AN ABSTRACT OF THE THESIS OF

KEE-CHAI CHONG for the degree of DOCTOR OF PHILOSOPHY

in AGRICULTURAL AND RESOURCE ECONOMICS presented on June 9, 1978

Title: RESOURCE COMBINATION AND PRODUCT-MIX IN OREGON SEAFOOD PROCESSING

Abstract approved:
Frederick J. Smith

This study is concerned with the economics of seafood processing. It is hypothesized that seafood processing plant performance prevalent in Oregon is significantly less than that which is feasible within the existing economic and institutional environment. However, to determine the relationship between performance and supply, part of the analysis assumes that supply of fish and shellfish is unconstrained. Also, it is hypothesized that resource combination, product-mix and input-output ratios within existing processing plants are the primary factors affecting seafood processing plant performance.

These hypotheses are examined by modeling a representative plant, observing expected net revenue levels and deviations with existing or status quo resource combination, product-mix and input-output ratios, and comparing these expected net revenue levels and deviations with those generated by the linear programming model with optimum resource combination, product-mix and input-output ratios. In this study, the optimum product-mix is that which maximizes expected net revenues within a linear programming framework.

The model delineates optimum resource input-product output decisions under a given economic and institutional environment and two sets of technological conditions. Specifically, the model identifies the types and quantity of resource inputs that are procured and the kinds of product output by species and product-forms, and quantity of the products that are processed to maximize expected net revenues to the plant's fixed facilities. The optimum solutions as determined by the model call for increased procurement of salmon, shrimp, Dungeness crab, ling cod and petrale sole, and the elimination of all the other remaining species, some of which are currently being processed. Therefore, the model indicates that if more of Chinook salmon, petrale sole, ling cod, shrimp and green Dungeness crab are available, then the conditions are met to provide the basis for improved performance.

The expected net revenues decrease significantly when the excluded species are forced into the optimum solutions. Under unconstrained procurement of fish, the plant's model determined expected net revenues were on the average 90 percent greater with optimum resource combination and product-mix than net revenues associated with existing resource combination and product-mix, both with existing technology. On the basis of one linear programming solution covering four months operation and under constrained procurement of fish, model determined net revenues are two percent greater with existing resource combination and product-mix, and new technology than net revenues with existing resource combination and product-mix, and existing technology. Under unconstrained procurement of fish new technology contributes a 13% increase to expected net revenues.

Therefore, given present profitability levels of seafood processing plants and the existing fisher-consumer seafood price spreads, these percentages represent a significant improvement in seafood processing performance. The present performance level of the seafood processing plant is thus found to be significantly less than what is feasible within existing conditions. Improved performance, however, requires greater availability of fish. Greater availability of fish would provide some of the conditions needed for improved resource combination, product-mix and the introduction of new technology within the linear programming framework. Greater availability of fish would utilize more fully the present excess capacity. Improved resource combination, product-mix and new technology would improve plant performance but only under unconstrained procurement of fish does new technology contribute more to improved performance than present or existing technology. However, under present technology and unconstrained procurement of fish, improved resource combination and product-mix contributes more to performance than existing resource combination and product-mix. Further, under unconstrained procurement of fish, improved resource combination and product-mix contributes more to performance than new technology.

Increased availability of fish, however, requires important changes in the existing raw materials and final products markets. The present arrangement in supplying fish to processors is not expected to encourage the landings of more fish. Further research is indicated to determine how greater quantities of fish can be made available.

Resource Combination and Product-Mix
in Oregon Seafood Processing

by

Kee-Chai Chong

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Completed June 9, 1978

Commencement June 1979

APPROVED:

Professor of Agricultural and Resource Economics

in charge of major

Head of Department of Agricultural and Resource Economics

Dean of Graduate School

Date thesis is presented June 9, 1978

Typed by Clover Redfern for Kee-Chai Chong

ACKNOWLEDGEMENTS

I am thankful to the many fishers, seafood processors, and employees of Federal and State Fisheries Agencies for their time and contribution in the preparation of this thesis. Special thanks must also go to:

Dr. Frederick J. Smith, an excellent major professor, for his professional supervision and personal counsel throughout the duration of this study.

Dr. Richard S. Johnston who served as major professor while Dr. F. J. Smith was on sabbatical leave, for his encouragement and insights.

Dr. A. Gene Nelson for his constructive comments regarding linear programming methods and procedures.

Drs. Richard E. Towey and W. Bruce Shepard for their helpful comments and suggestions in the preparation of this thesis.

I am also indebted to my family especially my wife, Li-Foong for their sacrifice and constant encouragement throughout my undergraduate and graduate training.

Last but not least, the reception I received both on-and off-campus throughout my education in the United States has been very warm. For this I am grateful.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

RESOURCE COMBINATION AND PRODUCT-MIX IN OREGON SEAFOOD PROCESSING

I. INTRODUCTION

Background Information and Justification

Fish[1/] are a valuable resource to Oregon. The 1976 commercial landings of finfish and shellfish in Oregon were about 98.9 million pounds valued at $48.7 million at the ex-vessel level (U.S. Dept. Comm., 1977). A 1975 statewide angler survey showed that anglers caught about 14.9 million fish. They spent a total of 5.25 million recreation-days in pursuit of their sport (Oregon Dept. Fish Wild., 1976).

Since Sea Grant was formalized in 1968, many aspects of the United States' fishing industry have been scrutinized in detail with a view toward improving the industry performance. With the enactment of the U.S. extended fisheries jurisdiction there is added impetus for improving the performance of the industry. This study represents an effort to suggest opportunities for improving industry performance,[2/]

[1/] Fish is used to include finfish and shellfish. Further, fisher/fishers will be used to refer to fisherman/fishermen in this study (U.S. Dept. Labor, 1976).

[2/] This study is part of a larger project on "Seafood Market Structure and Performance." It is hoped that the present study would provide information with a view toward improving the performance of the Oregon seafood processing and marketing sector, and thereby specifically within the fresh/frozen seafood processing sector.

The Oregon fishing industry is basically a seafood industry. Very few fish are used for non-human consumption.[3/] Most of Oregon-produced seafood goes to market in a fresh or frozen form. This study is concerned only with the fresh and frozen products.[4/]

Much of the fishery employment in Oregon is on a part-time basis. This is true not only for the fishing sector but also true for the processing sector. The majority of seafood processors or entrepreneurs in Oregon are located along the coast where fish are landed, a location consideration dictated by the nature of the industry. The typical Oregon seafood processing plant[5/] is situated on a bay or estuary.

improve the economic welfare of producers (fishers, processors, wholesalers, retailers) and consumers. In short, it hopes to contribute to improved performance of the seafood processing sector, thus enabling it to become economically more viable and to prosper along with the other food processing sectors.

[3/] In general, about one percent of commercial fish landings is used for mink food.

[4/] Oregon canned seafoods comprise about 26 percent of the total commercial landings in 1975 (John Bishop, personal communication). Although the figure is significant, the reader is reminded that there are only two plants which can (canned products) significant quantities of fish and shellfish. These two plants represent about nine percent of the total number of plants in the canned seafood sector. According to Bishop, canning is declining in importance in Oregon.

[5/] A seafood processing firm may own more than one plant in which case it is a multi-plant firm whereas some firms may be single-plant firms. In this study, the focus of the analysis is on a plant. Plant and firm are used interchangeably.

It processes bottomfish (sometimes called groundfish or wetfish) such as various species of flatfish (e.g., petrale sole, Eopsetta jordani, English sole, Parophrys vetulus, and Dover sole, Microstomus pacificus), various species of rockfish (e.g., Pacific Ocean perch, Sebastes alutus, and canary rockfish, Sebastes pinniger), and various species of roundfish (e.g., ling cod, Ophiodon elongatus, Pacific (true) cod, Gadus macrocephalus, and sablefish or black cod, Anoplopoma fimbria). Various species of crab (e.g., Dungeness crab, Cancer magister, king crab,[6/] Paralithodes camtschatica, and snow crab,[7/] Chionoecetes species), and shrimp (e.g., pink shrimp, Pandalus jordani) may also be processed. Salmon (e.g., Chinook salmon, Oncorhynchus tshawytscha, coho salmon, O. kisutch, and chum salmon, O. keta) is also handled[8/] at the typical Oregon seafood processing plant.

The Industry

The overall economic picture of the U.S. fishing industry is generally one of high production costs, overinvestment in boats and

---

[6, 7/] King crab and snow crab are not harvested locally but are shipped in from Alaska and Washington for further processing.

[8/] Technically speaking, salmon is not processed as there is no change in product form, only the viscera are removed (most while at sea). The processor merely washes and packs them in ice. (Sometimes he removes the salmon heads before shipping.)

gear (Crutchfield, 1961, 1969; O'Rourke, 1971; U.S. Department of Commerce, 1975), absence of growth in fish landings (U.S. Department of Commerce, 1975), many old and inadequate boats, and hitherto low government support relative to other nations (U.S. Department of Commerce, 1975). The industry is in a cost-price squeeze which is directly or indirectly attributable to intense foreign fishing pressures off the U.S. coast,[9/] (U.S. Department of Commerce, 1975) and increased foreign competition from imports of fish blocks, slabs and fillets,[10/] shrimp and other miscellaneous fishery products.[11/]

[9/] However, the Fishery Conservation and Management Act of 1976 (P. L. 94-265), which became law on April 13, 1976 provides for the phased scaling down of foreign fishing activities off the U.S. coast. This transition period would allow the U.S. fishing industry to eventually develop into a more competitive industry, thus making future protective legislation unnecessary.

[10/] In this study the following description of product-forms is used: fillets are the sides of the fish cut lengthwise separating the flesh from the skeletons. They can be skin-on or skin-off fillets. A limited quantity of fish is sold as dressed whole fish. In this study we are not concerned with fish blocks and slabs.

[11/] Imports accounted for about 63 percent of the total fish products consumed in the U.S. (U.S. Dept. of Comm., 1977). The waters off the U.S. coast (within 200 miles) are potentially capable of yielding at least 18 billion pounds of fish annually on a sustained basis for food and recreation. Foreign fishing accounted for about one-half of the fish caught within this zone and most of the foreign catch ultimately finds its way back into the U.S. markets. Further, some of the imported fish are from U.S.-owned subsidiaries in foreign countries such as Canada. Thus, a major objective of the National Fisheries Plan is to encourage increased domestic production and reduce the dependence of the U.S. consumers on seafood from abroad.

The seafood processing industry is also characterized by small enterprises. According to the National Plan for Marine Fisheries, about 42 percent of the processing plants in the United States have annual sales of less than $100,000; only 17 percent have sales over $1 million and only 2.4 percent or 43 plants have sales of over $10 million.

The situation facing Oregon is no different from that of the national picture described above. There were approximately 62 seafood processing establishments (canning establishments and retail processing outlets included) in Oregon in 1975 (U.S. Department of Commerce, 1977). Out of about 17 ports that handle commercial fish landings, five ports (Astoria, including Columbia River, Coos Bay, Newport, Tillamook Bay and Brookings) handle the majority of fish landed in Oregon. Table 1 shows that these ports landed over 90 percent of Oregon's catch.

A wide range of economic problems confronts the industry. This is more so presently than in the past. For example, seafood processing is an industry which is dependent on primary raw materials that are highly seasonal and variable in supply. Furthermore, in recent years, the seafood processor has had to contend with large variations in size and quality of fish as well as decreasing size of some species. A New England study found that a decrease in the mean size of flounder and thus a corresponding decrease in average percent fillet yield, increased the average processing costs (Gates and Norton, 1974). Other problems faced by a typical Oregon seafood processor include the difficulty in obtaining and retaining skilled filleters, crab-shakers-pickers and shrimp pre-pickers. There is also a lack of complementarity in the use of equipment and facilities within the plant. Only a limited amount of equipment is shared among the different processing activities.

Table 1. Quantity of fish landed and number of processing plants in Oregon ports for 1976.

Port	Quantity Landed (Pounds)	Number of Processing Plants*
Astoria	37,010,989	11
Coos Bay (Charleston)	17,979,848	5
Newport	16,613,614	5
Tillamook Bay	5,000,690	3
Columbia River	4,509,835	(included in Astoria)
Brookings	4,062,926	2
Port Orford	3,133,256	1
Winchester Bay	2,881,671	1
Pacific City	840,547	-
Bandon	637,003	1
Depoe Bay	537,338	1
Gold Beach	260,070	-
Florence	180,614	-
Waldport	42,337	-
Nehalem Bay	2,939	-
Netarts Bay	368	-
Siletz Bay	100	-
Total	93,694,145	30

Source: Oregon Dept. Fish Wildlife, 1976 and survey conducted by the writer.

*Does not include retail establishments that process fish. Plants in ports within the vicinity of major ports are combined together (e.g., plants in Portland, Hammond, Seaside, Warrenton are included in Astoria).

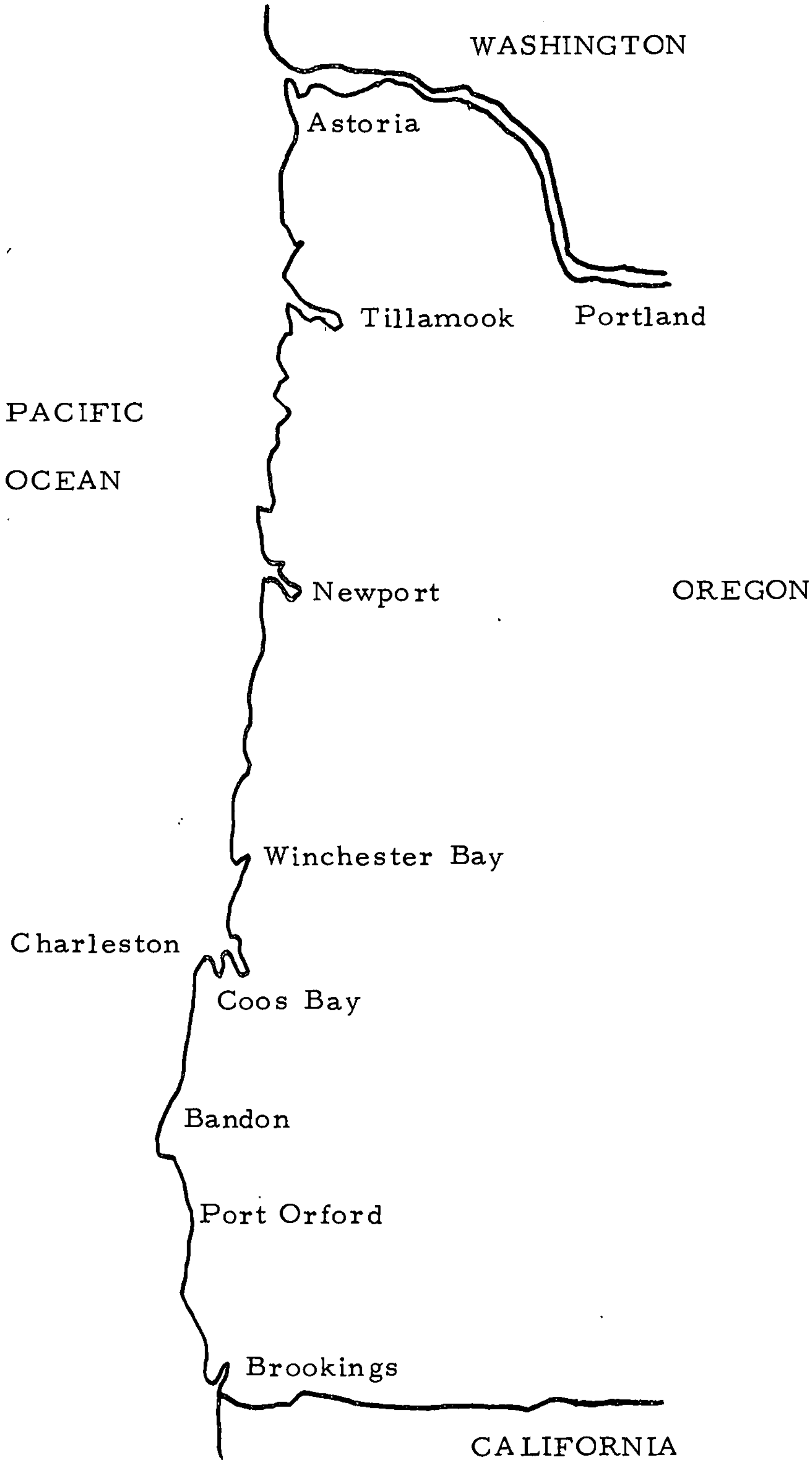

Figure 1. Coastline and fishing ports of Oregon. Source: Oregon Dept. Fish Wildlife.

With a few exceptions the technology adopted is "antiquated."[12/] According to one industry spokesperson,[13/] most of the seafood processing plants along the Oregon coast are in a state of disrepair, the processors having moved into buildings/structures that were not necessarily set up for seafood processing. Plant-layout is not one that is necessarily the most efficient. "Making the most out" of the available floor space appears to be the overriding criterion. Equipment are fitted to the available space. According to Peterson (1974), there is less than adequate plant sanitation. Sanitation requirements are partly alleviated by processing the different species in isolated areas, thus ensuring that the products do not flow through the same production lines. Contamination is avoided. At any rate, the actual processing requires separate set-up and involves different pieces of equipment.

[12/] An industrial engineering study at Oregon State University found that the facilities and equipment are old and inadequate for seafood processing, besides the work-place design and processing practices are poor (Peterson, 1974). O'Rourke (1971) also found that there is a tendency to postpone indefinitely replacement of outmoded equipment and other facilities.

[13/] Seminar on seafood processing given by Mr. Wayne Johnson, New England Fish Company at the Oregon State University Marine Science Center, Newport in 1977.

Fishing

Unlike land-based production activities fishing lacks the "visual advantage" the former enjoys because fish live in water. The degree of choice and selectivity of species sought are made considerably more complicated by the fact that fish live in such viscous-like medium. Modern technology has been applied in harvesting. But harvesting or capturing fish species selectively is still new to the fishery. Some gear such as the long line is to a greater or lesser extent species-specific.

Species Composition

To a large extent fishing is still non-discriminatory.[14/] Otter trawl fishing off the Oregon coast is an example of non-discriminatory fishing. Otter trawl fishers fish on mixed stocks of different species of bottomfish and others. As such it is difficult to determine the species composition of the fish landed in the state.

Trawl gear can be rigged to a limited extent so that it can be species-specific.[15/] Also, there is a growing interest in developing

---

[14/] Only in a few exceptions is fishing discriminatory in the sense that specific species are captured (e.g., long-line, troll line).

[15/] Presently some species caught are not landed because they do not have a ready market. These "discards", as they are called, are thrown over-board. Many factors influence the species composition (e.g., time of year, area fished, depth fished, speed of tow).

species-specific gear. Such gear technology is still at its early stage of development. Fishers do not foresee such gear developed in the near future (Interview, 1977).

Furthermore, before trawlers leave for the fishing grounds they check with the seafood processors they are supplying as to what species are required. Once at sea the seafood processors are in radio-contact with the fishers. At this time the processors can revise their needs. According to seafood processors one of the most important responsibilities of a manager is his ability to procure the main factor of production: fish and shellfish. The manager establishes a close rapport with the fishers who supply him with fish.

On board the trawler a standard practice is to separate the catch landed into three categories: flatfish, roundfish and rockfish. Sometimes, the flatfish are further separated according to species: Dover, English and petrale sole. The fishers are penalized by the processors if they do not separate the fish when they deliver the catch. This is because the filleters have to sort them out when they fillet them resulting in delays on the fillet lines and a decrease in the filleting rates.

Marketing

In this study we are mainly concerned with salmon, Dungeness crab,[16/] shrimp and bottomfish. With extended fisheries jurisdiction

[16/] Some partially processed Alaskan king and snow crab are further processed in Oregon.

supplemented in part with more refined management and enhancement programs (e.g., hatchery programs), some increase in landings of these fish species is expected (Noetzel and Vondruska, 1975).

A limiting factor for Oregon seafood processors would be their competitive positions vis-a-vis seafood processor-suppliers in other regions to service the local as well as the national markets and the extent of the national market for these fishery products.

Bottomfish generally have lower dockside price per pound when compared to salmon, tuna, shrimp and crab. Although bottomfish constitute the largest quantity of fish landings in Oregon, it is fifth to salmon, tuna, shrimp and crab in value as can be seen from Table 2.

Table 2. Quantity and estimated value (ex-vessel) of Oregon's fish landings in 1976.

	Landings in 1976			
Species	Quantity	Percent	Value	Percent
Bottomfish	26,799,821	28.6	$ 3,751,974	9.3
Shrimp	25,456,037	27.2	5,091,207	12.6
Tuna	17,349,410	18.5	5,887,213	14.5
Salmon	14,604,164	15.6	20,069,398	49.5
Crabs	8,134,065	8.7	4,880,439	12.0
Others	1,350,648	1.4	843,754	2.1
Total	93,694,145	100.0	40,523,985	100.0

Source: Oregon Department of Fish and Wildlife.

The bulk of Oregon bottomfish is marketed in the form of fresh fillets. Current markets are in California--primarily Los Angeles and San Francisco; Washington; Oregon and Canada[17/] (Environment Canada, 1975). However, there is a growing trend toward air shipment of fresh and frozen bottomfish fillets to Midwestern and Eastern United States and European markets as competition from Eastern U.S. and foreign suppliers declines (see footnote No. 17). Evidence indicates that these markets continue to grow. In addition prices for the more important species of bottomfish continue to rise at a relatively steady rate. These trends are further reinforced by the observation that the eating-quality of bottomfish and thus consumer acceptance are slowly getting established among more and more people in this country. According to Crutchfield (1967), the demand for bottomfish fillets and products is quite price elastic. Past expansion in the quantity demanded for bottomfish was met in large part by imports (e.g., supplied by U.S. subsidiaries in Canada; Newton, 1972).

Increasing per capita income, growing population and expanding geographical markets have resulted in an increased demand for salmon, especially fresh salmon. Current out-of-state markets for salmon are in California, U.S. Midwest, Eastern United States and in Europe.

Among shellfish, Dungeness crab and shrimp are relatively popular seafoods and the quantity demanded continues to rise.

[17/] Interviews with seafood processors.

