86}	(Machine hour per unit)	= 1 hr./unit
$a_{11,6}$	(Shrimp meat from each unit of raw shrimp after storage)	= 250 lbs./unit
$a_{11,7}$	(Shrimp meat unit)	= 250 lbs./unit

$a_{11,8}$	(Shrimp meat unit)	= 250 lbs./unit
a_{58}	(Overtime inspector hour per unit)	= 6 hrs./unit
$a_{12,8}$	(Shrimp meat unit)	= 250 lbs./unit
$a_{12,9}$	(Shrimp meat unit)	= 250 lbs./unit
a_{69}	(Packer hour per unit)	= 2 hrs./unit
$a_{13,9}$	(Number of five-pound cans per unit shrimp meat)	= 50 cans/unit
$a_{12,10}$	(Shrimp meat unit)	= 250 lbs./unit
$a_{7,10}$	(Overtime packer hour per unit)	= 2 hrs./unit
$a_{13,10}$	(Number of five-pound cans per unit shrimp meat)	= 50 cans/unit
$a_{13,11}$	(Five-pound can unit)	= 50 cans/unit
$a_{14,11}$	(Five-pound can unit)	= 50 cans/unit
$a_{13,12}$	(Five-pound can selling unit)	= 1 can/unit
$a_{15,12}$	(Demand unit of five-pound can)	= 1 can/unit
$a_{14,13}$	(Five-pound can selling unit)	= 1 can/unit
$a_{15,13}$	(Demand unit of five-pound can)	= 1 can/unit

Figure 99 shows the computer input of the linear programming model for *REX^{29/} program and Figure 100 shows the computer output.

^{29/} *REX was developed by H. Lynn Scheurman at Oregon State University.

```

ROWS
$PROFIT <SUPPLY <MAN <MANOT <INS <INSOT
<PACK <PACKOT <MACHIN <RAW1 <RAW2 <MEAT1 <MEAT2
<CAN5 <CAN55 <DEMD5
COLUMNS
BUY PROFIT -147.3 SUPPLY 1000 RAW1 -1000
STORER PROFIT -0.4 RAW1 1000 RAW2 -1000
PRO1 PROFIT -4 RAW1 1000 MACHIN 1 MAN 1 MEAT1 -200
PROOT1 PROFIT -6 RAW1 1000 MACHIN 1 MANOT 1 MEAT1 -200
PRO2 PROFIT -4 RAW2 1000 MACHIN 1 MAN 1 MEAT1 -250
PROOT2 PROFIT -6 RAW2 1000 MACHIN 1 MANOT 1 MEAT1 -250
PECT PROFIT -15 MEAT1 250 INS 6 MEAT2 -250
PECTOT PROFIT -13 MEAT1 250 INSOT 6 MEAT2 -250
AGE5 PROFIT -6 MEAT2 250 PACK 2 CAN5 -50
AGEOT5 PROFIT -7 MEAT2 250 PACKOT 2 CAN5 -50
STORES PROFIT -0.5 CAN5 50 CAN55 -50
SELL5 PROFIT 7.5 CAN5 1 DEMD5 1
SELLS5 PROFIT 7.5 CAN55 1 DEMD5 1
RHS
RESOURCE SUPPLY 1500000 MAN 1792 MANOT 448
RESOURCE INS 10752 INSOT 2688 PACK 3584 PACKOT 896
RESOURCE MACHIN 4200 DEMD5 80000
EOF

```

Interpretation of the variables in the computer input:

PROFIT = Z

SUPPLY = Y_1	MEAT1 = Y_{11}	BUY = X_1	STORE5 = X_{11}
MAN = Y_2	MEAT2 = Y_{12}	STORER = X_2	SELL5 = X_{12}
MANOT = Y_3	CAN5 = Y_{13}	PRO1 = X_3	SELLS5 = X_{13}
INS = Y_4	CAN55 = Y_{14}	PROOT1 = X_4	
INSOT = Y_5	DEMD5 = Y_{15}	PRO2 = X_5	
PACK = Y_6		PROOT2 = X_6	
PACKOT = Y_7		PECT = X_7	
MACHIN = Y_8		PECTOT = X_8	
RAW1 = Y_{10}		AGE5 = X_9	
RAW2 = Y_{11}		AGEOT5 = X_{10}	

Figure 99. Computer input for *REX.