However, the Dungeness crab fishery is not expected to be able to sustain increased production (Smith, 1971). The shrimp fishery may be able to support a moderate increase in harvest through the discovery of shrimp grounds.

The price levels for these seafood items are expected to continue their upward trends, arising principally from growing population level, rising per capita income and affluence-related wants. The growing consumer acceptance of seafood, in particular frozen seafood and conveniently packed seafood items would boost consumption.

The expanding recreational sport and/or the "pseudo-subsistence" fishery will affect the commercial supply of and demand for seafood. Salmon numbers taken by these user groups have been increasing and certainly will continue to increase until congestion in the waterways diminishes the pleasure derived from such activities. The same may be said for bottomfish fishing and crabbing with only minor qualifications.

The future expansion of Oregon fisheries depends in part upon improved performance in seafood processing and greater utilization of heretofore lightly exploited stocks of marketable bottomfish available in local waters.

Seafood Processing

Disassembly/assembly processes of raw materials and partially processed products are carried out at definite stages in the production line. Rates of product flows along the production line are controlled by the rates at which inputs are fed into the line. Within a production line each stage with its activity or process (e.g., filleting) has its own production function. This stage-production function is a component of an overall production function along the production line in the plant. For example at the filleting stage along the production line for processing bottomfish, filleting labor, services of the filleting knife, whole fish, are "transformed" into fillets. The processing of each of these products occurs within different (and sometimes over-lapping) seasons. A brief description of the different types of seafood processing is given below.

Bottomfish Processing

Processing bottomfish involves the following operations:

Unloading fish from trawlers → Temporary storage prior to filleting → Washing in rotary washer → Distributing fish to filleters → Filleting → Weighing → Packaging.

Concern for the overall engineering efficiency of Oregon seafood processing plants led the Industrial Engineering Department at Oregon State University to conduct several studies aimed at improving existing engineering performance of these plants and to suggest new technologies. Specifically, the Department investigated the design of the immediately feasible system and the ultimately feasible system (Peterson, 1974). The immediately feasible system for bottomfish processing could be implemented without extensive changes in equipment. The benefits include reduced costs, better product quality and higher fillet yields. The suggested improvements include improved fish storage on-board the vessel, containerized unloading and holding system which will reduce processing time, improved manual fillet method, improved workplace design, continuous pre-washing and brining, automatic packaging and improved manual packaging. The ultimately feasible system for bottomfish processing involves the adaptation of the existing system and the development of new systems.

Such adaptation requires the introduction of mechanization. The ultimately feasible system consists of holding the fish in carbon-dioxide saturated refrigerated brine system both on-board the vessel and in the plant and mechanized filleting. Peterson, however, cautioned that the above "recommendations need to be evaluated by each processor in light of his own operations to determine the processing and quality benefits he may receive."

Crab Processing

In addition to Dungeness crab, king crab and snow crab are (further) processed in Oregon. Crab processing involves:

Unloading from boat → Temporary storage → Sorting, debacking and butchering → Cooking/Thawing → Distributing to pickers → Shaking and picking → Weighing → Brining → Dewatering and freshening → Packaging.

As it is for bottomfish processing, the immediately feasible system for Dungeness crab processing involves the development of a butchering machine, work design of a new crab shucking method and using a shaker table to combine the freshening, inspection, dewatering and can-filling operations (Adams, 1971). The benefits of this immediately feasible system are reduced labor costs, improved product quality and processing efficiency.

The ultimately feasible system requires significant processing changes which depart from traditional crab processing. The suggested changes are live crab holding tanks, crab meat centrifuge, meat forming machine and cryogenic freezing system.

Shrimp Processing

The recent introduction of the shrimp peeling machine which allows small shrimp to be processed without undue labor costs has encouraged its exploitation. These mechanical peelers have been in existence for about eight years. Presently, no shrimp is hand-picked although pre-picking still depends on manual labor. Shrimp processing involves the following stages:

> Unloading from shrimp trawler → De-icing → Temporary storage → Cooking → Peeling → Separating → Pre-picking → Brining → Dewatering → Packaging → Sealing.

A study by Cheung (1976) investigated the feasible and practical solutions to improve the efficiency of the Oregon shrimp processing industry. His study dealt with the economic analysis of equipment, facility layout, quality control, processing procedure and processing costs. The cumulative benefits of all the different suggested pieces of equipment were not determined. Some benefits of the shrimp peeling machine are reduction of material handling and thus bacteria exposure time, better product quality, higher product rate and yield, reduced labor costs and improved processing efficiency.

Economic and Legal Environment

The fishing industry (fishing, processing, distributing), especially the fresh and frozen seafood industry, does not fit conditions of pure competition: that is, perfect knowledge, large numbers of sellers and buyers, free entry and exit of industry participants, homogenous products, inability of sellers and buyers to influence prices (Ferguson, 1966; Stigler, 1952; Bilas, 1967).

There is, however, considerable homogeneity in terms of methods of operations. Although no two plants are identical, they do handle a fairly uniform product-mix and own similar pieces of equipment. Further, there is some uniformity in size of operations. The industry is also characterized by varying degree of horizontal integration (e.g., owning another plant and/or buying station in another port) and vertical integration (e.g., owning retail outlets).

There is also a certain degree of interaction among firms in the individual firm's management decision-making process in the sense that aggressive pricing decisions are not undertaken. The anxiety or concern for (possible) retaliation by his competitors especially in terms of aggressive procurement of fish is a conscious consideration in their decision process. This interaction, though, is on a tacit level.

Of 62 plants in Oregon which process seafoods (including retail outlets which do some processing, and canneries), 28 plants process fresh and/or frozen products. The Oregon seafood industry can be described as being characterized by a few relatively large firms and a fringe of smaller firms. In 1973 the largest four[18/] plants processed

[18/] Plants which processed fresh and/or frozen products: bottomfish, crab, shrimp and salmon.

about 59 percent of the total fish landed in Oregon. In addition, most of the larger firms have a branch or subsidiary processing plant or buying station in the smaller ports with their main plant/office in the larger metropolitan areas. While there is some tacit interaction among firms on certain levels of decision-making affecting them, there is, to a certain extent, considerable independence of actions among these entrepreneurs (U.S. Department of Commerce, 1975).

These 62 entrepreneurs employ about 2,215 persons per season (U.S. Department of Commerce, 1977) on average. Some of these entrepreneurs are confronted with labor unions in the labor markets. Wage rates and working conditions are negotiated and renegotiated periodically between the management of the labor unions and the seafood processing plants. Seafood processing plants also conduct business with other enterprises: firms which supply materials to them--packaging materials (tin cans and plastic bags), equipment and equipment parts, salt, utilities (electricity and water). Transportation/trucking services are purchased from other firms if they do not already have their own trucking fleet. Credit is obtained from various sources to finance their plant operations.

Supplying these processing plants are about 5,000 commercial fishers who are mostly owner-operators. Of these, about 23 percent are full-time fishers and the rest fish on a part-time basis (U.S. Department of Commerce, 1976). They market their catches at various ports, primarily to processors or in limited instances directly to distributors and retailers. Landings of bottomfish on the West Coast are concentrated in ports in Oregon and Washington. However, it is not uncommon that Oregon landings are shipped to California or Washington for processing. These fish are usually purchased through local buying stations.

To a limited extent the fishers are organized into some type of fishers' associations. An example is the All Coast Fishermen's Marketing Association in Charleston, Oregon and the Fishermen's Marketing Association in Eureka, California.[19/] These fishers' associations bargain with the seafood processors for price usually before the start of the fishing season. For example, minimum prices allowable for bottomfish are published by the Fishermen's Marketing Association, Eureka, California under a Market Order Agreement with the processors. Recently, this fishers' group went on strike to seek a 15 percent increase in the price they receive for fish delivered to the processors (Oregonian, October 20, 1977). The 250 fisher-members operate 70 trawlers and they account for about 40 percent of the bottomfish landed on the West Coast (Oregonian, October 20, 1977).

The relative competitive positions among the seafood processing firms and vis-a-vis the firms with which they do business, and hence

---

[19/] While the former does not bargain on bottomfish, the latter solely represents bottomfish fishers.

the relative market power of each which stems, in part, from their respective productive efficiency, defines the market structure, conduct patterns and performance of the industry.

In the legal environment, the seafood processing firms have to cope with diverse federal, state and local laws and regulations. Since most seafood processors distribute their products nationwide as well as in a number of different countries, they come under the interstate commerce statutes. One such regulation concerns plant and product sanitation which processors have to meet. The presence of government agencies which regulate the seafood industry is to ensure that seafood processors are operating their businesses consistent with consumer interests and the law. For instance, the anti-trust provisions limit the extent or legality/illegality of concerted industry activities which are detrimental to free enterprise.

A large number of fishers are gradually organizing themselves into some type of fishers' associations to obtain greater leverage in their transactions with the firms with whom they do business, notably the strong independent seafood processors. The strike by the Fishermen's Marketing Association members was a case in point. Seafood processors have also been known to be organized,[20/] in their business

---

[20/] Interviews with fishers. Some processing firms are organized as corporations.

transactions with fishers. However, this "bigness" of fishers' associations in terms of concentrated economic power is not inconsistent with the performance it gives rise to under conditions of atomistic competition because the "concentration" is in the hands of a large number of fisher members.

The Problem

While extensive research on the economics of cattle, hog, turkey and poultry processing has been reported, very little information is available on the economics of seafood processing and seafood processing management. A review of the literature on the economics of seafood processing is provided in Chapter IV.

Throughout the industry there is and has been a concern and drive for greater efficiency and improved performance. However, this concern for improved performance has been carried out with very little "outside" economic research. Also, research using the "scientific method" is found lacking on the management and decision-making process affecting performance, resource combination and product-mix in seafood processing plants. In particular, the potential benefits of present day electronic computer capabilities as a management tool have not been felt in the seafood processing sector in helping entrepreneurs make sound decisions based on informed judgement. Similar research in cattle, hog, turkey and poultry processing has demonstrated that it has benefited these industries by providing timely information for decision-making (Snyder, et al., 1963; Belden, 1972).

Maximizing expected net revenues remains one of the fundamental objectives of businesses. This is not to say that other objectives are not important. They are, however, related to the profit motive.[21/] The seafood processor given his plant-and/or entrepreneur-imposed constraints such as the plant's fixed resources (external and internal),[22/] also attempts to maximize his expected net revenues in the long run. One way of accomplishing this is by optimizing his plant resource combination and product-mix, that is, economizing and adjusting his plant production. It is assumed that improved resource combination and product-mix would contribute significantly to improved plant performance.

Smith (1971) estimates an average return to total assets for 11 Pacific Northwest seafood processing firms to be 6.04 percent. This figure is lower than the national average of 8.65 percent for manufacturing firms calculated on the same basis. Further, it is even

---

[21/] Entrepreneurial objectives are discussed elsewhere.

[22/] By external it is meant that the constraints are not under the control of the entrepreneur (e.g., market conditions) while internal is taken to mean that the constraints are under his control or at least he can exercise some degree of control in his decision-making process (e.g., hiring of employees).

lower than the percent return to total assets for a sample of 139 meat packing firms (8 percent) and less than the current market interest for this type of asset. Seafood processing appears to have undetected cost reductions and unrealized revenues and these represent opportunities to cut costs and increase revenues which are foregone. The costs stemming from a lack of a more efficient utilization of available resources often go undetected using present ad hoc or piecemeal decision-making process. It may be that the entrepreneur's current production system is working well for him but a closer examination of the entire existing production system may reveal certain areas where further improvements in resource utilization may be obtained.

Further, the fresh seafood industry, especially the processing sector, typified by short and intermittent (both natural and regulated) fishing and hence processing seasons, lacks a <u>constant</u> output month after month. A typical Oregon seafood processor faces a variety of problems at the plant level on which decisions are needed. He has to make decisions on: procurement of required materials and fish (due principally to variations in supply because of the vagaries of Nature), prices to pay for them, plant production by types of species and product forms (e.g., fillets, Rex-style fish,[23/] skin-on fillets), sale of his finished products (crabmeat in five-pound cans or in 15-pound long

---

[23/] Rex-style fish are dressed whole fish with the viscera and head removed. Also, Rex sole are too small to fillet.

johns,[24] whole or shell crab,[25] shrimp meat and fish fillets), prices to charge, use of overtime labor during the peak of the season, timing of production and utilization of his fixed plant facilities.

Statement of the Problem

Consumers often ask why is it that it costs more to get food from the sea to the consumer than food from land-based activities. The table below provides a quick comparison of the cost of marketing differences between seafood and redmeat. Preliminary analysis indicates that seafood processing plant performance prevalent in Oregon is significantly less than that which is feasible within the existing economic and institutional environment.

Table 3. Comparison of market spread between food from the sea and land-based food producing activities.

Type	Price Received	Consumer Pays	Spread	Yield	Percent Spread
Hog farmer	$0.41	$1.02	$0.61	71%	149%
Cattle feeder	$0.35	$1.31	$0.96	45%	274%
Crab fisher	$0.60	$4.29	$3.69	24%	615%
Dragger	$0.12	$2.39	$2.27	26%	1892%

Source: F. J. Smith, Unpublished Research, 1975.

[24] Long johns are slender containers measuring 36" x 33" x 5" for freezing king and snow crabmeat (salad pack).

[25] Cooked and usually weighing about 1-1 3/4 pounds.

The greater costs of seafood marketing may be attributed to the characteristics of the product and/or characteristics of processing and marketing. As indicated, seafood processing is a complex process which is carried out in a restrictive institutional and uncertain economic environment. The performance within seafood processing plants may therefore be a major factor contributing to performance of the seafood industry as a whole. A test of performance within seafood processing will provide valuable information regarding performance of the industry as a whole and may contribute to an improvement in that performance. This study is only concerned with the fresh/frozen seafood processing sector. This sector is only one sector among several in the market channel of seafood from the sea to the final consumers. Therefore, the analysis and test of performance of this sector is only part of the whole "sea to consumer" industry.

Objectives of the Study

The overall objective of the study is to determine changes in plant expected net revenues resulting from a change from status quo resource combination and product-mix to a model-determined optimum resource combination and product-mix given demand and resource availability.

Other objectives include:

1. to analyze the resource requirements, cost and returns for various activities involved in seafood processing;
2. to investigate product and product-mix determination involving modeling of decision process over time including data available, alternatives and constraints;
3. to examine the sensitivity of the model (optimum) solutions in terms of prices and resource constraints;
4. to develop an analytical normative computer-based decision-making model to facilitate entrepreneurial decision-making process in utilizing and combining resources for improved decision-making efficiency and thus improved plant performance.

The cooperating plant modeled represents a typical seafood processing plant in Oregon. The plant modeled shares similar characteristics such as number of employees, equipment types, modes of plant operations and similar product-mixes with other Oregon plants. These plants as described constitute at least 48 percent of the industry.[26] Therefore, it is hoped that by studying one plant in detail, the methodology and results obtained may be applicable to Oregon seafood processing plants in general.

---

[26] Based on the author's field survey and personal communication with Professor W. F. Engesser, Department of Industrial Engineering, Oregon State University.

Hypothesis

The hypothesis to be tested is that the seafood processing plant performance prevalent in Oregon is significantly less than that which is feasible within the existing economic and institutional environment based on expected net revenue maximization as an entrepreneurial objective. However, to determine the relationship between performance and supply, part of the analysis assumes that supply of fish and shellfish is unconstrained. This means that a level of optimum plant performance attainable in relation to its existing level of performance, the basis for comparing the existing level and the feasible alternative optimum level of performance will be rigorously tested.

Further, it is hypothesized that resource combination, product-mix and input-output ratios within existing processing plants are primary factors affecting seafood processing plant performance.

In order to test the hypothesis the actual patterns of seafood processing activities are replicated. This is then evaluated and compared to the optimum solutions obtained by the model under (a) existting technology, and (b) currently available (new) technology but which has not been adopted extensively by Oregon plants. This is done by observing expected net revenues with existing or status quo resource combination, product-mix and input-output ratios, and comparing these expected net revenues with those generated by the model with optimum resource combination, product-mix and input-output ratios within a linear programming framework.

II. THEORETICAL BASE

Neoclassical economic theory has traditionally assumed that firms operate with technically efficient production functions.[27/] Since this is not always true in the real world, the determination of technical efficiency is quite important for applied economists (French, 1977). Further, French states that:

> Firms that are technically efficient still may be inefficient in a pricing sense if they fail to combine inputs so that marginal revenue products are equal to factor prices (or marginal factor costs). Firm pricing efficiency, or preferably allocative efficiency, is measured relative to the efficient production function as the ratio of cost with optimal input proportions to cost with the input proportions actually used. The product of the index of technical efficiency and the index of allocative efficiency is a measure of economic efficiency of the firm. A firm that is efficient both technically and allocatively has an economic efficiency index of 1.0. Note that a plant may be both technically and economically efficient for its scale but inefficient with respect to its optimum scale. Optimum scale may also vary with relative factor prices (French, 1977).

Theoretical concepts that help determine economic efficiency will be reviewed. This will provide the conceptual basis for the model used in this study.

[27/] Technically efficient production functions are defined from the engineer's point of view, specifying all technically efficient combinations of inputs and outputs.

Production Economics Theory

Seafood processing is a production line (disassembly/assembly) operation. Various inputs such as fish and shellfish, labor services, energy and equipment services are "combined" to produce outputs. As in any production process, the inputs and/or the services of inputs used in the production of outputs can be expressed as functional relationships. As a result, technological relationships between and among inputs and outputs are important to our understanding of the production system. These inter-relationships are expressed by means of a production function. A production function specifies all technically efficient combinations of inputs and outputs.[28/]

An input is anything the seafood processor acquires for use in his production process; an output is any product he produces for sale, involving what Georgescu-Roegen called a transformation of low entropy into high entropy, that is, into waste,[29/]

[28/] With the production function specified, the objective of production then is to select the most profitable point on the production function.

[29/] See Nicholas Georgescu-Roegen, The Entropy Law and the Economic Process, Cambridge: Harvard University Press, 1971 for details. A reassessment in the disposal and possible use of these wastes derived from the economic process is shaping among resource users (producers and consumers alike). This is in recognition and concern for the environment. For instance, shrimp wastes are used as soil dressings, machines which separate flesh from bones of fish skeletal carcasses are now being used to reduce waste and increase the quantity of usable products.

Following Baumol (1961), we distinguish four decision problems:

1) how much of each final output to be produced?

2) how much, in total, should be spent on the acquisition of inputs (budget)?

3) how should this budget be allocated among the various inputs?

4) how much of each type of input will be allocated to each type of output?

These four decision problems are dependent on the production function:

$$g(Y_1, Y_2, \ldots, Y_n) = f(Yi, X_1, X_2, \ldots, X_m). \quad i \neq 1, \ldots, m$$

It states that Yi is the maximum quantity of output which can be produced when x_1 units of X_1 and x_2 of X_2 and so on are "combined" together given the levels of other Y's. Yi might be the quantity of fillet of species i, Xj might be the quantity of input j, e.g., whole fish.

Production Isoquants

A production isoquant or indifference curve is the locus of resource input combinations all of which are capable of producing the same level of output. The selection of the combinations of whole fish according to species and the quantity of the raw materials to be procured in a seafood processing plant with limited facilities is an important decision. The relationships between and among such inputs are embodied in the production isoquants which in turn are dependent on the production functions of the various plant activities.

Thus far, no discussion of the price relationships of the inputs and outputs is introduced. Without this price information, it is impossible to determine the seafood processing plant's optimal decisions in terms of level of input and resource combinations, level of output and product-mix. A budget constraint represents all combinations of inputs which can be acquired for a fixed budget. Thus, for a given budget, the net revenue maximizing entrepreneur will try to obtain as high a level of production as possible consistent with prevailing prices. Figure 2 depicts the situation further. The conceptual exposition is done for the case of convex isoquants.

The tangency between the given budget line and the isoquant gives the net revenue maximizing combination of inputs, levels of inputs and levels of output and indirectly the "product-mix." Point T is such a point with x_1 units of X_1 and x_2 units of X_2 as its optimum resource combination. Point T is at once the point where costs are minimized for a given output and the point where output is maximized from given costs. Seafood processors attempt to do both simultaneously.[30/] Without fish there is no production and at the

[30/] This is true for fresh seafood processors more so than other food processors because seafood-processors do ~~not~~ have control over the "when" or "how much" of fish landings. Fish are highly perishable commodities.

same time some personnel are on payroll. On the other hand, when more fish are landed than can be handled by the regular corps of filleters and pickers, additional filleters and pickers on-call are brought in. It arises because of the method of production.

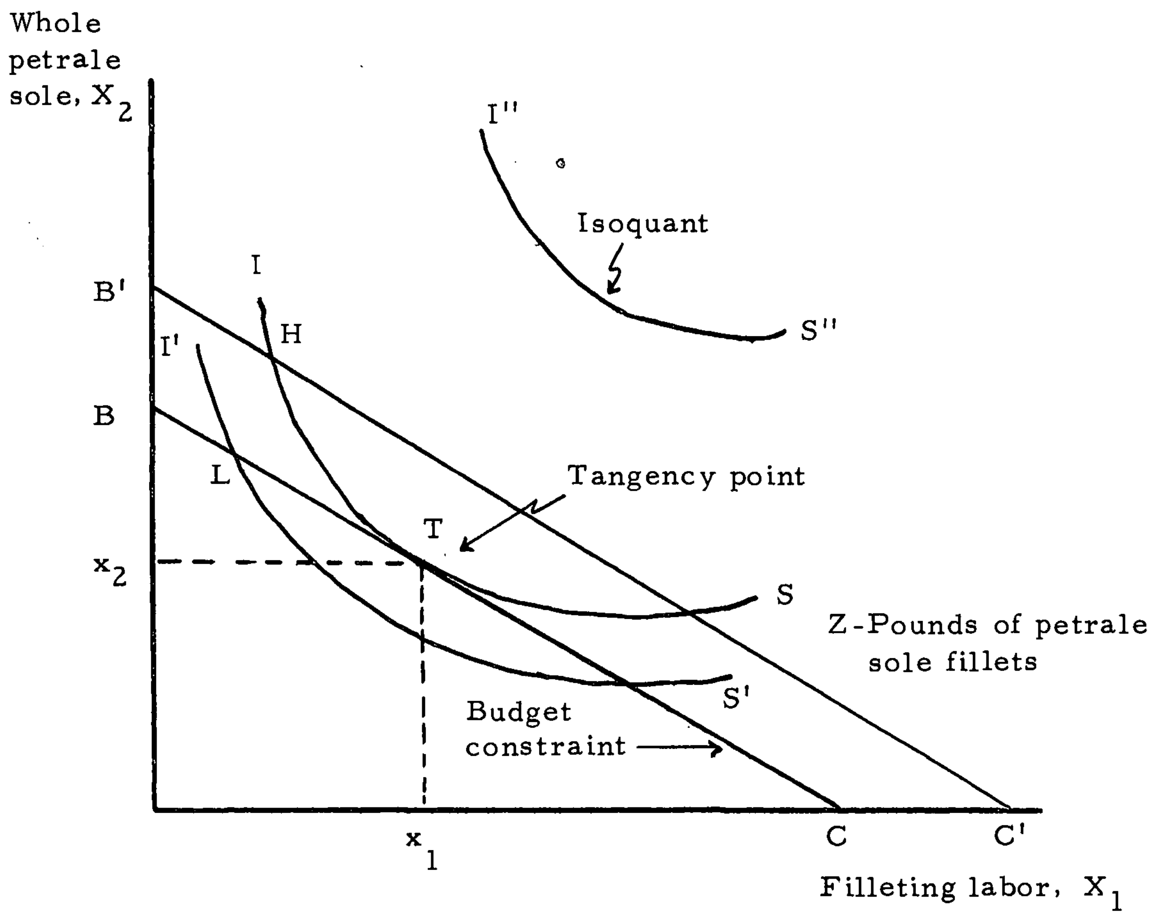

Figure 2. A production isoquant and budget line.

Given the fixed budget, BC, point T on isoquant IS is attainable. Other combinations of X_1 and X_2 are also possible but would cost more than the combination at T. One example is Point H on B'C', a higher budget outlay. Point L is attainable with the given budget line, but it is on a lower isoquant, I'S'. Isoquant I''S'' which is higher than IS is not attainable given the budget line, BC.

Through a series of budgets and isoquants the plant's expansion path could be traced. The expansion path is the locus of all points of tangency relating different budgets and isoquants. It indicates how the plant's net revenue maximizing resource combination will vary when the size of the budget changes. The equation for this condition is given by:

$$\frac{MPP_{x_1}}{MPP_{x_2}} = \frac{P_{x_1}}{P_{x_2}} = \ldots$$

Where

MPP_{x_i} = marginal physical product of Xi

P_{x_i} = price of input Xi

Having obtained the plant's expansion path, the plant's total, average and marginal cost curves could be derived. The total cost curve shows how total plant outlays vary with its level of production.

Each tangency point between the budget constraint and the production isoquant corresponds to a point on the total cost curve since the price line indicates the total budget and the isoquant the level of output and product-mix.

Production Possibility Frontiers

A production possibility frontier is a locus of all product-mixes or combinations forthcoming, indicating the maximum attainable output of one product for each output of the other product given the fixed stock of resource inputs. The curve AB in the figure below represents such a frontier when a given resource base is used to produce two products (e.g., petrale sole fillets and ling cod fillets).

The selection of the combinations of seafood products according to species (and sometimes product forms) and the quantity of the products to be processed in a seafood processing plant with limited facilities and resource inputs is a key decision. The relationships between and among inputs and outputs are embodied in the production possibility frontiers, also otherwise known as the transformation curves, which in turn are dependent on the production functions for the various activities.

Point I within the frontier reflects economic inefficiency. With given resource base, more of one product can be produced without a sacrifice in another product and vice-versa as the resource inputs are adjusted to allow a movement towards the outermost frontier. A movement from I to C permits an increase in Y_1 without a decrease in Y_2. Similarly, moving from I to D also allows an increase in Y_2 without a decrease in Y_1. Thus, any movement from I in a northeasterly direction within the quadrant ICD to the frontier AB allows a simultaneous increase in both products from the given stock of resource inputs.

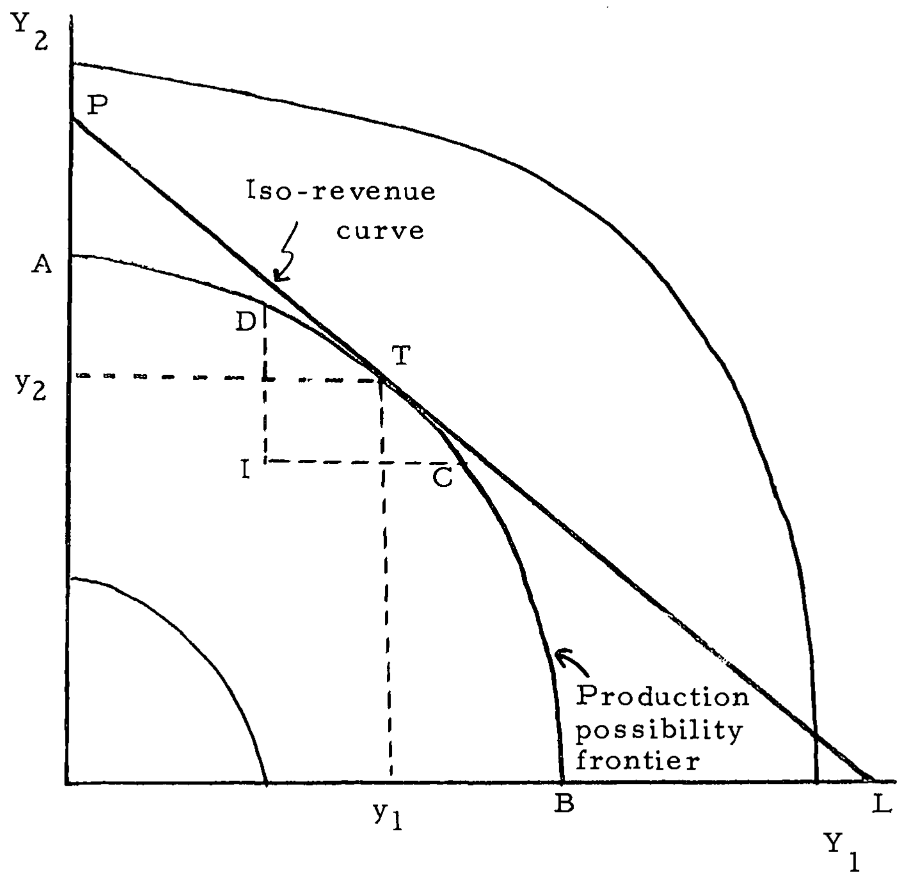

Figure 3. A production possibility frontier and iso-revenue curve.

However, the optimum allocation of given resources between or among different products on the frontier cannot be known unless an iso-revenue curve is provided. An iso-revenue curve is the ratio of product prices prevailing in the market; it defines all of the possible combinations of the competing products which will bring in an equal revenue to the entrepreneur. That point on the production possibility frontier is obtained when:

$$\frac{\Delta Y_1}{\Delta Y_2} = \frac{Py_2}{Py_1}$$

where

$\Delta Y_1 / \Delta Y_2$ = marginal rate of product substitution of Y_2 for Y_1

Py_2 / Py_1 = product price ratios of Y_2 and Y_1

Maximum net revenue is thus obtained only by the tangency of the production possibility frontier and the iso-revenue curve. It is only at this tangency point, T that the marginal value products of each resource input are equal among products and are equal to their respective factor prices. It is also at this point (of tangency) that the ratios of the marginal costs of the competing products are equal to the ratios of their respective prices.

While it is true that the iso-revenue line, PL, denotes the maximum revenue which can be attained with a given resource base, this given resource base or cost outlay defines the production possibility frontier and thus it represents the minimum cost which will provide a given revenue represented by PL. In a similar vein, while the budget constraint represents the minimum cost to attain the given output as denoted by the isoquant, IS in Figure 2, correspondingly, output as represented by IS in Figure 2 is maximized given cost outlay, BC.

It should be noted that while the expository review of the concepts underlying the model has utilized geometric illustrations and thus involves two variables (two-dimensions), the principles and conditions set out are applicable to more than two variables.

Technology and Production Possibility Frontiers

The production possibility frontier will shift out in a northeasterly direction if changes in production techniques or improved resource utilization are introduced either with the same stock of resources (budget) or with a new resource outlay.[31/] An improved resource utilization within the plant through informed decision-making would shift the frontier out, allowing the attainment of a greater revenue to the plant. In like fashion, currently available technology on seafood processing which has not been extensively adopted by the

[31/] A change in the slope of the production possibility frontier or a shift in the location of the production possibility curve may occur.

industry can result in relatively significant change[32/] in the production possibility frontier. In other words, the selection of techniques of production (e.g., manual filleting versus filleting machine) which does not result in product-mix on the outermost production possibility frontier where the choice is based on a lack of information is irrational and the selection of technology could be improved. Other examples could be cited.

Heady (1952) captures the essence of the situation when he states that each postponement in adoption of techniques where they are clearly profitable to the individual or society, spells economic sacrifice or efficiency foregone. He also states that by "economic," he means that while the first-adopting farmers may increase returns temporarily..., all farmers may "end up" with smaller returns (depending on demand elasticities). Further, "yet those whose returns are lessened can still 'minimize profit reduction' by adopting the new technique (if they are to remain in the industry)."

Efficiency and Performance

According to Bain (1968),

> internal efficiency refers to the relative efficacy of the internal organization and management of the firms in minimizing costs. . . thus reflecting the degree of

---

[32/] A change in the slope of the production possibility frontier or a shift in the location of the production possibility curve may occur.

> managerial wisdom in selecting. . . productive techniques and methods . . . cost-minimizing combinations of productive factors. . .

A plant is regarded to be technically efficient if its production function yields the greatest output for any set of resource inputs.

Performance[33/] is in part determined by the nature of the relationships between market participants and users of resources. For example, one dimension of performance, according to Bain (1968) is the relative technical efficiency of production so far as this is influenced by the scale or size of plants and firms (relative to the most efficient), and by the extent, if any, of excess capacity.

Leibenstein (1966) refers to actual productive performance relative to the production (possibility) frontier as "X-efficiency." He includes as reasons for deviations from the frontier, incomplete knowledge of available techniques, motivations, learning and psychological factors. Further, he states:

> There is one important type of distortion that cannot easily be handled by existing microeconomic theory. This has to do with the allocation of managers . . . . Managers determine not only their own productivity but the productivity of all cooperating units in the organization. It is therefore possible that the actual loss due to such a misallocation might be large (Leibenstein, 1966).

[33/] One other dimension of performance is the rate of progressiveness of the industry in developing both products and techniques of production, relative to rates which are attainable, and also economical in view of the costs of progress (Bain, 1968).

Quoting Professor Leibenstein further:

> Professor Eric Lundberg in his studies of Swedish industries points to the case of the steel plant . . . that was left to operate <u>without</u> any new capital investment or technological change, and furthermore maintenance and replacement were kept at a minimum, and yet output per man hour rose by two percent per annum. Professor Lundberg asserts that according to his interviews with industrialists and technicians "sub-optimal disequilibrium in regard to <u>technology and utilization of existing capital stock</u> is a profoundly important aspect of the situation at any time." If a sub-optimal disequilibrium exists at any time, then it would seem reasonable that under the proper motivations managers and workers could bestir themselves to produce closer to optimality, and that under other conditions they may be motivated to move farther away from optimality (author's emphasis) (Leibenstein, 1966, p. 398).

In his study on X-efficiency, Leibenstein also observed that the cost-reducing methods used do not involve additional capital nor . . . any increase in depreciation or obsolescence of existing capital. The methods usually involve some simple reorganizations of the production process, e.g., plant-layout reorganization, materials handling, waste controls, work methods, and payments by results (1966). Another explanation for possible variable performance within a given plant/industry is found in the restrictive implicit assumption of the theory of the firm: inputs have a fixed specification and yield a fixed performance. Leibenstein argues that inputs do not have a fixed specification and a fixed performance. This is especially true of seafood processing. For example, machinery and equipment may have a fixed specification but their performance may be variable depending on how these mechanical inputs are used. The shrimp peeler is a case in point: it has a fixed specification in terms of output rate but the actual performance in the field is variable depending on a host of factors such as aging of the shrimp. Filleting, crab-picking and shaking labor are examples of inputs which have variable specifications and yield variable performance: no two filleters or crab shakers and pickers are exactly alike. This, in part, explains the mode of remuneration of filleters and crab shakers: payment by results.[34/]

Linear Programming and Performance

Linear programming is useful in that it can provide a normative benchmark of optimum resource combinations and product-mix against which comparisons can be made. It can be used to simulate various plant activities and thus provides a basis for testing plant performance. Performance is affected by the way resource inputs are combined and by the way entrepreneurs organize their production activities. Performance is also tempered by the economic, social and legal environment within which the firms operate (institutions). Linear programming is used as a model in this study because it provides for optimization of the entire production system. It is especially suited for this

---

[34/] Note, however, that not all plants pay by results. Hourly wages or a combination of both systems of remuneration are adopted.

study because it takes into account the impact of resource combination and product-mix on the performance of the total system.

The performance of the plant can be measured in terms of differences between existing resource combination and product-mix and optimum resource combination and product-mix as obtained by linear programming. Results of the linear programming model simulating existing resource combination and product-mix under existing technology and "what could be" under existing technology can be compared. On the basis of the results obtained, if it is determined that there are significant deviations, then it can be said with caution that the presence of such deviations according to the criterion of expected net revenue maximization provides evidence of "misallocation" of scarce resources within the plant modeled and possibly within the industry. Performance is therefore said to be significantly less than that which is feasible or could be.

Last but not least, the choice of linear programming is based on the fact that it could be used both as a normative and positive analytical tool. Linear programming also meets the objectives and methodological requirements of the study. Its ease of application and relatively inexpensiveness of programming compared to other analytical tools are also important factors. This is especially critical if it is to be used by the industry as envisaged. The normative aspects of the model allow for the evaluation of performance of the seafood processing plant and the seafood processing industry as a whole.

Plant Performance

An approximate measure of plant performance can be obtained by comparing what the plant should be producing versus what it is actually producing (status quo) under present technology. Further, this status quo case can be compared with what the plant could have processed under new technology which is presently available but which has not been adopted.

This means that the effectiveness of plant performance can be measured by the short-run contribution to "profit and overhead". Expected net revenue maximization is assumed to be compatible to longer run objectives. In other words, the ratio of output to input as measured by the value of the objective function obtained from the existing "production function" relative to the ratio of output to input forthcoming from the most efficient function employing the same stock of resources is a measure of performance.

Industry Performance

According to French (1977), the total marketing system or an industry subsystem may be said to be efficient if a) all firms are economically efficient, b) the industry is organized to utilize capacity and to take full advantage of scale and location economies, and c) the industry operates under exchange mechanisms that generate prices which conform to a competitive standard such as the perfect market. Further, he states that the degree to which (a) and (b) are achieved together is commonly referred to as productive efficiency, and the degree to which (c) is achieved is referred to as pricing efficiency.

The performance of the Oregon seafood processing industry can be improved if either the productive or pricing efficiency can be improved. The present study focuses on the former. The optimum patterns of seafood processing plant activities for a representative plant will be identified. Although only one plant is modeled, the results obtained can provide valuable information to provide insights regarding the Oregon seafood processing industry. The plant modeled is sufficiently representative of the conditions existing in the Oregon seafood industry.

Decision-Making Process

In order to improve performance, right decisions made at the right time are essential. Decision-making requiring a choice among a large number of alternatives and constraints can be facilitated with the help of linear programming. It is versatile in that it permits a manager of resources to test a wide range of alternatives and to analyze their consequences on paper first! Linear programming solutions can provide timely and useful information to the seafood processor in his decision-making process.[35]

Coordination within a production system is an important function of the manager. Decisions made at any one operating stage will bear directly and will have an impact on the decisions and performance of the antecedent/subsequent operating stages. It may be that a decision (judged to be optimal) made at one stage may turn out to be less than optimal in the final analysis. Thus, the performance of the entire production system depends on the whole set of decisions of all the operating flow-oriented as well as the non-flow-oriented stages. In short, decisions made at any one stage must be evaluated in terms of their impact on the entire system. This means that given the linkages between and among the various components of the entire production system as well as the relationships between subproblems and subgoals, a total systems approach is important for attaining improved performance. Total systems approach decision-making techniques (e.g., linear programming) are available which may contribute to more accurate and efficient decisions by plant managers. More efficient and accurate decisions will contribute to improved plant and industry performance.

---

[35] Linear programming has been and is used extensively in agricultural economics because of its capability of solving production problems. It can also be used to evaluate major plant adjustments.

Linear Programming and Economic Theory

Problems which seek to find the optimum allocation of scarce resources towards pre-determined objectives can be formulated as the familiar maximization or minimization of a mathematical function subject to a set of constraints. Linear programming and differential calculus (with Lagrangian multipliers) can be used to solve such problems. Both methodologies seek to find the most profitable point on the production function although with different orientation.

While Dorfman (1958) cautions that it would be misleading to contrast the linear programming methodology with the marginal analysis approach in general, it is useful to show the differences in approach: while linear programming stresses the linearity of its objective function and constraints, differential calculus is only restricted to continuous functions. Under the differential calculus formulation, the productive process allows unrestricted variations in resource input proportions and/or substitution, and the optimum position is reached through equating marginal revenue and marginal cost. Such is not true of linear programming. Dorfman (1958) states that linear programming does not seek to determine directly the optimal quantity of each resource input and product but, instead, the optimal level of each activity.

With reference to Figure 4, curve I represents the iso-Dungeness crab curve, curve II the iso-labor curve and curve III the iso-crab cooker curve. Each of these three curves show the quantities of two products, let us say whole cooked Dungeness crab and Dungeness crab meat which can be produced with the fixed quantity of the particular resource inputs given that all other inputs are available in the required amounts. Therefore, given the quantity of each of the three resource inputs available, the possible product-mix is represented as the linear segment or feasible "frontier," abcd (see Figure 3).

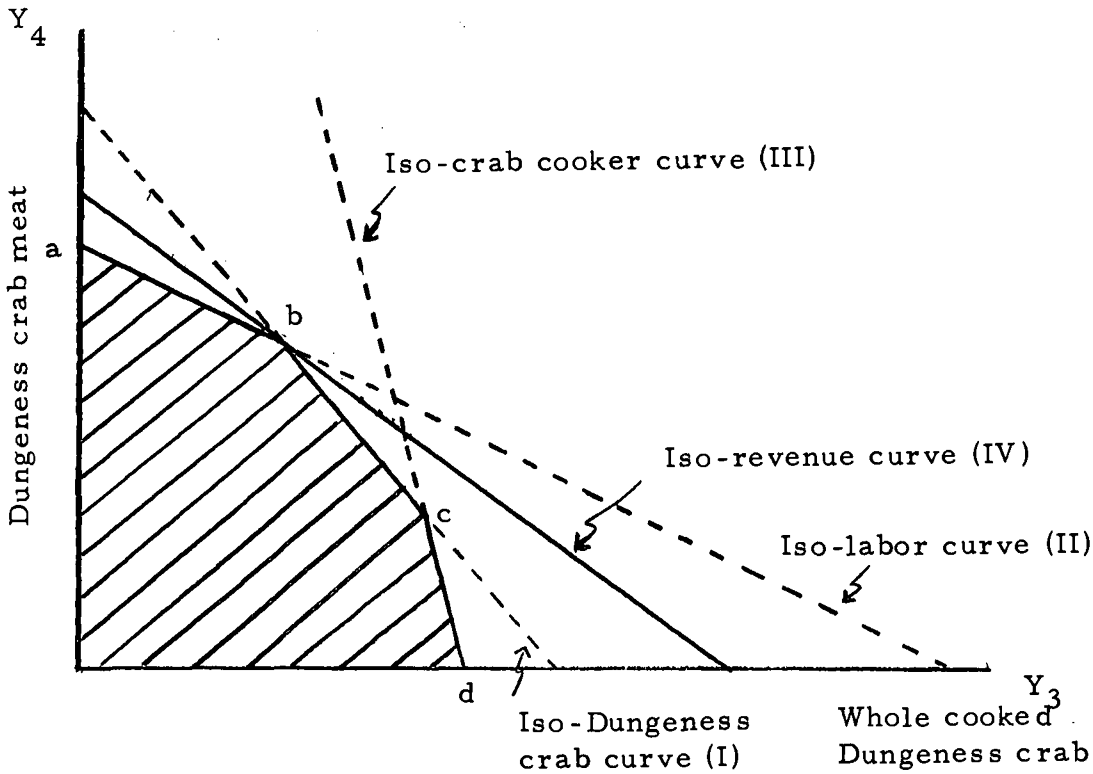

Figure 4. Resource constraints and feasible frontier.

If we now draw in another curve, such as curve IV, representing the iso-revenue curve, then the net revenue maximizing combinations of whole cooked Dungeness crab and Dungeness crab meat will be obtained at b. Having now determined the optimum resource combination and product-mix, we can extend the analysis to estimate the value productivity of using more of a particular resource input. For instance, if the seafood processor now decides to add more green Dungeness crab to the operation. This would be represented by a parallel shift of curve I in a northeasterly direction (not shown). This new curve I will define another new feasible "frontier," or "production possibility frontier." This can be done for other resource inputs such as labor.

Opportunity Costs or Shadow Prices

Opportunity cost, shadow price or sometimes referred to as alternative cost is the maximum value that a productive factor could produce in an alternative use. This means that it is the value of the best opportunity which is foregone by not using the productive factor in another way (Cohen and Cyert, 1965).

More specifically as it relates to linear programming, the shadow price for business activities indicates how much revenue (value of the objective function) would be penalized or sacrificed if an additional unit of the activity was forced into the final solution or in producing another alternative.[36/] Species which are not in the "optimum solution" are forced into the solution to portray existing conditions of processing plants. However, as opportunity cost relates to limiting resources or facilities (constraints), the shadow price for disposal activities provides information on the productivity of added resources or facilities, that is, the relaxation of constraints.