ROWS		303449.9999992	-303449.9999992
PROFIT	Z	303449.9999992	-303449.9999992
SUPPLY	U	1500000.0000000	0
MAN	B	1500.0000000	292.0000000
MANOT	B	0	448.0000000
INS	B	9000.0000000	1752.0000000
INSCOT	B	0	2688.0000000
PACK	B	3000.0000000	584.0000000
PACKOT	B	0	896.0000000
MACHIN	B	1500.0000000	2700.0000000
RAW1	U	0	0
RAW2	U	0	0
MEAT1	U	0	0
MEAT2	U	0	0
CANS	U	0	0
CANS5	U	0	0
DEMOS	B	75000.0000000	5000.0000000
COLUMNS			
BUY	B	1500.0000000	-147.3000000
STOPER	B	1500.0000000	-0.4000000
PRO1	L	0	-4.0000000
PROOT1	L	0	-6.0000000
PRO2	B	1500.0000000	-4.0000000
PROOT2	L	0	-6.0000000
PECT	B	1500.0000000	-15.0000000
PECTOT	L	0	-13.0000000
AGE5	B	1500.0000000	-5.0000000
AGEOT5	L	0	-7.0000000
STORES	L	0	-0.5000000
SELL5	B	75000.0000000	7.5000000
SELLS5	B	0	7.5000000
EOF			

MINF		PINF	-1.000000
MINF	1500000.000000		.202300
MINF	1792.000000		0
MINF	448.000000		0
MINF	10752.000000		0
MINF	2688.000000		0
MINF	3584.000000		0
MINF	896.000000		0
MINF	4200.000000		0
MINF		0	.349600
MINF		0	.350000
MINF		0	1.416000
MINF		0	1.476000
MINF		0	7.500000
MINF		0	7.500000
MINF	80000.000000		0
0	PINF		0
0	PINF		0
0	PINF	70.400000	
0	PINF	72.400000	
0	PINF	0	
0	PINF	2.000000	
0	PINF	0	
0	PINF	3.000000	
0	PINF	0	
0	PINF	1.000000	
0	PINF	.500000	
0	PINF	0	
0	PINF	0	

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In Figure 101, the amount produced in each process, opportunity cost, residue in each resource, shadow price and profit are shown in the RPM model. The computer output shows the ideal way to utilize resources and produce output - shrimp meat. In reality, it may be very difficult if not impossible to follow what the computer output indicates because the RPM model is only a simplified representation of the actual situation. However, by comparing the actual results with the computer results, a processor can have a better knowledge about where he should cut down costs, change production scheduling, and change labor requirement.

Training of Workers

Shrimp processing in Oregon is not a year round operation because shrimp harvesting at the Oregon coast is limited from April to October. During the off-season period, workers who used to work on shrimp processing are either shifted to work on other seafood processing or they are laid off. It is the processors' advantage to utilize their facilities and cold storage on other seafood processing - bottom fish filleting, crab shaking, and oyster shucking, etc. Then the processors do not have to lay off their workers but let them work on other seafood. Usually, processors will confront another problem, the high cost of training - low efficiency and high waste of beginners. A C&E diagram is shown in Figure 103. Training programs can be done by means of achievement chart, loop films, and close circuit television. Loop films are highly recommended by Engesser because it is inexpensive and effective. It costs the processor about \$400 to purchase a loop-film projector and the appropriate training loop films^{30/}. A picture of a loop-film projector is shown in Figure 102. This kind of training program is easy to operate and it helps workers attain proper work skill faster. The result may be less waste and higher productivity. The cost of this program is very low in comparison with hiring a supervisor to do the training. With a stable workforce, processors pay less unemployment compensation also.

^{30/} Engesser, W. F. Engineering Standards for Shrimp, Crab, Oyster, Bottom-Fish and Product-Mix Specie. Paper presented at Pacific Coast Section - National Shellfisheries Association, September 5, 1975, Tyee Motor Inn, Tumwater, Washington.



Figure 102.
Loop-film projector.