As the discussion above shows, opportunity costs, shadow prices or penalty costs represent the marginal value products of the limiting resources and excluded activities. They also represent break-even points.

Disposal or Slack Activities

The presence of slack variables allows for non-use of resources. Disposal activities are unnecessary if the activities completely utilized all the available resources. However, it is seldom possible to exhaust all available resources.

[36/] The latter is very pertinent by virtue of the species composition of the trawl landings and the necessity of seafood processors to take all that are brought in by the boat. The status quo or existing "solution" was simulated as a basis for comparison with the optimum solution obtained by the model. Such bounds (lower and upper bounds) and constraint equations were used extensively.

Competition and Market Structure

The structure of markets in which firms sell and buy determine, in part, the market conduct and performance of the firms. By conduct and performance, we mean the behavior of firms in the markets in general; more specifically, we refer to the determination of output levels, product-mix and prices of the firms.

Although many standard microeconomic texts emphasize that either the conditions of competition or competitive pressures would assure maximum technical (and thus allocative or pricing) efficiency, Schwartzman argues that maximum technical efficiency under competition is not assured (1973). He also argues that "even the more modest claim for the superiority of technical efficiency under competition than under alternative market structures remains questionable." Further, he argues that competition does not even guarantee that an inefficient technique will disappear.

Under the conventional theory market imperfections and a lack of information (partly stemming from market imperfections), among others, have been given as reasons why competitive firms do not achieve lowest average costs (Due and Clower, 1966).

Therefore, even if the manager has the best decision-making information and tools, optimum resource combinations and product-mix may still not be achievable. It is important to understand the

the nature of competition and structure in seafood marketing before conclusive normative statements about seafood processing plant performance can be made. Entrepreneurial objectives and the characteristics of the products handled are also important in understanding performance.

III. ENTREPRENEURIAL OBJECTIVES

The seafood processor's or entrepreneur's attitude and judgement towards risk and uncertainty associated with different products in terms of price is very important in his determination of product-mix and hence of raw material procurement for his plant. The total number of products or product-mix depends on the information available to him and his experience in the market. His knowledge of the market tells him about the products that move fast, move slowly or not at all. His information on the price-quantity relationships of the various possible product candidates helps him to narrow his choice of product-mix. Species of fish and their recovery rates, available facilities and resources and costs of production are also important considerations. Further, in deciding on product-mix, the processor may also take into account the estimated production of his competitors.[37/]

The above is generally true of most industries. However, an important qualification is needed in the case of seafood processing. As was alluded to in the discussion on species composition, there is really little control on the choice of bottomfish species that fishers

---

[37/] Even with information available to him but which is not systematically analyzed as undertaken in this study, one drawback is that the choice of product-mix may be biased and therefore be less than optimum.

want to land especially the more sought-after species.

This lack of choice in specifying the raw materials needed renders the method of raw material procurement unusual. A processor is reluctant to tell his fishers who are supplying him when these fishers return to port with a load of bottomfish that he is only interested and would only buy for example, petrale sole, ling cod and sand sole. He has to buy the whole boat load.[38] If he does not, he faces the strong possibility that these fishers would not supply him the next time. This arrangement has evolved over time and has even been "institutionalized." Thus, in this respect, even though some species are not profitable for the processor to buy, he is compelled to buy them to maintain good rapport with the fishers.[39]

Besides, the quantity of the most desired or sought-after species is not landed in large enough quantities to even out plant production fluctuations. Therefore, it may also be in the interest of the seafood processors to buy them so as not to keep his plant idle. However, given the kind of information which can be made available to the processor from this study, he can exercise some degree of control over his purchases.

---

[38] An indication of the composition of bottomfish landed for Oregon is 28 percent of rockfish, 27 percent of codfish or roundfish, 18 percent Dover sole, 7 percent of petrale sole and 5 percent of English sole (Oregon Department of Fish and Wildlife, 1972). Soles are flatfishes.

[39] He may be able to influence the price.

Although profits are the recognized means of sustenance of any firm bent on surviving in the business, there are often other objectives sought as well. Entrepreneurial goals are often poorly defined and much analytical work done previously has been based on simplifying assumptions such as profit maximization or utility maximization.[40/]

For a seafood processor expected net revenue maximization may not be the only objective sought. He may also want to preserve and/or expand his market share/power and firm size. With stricter legislation on work place environment and seafood plant sanitation (e.g., Occupational Safety and Health Administration requirements) and the like, the seafood processor has to meet the legal requirements of these government standards. For fear of provoking retaliatory action from his rivals, he may even restrain his procurement and selling aggressiveness. Maintaining good labor relations or meeting labor contractual obligations as well as meeting product contractual agreements with buyers may be his secondary objectives. However, these secondary objectives may be pursued primarily because they contribute to profits.

Interviews with seafood processors reveal that if conditions permit, they would rather handle salmon only and nothing else.[41/]

[40/] Utility maximization which involves a different methodology and analysis would not be used in this study.

[41/] One model solution of this study confirms this finding, even with a 15 percent increase in the cost of procurement for salmon the

They also reveal that procuring and handling as much salmon as possible is an "ego trip" and have the complete fascination of many processors. This phenomenon is dramatized even to a greater extent by the finding that seafood processors "imposed" on fishers the condition, among others, that salmon fishers have to sell them all their salmon catch if they wish to also sell their Dungeness crab. In this way, the processors can help assure themselves of a supply of salmon each season.

The linear programming formulation is versatile in that it is capable of incorporating the different entrepreneurial objectives in the model. These objectives can be as subjective as the decision-maker wants them to be as long as he is coherent. Self-imposed objectives and constraints are common and are partly determined by the perception of the decision-maker. For instance, the seafood processor may decide that he would process no more than 100,000 pounds of hake fillets because of the risks involved. This may be because his perception and experience of the U.S. seafood market is that the market is highly selective in terms of marketable species.

Other objectives and/or constraints may be institutional, contractual, and/or personal. Building cordial relationships with

---

optimal product-mix consists of only salmon. When salmon procurement cost was increased 50 percent, shrimp processing was suggested and no salmon came into the final solution.

customers, fishers and others, and meeting actions of competitors are some examples of constraints. Some Oregon seafood processors bring in partially processed Alaska king and snow crab sections for further processing despite the fact that it cannot be immediately justified in terms of resource price and substitution ratios. This is done to take up idle periods when insufficient quantity of local fish and shellfish are landed. This example of a less-than-optimum use of resources for king and snow crab, however, may reflect "rational" decision even where "profit maximization" is the entrepreneurial objective.

Therefore, no matter how diverse and subjective the entrepreneurial objectives are, the linear programming formulation is amenable to suit particular requirements of the modeled decision-maker. It allows for personal choices to be built into the model. These personal choices can be as subjective as he wants and can range from total dislike for a certain fish species to complete fascination of another species.

The attainment of ideal conditions is seldom a practical proposition. Further, most decisions affecting seafood processing management are not solely based on economic considerations. Both of these conditions are widely recognized in the literature on seafood processing. However, the shortcomings not withstanding, it is possible to reach closer to ideal or optimum conditions if relevant information on these shortcomings are available to decision-makers.

IV. LITERATURE REVIEW

Far more research effort has been devoted to the study of the conservation of the fisheries resources and to a certain extent on the analysis of primary producers (fishers) than other aspects of the industry. It is true that some attention has been given to the process by which fish and shellfish are brought to the final consumers but in this writer's opinion, not enough has been done to study the economics of seafood processing and seafood processing management.[42/]

An "Expert Consultation on Quantitative Analysis in Fishery Industries Development" was convened by the Food and Agriculture Organization of the United Nations in January 1975. One of the six volumes of reports that resulted from the meeting: "A Review of Quantitative Methods for the Management of Fish Processing Plants" surveyed the literature on published techniques and experience related to fish processing plants (Haywood, 1975).[43/] In that review, Haywood states that over the past ten years, consideration has been given to the way in which companies are financed and organized, the

---

[42/] Preliminary literature search indicates this to be so. In fact, past studies have been concerned with fisheries policies., However, since Sea Grant, attention is increasingly being given to study the microeconomic aspects of the industry.

[43/] This is an excellent review on the subject. This writer has drawn extensively from it for his discussion on the review of literature for his study. Only papers germane to this study are highlighted.

way in which their information and data systems operate and the manner in which their managers think and work. He also notes some emphasis on management education and training courses in the fish processing industry. This interchange of ideas between managers and quantitative analysts and the opportunity provided for managers to review their performance under simulated conditions of pressure and stress have been beneficial to both parties (Haywood, 1975). He argues that although certain of the proposed techniques may seem trivial compared with some of the complex modeling that he has reviewed, they are essential to the total management function. According to him,

> Simple techniques may solve strategic problems but more often, they will solve problems in the tactical decision-making category. The solution of these may be a prerequisite for the solution of the strategic problems anyway (Haywood, 1975, page 1).

Early in his review, Haywood states that optimization, in the absolute sense, is not a practical proposition, as evidenced from the papers he surveyed. The papers show a combination of the principles of optimization and satisficing-optimization with respect to profitability and satisficing with respect to qualitative or even quantitative variables. He cites the examples of the optimization of freezing plant throughput capacity with respect to a quality specification, or the optimization of a fish meal plant supplied by a fleet of a particular capacity. Although Haywood (1975) reviewed four categories of papers: industrial fish processing, processing at sea, location of plant and processing on shore, for the purpose of this study, only the latter will be discussed here. He identified three papers (Theodore, 1965; FAO Secretariat, 1965; Kerr, 1965) with management techniques applications. They suggested the range of techniques that might be useful. According to Haywood, the authors had little or no experience of the fishing industry, but proposed several problems and applied techniques for solution, including accounting methods, operations research and statistical forecasting techniques. He also reviewed a paper (Henriksen, 1965) which explains the use of break-even analysis and direct costing techniques. Henriksen also showed how full cost and direct cost accounting methods may produce contradictory results in multi-product processing plants.

Another paper (Kroger, 1966) reviewed by Haywood examines the discontinuous raw material supply and how in difficult periods, the management cannot maintain the required mix of processed herring. On the other hand, at the height of the season the plant receives more herring than it can process. The problem identified is characteristic of the fishing industry. Forecasts of supply, production capacity and changes in the product-mix over discrete short term periods were investigated using parametric linear programming. The parametric linear programming technique was used in two other papers (Kroger, 1966 and Shavanova, 1969) reviewed by Haywood. Part of the abstract of the second paper is provided:

> . . . covering the production planning for a range of products from a number of multi-department plants, using all the incoming raw material within production capacity limits, with maximum output and minimum production hold-ups, . . . (Shavanova, 1969).

Haywood also rightly points out that even with the aid of a computer it is virtually impossible to organize and design a game[44/] that is capable of introducing all of the complex facets of decision-making, etc. which go up to make a modern business enterprise. He further states that the most that can be hoped for is that sufficient detail and sufficient realism can be introduced into the game to bring to life, and to exercise, the knowledge and information that the trainee has gained from other sources.

In his conclusion, Haywood states that it appears that "decisions for shore-based or vessel-based processing plants have been made on the basis of factors other than optimal economics. . . (however), some effort has been made to use quantitative methods for the solution of processing plant capacity problems within each of these areas." Overall, Haywood feels that attention has been given to the problems

---

[44/] This is the White Fish Authority business management game. The game simulates the operations of a group of fish processing companies in competition with each other. The operations include a) purchase of raw materials and production (i. e., scheduling the processing plant, deciding on storage facilities, purchase of new equipment, recruitment of labor, etc.), b) product costing and financial control, c) marketing.

of planning the fish processing function and the associated difficulties of product-mix.

More importantly, he recognizes that these problems are particularly difficult in the fishing industry because of the discontinuous supply of fish and the changing market requirements but the techniques used in the area appear to be satisfactory and some success has been achieved.

Recent interest in management education in seafood processing management can also be found in the work done by Frederick J. Smith and collaborators: Seafood Management and Marketing workshops held in various locations along the U.S. West Coast. These workshops emphasize the importance of management, notably the role played by a financial audit. Key management concepts as they relate to procurement of fish, actual processing of fish and marketing were stressed and the impacts of one to the other were related. Creative management ideas exploring the human equation were further reinforced.

This literature review is closed with the following note as excerpted from the introductory address by the Assistant Director-General of the Technical Department of the Food and Agriculture Organization (1965). The 1964 "Meeting on Business Decisions in Fishery Industries" sponsored by FAO was acknowledged as a step in a new direction for FAO. This is because to date, the organization has taken up problems of industrial development in fisheries only insofar as they affect public policy. This time we want to widen the lens and look at these problems through the eyes of the industrial manager who has the responsibility for actually solving them. We want to help him find better tools for decision-making. We believe that improved methods of decision-making will lead to improved utilization of fisheries resources. Improved utilization of fisheries resources, again, will enable man to add to future supplies and to help him in his struggle against hunger (author's emphasis).

V. METHODS

Commercial fishing is a hunting enterprise and hence the extent of fishery effort and yield are dictated by the vagaries of Nature.[45] An industry so characterized and governed by both natural and regulated seasons renders the selection of a planning horizon somewhat complex. Several alternative horizons were investigated, namely a yearly, quarterly, monthly and weekly interval. The yearly and quarterly models were judged to be too long a horizon to be useful to management for planning purposes given the nature of the fishing environment as outlined above. The decision to disaggregate the planning horizon of a typical processing year into 12 monthly periods appears superior to the others which were considered. Its selection is based on the information needs of the study. A weekly horizon was not chosen because it would entail considerably more analysis.

Further, we assume that the plant's production activity for a whole year is so arranged that the production in each of the 12 months is independent of the production of both the preceding and subsequent months. In other words, the plant is interested in the production activity of only one month at a time. Further, each month's

[45] It thus renders the landing and supply of the basic raw materials "discontinuous" over time and processing intermittent.

production is determined by the conditions prevailing in that month only.[46/]

In seafood processing the major production process involves the disassembly of the primary raw materials (fish and shellfish) into finished products: fish fillets, crab and shrimp meat, and dressed salmon. Before the formal model is presented, a brief statement of the activity types and constraint types is provided. There are altogether 80 business activities and at least 16 constraints in the model for an average month.

Activity Types

The activities of a typical Oregon seafood processing plant fit three major categories: raw material procurement, methods of production (e.g., filleting fish, picking and shaking shrimp or crab) and sale of finished products.

Raw Material Procurement

Altogether there are 19 activities in this major category: purchasing 13 species of bottomfish, three crab species, two salmon species and one shrimp species. The objective function coefficients

[46/] See Sune Carlson, "A study on the pure theory of production," for a discussion of mono-periodic production. The nature of the highly seasonal and volatile patterns of fishing activity justifies this assumption.

for this set of activities, referred to as procurement prices are the ex-vessel prices per thousand pounds as shown in Table 4.

Table 4. Ex-vessel prices of fish and shellfish (1,000 pounds) 1976.

Species	Procurement Price (Ex-vessel price)
Dover sole	$ 168.00
Petrale sole	290.00
Sand sole	270.00
English sole	250.00
Rock sole	230.00
Rex sole	220.00
Flounder	135.00
Sand dab	230.00
Ling cod	160.00
Pacific cod	150.00
Black cod	137.00
Rock fish	155.00
Pacific Ocean perch	155.00
Shrimp	230.00
Dungeness crab	550.00
King crab	2,900.00
Snow crab	1,300.00
Chinook salmon	1,530.00
Coho salmon	1,250.00

Source: Fishermen's Marketing Association, Eureka, California.

There is a traditional arrangement of buying fish and shellfish from fishers. Friendship and family ties dominate the purchasing scene. Some processors have their own boats supplying their requirements. Further, some processors fill their raw material requirements by acquiring supplies from out-of-town buying stations. Processors have contractual arrangements with fishers that enable the processors to assure them of a portion of the total supply of fish, to exercise some control on the fishing operations and indirectly control the composition of the catch delivered to them. However, the supply of the different species in total and/or to the individual processor is constrained by when the regulated fishing season begins and ends (see Figure 5). This set of activities supplies the basic ingredients for the next activity set.

Methods of Production

The raw materials carried over from the above define the main production activities: filleting, picking and shaking, brining and packaging. The products are processed through several work stations in a production line, for example, a fillet production line. Each work station has a limited number of hours available to carry out the necessary functions. The hours available are determined by the hours the plant is open for work.

The production activities have definite processing dates. They employ the services of labor and equipment such as the Laitram Precooked Model A (PCA) shrimp cooker and peeler, fillet knives and boards, crab cooker, briner, etc. during the specified processing dates. For instance, the Laitram cooker and peeler is idle between November and April. This is because the shrimp season runs from

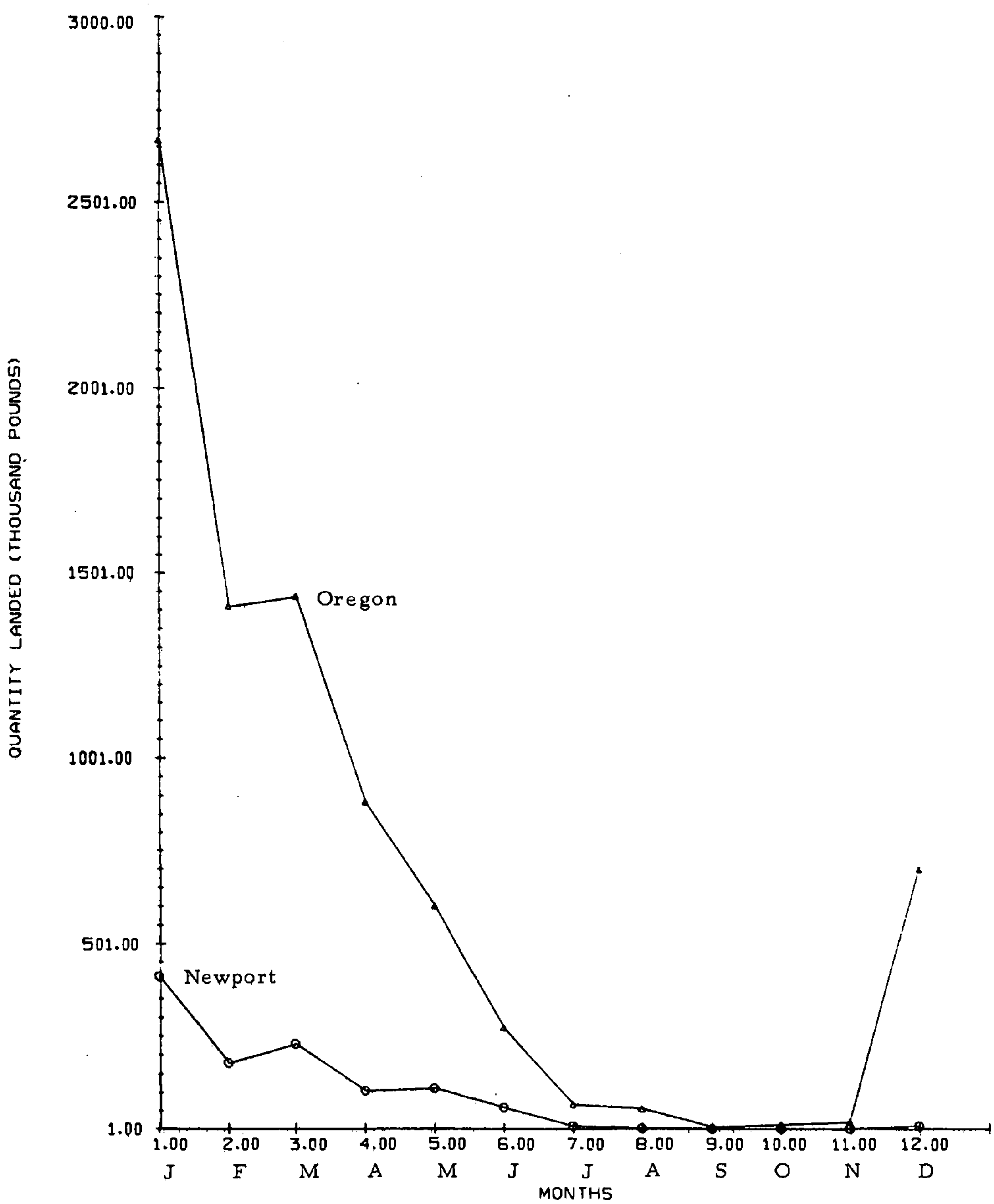

FIGURE 5 OREGON AND NEWPORT LANDINGS OF DUNGENESS CRAB FOR 1976

April through October. The coefficients for the objective function of these 41 activities are the variable production costs of each activity. These coefficients are provided in the Appendix.

Sales of Finished Products

Product demand and hence product-mix must of course relate to the procurement of necessary raw materials.[47/] This set of activities describes the sale of the different finished products almost the same day they are processed or on the average after one to three days of cold storage. The longest the processor can store his products is a week before the prices are affected.

The finished products are assumed to be sold at prevailing market prices to the limit of productive capacity. It is, however, known that prices do vary from processor to processor depending on traditional relationships between the processors and their customers.[48/]

[47/] Although 19 species are procured, there are 20 finished products, thus reflecting the various product forms.

[48/] Almost all the transactions are conducted over the telephone. Either the buyers will call the processors up to find out what is available for the day or two, what the price outlook is like, place their orders after some haggling, or the processors will call their established buyers up to let them know what is available and the price situation. Usually the conversation is very casual and can drift to almost any topic with the last few minutes spent on actual transactions. This relationship works well for both parties and reflects the characteristic nature of the seasonal and discontinuous supply of fish.

Prices also do vary from port to port.[49/] Table 5 gives the objective function coefficients: the prices of fish fillets, salmon, shrimp and crabmeat (wholesale price, F.O.B. plant).

Table 5. Wholesale prices of fish and shellfish (1,000 pounds) 1976.

Product Form	Prices*
Dover sole fillet	$1,300.00
Petrale sole fillet	1,750.00
Sand sole fillet	1,550.00
English sole fillet	1,370.00
Rock sole fillet	1,650.00
Rex sole (dressed)	1,170.00
Flounder fillet	1,250.00
Sand dab fillet	1,170.00
Ling cod fillet	1,000.00
Pacific cod fillet	1,000.00
Black cod fillet	790.00
Rock fish fillet	850.00
Pacific Ocean perch fillet	800.00
Shrimp meat	2,200.00
Whole Dungeness crab	850.00
Dungeness crab meat	3,560.00
King crab meat	3,500.00
Snow crab meat	3,500.00
Dressed Chinook salmon	2,980.00
Dressed Coho salmon	2,290.00

*Wholesale price, F.O.B. plant.
Source: Interviews with seafood processors, and National Marine Fisheries Service unpublished data.

[49/] It is acknowledged that supply and demand conditions are important in determining the prevailing prices. However, this is not explored here because it is not needed for the purpose of this study. Prices are assumed to be constant.

For multi-plant firms, it is an operating procedure to sell their finished products through the parent company. For these plants the finished products are sent to the parent plant, usually to fill larger orders. However, this practice does not preclude the manager of the subsidiary plant from selling directly.

Constraint Types

The 60 transfer equations constitute part of the constraint requirements of the model. They function as accounting procedures to transfer the raw materials and partially processed products from one stage to another in the production line.

The next set of constraints represents limitations of the plant's facilities and resources at the management's disposal. For all practical purposes, the plant must adhere to these limitations. These constraints can be of any form (equalities or inequalities).[50/]

There are two unloading labor constraints which specify the labor requirements to unload 1,000 pounds of bottomfish, shrimp, crab and salmon respectively and also the number of hours available under this constraint category. In like fashion, other constraints specify the input-output coefficients and the total availability of each

[50/] Details of the linear programming formulation can be found in most standard texts on the subject (see for example R. Dorfman, et al., Linear Programming and Economic Analysis. New York: McGraw-Hill Book Company. 1958).

to the plant: rotary washer capacity, sorting, debacking and butchering Dungeness crab labor, crab cooker capacity, de-ice washer capacity, Laitram PCA cooker and peeler capacity, fish filleting labor, crab picking labor, shrimp pre-picking labor, continuous briner capacity, three packaging labor constraints for fish fillets, crab and shrimp meat respectively, automatic seamer capacity and lastly, cold storage capacity. The specific input-output coefficients and the total availability of each are provided in the Appendix.

Both lower and upper bounds are used to specify other features of the model. Almost all procurement activities are bounded at the modeled plant's previous production levels to simulate the existing state of affairs. This provides the basis for comparing and relating the optimal resource combination and product-mix (according to the study's criterion of expected net revenue maximization) as obtained by the model and the existing resource combination and product-mix. The differences between the two resource combinations and product-mix enable the comparison of the performance of the plant under the existing conditions and "what could have been" situation. It also serves to verify the model.

In evaluating the impacts of new technology, procurement activities of the seafood processing plant will be constrained at below the quantity of fish being landed in the port in which the plant is operating. This is done to make sure that the plant does not get more than its share of fish supply in that port and also not more than what is landed in that port. Clearly, there are other plants competing with it for the same supply.

A Species-by-Species Model

Recognizing the difficulty in developing an exact species composition model of the plant (which will be useful), a species-by-species model was then developed as the next best approximation. The species composition of the bottomfish is thus not reflected in the model.

A Formal Statement of the Model

A first step in the application of the linear programming technique is to determine the alternative processing activities which are feasible within the resource limitations of the plant modeled. The production possibilities available to the manager of the plant modeled can be formulated as a system of equations. This system of equations represents the linear programming model and is written in matrix form. It is the mathematical representation and specification of the seafood processing plant operations. Every effort has been made to closely approximate the plant's practices and policies. The formal model is presented below:[51]

Maximize

$$- \sum_{j=1}^{k} C_j X_j + \sum_{j=k+1}^{\ell} P_j X_j \qquad j = 1, \ldots, k, \ldots, \ell$$

Subject to

$$\sum_{j=1}^{\ell} aijX_j \leq ri \qquad i = 1, \ldots, m$$

$$X_j \geq 0$$

Where C_j, P_j, aij and ri are constants.

The model represents all production possibilities for bottomfish, crab, shrimp and salmon. The processing of each of these products occurs within the monthly availability of the resource inputs. For more details, refer to Table 6 and the Appendix. The model seeks to find the values $(X_1, \ldots, X_k, \ldots, X_\ell)$ which maximize the expected net revenues to the plant subject to the specified constraints. This means that it is maximizing "profit" to fixed factors. The solution

[51] This model represents a static equilibrium processing plan. The static equilibrium model is not viewed as a shortcoming for the purposes of the study because the model can provide almost instantaneous solutions to the optimal resource combinations and product-mix given any change in market conditions.

Table 6. A reduced version of the linear programming model.

Plant Constraints \ Plant Activities	PRPTS	PRLNG	PRROC	PRSHP	PRDCB	PRCHK	BFUNL	DCUNL	SHUNL	SMUNP	BFWSH	SHDCE	DCSRT	SHCKP	DCCKW	DCCKS	FPETS
OBJFN..............	-290.0	-160.0	-155.0	-230.0	-550.0	-1530.0	-1.19	-0.4	-0.81	-3.36	-0.23	-0.23	-9.79	-10.01	-0.56	-0.54	-73.40
TRF 1...............	-1.0	-1.0	-1.0				1.0										
TRF 2...............				-1.0					1.0								
TRF 12..............						-1.0											
TRF 15..............	-1.0																3.077
TRF 30..............															-1.0		
TRF 34..............																	-1.0
TRF 44..............																	-1.0
TRF 60..............																	
Conatrainta for a month..............																	
UNLO................							0.295	0.1	0.2								
RWAS................											0.2						
SOBC................													2.43				
CBCK................															0.52	0.28	
DEIC................												0.125					
PCAP................														0.55			
FSFL................																	18.2
CBPK................																	
PREP................																	
HANS................										0.833							
CNBR................																	
PACF................																	
PACC................																	
PACS................																	
SEMR................																	
CDST................																	

(continued)

Table 6. Continued.

P.C. \ P.A.	FLING	FRCKF	PKSHP	SPKDC	BRSHP	BRDCB	PACFF	PACSH	PACDC	SEALC	SLPET	SLLIN	SLRKF	SLSHP	SLDCW	SLDCM	SLCHK		Right hand side
OBJFN.......	-28.8	-31.0	-36.0	-365.0	-26.14	-29.41	-1.22	-11.03	-25.73	-4.04	+1750.0	+1000.0	+850.0	+2200.0	+850.0	+3560.0	+2980.0		
TRF 1.......																		=	0.0
TRF 2.......																		=	0.0
TRF 12......																	1.111	=	0.0
TRF 15......																		=	0.0
TRF 30......															1.111			=	0.0
TRF 34......	-1.0	-1.0					1.0											=	0.0
TRF 44......											1.0							=	0.0
TRF 60......									-1.0							1.0		=	0.0
Constraints for a month.																			
UNLO........																		≤	352.0
RWAS........																		≤	176.0
SOBC........																		≤	176.0
CBCK........																		≤	176.0
DEIC........																		≤	176.0
PCAP........																		≤	374.0
FSFL........	7.14	7.69																≤	3520.0
CBPK........				73.0														≤	4400.0
PREP........			10.0															≤	1056.0
HANS........																		≤	352.0
CNBR........					3.39	3.81												≤	352.0
PACF........							0.316											≤	528.0
PACC........									6.67									≤	176.0
PACS........								2.86										≤	176.0
SEMR........										1.0								≤	176.0
CDST........											1.0	1.0	1.0	1.0	1.0	1.0	1.0	≤	610.0

Legend to Table 6: (please see the Appendix for a complete list of data used in the larger model).

OBJFN	= Objective function.
TRF	= Transfer equations 1-60.
PRPTS	= Procurement of petrale sole, in thousand pounds.
PRLNG	= Procurement of ling cod, in thousand pounds.
PRROC	= Procurement of rock fish, in thousand pounds.
PRSHP	= Procurement of shrimp, in thousand pounds.
PRDCB	= Procurement of Dungeness crab, in thousand pounds.
PRCHK	= Procurement of Chinook salmon, in thousand pounds.
BFUNL	= Unloading bottomfish.
DCUNL	= Unloading Dungeness crab.
SHUNL	= Unloading shrimp.
SMUNP	= Unloading and packing salmon.
BFWSH	= Washing bottomfish in rotary washer.
SHDCE	= De-icing shrimp in de-icer.
DCSRT	= Sorting, de-backing, and butchering Dungeness crab.
SHCKP	= Cooking shrimp.
DCCKW	= Cooking whole Dungeness crab.
DCCKS	= Cooking Dungeness crab sections.
FPETS	= Filleting petrale sole.
FLING	= Filleting ling cod.
FRCKF	= Filleting rock rish.
PKSHP	= Prepicking shrimp.
SPKDC	= Shaking and picking Dungeness crab.
BRSHP	= Brining shrimp meat.
BRDCB	= Brining Dungeness crab meat.
PACFF	= Packing fish fillets.
PACSH	= Packing shrimp.
PACDC	= Packing Dungeness crab meat.

SEALC = Sealing and canning shrimp and Dungeness crab meat.

SLPET = Sale of petrale sole fillets.

SLLIN = Sale of ling cod fillets.

SLRKF = Sale of rockfish fillets.

SLSHP = Sale of shrimp meat.

SLDCW = Sale of whole Dungeness crab.

SLDCM = Sale of Dungeness crab meat.

SLCHK = Sale of Chinook salmon.

UNLO = Unloading labor.

RWAS = Rotary washer capacity.

SOBC = Sorting, debacking and butchering Dungeness crab labor.

CBCK = Crab cooker capacity.

DEIC = De-icer capacity.

PCAP = Laitram PCA peeler capacity.

FSFL = Fish filleting labor.

CBPK = Crab picking labor.

PREP = Shrimp prepicking labor.

HANS = Salmon handling labor.

CNBR = Continuous briner.

PACF = Packaging fish fillets labor.

PACC = Packaging crab meat labor

PACS = Packaging shrimp meat labor.

SEMR = Automatic seamer capacity.

CDST = Cold storage capacity.

(Note: Activities are based on 1,000 pounds of the raw materials and finished products. Constraints are expressed in hours available per month or pounds of cold storage available per month.)

which maximizes "profit" to fixed factors is also maximizing net "profit" to the plant.

$$-\sum_{j=18}^{19} C_jX_j \quad \text{denotes} \quad -(C_{18}\text{PRCHK} + C_{19}\text{PRCOH}) \quad \text{where}$$

PRCHK and PRCOH mean procurement of Chinook and Coho salmon respectively in 1,000 pounds, and C_{18} and C_{19} are the costs of procurement of the two salmon species. Similarly, $-\sum_{j=41}^{42} C_jX_j$ is

$-(C_{41}\text{FSDAB} + C_{42}\text{FLING})$ where FSDAB and FLING are filleting 1,000 pounds of whole sand dab and ling cod respectively and C_{41} and C_{42} are their respective costs of filleting.

On the revenue side, $\sum_{j=74}^{75} P_jX_j$ is $(P_{74}\text{SLSHP} + P_{75}\text{SLDCW})$ where SLSHP and SLDCW are sales of 1,000 pounds of shrimp meat and whole cooked Dungeness crab respectively and P_{74} and P_{75} are the relative 1976 wholesale prices of shrimp meat and whole cooked Dungeness crab (F.O.B. plant).

An example of a constraint equation, unloading labor available,

$$\sum_{j=20}^{24} aijX_j \leq ri \quad \text{is}$$

$$(a_{6120}\text{BFUNL} + a_{6121}\text{DCUNL} + \ldots + a_{6124}\text{SCUNL}) \leq 352$$

hours of unloading labor for April. BFUNL, DCUNL, . . . , SCUNL are repsectively unloading 1, 000 pounds of bottomfish, Dungeness crab, . . . , snow crab; aij's are the coefficients of the various activities representing the number of hours required to unload 1, 000 pounds of species j.

The next step is to convert the theoretical economic model into an operations research model. A computer package put together at Northwestern University called Multi Purpose Optimization System (M. P. O. S. version 3. 2) was used to solve the problem on CDC 6000/ CYBER computers. REX (version 1) Linear Programming System developed at Oregon State University was also used. Three versions of the model were run on the CDC 6000/CYBER computers. However, the results of version 1 were analyzed.

Assumptions of the Model

> In addition, we know so little about the mechanisms at work in the economic sphere that there is enormous arbitrariness in any specifications. Economic theory provides several alternative models for explaining economic behavior but does not really help to narrow the range of hypotheses. Furthermore, passively generated data, for which we cannot control variables, and isolate relations, are often consistent with a variety of hypotheses. This means that there is considerable difficulty in discriminating among alternative hypotheses and some questions about whether our theories can be tested and whether the quantitative results have validity for any broader body of data (Martin, 1977).

Therefore, any statement of a model should include a statement of the assumptions that have been made, lest characteristics and niceties be attributed to the model that it does not possess. The niceties of the linear programming formulation hold true under certain assumptions.

One assumption of the linear programming formulation is that the ratio of output to input of any process is constant (linear) regardless of the level at which the process is being used.[52/] For instance, if 100 pounds of whole petrale sole yields 32.5 pounds of petrale sole fillets, then 200 pounds would give 65 pounds. This assumption neglects such factors as those caused by damaged or bruised fish (caused by overpacking the fish to a depth of more than one foot in the fish hold) and labor fatigue.[53/] However, O'Rourke (1971) states that this constant return to scale phenomenon can be defended because in an industry with simple technology (as in seafood processing) the labor input contributes the most to output.

The model also assumes that it will cost twice as much to double production and that sales revenues would also double with this twofold increase in production.[54/] Further, it is assumed that the

---

[52/] Note that "linear" is required only over a certain range.

[53/] Labor fatigue arising from poor work place design.

[54/] It neglects increases in production and thus reduction of sales prices due to increases in supply of the product.

procurement or acquisition costs of inputs are the same for all plants and that these resources are mobile. The model assumes that the processors can buy their fish from different fishers. However, it is known that the procurement costs of inputs in the seafood processing industry may very well vary from plant to plant and from geographical area to geographical area. In other words, these resources may not be entirely mobile due to traditional purchasing arrangements. This model assumes that these fish are available in unlimited quantities at the prevailing market prices (ex-vessel). This assumption allows for the analysis of the relationship between supply of fish and performance.

Further, a finite number of alternative business activities is assumed. For this study, the plant is assumed to maximize expected net revenues over variable costs to the plant as the relevant objective function, a measure of performance. Other assumptions as they relate to the model and/or to the linear programming formulation are pointed out as they occur.

Sources of Data

Ideally, the best source of data for linear programming formulation is from the records of the enterprise. For this study, it was not entirely possible to secure such complete cooperation from the industry. The input-output coefficients for the various activities to be compared and an estimated measure of the supply of the plant's facilities and resources were obtained from a number of different sources both primary and secondary. The constraints or supplies of resources and facilities available are stated in terms of the units in which they will be used in the model. For example, labor is separated into various categories, namely, filleting labor, shrimp prepicking labor and packaging labor.

The input-output coefficients of the 80 activities relate to 1,000 pounds of the activities, costs of raw materials and production process, and revenues from sales of 1,000 pounds of the finished products. The labor requirements for the various activities are expressed in hours per 1,000 pounds of the activity. The distribution of the labor is shown by month--January to December.

Standard recovery rates of unprocessed raw materials to finished products are used. Transfer equations as accounting procedures to transfer raw materials and partially processed products from one stage of the production line to another are employed to relate the conversion of 1,000 pounds of raw materials to 1,000 pounds of finished products (see Table 7 for recovery rates).

The reliability of the linear programming solutions is dependent on the accuracy of the data used in the model. Seafood processors, equipment manufacturers and fishers were interviewed in order to obtain the necessary data for the study. Data were also obtained from published reports and unpublished theses. The latter was mostly from the Oregon State University Department of Industrial Engineering. Federal and state employees concerned with the fishing industry also furnished some of the data used in this study.

Table 7. Recovery rates for fish and shellfish processing.

Species	Recovery Rates*
Dover sole	29% (3.448)
Petrale sole	32.5% (3.077)
Sand sole	32.5% (3.077)
English sole	27% (3.704)
Rock sole	30% (3.333)
Rex sole	40% (2.500)
Flounder	22% (4.545)
Sand dab	40% (2.500)
Ling cod	30% (3.333)
Pacific cod	28% (3.571)
Black cod	30% (3.333)
Rock fish	30% (3.333)
Pacific Ocean perch	30% (3.333)
Shrimp	21% (4.762)
Dungeness crab (whole)	90% (1.111)
Dungeness crab (meat)	25% (4.000)
King crab	39% (2.564)
Snow crab	37% (2.703)
Chinook salmon	90% (1.111)
Coho salmon	90% (1.111)

*Figures in parenthesis are the pounds of whole fish and shellfish required to yield one pound of finished product.

The various physical operations and policies of the plant have been made explicit. Attempts have also been made to synthesize most of the features of the Oregon seafood processing plants, thus reflecting Oregon's production and marketing system for seafood. Additionally, it is desirable that a linear programming model such as undertaken in this study should incorporate all of the variable costs associated with the plant activities. This ensures more accuracy.[55/]

Overall, the data used is based on four O. S. U. Industrial Engineering studies, performance records, labor union records and interviews with 8 seafood processors (see Appendix). However, the main thrust of the model is to provide the conceptual "framework" necessary for possible adaptation to specific individual plants using data from their own records. A discussion on the development of an algorithm is presented in a subsequent section.

Validation

Validation is a necessary and important part of a study seeking to understand the problem being investigated. It provides the basis for further understanding of real world phenomena.

[55/] In this study most if not all of the labor costs are included. This is because labor costs typically comprise 50 percent of the total processing costs. That is, processing, handling and other costs associated with the activities directly are included in the model. However, non-flow production stage activities like maintenance costs, and office and clerical costs are excluded.

For the purpose of this study key decisions in seafood processing management were mapped and highlighted. These incorporated decisions suggest sufficiently realistic modeling of the cooperating plant. Consultations with industry personnel were resorted to seek validation of the model. Results of the linear programming solutions were shown and reviewed by the manager of the cooperating plant. Particular attention was paid to the input-output relationships. The manager of the cooperating plant confirmed the realistic modeling of the production system.

The above confirmation and consultation with the Oregon seafood processing industry personnel regarding model building and model validation thus provide a reasonable level of confidence on the inferences or conclusions that will be drawn from the study.

Suggested Technological Changes

For the purpose of this analysis, the candidates for modernization, that is, introducing new technology would be mainly for bottomfish processing. Evaluating the impact of new technology is limited to bottomfish processing because of the following underlying reasons. First and foremost, there is presently no satisfactory mechanical devices suitable for Dungeness crab processing. As for shrimp processing there is industrywide application of the Laitram PCA shrimp cooker and peeler together with its complementary attachments. At the last count, there are at least 58 units in operation in Oregon. Manual shrimp "processing" is a thing of the past: "manual processing" at $514.00/1,000 pounds of shrimp was contrasted with "machine processing" at $158.00/1,000 pounds (Cheung, 1976). Salmon, as was pointed out earlier, does not require extensive processing. However, there are some new techniques of production which could be profitably adapted for industry use. Such a technique is the pneumatic "vacuum" unloading system. This can be used for all species except crab.

Pneumatic "vacuum" unloading system and the fish skinning machine[56/] constitute the "new technology" that is evaluated. Undoubtedly, there are other possibilities but the "technology package" selected will serve to illustrate the point.

Levels of Expected Net Revenues and Performance

The levels of expected net revenues and their deviations from each other, especially the deviations of the status quo solutions from the optimum solutions under existing technology and from the optimum solutions under new technology as obtained by linear programming would provide an approximate measure of plant performance. To a limited extent the impact of changing species composition on the

---

[56/] The fish filleting machine is not included because it is not "perfected" to be used for bottomfish species landed locally.

expected net revenues would give an indirect indication of the kind of environment the seafood processing plants are operating under. The percentages of the expected net revenues of the various processing solutions (including the status quo solutions) as obtained by linear programming with changing species composition relative to the optimum solutions would provide some indication of the reductions in expected net revenues from the optimum levels. These indicators may provide some clues regarding the barriers to improved performance of the seafood processing industry.

Small or large reductions in expected net revenues would arise when relatively small or large losses in expected net revenues result from the inclusion of excluded species into the processing solutions thus reflecting the species composition of the trawl haul and the maximum quantity of bottomfish actually landed by fishers. The lack of control of critical decision variables in the seafood environment may also give an indication of the kind of seafood market structure that has evolved over time.

VI. ANALYSIS

Modeled seafood processing plant performance is first analyzed, followed by a discussion on the performance of the fresh and frozen seafood processing industry. The plant operations analysis is presented next: analysis on material procurement, reserve procurement, product-mix and utilization of physical plant facilities.

The computer model solutions contain the following information (not all the information available in the solution will be reported):

1. Maximum value of objective function
2. Optimum raw material procurement
3. Optimum product-mix
4. Optimum pattern of resource use
5. Opportunity costs of activities, limiting resources and facilities
6. Computed right hand sides and slack constraints
7. Range right hand sides
8. Range objective function coefficient values

The results will be reported in tabular form. Further, the results are presented according to the month in which they occur. The following analysis is based on the results of the model based on version 1. The figures or values of the expected net revenues are used only for comparison purposes, that is, to test the hypothesis on plant performance within the linear programming framework. In no way, do these values on expected net revenues suggest that these levels of expected net revenues can actually be attained. This is because this part of the analysis assumes unconstrained supply of fish, and that other costs of seafood processing have not been included in the model. Also, some entrepreneurial objectives are not capable of being quantified within the model.

Levels of Expected Net Revenues and Plant Performances

Existing Technology

Table 8 provides a measure of the levels and deviations of the expected net revenues of the existing or status quo solutions from the optimum solutions (unconstrained supply) under both existing and new technologies within a linear programming framework. In addition, Table 9 describes the impact of the changing species composition on the expected net revenues of the plant modeled. Together they provide a reasonably reliable measure of the performance of the representative plant in utilizing and combining resources at the plant's disposal to produce the finished products.

Table 8 provides the absolute values of the objective function for 12 months under two technological conditions. These values provide a relative month-by-month comparison of the modeled plant performance. The product-mix of the optimum solutions is different from the

Table 8. Expected net revenue differences between status quo and optimum* solutions under present and new technologies. (Note: These figures are used only for comparison purposes. They do not suggest levels of expected net revenues that can actually be attained.)