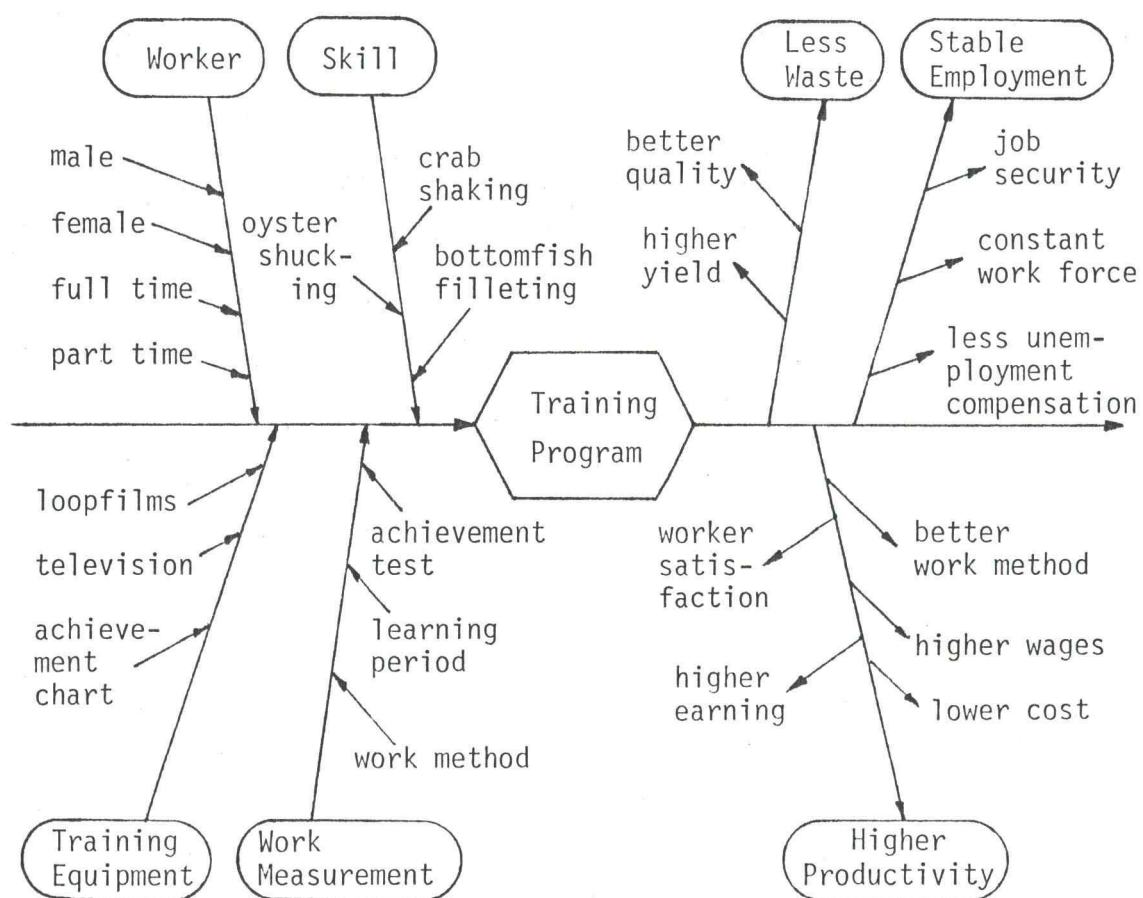


Figure 103. Cause-and-effect diagram of training program.

VIII. SUMMARY OF ANALYSIS

Processors use a different mix of equipment dependent upon their goals, incoming shrimp costs, quality, yeilds, volume, size, waste utilization, production rates and expected selling prices. Because of these differences, the major equipment, accessories and conveyors vary from a maximum of 23 pieces to a minimum of 15.

A comparison of the most mechanized and the least mechanized processing system is shown in Figures 104 and 105. All Oregon plants use the PCA cooker-peeler and separator which is pictured in Chapter 5. The frequency of equipment accesory and the type of conveyance used appear in Table VIII, Chapter 5.

A processor can conduct his own analysis with the process-chart mathematical model described in Chapter 7, to reflect the cost, yield, quality, and production rate changes. Each processor must alter his mathematical model to fit the equipment-benefit sensitivity chart to his desires.

If the processor chooses to go beyond a cost analysis, he can plan, predict and control profits by using the RPM model shown in Chapter 7. In the RPM model analysis, the computer results in Figure 100 show the ideal way to process shrimp is to process raw shrimp after adequate time and to sell the shrimp meat immediately after packaging. However, in reality, the fluctuation of raw shrimp supply, shrimp meat demand, price speculation, and the general economy affect the decision of management. The result of the RPM model should be used as a goal. In his study, Willie Mercer conducted a product mix study with linear

programming portrayal in RPM models (14). The product mix study was concerned with the addition of two seafood types, shrimp and crab, to the processing of beans and corn in a food processing plant. A product mix strategy, what and how much to process, and an optimal profit figure were known as a result of the study (8).

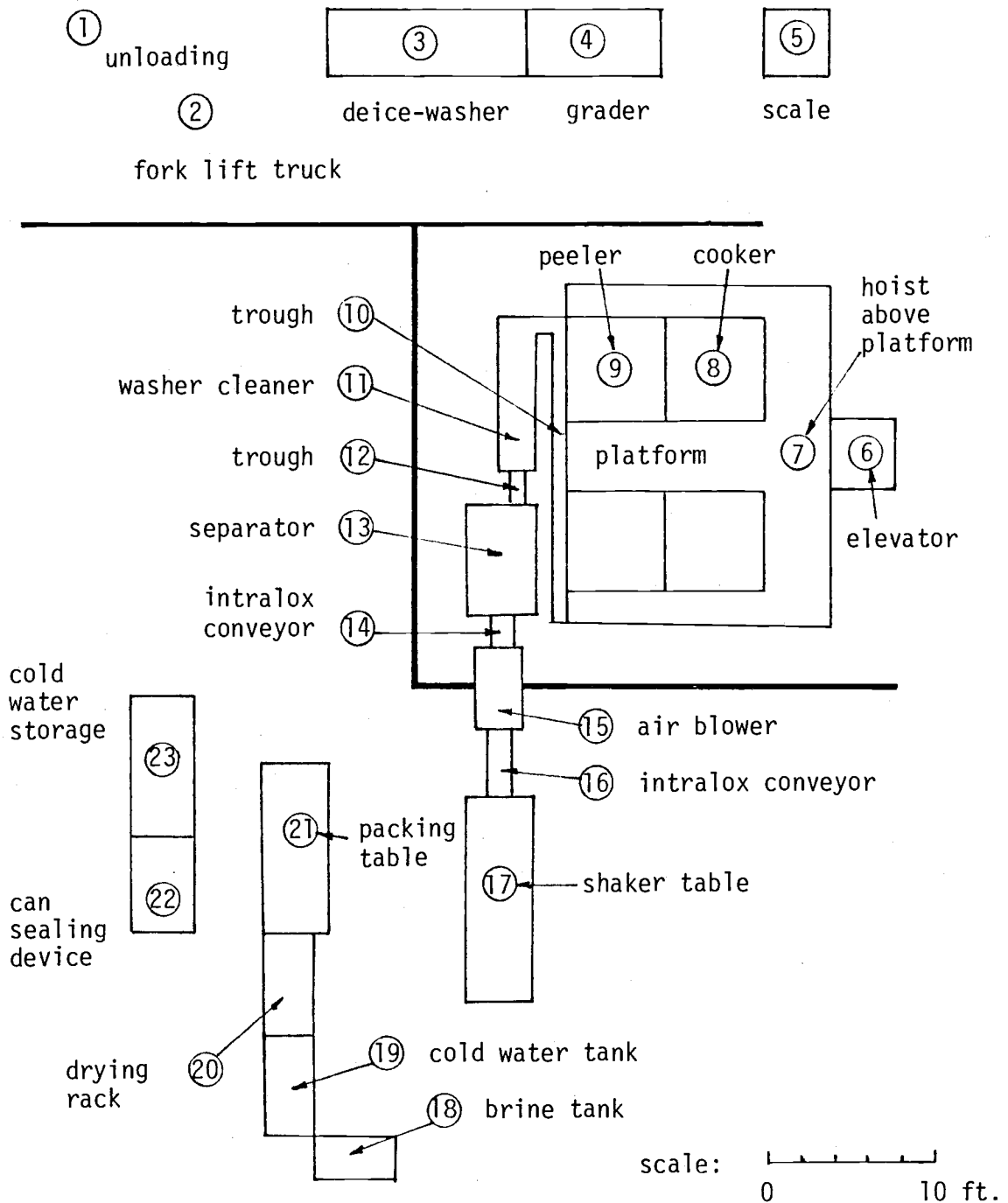


Figure 104. A layout model showing the maximum of equipment used by a shrimp processor.

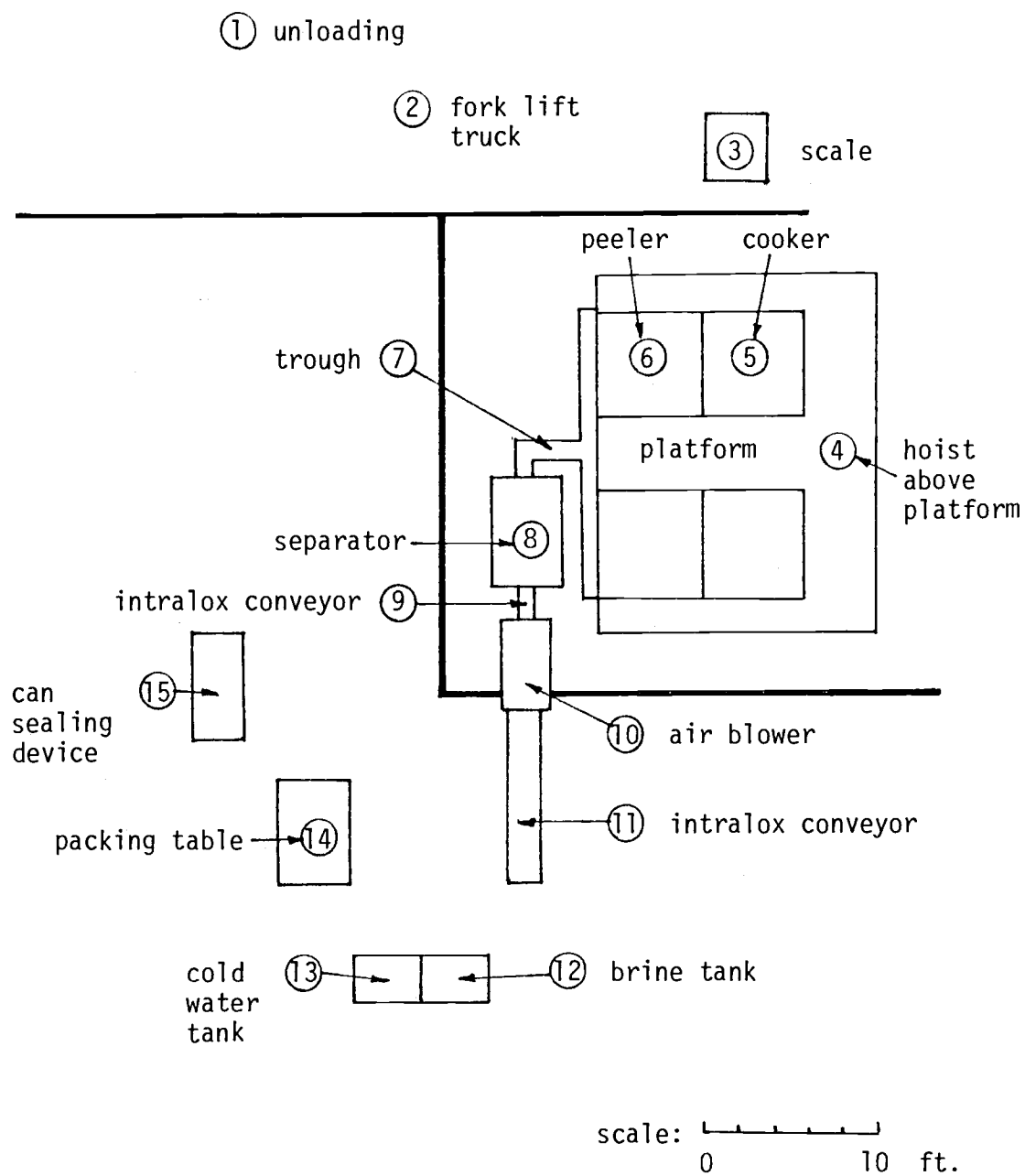


Figure 105. A layout model with the minimum of equipment used by a shrimp processor.