	Solutions								
	(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)
Month	$	%		%	%	$	$	$	%
January	7619.23	4		--	--	183719.94	-	-	--
February	11786.19	6		--	--	183719.94	-	-	--
March	2196.82	1		--	--	183719.94	-	-	--
April	55487.51	23		--	--	243714.39	-	-	--
May	97490.52	14		98	12	678460.74	99038.38	780802.04	13
June	110907.54	16	$\bar{X} = 17$	98	14	678460.74	112700.91	780802.04	14
July	142447.03	21		98	18	678460.74	144763.60	780802.04	19
August	121318.07	18		98	16	678460.74	123499.81	780802.04	16
September	78515.79	12		--	--	676392.57	-	-	--
October	40238.07	6		--	--	676392.57	-	-	--
November	4046.62	3		--	--	148317.58	-	-	--
December	21112.00	11		--	--	183719.94	-	-	--
Mean	57763.78	11.25		98	15	432795.00	120000.67	780802.04	15.5

(1) Status quo solution with present technology.
(2) Status quo solution with present technology as a % of optimum solution with present technology.
(3) Status quo solution with present technology as a % of status quo solution with new technology.
(4) Status quo solution with present technology as a % of optimum solution with new technology.
(5) Optimum solution with present technology.
(6) Status quo solution with new technology.
(7) Optimum solution with new technology.
(8) Status quo solution with new technology as a % of optimum solution with new technology.

* "Optimum" as used in this study allows for various levels of fish procurements beyond status quo supply. To the extent that fish are not available beyond status quo supply, these optima may be unattainable.

Table 9. Impact of changing species composition on expected net revenues of status quo conditions of the modeled plant for 12 months.

	Expected Net Revenues as a Percentage of the Optimum Solution											
Solution	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.1	100	100	100	100	100	100	100	100	100	100	100	100
1.2	78	72	78	78	79	78	77	77	75	71	88	73
1.3	69	50	46	64	36	34	36	31	28	24	65	57
1.4	62	49	45	56	33	29	31	27	23	19	58	51
1.5	56	47	43	52	27	28	29	26	21	17	52	47
1.6	53	21	17	49	25	25	28	25	20	16	44	43
1.7	49	6	1	46	24	23	27	24	18	14	24	28
1.8	27	-	-	35	20	20	24	21	15	10	18	24
1.9	22	-	-	32	16	19	23	20	14	9	3	11
1.10	4	-	-	23	14	16	21	18	12	6	-	-

Results of the model as the species are constrained at their 5-year average availability of fish to the plant modeled as they appear in the solution. These excluded species are forced into the solution in addition to the optimum species as determined by the model. The inclusion of the excluded species thus would penalize the value of the objective function.

(Note: Solution 1.1 is the optimum solution while solutions 1.2 through 1.10 reflect status quo supply conditions with changing species composition. The last solution in each column is the actual status quo solution.)

product-mix of the status quo solutions in that the former product-mix suggests the processing of fewer species but in larger quantities. The status-quo product-mix consists of a larger number of species but in smaller quantities. Details are provided in a later section.

In terms of absolute difference in expected net revenues the January status quo solution value of \$7619.23 versus the January optimum solution value of \$183719.94 both under existing technology show an actual deviation of \$176100.71. This absolute difference is 96 percent of the value of the optimum solution. For July the absolute deviation between the two solutions under existing technology is \$536013.71 or 79 percent of the value of the optimum solution. On the average for 12 months the deviation between the two solutions under existing technology (i.e., status quo versus optimum solutions) is 88.75 percent. The range is between 77 to 99 percent. Further details can be seen from Table 8.

The value of the status quo objective function for January under existing technology constitutes only four percent of the value of the optimum solution under existing technology whereas in July it is 21 percent of the value of the optimum solution under existing technology. The average value of the status quo solution under existing technology for 12 months relative to the optimum solution is 11.25 percent. The range is between 1 to 23 percent.

Further, Table 9 indicates the impact of changing species composition on expected net revenues of the status quo solutions for 12 months relative to the optimum solutions for 12 months as the excluded species are forced into the solutions to reflect the existing 5-year average procurement levels of the modeled plant. For the month of August the percentage of the expected net revenue levels of the status quo solution in relation to the optimum solution goes from 100 percent (optimum solution) to 18 percent. Specifically, the levels of expected net revenues drop rapidly from 100 to 77 to 31 percent and thereafter drop relatively slowly to 18 percent as a result of including the excluded species into the solutions.

The above analysis provides evidence that the performance of the seafood processing plant modeled is significantly less than what is feasible. In other words, the existing resource combination and product-mix relative to the otpimum resource combination and product-mix for 12 months using the criterion of expected net revenue maximization is found to be significantly less than optimum.

New Technology

When new technology was introduced (as embodied in the suggested technology package) the status quo solution value of the objective function with existing technology is 15 percent of the optimum solution value under new technology for May, June, July and August combined. For the same four months combined the value of the status quo solution with existing resource combination and product-mix but under new technology is 15.5 percent of the value of the optimum solution under new technology. The range is from 13 to 19 percent for the latter case, that is, under new technology. The month to month differences are found in Table 8.

Differences between programmed or optimum resource combination and product-mix and existing resource combination and product-mix under both existing and new technologies occur primarily because of the availability of fish. Given the present limited landings of fish, new technology contributes an insignificant improvement to performance of the modeled plant, about 2 percent (status quo solution with existing technology is only 98 percent of the status quo solution with new technology). In fact, under present limited landings of fish or constrained procurement level of fish, improved resource combination and product-mix contributes slightly more to performance than new technology, 17 percent as opposed to 15 percent for May, June, July and August combined.

Under unconstrained procurement of fish, new technology contributes modest improvement to plant performance, about 13 percent. This is obtained by comparing the optimum solution net revenue ($678460.74) with existing or present technology and the optimum solution net revenue ($780802.04) with new technology. The optimum solution value with existing technology is only 87 percent of the optimum solution value with new technology.

Operations Analysis

The analysis in this section will be discussed by consolidating the months with similar fishing seasons. The analysis for the status quo solutions which require that these solutions be constrained or bounded at the 5-year average availability of fish to the plant modeled will be discussed by selected months. The months selected are only for expository purposes.

Optimum Solutions with Existing Technology and Unconstrained Procurement of Raw Materials

January, February, March and December Combined: Raw Material Procurement. Optimum raw material procurement as obtained by linear programming will be presented first followed by the status quo raw material procurement. Three of a possible 16 species are procured in the linear programming solution obtained. Procurement rates range from 446.66 thousand pounds to 72.43 thousand pounds. These activity levels represent the values of the basis variables when an optimum solution is reached.

Table 11 shows the 13 remaining species which did not enter the linear programming solution for January, February, March and December combined. The opportunity or penalty cost and the highest

Table 10. Linear programming determined raw material procurement for January, February, March or December.

	(Thousand Pounds)		
Species	Procurement Price	Activity Levels	Price Ranges Within Which Solution is Optimum
Ling cod	$160.00	446.66	$ 36.54-$197.95
Petrale sole	$290.00	433.34	$185.22-$335.00
Dungeness crab	$550.00	72.43	$INF -$773.22

(Note: The solution for each of the four months was identical.)

Table 11. Linear programming determined reserve raw material procurement for January, February, March and December combined.

	(Thousand Pounds)		
Species not in the Solution	Procurement Price	Opportunity Cost	Highest Feasible Price
Sand sole	$270.00	$45.00	$225.00
Rock fish	155.00	46.06	108.94
Black cod	137.00	66.25	70.75
Rock sole	230.00	71.97	158.03
Flounder	135.00	100.74	34.26
Rex sole	220.00	139.89	80.11
Sand dab	230.00	149.89	80.11
Snow crab sections	1,300.00	162.59	1,137.41
Dover sole	168.00	165.68	2.32
Pacific Ocean perch	155.00	176.98	-21.98
English sole	250.00	283.75	-33.75
Pacific cod	150.00	290.41	-140.41
King crab sections	2,900.00	1,691.00	1,209.00

feasible price for them are also shown in Table 11. The highest feasible price is the maximum price of the raw materials that should be paid within the linear programming framework. It is obtained by subtracting the opportunity (penalty) cost from the procurement price. For example, in January, February, March and December combined the linear programming solution indicates a maximum price of \$2.32/1000 pounds for Dover sole. In other words, if the manager of the plant modeled wants to process 1,000 pounds of Dover sole, the objective function value is penalized \$165.68 per 1,000 pounds. More startling is the finding on English sole, Pacific cod and Pacific Ocean perch. According to the solution obtained, seafood processors are losing money by processing these three species. For example, the linear programming result shows that bottomfish fishers may have to pay processors \$33.75/1,000 pounds of English sole the processors agree to buy from them. The range for these negative highest feasible prices is from -\$21.98/1,000 pounds for Pacific Ocean perch to -\$140.41/1,000 pounds for Pacific cod. Thus, the linear programming determined reserve raw material procurement can provide useful information to base procurement decisions on the next best raw materials to buy after the optimum raw materials are bought, that is, if there is a shortage of the optimum species or unavailability of such optimum species as determined by the model.

Price Sensitivity

Price sensitivity analysis can be done in one of two ways: 1) parametric analysis involving the change of one price at a time or 2) the objective function coefficients can be ranged by the linear programming routine. There is a difference in approach and result. The former involves the change of one price at a time and is carried out exogenously to the algorithm in the sense that the "old price" is removed and replaced with a "new price." The latter is done within the algorithm.

Price sensitivity through a parametric analysis of procurement costs (ex-vessel price) is not carried out extensively in this study except in one instance when Chinook salmon price was increased 15 and 50 percent respectively. The result of this parametric analysis was discussed in footnote 41. For parametric analysis to be valid, it has to consider one price change at a time.

Ranging within the linear programming routine measures the magnitude of procurement price change that can occur without affecting the final solution. Using the "RNGOBJ" command causes the algorithm to compute the range of the minimum and maximum values the C_j can assume without altering the final solution.

For the purpose of this study, price sensitivity was carried out using "RNGOBJ" command. This approach saves considerable time. Sensitivity of the expected net revenue maximizing procurement levels to "changes in procurement prices" is included in Table 10. Procurement price ranges are provided for each of the three species included in the optimum solution. Petrale sole, for example, priced at \$290.00/1,000 pounds is purchased at a rate of 433.34 thousand pounds in the final solution. The procurement of petrale sole remains optimum as long as petrale sole procurement price is between \$185.22 and \$335.00/1,000 pounds. Prices below \$185.22/1,000 pounds would result in increased procurement of petrale sole and if price of petrale sole is above \$335.00/1,000 pounds, procurement of petrale sole would be reduced from the final linear programming solution. Other species would then be substituted for petrale sole. Similar ranges are provided for ling cod and Dungeness crab which are in the final solution. These price ranges are wide (\$149.78 to \$161.41), thus indicating that they are not very price sensitive. However, if either side of a given price range falls close to the procurement price, the particular species becomes price sensitive and causes the procurement of that species to be reduced.

Dungeness crab procurement at 72.43 thousand pounds with a price range of \$INF to \$773.22 is at the maximum procurement level.

In other words, this means that the quantity of green Dungeness crab procured cannot be increased no matter how much the price of Dungeness crab is reduced. $INF indicates that this lower price range is unlimited. The upper range, $773.22 shows that 72.43 thousand pounds will be procured in the linear programming solution as long as the price does not go above $773.22/1,000 pounds. In short, if either side of a price range is unlimited, it indicates that the procurement is at the minimum or maximum level.

In closing, it is worthwhile to point out that price ranges which keep the solution optimum are valid only if they are considered one at a time. Therefore, if procurement price changes involve numerous species, a new optimum solution has to be computed again.

Product-Mix. The composition of products is in part determined by the raw material procured according to the linear programming solution presented earlier. "In part," because there is one difference, namely product forms may be varied. Therefore, the total number of finished products is dependent on the product form alternatives which in turn are determined by costs of processing, recovery rates, raw material and product markets conditions and plant's facilities.

A total of 880 thousand pounds of bottomfish and 72.43 thousand pounds of green Dungeness crab were procured in the solution for each of the four months. These yield 140.83 thousand pounds of petrale sole fillets and 134.01 thousand pounds of ling cod fillets and 18.11

thousand pounds of Dungeness crab meat per month. Table 12 summarizes the product-mix solution within the linear programming framework.

Table 12. Linear programming determined product-mix for January, February, March and December combined.

Product forms	Selling Price	Activity Levels	Price Ranges Within Which Solution is Optimum
	(Thousand Pounds)		
Ling cod fillets	$1,000.00	134.01	$873.52-$1,411.50
Petrale sole fillets	1,750.00	140.83	1,611.50- 2,072.40
Dungeness crab meat	3,560.00	18.11	3,484.40-$INF

Utilization of Physical Facilities. Only the non-slack resources will be highlighted and the ranges within which the final linear programming solution remains optimum are given. Table 13 summarizes the optimum utilization of the plant's facilities. It involves the complete utilization of the fish filleting labor at 3,520 hours, rotary washer capacity at 176 hours, and sorting, debacking and butchering Dungeness crab labor at 176 hours. The other eight constraints have excess capacity. Since all of the filleting labor, washer capacity and butchering labor are used up they would have opportunity costs associated with their limited supply. For example, an additional hour of filleting labor is worth $32.73 to the plant modeled. Technically, this means that the marginal value product of the filleting labor is

Table 13. Linear programming determined utilization of plant facilities for January, February, March and December combined.

Plant Facilities	Available Capacity* (Hours)	Capacity Used (Hours)	Excess Capacity (Hours)	Range of Capacity Within Which Solution is Optimum (Hours)
Rotary washer capacity	176	176	None	119.02-233.73
Sorting, debacking and butchering Dungeness crab labor	176	176	None	0 -256.48
Fish filleting labor	3,520	3,520	None	1,885.1 -5,205.1
Unloading labor	352	266.84	85.16	-
Crab cooker capacity	176	20.28	155.72	-
Crab picking labor	4,400	1,321.8	3,078.2	-
Continuous briner cap.	352	68.99	283.01	-
Packaging fish fillets labor	528	86.85	441.15	-
Packaging crab meat labor	176	120.77	55.23	-
Automatic seamer cap.	176	18.11	157.89	-
Cold storage capacity (pounds)+	610,000	292,950	317,050	-

*8-hour day for 22 days/month.

+Based on 55,000 pounds at 3-day turnover rate and 60,000 pounds truck cold storage parked outside plant.

$32.73/hour. Similar interpretations hold for the other non-slack facilities or resources.

Status Quo Solutions with Existing Technology and Constrained Procurement of Raw Materials

The above has been concerned with "what could be" or optimum conditions of the modeled plant, that is, no external bounds or constraints on procurement activities are placed on the plant modeled. However, in order to simulate existing or status quo conditions for comparison purposes, it is necessary to place constraints on procurement. These constraints reflect the 5-year average procurement activities of the plant modeled. The data are similarly broken down by months (January is illustrated for expository purposes).

Constraints on Procurement Activities. The availability of fish and shellfish to the plant modeled based on a 5-year average is provided in Table 14. For example, the 5-year average procurement level of green Dungeness crab in January is 30,000 pounds.

January (Constrained Solution-First Version): Raw Material Procurement. Since petrale sole, ling cod and green Dungeness crab cannot be procured at the quantities as determined by linear programming, these three species are then constrained to their 5-year average availability to simulate existing conditions. After satisfying the 5-year average availability of the raw materials procurement for

Table 14. 5-Year average availability of fish and shellfish to plant--1973-77 (thousand pounds).

Species	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Dover sole	--	--	--	19	44	44	33	31	32	31	8	25
Petrale sole	4	2	2	19	35	43	95	55	57	27	7	11
Sand sole	6	5	4	7	11	3	2	13	7	4	3	2
English sole	85	34	9	31	37	24	29	39	54	68	52	47
Rock sole	1	--	--	1	2	-	3	5	1	-	--	--
Rex sole	1	1	1	3	5	5	4	3	5	4	1	1
Flounder	3	8	4	6	4	1	1	5	5	5	1	9
Sand dab	1	1	1	1	3	2	3	2	3	4	7	4
Ling cod	3	2	2	10	14	42	83	56	30	10	4	3
Pacific cod	--	--	--	-	-	-	-	-	1	-	--	--
Black cod	--	--	--	2	8	13	9	10	13	6	2	6
Rock fish	6	6	3	38	32	30	47	58	50	11	34	11
Pacific O. perch	--	--	--	17	31	49	51	55	14	8	1	8
Shrimp	--	--	--	175	292	256	257	266	213	121	--	--
Dungeness crab	30	84	40	46	80	59	15	4	4	-	--	82
Chinook salmon	--	--	--	-	1	5	10	10	2	1	--	--
Coho salmon	--	--	--	-	-	19	39	25	5	1	--	--

Source: Memorandum of Agreement does not allow disclosure of source.

petrale sole, ling cod and Dungeness crab, the linear programming solution indicates the following procurement as seen in Table 15. In addition to petrale sole, ling cod and Dungeness crab at the specified 5-year average procurement levels, the linear programming solution indicates the purchase of sand sole at 409.05 thousand pounds and rock fish at 463.95 thousand pounds. Table 16 provides the breakdown of the species that did not appear in the solution when ling cod, petrale sole and Dungeness crab procurement were specified at their 5-year average procurement levels. In addition, Tables 17 and 18 present the constrained product-mix and utilization of physical facilities solutions for January.

However, both sand sole and rock fish have procurement restrictions under existing conditions. These are then specified into the model and the solution obtained. Table 19 presents the order in which the different species come into the solution after the respective procurement restrictions are specified. These fish and shellfish resources constrained at their 5-year average procurement levels consequently have opportunity costs associated with them.

Cost of Deviation

The costs of deviation from the optimum solution as obtained by the linear programming model is presented next. The opportunity cost and the highest feasible price in Table 19 are interpreted in a

Table 15. Linear programming determined constrained raw material procurement for January.*

Species	Procurement Price (Thousand Pounds)	Activity Levels	Opportunity Cost	Price Ranges Within Which Solution is Optimum
Ling cod	$160.00	3.00	$ 46.11	-
Petrale sole	290.00	4.00	45.00	-
Dungeness crab	550.00	30.00	223.23	-
Rock fish	155.00	463.95	-	$110.90-162.78
Sand sole	270.00	409.05	-	250.06-289.06

*This table relates to the situation where constraints are specified for the optimum raw material.

Table 16. Linear programming determined reserve constrained raw material procurement for January.*

Species not in the Solution	Procurement Price (Thousand Pounds)	Opportunity Cost	Highest Feasible Price
Rock sole	$230.00	-	-
Black cod	137.00	$ 20.35	$ 116.65
Flounder	135.00	55.44	79.56
Rex sole	220.00	95.77	124.23
Sand dab	230.00	105.77	124.23
Dover sole	168.00	121.45	46.55
Pacific O. perch	155.00	131.85	23.15
Snow crab sections	1300.00	162.59	1137.41
English sole	250.00	239.75	10.25
Pacific cod	150.00	244.30	-94.30
King crab sections	2900.00	1691.00	1209.00

*This table relates to the situation where constraints are specified for the optimum raw materials.

Table 17. Linear programming determined constrained product-mix for January.*

Product Forms	(Thousand Pounds)		
	Selling Price	Activity Levels	Price Ranges Within Which Solution is Optimum
Ling cod fillet	$1000.00	0.90	$ 846.30-$INF
Petrale sole fillet	1750.00	1.30	1611.50-$INF
Dungeness crab meat	3560.00	7.50	3484.40-$INF
Rock fish fillet	850.00	139.20	824.08-996.97
Sand sole fillet	1550.00	132.94	1491.30-1611.30

*This table relates to the situation where constraints are specified for the optimum raw materials.

Table 18. Linear programming determined constrained utilization of plant facilities for January.*

Plant Facilities	Available Capacity (Hours)	Capacity Used (Hours)	Excess Capacity (Hours)	Range of Capacity Within Which Solution is Optimum (Hours)
Rotary washer capacity	176	176.00	None	119.41-233.73
Sorting, debacking and butchering dungeness crab labor	176	72.9	103.1	-
Fish filleting labor	3520	3520.00	None	2044.3-5193.8
Unloading labor	352	262.64	89.36	-
Crab cooker capacity	176	8.4	167.6	-
Crab picking labor	4400	547.5	3852.5	-
Continuous briner capacity	352	28.58	323.43	-
Packaging fish fillet labor	528	86.69	441.31	-
Packaging crab meat labor	176	50.03	125.97	-
Automatic seamer capacity	176	7.5	168.5	-
Cold storage capacity (pounds)	610,000	292,429	317,571	-

*This table relates to the situation where constraints are specified for the optimum raw materials.

Table 19. Linear programming determined constrained raw material procurement and the order in which they appear in the solution. +

Species in Order of Appearance	Procurement Price	(Thousand Pounds) Activity Levels	Opportunity Cost	Highest Feasible Price
Ling cod	$160.00	3.0	$129.60	$289.60
Petrale sole	290.00	4.0	253.06	543.06
Dungeness crab	550.00	30.0	223.23	773.23
Rock fish	155.00	6.0	88.94	243.94
Sand sole	270.00	6.0	208.07	478.07
Rock sole	230.00	1.0	232.99	462.99
Black cod	137.00	*	150.31	287.31
Rex sole	220.00	1.0	-	-
Flounder	135.00	3.0	118.60	253.60
Sand dab	230.00	1.0	200.21	430.21
Dover sole	168.00	*	204.17	372.17
Pacific Ocean perch	155.00	*	178.81	333.81
English sole	250.00	85.0	80.57	330.57
Snow crab sections	1300.00	62.17	-	-

+Represents status-quo conditions

*None purchased by plant in January for the last five years.

slightly different fashion as compared to its usage in earlier sections. This is because procurement levels for raw materials were specified thus, not allowing the procurement of the most economical raw materials in the desired quantities as determined by linear programming according to the criterion of expected net revenue maximization.

Table 20. Linear programming determined constrained product-mix for January. +

Product Forms	(Thousand Pounds) Selling Price	Activity Levels	Price Ranges Within Which Solution is Optimum (1)
Ling cod fillet	$1000.00	0.90	$568.03-$INF
Petrale sole fillet	1750.00	1.30	971.32-INF
Dungeness crab meat	3560.00	7.50	3484.40-INF
Rock fish fillet	850.00	1.80	553.57-INF
Sand sole fillet	1550.00	1.95	909.78-INF
Rock sole fillet	1650.00	0.30	873.44-INF
Rex sole fillet	1170.00	0.40	INF-INF
Flounder fillet	1250.00	0.66	710.95-INF
Sand dab fillet	1170.00	0.40	669.47-INF
English sole fillet	1370.00	22.95	1071.60-INF
Snow crab meat	3500.00	23.00	(not available)

+Represents status-quo conditions.
(1) Represents the case when the species are constrained as they appear in the solution.

For example, the plant modeled has over the past five years procured up to 3,000 pounds of ling cod; however, the optimum solution as determined by linear programming indicates a procurement level of 446.66 thousand pounds. In other words, in order to maximize the expected net revenues to the plant modeled, it is required to

Table 21. Linear programming determined constrained utilization of plant facilities for January.+

Plant Facilities	Available Capacity (Hours)	Capacity Used (Hours)	Excess Capacity (Hours)
Unloading labor	352.0	37.5	314.5
Rotary washer capacity	176.0	22.0	154.0
Sorting, debacking and butchering Dungeness crab labor	176.0	72.9	103.1
Crab cooker capacity	176.0	25.8	150.2
Fish filleting labor	3,520.0	911.0	2,609.0
Crab picking labor	4,400.0	2,189.7	2,210.3
Continuous briner capacity	352.0	167.9	184.1
Packaging fish fillet labor	176.0	168.0	8.0
	52.8	9.7	518.3
Automatic seamer capacity	176.0	7.5	168.5
Cold storage capacity	610,000.0	61,158	548,842

+Represents status-quo conditions.

process 446.66 thousand pounds of ling cod, among others. But the plant modeled only was able to buy an average of 3,000 pounds of ling cod in January in the past five years. The plant modeled is, therefore, foregoing one of the best or optimum alternatives based on expected net revenue maximization. As such, the plant modeled is sacrificing considerable revenues by processing other species not included in the linear programming solution. By being limited to only 3,000 pounds of ling cod and no more for the last five years, the plant modeled is foregoing \$129.60 for every 1,000 pounds of ling cod. The modeled plant's objective function value is thus reduced by \$129.60 for every thousand pounds of ling cod the plant modeled is not able to procure and process. In other words, the plant modeled can pay up to \$289.60/1,000 pounds of ling cod (i.e., procurement price plus the opportunity cost = highest feasible price) instead of the \$160.00/1,000 pounds procurement price.

<u>January (Constrained Solution-Second Version)</u>: A slightly different approach was taken to run the same model discussed above: instead of constraining the raw material procurement activities as they appear in the solution, the model was run with all the procurement activities specified at their 5-year average procurement levels in one run. In other words, the order in which the various species appear in the solution as they are constrained was not required in the second version. Except for the manner in which the constraints were

specified, the second version is the same as the first version.

Raw Material Procurement. The final linear programming solution and the value of the objective function remain the same as the results of the first version. There is, however, additional information in the second version which is not available in the first version. Further, details on opportunity costs available in the first version are found under the artificial variables in the second version and they are known as constraint costs or specification costs. Table 22 presents the linear programming results of the second version. The slack column indicates whether the specified procurement levels are restrictive. The zero slack values throughout indicate that these constraints are limiting. However, if the slack value comes into solution at a positive level, the constraint is not limiting (IBM, no date).

Table 22. Procurement constraints and constraint costs for January.

	(Thousand Pounds)				
Species	Constraint Level	Slack	Minimum Level	Maximum Level	Constraint Costs
Petrale sole	4	0	0	445.09	$253.06
Sand sole	6	0	0	447.09	208.07
English sole	85	0	0	365.10	80.57
Rock sole	1	0	0	348.83	232.99
Rex sole	1	0	0	294.80	210.21
Flounder	3	0	0	537.13	118.60
Sand dab	1	0	0	294.80	200.21
Ling cod	3	0	0	773.00	129.60
Rock fish	6	0	0	776.00	88.94
Dungeness crab	30	0	0	34.79	223.23
Snow crab sections	62.17	0	0	66.38	-439.48

The constraint cost indicates the cost of incorporating the restrictions in the model.[57/] For example for the sand sole constraint the constraint cost is \$208.07/1,000 pounds. This means that for each 1,000 pounds of sand sole the modeled plant is able to process in addition to the 6,000 pounds specified at the 5-year average procurement level and up to 447.09 thousand pounds (i.e., the relaxation of the constraint), the expected net revenue is increased by \$208.07/1,000 pounds. Further, the range indicating the minimum and maximum levels in Table 22 tells us the range over which the constraint costs are applicable. In the case of sand sole, the constraint or marginal cost, \$208.07, is applicable from zero to 447.09 thousand pounds. The range for which these marginal costs remains the same is useful information on which to base changes in the linear programming solution (Puterbaugh, 1957).

January (Constrained Solution-Third Version): Another slightly different approach was yet taken to run the same model developed in the two previous cases. This time, instead of constraining the raw material procurement activities as they appear in the solution or

---

[57/] The constraint cost is known technically as the marginal cost. Also, at the optimum combination of species, the marginal cost for those species forming a part of the optimum solution is zero (Puterbaugh, 1957). See H. L. Puterbaugh, et al., "Analyzing the solution tableau of a simplex linear programming problem in farm organization," Journal of Farm Economics, Vol. XXXIX, No. 2, May 1957 for more information.

constraining the procurement activities at the specified 5-year average procurement levels at the outset, the third version specifies the 5-year average procurement levels endogenously as ratios. This means that the ratios of the procurement proportions of the various species are built into the model. These ratios are reflected in the bottomfish mix. While the procurement levels were specified exogenously in the first two cases, the third version specified them endogenously.

Raw Material Procurement. An entirely different solution was obtained from the third version as compared to the other two versions. This is because the procurement levels are not specified at their absolute quantities and thus the model solution indicates an optimum solution reflecting the built-in procurement ratios for the 5-year average availability of bottomfish. Table 23 provides a comparison of the three versions.

The procurement levels of the third version are different from those of Versions 1 and 2 because of the nature of the procurement specifications. Versions 1 and 2 represent constrained procurement levels whereas the third version assumes unconstrained procurement levels. Version 3 seeks to identify the "what could be" situation as opposed to "what is" condition given the ratios of the availability of bottomfish for the last five years. Version 3 differs from the first version in one important respect, that is, in the first version no such procurement ratios of the availability of bottomfish were specified. The first version assumes that all the species are available freely without any ratios relating one species to another. Species composition of trawl haul or the ratios/proportions of the availability of bottomfish for the last five years were ignored in the first version.[58/]

Table 23. Comparison of Versions 1, 2 and 3 procurement levels for January.

Species	(Thousand Pounds) Version 3	Version 1	Version 2
Petrale sole	15.3	4	4
Sand sole	23.4	6	6
English sole	328.5	85	85
Rock sole	3.8	1	1
Rex sole	3.8	1	1
Flounder	11.5	3	3
Sand dab	3.8	1	1
Ling cod	11.5	3	3
Rock fish	23.4	6	6
Dungeness crab	30.0	30	30
Snow crab sections	62.2	62.2	62.2
Objective function value	$39181.00	$7619.23	$7619.23

[58/] Version 3 did not address the species composition issue although it attempted to reflect the ratios of the availability of bottomfish in the last five years.

VII. RESULTS AND RECOMMENDATIONS

> . . . optimality is a logical property of formal models; whether or not it is a meaningful characteristic of human behavior is of course a subjective matter . . . . (however), . . . subject to such reservations, optimization theory and methods occupy key roles in the understanding and control of human economic affairs (Martin, 1977).

According to Heady (1958),

> programming often results in plans which are somewhat unlike those typically used by (farmers). Linear programming is mainly a procedure for providing answers to problems which are so formulated.

These programming solutions merely suggest certain desirable ADJUSTMENTS in existing conditions (in this study, in existing plant operations to improve plant performance based on expected net revenue maximization).

Given the disparity between a regulated-and-naturally occurring seasonal supply of fish and shellfish relative to a given demand pattern (as embodied in the data used), this chapter discusses the results and recommendations of the study. Results of the model should be interpreted with an eye on their underlying assumptions.

Plant and Industry Performance

Presented below are possible adjustments in existing conditions, or areas where seafood processing performance opportunities exist. The analysis of the linear programming solutions in terms of resource combinations and product-mix indicates that the level of the modeled plant performance is significantly less than that which could be feasible within existing conditions. The analysis also shows that the availability of the basic ingredients, fish, is the biggest single obstacle in ensuring improved plant performance within the linear programming framework. The various solutions on resource combination and product-mix as determined by the model are different for different quantities of fish and shellfish available.

Specifically, linear programming analysis has shown that the modeled plant performance could be increased by as much as 90 percent over the existing resource combination and product-mix. Plant performance could be improved if more fish are available and seafood processors have the management know-how. The results of this study also show that there is excess capacity in certain plant facilities for each of the 12 months given the existing levels of production and product-mix. Excess capacity would still arise in certain facilities even if the plant modeled processed the optimum (greater) quantities of fish as determined by the model for each of the 12 months.

Between the two methods of improving plant performance, that is, either (1) improving resource combination and product-mix or (2) introducing new technology, the analysis indicates that gains or increases in expected net revenues are modest when new technology is introduced. Expected net revenues to the modeled plant with improved resource combination and product-mix under <u>new</u> technology are about 13 percent higher than are expected net revenues with improved resource combination and product-mix under <u>present</u> technology. The absolute difference between the two methods of improving plant performance is \$780802.04 minus \$678460.74 = \$102341.30 or 13 percent under conditions of <u>unconstrained</u> procurement of raw materials. This means that the availability of certain fish must be greatly increased before the benefits of new technology can be obtained.

Based on the analysis of four months (May, June, July and August--months when all 19 species are landed), the linear programming results show only a difference of two percent between the existing resource combinations and product-mix, and the optimum resource combinations and product-mix under existing and new technologies respectively and <u>constrained</u> procurement levels. This means that new technology does not contribute significantly to plant performance under conditions of constrained procurement of fish. Therefore, the analysis of the existing and optimum resource combination and product-mix under present and new technologies with constrained procurement levels (or the present limited availability of fish) indicates that the plant modeled will not benefit as much from new techniques of production as it will from reorganizing the plant's resource combinations and product-mix. Such reorganization of production operation entails improved management know-how.

Barriers to Improved Performance

The deviations and levels of the expected net revenues or "profit rates" with changing species composition reflect the limited availability or landing of fish at the present time. There are risks associated with such limited quantity of fish landed. To be sure profits are made but these profit levels are so unstable as to make any effort on the part of the processors to improve performance to upset the individual status quo positions of the processors within the industry. Processors feel more secure in leaving things as they are presently instead of "rocking the boat" by upgrading their management skills or trying out new innovations which require substantial capital investment to improve performance.

Therefore, greater availability of certain fish must first be assured in order to secure improved plant and industry performance. To encourage greater availability of fish, however, would require important changes in the market place where fish are procured and finished products sold. The existing arrangement of supplying fish to processors based on traditions and mutual benefits between fishers and processors (as alluded to earlier) is not expected to encourage the landings of greater quantities of fish. Fishers also have to learn how to catch only certain fish. Some research into species-specific year technology is presently being done (Interview, 1977).

Even if there are greater availability of fish and a desire to improve performance, present management in the industry may not have the necessary information needed to accomplish it. This study has partly provided such information. With increased interest in ocean ranching for salmon the availability of salmon may be greatly increased. Such increase in salmon numbers as well as the anticipated increase in fish landings stemming from the 200-mile limit would provide some of the necessary conditions for processors to improve processing performance.

Patterns of Resource Utilization

This study has inquired whether current resources and facilities owned by the modeled plant are organized in a manner that will maximize expected net revenues to the plant. It also posed the questions of what products and in what product-forms should the plant undertake and also should the plant manager of the modeled plant undertake to process additional products by species or to eliminate some products from his existing product-mix?

The answer to the first question according to the model is that the seafood processing plant modeled is not organized in a manner that maximizes expected net revenues to the plant. The optimum solution which maximizes expected net revenues as determined by the model calls for greatly increased procurement of ling cod, petrale sole, shrimp, Dungeness crab and Chinook salmon and the elimination of all the other remaining species considered, some of which are being presently processed.

For the months of January, February, March and December combined Pacific cod, English sole and Pacific Ocean perch show negative highest feasible prices as determined by the model. These negative highest feasible prices mean that fishers have to pay the manager of the modeled plant if the manager agrees to buy these fish. This is because if the manager processes these three species, his expected net revenues would be reduced. Fishers are known to accept lower prices for discards or to throw discards overboard because seafood processors are not willing to accept them. However, one should recognize that procurement decisions are not determined unilaterally in the fish market.

And as for whether the green Dungeness crab should be processed into shell crab or Dungeness crab meat, the solution suggests that the green Dungeness crab should be processed into Dungeness crab meat and not whole cooked or shell crab. To process all of the green Dungeness crab into shell crab would have reduced the modeled plant's expected net revenues by $18.90 per thousand pounds in January, February, March and December combined. However, for July, to process all of the green crab into shell crab would decrease the value of the objective function by $525.11 for every thousand pounds.

Shell crab is not suggested in the optimum solution for February. However, the status quo solution for February indicates that the plant modeled should allocate the procurement of green Dungeness crab of 72.43 thousand pounds (although constrained at 84 thousand pounds) between shell crab and crab meat. Out of the 72.43 thousand pounds, the model indicates the allocation of 37.64 thousand pounds for shell crab and 34.79 thousand pounds for Dungeness crab meat. These yield 33.88 thousand pounds of shell crab and 8.70 thousand pounds of crab meat respectively.

Substitution Possibilities

Throughout the 12 months the computer results for the optimum solutions under present technology have the modeled seafood processing plant producing large quantities of petrale sole, ling cod, shrimp, salmon and Dungeness crab. These suggested quantities are more than what have historically (in the last five years, 1973-1977) been available to the state, let alone in each individual port or to each seafood processor. Such circumstances dictated by the nature or characteristics of the industry compel that fewer pounds be processed. These have ramifications for fishery management and enhancement programs.

Besides processing fewer pounds there are likely candidates for substituting excluded species for the "optimum species" with only minimal impact on expected net revenues. Table 24 gives the order of the species with those having the least impact on expected net revenues listed first. Such species include rock sole, sand sole, flounder, etc. for July.[59/]

Table 24. Excluded species in their order of ascending impact on expected net revenues for July.

Species	Opportunity Cost (Thousand Pounds)
Rock sole	$ 0.64
Sand sole	$ 45.00
Flounder	$ 52.72
Dover sole	$ 52.98
Pacific true cod	$ 98.47
Rex sole	$ 101.26
Ling cod	$ 104.02
Sand dab	$ 111.26
English sole	$ 129.66
Rock fish	$ 144.69
Black cod	$ 146.91
Pacific Ocean perch	$ 172.41
Coho salmon	$ 341.06
Snow crab sections	$ 450.67
King crab sections	$1994.70

In conclusion, it is seen that the linear programming model has been helpful in pinpointing critical procurement activities as they relate to expected net revenue maximization, critical resource areas and the marginal values of these critical resources. The model also

[59/] These opportunity costs are also found in the tables on reserve raw material procurement.

shows how the various species add to or subtract from the value of the objective function. It also shows the changes resulting from changes in prices, raw product availability and resource constraints.

Management Tool and Improved Decision-Making

By relying on a management tool such as linear programming, it is observed that a range of controllable decisions such as resource combination (utilization of resources, procurement of raw materials), pricing policy or guide, product-mix and input-output ratios (technology) can be made by the manager of the plant modeled which will adjust his plant operations to increase revenues in an otherwise relatively uncertain environment. Linear programming can provide management with useful information. More specifically, the level of output and the product-mix and their contributions to revenues is found to be dependent on the decisions of all the inter-related components of the entire production system. Suboptimization arising from ad-hoc or piecemeal decision-making is a problem and is found to contribute to low performance.

Besides identifying the optimum resource combination and product-mix of the plant modeled within the linear programming framework, this study has also shown the optimum mix of production techniques in seafood processing.

Fringe Benefits to Producers and Consumers

This study has important welfare-improving implications in that the conditions set out for attaining improvements in plant performance help to identify where improvements in resource utilization can be obtained. Although the study has revolved around the seafood processor per se, the welfare of society at large would be improved if the performance of the seafood processing industry is improved (including an increased availability of certain fish).

An Algorithm

A conceivable by-product stemming from this study would be to extend the information obtained to the target group: seafood processors. Along this line, a modified algorithm can be put together for direct application by seafood processors. It may be made available through the Oregon State University Marine Advisory Program Office, a service similar to the farm management service provided by the United States Department of Agriculture and land grant universities. In order that full benefits arising from the algorithm be realized, it is important that there be complete interaction and cooperation among research and extension personnel on the one hand, and seafood processors on the other. This is essential because without such interplay, the algorithm cannot be made meaningful and relevant to the processors' information needs. Alternatively, management consultants could be contracted to provide the same service.

Limitations of the Study

In retrospect, what was considered a limitation of the study turns out to be a redeeming feature. At the outset, it was sought to develop a model which would reflect the species composition of trawl landings. However, due to the unstable and unpredictable species composition, a model with the different species was adopted as the next best approximation. It turns out that the latter choice provides considerably more information: it gives information on species procurement, buying and selling prices and their price ranges. The "species composition" model would yield information on the mix as a whole because weighted averages would have been used to reflect the prices of the mix and other coefficients. Most of all, the availability of data and data weaknesses are considered to be a limitation to the accuracy of the analysis of this study. Such limitations notwithstanding this study has provided a test of the existing performance against an ideal performance of the Oregon seafood processing industry.

Discussion

Various authors have written on the existence of inefficiency (Leibenstein on X-inefficiency; Schwartzman on competition and non-guarantee of efficiency; Stigler's criticism on the existence of X-inefficiency). They attribute such inefficiency to various factors such as non-maximizing behavior, incomplete contracts, effort discretion, quality of supervision, traditions of a firm, employee morale, administrative and operating practices. Schwartzman (1973) argues that competition does not necessarily lead to the elimination of inefficiency.

Further Barriers to Performance: A Speculation

According to Schwartzman (1973),

> technical efficiency refers to the cost of a given output in a single firm and not to the effect of changes in output on cost either in a firm or in an industry. Consequently we can ignore the effect of the firm's demand curve on its output and thus the number of firms.

Ideal performance, according to economic theory, depends on the presence of competition and the use of the competitive model and its assumptions to explain such conditions. These are necessary but not sufficient conditions. Ideal performance depends on more than the presence of competition.

Although Schwartzman (1973) argues that a perfectly competitive market structure does not assure maximum technical efficiency (or at the least, competitive pressures do not eliminate inefficient techniques of production), it appears that the market structure in Oregon's seafood industry is imperfectly competitive. Imperfectly competitive markets are even much less likely to bring about maximum technical efficiency. Market relationships between fishers, processors and seafood distributors have evolved through years of traditions and these serve to maintain the seafood processors' status quo positions within the industry. The processor's control of his market (market share) enables him to make profits. Their market power takes the form of market control. In Oregon, the four largest processors buy 46 percent of the salmon (Smith, 1975), and in 1973 the four largest processors processed 59 percent of the total fish landed in Oregon. Further, based on Smith's research the four largest plants in Washington buy 98 percent of the tuna, 98 percent of the crab, 80 percent of the groundfish, 77 percent of the halibut and 40 percent of the salmon.

Oftentimes, the processors in their bid to procure fish engage in non-price competition. Processors are known to provide significant subtle fringe benefits to "loyal" fishers. Such benefits take the forms of bonuses, free ice, shower facilities and most importantly by openly telling their fisher-suppliers who fish multi- or combination fishery that they have to sell their salmon to the processors or the processors would not buy their Dungeness crab or shrimp.

The absolute small number of processors in relation to the large number of heterogenous fishers (draggers, trollers, shrimpers and crab fishers) in the primary raw material market therefore provides the processors an oligopsonistic leverage in their transactions with the fishers. Besides, their special ties with the fishers and seafood distributors as well as their specialized knowledge of the industry help to further sustain their status quo positions within the industry. However, it is possible that in the near future, a "bilateral monopoly" situation would arise stemming in part from the recent interest shown by fishers to organize themselves into fishers' associations. These fishers organizations would have more bargaining power in dealing with the processors. To a very small extent it is already occurring as indicated by the strike in California and Oregon. These fishers are seeking higher prices for their fish.

In addition to the individual firm's combinations of resources, operating conditions and quality of the resources used as determining performance, performance in seafood processing is also subjected to several factors unusual to the industry. Seafood processing performance is affected by perishability and poor keeping quality of fish, processing yield, man's inability to husband or culture fish, man's inability to control species composition, lack of species specific gear technology, stock availability of the desired species, unpredictable and volatile supply and imbued traditions. This implies that efficiency and performance of the seafood processing industry can be compared to "landfood" industry only with considerable recognition of these unusual factors discussed above. These unusual characteristics may act as barriers to improved performance of the seafood industry.

VIII. SUMMARY AND CONCLUSIONS

The performance of the seafood processing plant modeled is found to be significantly less than what it could be within the existing economic and technological conditions. Improved seafood processing performance requires greater availability of certain fish. Greater availability of fish would provide some of the conditions needed for improved resource combination and product-mix and the introduction of new technology within the linear programming framework. Both improved resource combination and product-mix or new technology would improve plant performance but new technology contributes more to improved plant performance under unconstrained procurement of fish than under constrained procurement of fish. However, under present technology and unconstrained procurement of fish, improved resource combination and product-mix contributes more to improved plant performance than existing resource combination and product-mix.

The magnitude of improvement in plant performance in terms of increased expected net revenues between existing and new technologies under unconstrained procurement levels is about 13 percent. Under constrained procurement levels, the magnitude of improvement in plant performance between new and existing technologies is only two percent. Under present technology and unconstrained procurement levels, the magnitude of improvement in plant performance between improved resource combination and product-mix, and the existing resource combinations and product-mix is about 90 percent. Further, under unconstrained procurement of fish, improved resource combination and product-mix contributes more to plant performance than new technology.