IX. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Conclusions

Oregon shrimp processing shrimp industry reduced almost 70% of its processing cost as mechanical peeling gradually replaced manual picking of shrimp. Now all processing plants use mechanical peelers and separators. Few plants operate with deice-washer, shrimp grader, washer-cleaner, air-blower, and food pump. This study describes the results of a preliminary analyses of the existing equipment. The lease of mechanical peeler based on current annual production rates is economically desirable. Among the equipment, deice-washer, shrimp grader, and air-blower seem to have great benefit potential and reasonable payback period when shrimp volumes are high. In all cases, the actual benefit of equipment depend upon the annual processing volume of the processor, raw shrimp price, quality and yield goals, and the shrimp meat price. Processors should consider IQF systems seriously in their long range planning. Although the initial cost of IQF systems are high, the benefit potential is also high but marketing test are still in the experimental stage.

For firmer cost-benefit estimates each processor should fit his basic costs yields, prices, and other pertinent data to the basic decision tables described in Chapter Six. If the values fall to the right of the decision-table the equipment is economically feasible. However, before any decision is made, other causal factors should be considered. To avoid omitting such factors, processors should review

their cause-and-effect diagram.

Cause-and-effect diagrams, unit time flow process charts, statistical control charts, and RPM models are introduced to processors. All these management tools can be used for production planning, analysis, and control purposes. As processors gain more experience in their use, these tools will provide means to monitor the performance of the process. In addition, improved training will eventually be reflected in higher profit which can be directly identified in the RPM charts.

It is hoped that this study will promote the productivity of the Oregon shrimp processing industry.

Recommendation For Future Research

Follow-up studies should be made to see how processors respond.

Areas for further research are:

1. Continue the net design for escapement of small immature shrimp and small fish in harvesting of shrimp.
2. Develop an efficient and easy to administrate sampling method for determining the size proportion of raw shrimp. Develop graphical tools like curves, charts, and tables to minimize calculations.
3. Study the relationship between shrimp size and recovery of shrimp meat. Regression analysis and variance analysis may be used.
4. Develop an efficient and easy way to perform bacteria count test on raw shrimp at the dock. This method should be able to be used by processors to control their incoming shrimp quality.
5. Study the marketing and packaging of IQF shrimp meat. This would involve the study of supply and demand relationship.
6. Study the forecasting of raw shrimp supply, raw shrimp price, shrimp meat demand, and shrimp meat price. This study would enable the processors to plan better.
7. Presently, inspection is the most labor consuming activity. Further mechanization of shrimp meat inspection would reduce labor cost.
8. Study the feasibility of importing raw shrimp from foreign

countries. During the off-season period processors may import shrimp to utilize their processing facilities.

9. Study the feasibility of shrimp farming in Oregon. This would allow better control of shrimp supply to the processors.

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APPENDIX

APPENDIX A

SHRIMP PROCESSING QUESTIONNAIRE

1. How do you get your shrimp supply? Is the source reliable?
2. How much do you pay for your shrimp?
3. What factors affect the price of raw shrimp?
4. How long is the shrimp processing season?
5. How long has this plant been processing shrimp?
6. Is shrimp processing a major portion of your business? What other seafood you process?
7. About how many shrimp do you process each year in the last five years?
8. What kinds of shrimp product do you produce? In what forms?
9. How much do you get from your product?
10. What kinds of customer do you have?
11. What factors affect the price of your shrimp product?

12. What major factors do you think influence the demand of shrimp product?
13. Do you satisfy with your shrimp processing operation?
14. What do you concern about your shrimp processing operation?
15. Please describe your shrimp processing procedure.