Increased availability of fish, however, requires important changes or modifications in the existing raw materials and final products markets. Further research on how to encourage greater quantities of fish to be landed is indicated. Present arrangement of supplying fish to processors would not encourage the landing of greater quantities of fish of certain species. However, if greater availabilities of fish cannot immediately be assured, then perhaps seafood processors may want to look into their price policy in procuring fish.

Improvement in plant and industry performance, in addition to the conditions discussed above also depends on improvement in the present decision-making process relied upon by seafood processors. The total systems approach used in the model is an improvement over the present approach. There are a number of such total systems approach tools available today to facilitate improved decision-making. One such tool, linear programming has been used in this study.

Reliance on adapting to change and systematic planning employing electronic computers (and thus increasing the quantity of information that can be processed and analyzed) is not common in Oregon seafood processing industry. Seafood processors have most of the data they need to improve their decision-making process if they would switch to computer data processing and analysis. These data are not presently analyzed in a systematic manner. The key to improved plant and industry performance is in the "how" as well as the "why." This study also shows the "how" through linear programming. Therefore, besides providing a test of performance, it is hoped that the results from this study may be of use to seafood processors by suggesting possible adjustments.

Management as a Factor of Production

One of the main concerns of this study has been with management as an important productive resource. The problem states that there is a lack of informed managerial input in Oregon seafood processing. From his findings that salaries comprise a large portion of fixed costs of seafood processing plants, Smith (1971) suggests that investment in top quality management and supervisory personnel is profitable. The results of this study suggests that such investment as acquiring computer data processing services and improved management know-how would increase plant revenues.

The lack of informed managerial input may arise from a lack of information which may result in a less than efficient production operation. The manager may be unaware of alternatives and their related costs and returns to be able to make the right decisions affecting his plant performance. Alternatives in the forms of technologies and inputs are not attempted unless they involve drastic cost advantages to the adopter. Alternatives represent possibilities to increase plant performance and thus solvency of his operation. The basis of management is informed decision-making and enlightened judgements. And at the core of informed decision is information. The basis of useful information is scientific inquiry.

Without a management tool as linear programming the manager would not be able to evaluate all feasible alternatives open to him (unless there are drastic cost reductions). Smith (1971) identified opportunities for improvements (in seafood processing) as better control of raw product purchasing and increased efficiency of in-plant labor.

The types of information as provided by the linear programming solutions of this study and the interpretations presented above are of some value to management. A few examples of applications will be given. For example, the penalty cost and the highest feasible price information could be used for bargaining purposes between seafood processors and fishers or representatives of fishers' associations. Presently, fishers or their representatives are involved in negotiating for prices and fish deliveries terms with seafood processors on a regular seasonal basis. This penalty cost information (such as found in Table 11) can provide both parties a basis for agreement. For instance, given an ex-vessel price of $155.00/1,000 pounds for rock fish (which is excluded from the optimum solution) and an opportunity cost of $46.06/1,000 pounds, the highest feasible price to pay for rock fish is $108.94/1,000 pounds. The seafood processor knows that at $108.94 or less, rock fish is a good buy and thus he will include rock fish in his procurement plan. If it costs more than $108.94, he will buy other fish species.

The penalty cost information could also help the seafood processor to decide on substitution of fish species if he is compelled to do so. Such compelling forces are numerous in the seafood business: a poor salmon run, poor Dungeness crab harvest or such shortages as caused by weather conditions, or alternatively, in peak seasons when there is a glut. In such circumstances the processor has the information to decide on alternative species, that is, to substitute the species which are in short supply for others that are abundant. Of course, the above is carried out if he is compelled to do so and only so because he does not want his plant to remain idle. This is partly to maintain good labor relationships with filleters and pickers. If filleters and pickers are laid off when there is no fish and called back when there is fish, these filleters and pickers would seek alternative employment which is regular. With the information as provided above, he can evaluate whether he is covering his variable costs.

Conclusions

This study sought to show that seafood processing performance prevalent in Oregon is significantly less than what it could be within the existing economic and technological conditions. Specifically, it sought to show that improved resource combination and product-mix or new technology could contribute to significant improvement in performance. Improved resource combination and product-mix and new technology are found to contribute significantly to improved seafood processing performance within the existing plants in Oregon. The study has also provided a test and measure of performance.

Such results as the above have important implications for plant adjustments in order to perform closer to the optimum level. First and foremost, larger quantities of certain fish must be available to secure improvements in performance. Ways and means to ensure a larger steady supply of fish over the present seasonal and volatile supply of fish have to be investigated. One encouraging mean which addresses the lack of a steady supply of fish is the enactment of the 200-mile legislation. Increased availability of fish would utilize more fully the existing excess capacity within the industry. This implies that new investments in processing plants and equipment are not needed as often advocated by industry personnal and policy-makers. What is required is improved management know-how and a change in market organization. Reorganizing the plant's resource combination and product-mix involves intra-reorganization of the existing production and marketing system. This implies that inter-plant/firm reorganization of production within the Oregon seafood processing industry would improve performance. A further implication drawn from the above is that processors have to reorient their marketing approach from marketing "what are brought back by fishers" to one that is determined by advanced planning.

Revitalization of the fishing industry requires that all the various sectors of the industry must be concerned with improving their respective performance. In this study the fresh and frozen seafood processing sector was studied. Barriers to improved performance must be removed before such improvements in performance can be attained. Further research is needed to examine these barriers. The results of this study have provided some information on the future prospects of the seafood processing industry. In this regard, policy makers and industry personnel may find this study to be of some use.

Further Research

The assumptions of the model and data weakenesses notwithstanding, the results of this study show that seafood processing performance can be improved. There are, however, barriers to such improved performance. The results of this study suggest the possible direction of future work in the economics of seafood processing if indeed processors want improved seafood processing performance. For example, the institutional arrangement of the market place for raw materials and final products needs to be examined to see what specific changes are in order to encourage the landings of greater quantities of certain fish. If artificial barriers are found to exist, research on alternative market structures may be indicated.

Existing government regulations affecting fisheries may be identified and analyzed to see if the various regulations are working at cross purposes in encouraging more fish from being landed. Research on aquacultural development may hold the answer to part of the problem of addressing the declining stocks of fish and is therefore an area of research to be greatly encouraged.

Another possible area for further research may be to determine whether the present number of seafood processing plants in the industry is too large for the quantity of fish presently landed. Could the number of plants in the industry be reduced to secure improved performance given the present limited landings of fish?

And actually the public may prefer to keep some known inefficiencies, rather than adopt new methods--especially if the prospective improvements in efficiency might reduce employment, decrease price competition, or lead to greater concentration of economic power.

- F.V. Waugh -

BIBLIOGRAPHY

1. Adams, B. W. System design for dungeness crab processing. Unpublished M. S. thesis, Oregon State University, 1971, 74pp.

2. Bain, J.S. Industrial organization. New York: John Wiley & Sons, 1968.

3. Baumol, W. J. Economic theory and operations analysis. Englewood Cliffs: Prentice Hall, Inc., 1972.

4. Belden, S. A. and L. F. Schrader. An analysis of coordination decisions in a turkey production and marketing system. Dept. of Agric. Economics, Cornell Univ. Agric. Expt. Station, 1972.

5. Bilas, R. A. Microeconomic theory. New York: McGraw-Hill Book Company, 1971.

6. Capalbo, S.M. An analysis of the market structure of the food fish processing sector of the U. S. fishing industry. Unpublished M. S. thesis, University of Rhode Island, 1976.

7. Carlson, Sune. A study on the pure theory of production. New York: Kelly & Millman, Inc., 1956.

8. Cheung, C. M. Shrimp processing in Oregon - planning, analysis and control. Unpublished M. S. thesis, Oregon State University, 1976.

9. Cohen, C. and J. Stein. Multi purpose optimization system, User's Guide (Version 3). Illinois: Northwestern University, 1976.

10. Cohen, K. J. and R. M. Cyert. Theory of the firm. Resource allocation in a market economy. New Jersey: Prentice-Hall, Inc., 1965.

11. Crutchfield, J. A. and A. Zellner. "Economic aspects of the pacific halibut fishery." Fishery Industrial Research, 1(1). Washington. U. S. Bureau of Commercial Fisheries, U. S. Dept. of the Interior, 1961.

12. Crutchfield, J.A. Pacific Northwest Fisheries, Vol. II, part 8, Bureau of Commercial Fisheries, and Bonneville Power Administration, U.S. Dept. Interior, 1967.

13. Crutchfield, J.A. et al. The pacific salmon fisheries. A study of irrational conservation. Baltimore: The Johns Hopkins press. Resources for the future, Inc., 1969.

14. Dorfman, R. et al. Linear programming and economic analysis. New York: McGraw-Hill Book Company, 1958.

15. Due, J.F. and R.W. Clower. Intermediate economics analysis. Homewood: R.D. Irwin, 1966.

16. Engesser, W.F. Personal communication. Dept. of Industrial Engineering, Oregon State University.

17. Environment Canada. Annual statistical review of Canadian Fisheries, Volume 8, Ottawa: Fisheries and Marine Service, 1975.

18. Ferguson, C.E. Microeconomic theory. Homewood: Richard D. Irwin, Inc., 1966.

19. F.A.O/U.N. 1965. Report of the meeting on business decisions in fishery industries. Edited by R. Hamlisch with the assistance of A.A. Kerr. F.A.O. Fish. Rep. (22), Vol. 1., 30pp.

20. F.A.O/U.N. 1965. Meeting on business decision in fishery industries. Rome, 21-25 September, 1964. F.A.O. Fish. Rep. (22.3): 458pp.

21. F.A.O. Secretariat. The application of linear programming to the analysis of fishery industry problems. F.A.O. Fish. Rep., No. 22, Vol. 3, 385-401pp. 1965.

22. French, B.C. The analysis of productive efficiency in agricultural marketing: Models, methods, and progress, in (Ed) Lee R. Martin. A survey of agricultural economics literature, Vol. 1. Minneapolis: University of Minnesota Press, 1977.

23. Haywood, K.H. A review of quantitative methods for the management of fish processing plants, Expert consultation on quantitative analysis in fishery industries development. Rome, 16-24 January 1975. Volume 4. F.A.O. Fish. Rep., (167) Vol. 4: 14pp., 1975.

24. Gates, J.M. and V.J. Norton. The benefits of fisheries regulation: A case study of the New England Yellowtail Flounder Fishery. Kingston: Sea Grant, University of Rhode Island, Marine Tech. Rept. No. 21, 1974.

25. Georgescu-Roegen, N.. The entropy law and the economic process. Cambridge: Harvard University Press, 1971.

26. Heady, E.O. Economics of agricultural production and resource use. Englewood Cliffs: Prentice-Hall, Inc., 1952.

27. Henriksen, H. and A. Nordset. Some cost accounting problems of the Norwegian fish processing industry. F.A.O. Fish. Rep., No. 22, Vol. 2, 287-298pp. 1965.

28. IBM. Linear Programming - Feed Manufacturing. Data Processing Application. New York (no date).

29. Interviews with commercial fishers..

30. Interviews with seafood processors.

31. Jensen, H.R. Farm management and production economics, 1946-1970, in a Survey of Agricultural Economics Literature, Vol. 1, Traditional fields of agricultural economics, 1940s to 1970s, Lee R. Martin (Ed), Minneapolis: University of Minnesota Press, 1977.

32. Johnson, W.H. Seafood processing, Seminar at Oregon State University Marine Science Center, Newport, Oregon.

33. Johnson, W.H. Personal communication, New England Fish Company.

34. Kerr, A.A. Correlation and regression analysis as a tool in management decision making. F.A.O. Fish. Rep., No. 22, Vol. 3, 403-420pp, 1965.

35. Kroger, F. and P. Streufert. Steuerung der produktion der verarbeitungsbetriebe der VVB hochseefischerei rostock in abhangingkeit von der menge des fur einen bestimmten zeitraum zur verfugung stephenden herings. Fischereiforschung, 4(3):37-42, 1966.

36. Leibenstein, H. "Allocative efficiency vs. "X-efficiency," Amer. Econ. Rev., 56:392-415, June 1966.

37. Martin, L.R. (gen. editor). A survey of agricultural economics literature, Vol. 2, Quantitative methods in agricultural economics 1940s to 1970s, Minneapolis: University of Minnesota Press, 1977.

38. Newton, C. The effect of tariff reduction on the production of fish sticks and portions in the United States. Unpublished Ph. D. dissertation, University of Rhode Island, 1972.

39. Noetzel, B.G. and J. Vondruska. Future investment in U.S. fish harvesting and processing - a discussion of possible alternative requirements through 1985, NMFS, NOAA, U.S.D.C., October 1975.

40. Oregon Department of Commerce, Economic Development Division, Census of Manufacturers, Portland 1976.

41. Oregon Dept. Fish Wildlife. (formerly the Fish Commission of Oregon, Research Division). "Annual catch statistics for some Oregon & Pacific Coast Marine Fisheries in pounds round," revised, Nov. 13, 1972.

42. Oregon Dept. Fish Wildlife, unpublished data, various years.

43. Oregonian, The, October 20, 1977.

44. O'Rourke, A. D. et al. The California fresh and frozen fishery trade. Berkeley. University of California, Agric. Exp. Sta. Bul. 850. 1971.

45. Peterson, R. H. Systems design for bottomfish processing. Unpublished M. S. thesis. Oregon State University, 1974, 102pp.

46. Scheurman, L. Rex (version 1) Linear programming system, Oregon: Oregon State University, 1970.

47. Schwartzman, D. Competition and efficiency: comment, J. Political Economy, Vol. 81, No. 3, May/June 1973.

48. Shavanova, E. V. The using of a method of parametric linear programming for the optimization of plans of fish - processing plants on shore. (RU) Mater. Rhbokhoz. Issled. Sev. Bass., 15:136-51, 1969.

49. Smith, F. J. Economic condition of selected Pacific Northwest seafoods firms, special report 327, Sea Grant, Corvallis: Oregon State University, 1971.

50. Smith, F. J. Unpublished Research, 1975.

51. Snyder, J. C. and C. E. French. Disassembly - assembly models for meat packing management, Research bulletin No. 764, Purdue University. Indiana, 1963.

52. Theodore, C. A. Some quantitative techniques for fisheries management. FAO Fish. Rep., No. 22, Vol. 3, 337-383, 1965.

53. U. S. Dept. of Commerce, NOAA, Retail identification plan for fishery products, March 1975.

54. U. S. Dept. of Commerce. National Marine Fisheries Service. National plan for marine fisheries. 1975.

55. U. S. Dept. of Commerce, NOAA, NMFS, Fisheries of the United States, 1975, Current fishery statistics No. 6900, March 1976.

56. U. S. Dept. of Commerce, National Marine Fisheries Service, Fisheries of the United States, 1976, Current fishery statistics No. 7200, Washington, D. C., April 1977, 96pp.

57. U. S. Dept. Labor. Job title revisions to eliminate sex- and age-referent language from the dictionary of occupational titles, third edition, 1975.

APPENDIX

```
PROGRAM LIST       73/74    OPT=1                              FTN 4.6+452        78/03/24. 23.02.59       PAGE      1

                 PROGRAM LIST (INPUT,OUTPUT)
                 DIMENSION LINE(8)
          1      READ 10, LINE
                 IF (EOF(5LINPUT).NE.0.0) STOP
          10     FORMAT (8A10)
                 PRINT 20,LINE
          20     FORMAT (1X,20X,8A10)
                 GO TO 1
                 END
          USER,AGEI5C,KEEC.
          CHARGE.765284,FISH.
          SETTL.1000.
          TITLE.   CHONG.
          ATTACH,MPCS/UN=LIBRARY.
          MPOS.
          * THIS IS A RESOURCE COMBINATIONS AND PRODUCT MIX PROBLEM OF A MODEL FISH
          * PROCESSING PLANT
          * MAXIMIZE THE NET REVENUE FROM PROCESSING BOTTOMFISH, CRAB, SHRIMP AND SALMON
          * VARIABLE DEFINITIONS
          * PRDVS = PROCUREMENT OF DOVER SOLE IN THOUSAND POUNDS
          * PRPTS = PROCUREMENT OF PETRALE SOLE IN THOUSAND POUNDS
          * PRSSL = PROCUREMENT OF SAND SOLE IN THOUSAND POUNDS
          * PRENG = PROCUREMENT OF ENGLISH SOLE IN THOUSAND POUNDS
          * PRRKS = PROCUREMENT OF ROCK SOLE IN THOUSAND POUNDS
          * PRREX = PROCUREMENT OF REX SOLE IN THOUSAND POUNDS
          * PRFLN = PROCUREMENT OF FLOUNDER IN THOUSAND POUNDS
          * PRDAB = PROCUREMENT OF SAND DAB IN THOUSAND POUNDS
          * PRLNG = PROCUREMENT OF LING COD IN THOUSAND POUNDS
          * PRPAC = PROCUREMENT OF PACIFIC TRUE COD IN THOUSAND POUNDS
          * PRBLK = PROCUREMENT OF BLACK COD/SABLEFISH IN THOUSAND POUNDS
          * PRROC = PROCUREMENT OF ROCK FISH IN THOUSAND POUNDS
          * PROCN = PROCUREMENT OF PACIFIC OCEAN PERCH IN THOUSAND POUNDS
          * PRSHP = PROCUREMENT OF SHRIMP IN THOUSAND POUNDS
          * PRDCB = PROCUREMENT OF DUNGENESS CRAB IN THOUSAND POUNDS
          * PRKCB = PROCUREMENT OF KING CRAB IN THOUSAND POUNDS
          * PRSCB = PROCUREMENT OF SNOW CRAB IN THOUSAND POUNDS
          * PRCHK = PROCUREMENT OF CHINOOK SALMON IN THOUSAND POUNDS
          * PRCOH = PROCUREMENT OF COHO SALMON IN THOUSAND POUNDS
          * BFUNL = UNLOADING BOTTOMFISH
          * DCUNL = UNLOADING DUNGENESS CRAB
          * SHUNL = UNLOADING SHRIMP
          * KCUNL = UNLOADING KING CRAB
          * SCUNL = UNLOADING SNOW CRAB
          * SMUNP = UNLOADING AND PACKING SALMON
          * BFWSH = WASHING BOTTOMFISH IN ROTARY WASHER
          * SHDCE = DEICING SHRIMP IN DE-ICER
          * DCSRT = SORTING AND DEBACKING DUNGENESS CRAB
          * SHCKP = COOKING SHRIMP
          * DCCKW = COOKING WHOLE DUNGENESS CRAB
          * DCCKS = COOKING DUNGENESS CRAB SECTIONS
          * KCTWS = THAWING KING CRAB SECTIONS
          * SCTWS = THAWING SNOW CRAB SECTIONS
          * FDOVS = FILLETING DOVER SOLE
          * FPETS = FILLETING PETRALE SOLE
          * FSAND = FILLETING SAND SOLE
          * FENGS = FILLETING ENGLISH SOLE
          * FROCS = FILLETING ROCK SOLE
          * FREXS = FILLETING REX SOLE
          * FFLDR = FILLETING FLOUNDER
          * FSDAB = FILLETING SAND DAB
```

```
* FLING = FILLETING LING COD
* FPCOD = FILLETING PACIFIC TRUE COD
* FBLKC = FILLETING BLACK COD/SABLEFISH
* FRCKF = FILLETING ROCK FISH
* FOCNP = FILLETING PACIFIC OCEAN PERCH
* PKSHP = PREPICKING SHRIMP
* SPKOC = SHAKING AND PICKING DUNGENESS CRAB
* SPKKC = SHAKING AND PICKING KING CRAB
* SPKSC = SHAKING AND PICKING SNOW CRAB
* BRSHP = BRINING SHRIMP MEAT
* BRDCB = BRINING DUNGENESS CRAB MEAT
* BRKCB = BRINING KING CRAB MEAT
* BRSCB = BRINING SNOW CRAB MEAT
* PACFF = PACKING FISH FILLET
* PACSH = PACKING SHRIMP
* PACDC = PACKING DUNGENESS CRAB MEAT
* PACKC = PACKING KING CRAB MEAT
* PACSC = PACKING SNOW CRAB MEAT
* SEALC = SEALING AND CANNING SHRIMP AND DUNGENESS CRAB MEAT
* SLDOV = SALE OF DOVER SOLE FILLET
* SLPET = SALE OF PETRALE SOLE FILLET
* SLSND = SALE OF SAND SOLE FILLET
* SLENG = SALE OF ENGLISH SOLE FILLET
* SLROC = SALE OF ROCK SOLE FILLET
* SLREX = SALE OF REX SOLE FILLET
* SLFLN = SALE OF FLOUNDER FILLET
* SLDAB = SALE OF SAND DAB FILLET
* SLLIN = SALE OF LING COD FILLET
* SLPAC = SALE OF PACIFIC TRUE COD FILLET
* SLBLK = SALE OF BLACK COD/SABLEFISH FILLET
* SLRKF = SALE OF ROCKFISH FILLET
* SLOCN = SALE OF PACIFIC OCEAN PERCH FILLET
* SLSHP = SALE OF SHRIMP MEAT
* SLOCW = SALE OF WHOLE DUNGENESS CRAB
* SLDCM = SALE OF DUNGENESS CRAB MEAT
* SLKCM = SALE OF KING CRAB MEAT
* SLSCM = SALE OF SNOW CRAB MEAT
* SLCHK = SALE OF CHINNOK SALMON
* SLCOH = SALE OF COHO SALMON
* TRF   = TRANSFER EQUATIONS
TITLE
SEAFOOD PROCESSING MANAGEMENT PLAN FOR MAY  -  ULTIMATE
PREVISED
VARIABLES
PROVS  PRPTS  PRSSL  PRENG  PRRKS  PRREX  PRFLN  PRDAB  PRLNG  PRPAC  PRBLK
PRROC  PRCCN  PRSHP  PRDCB  PRKCB  PRSCB  PRCHK  PRCOH  BFUNL  DCUNL  SHUNL
KCUNL  SCUNL  SHUNP  BFWSH  SHCOE  DCSFT  SHCKP  DCCKW  OCCKS  KCTHS  SCTHS
FDOVS  FPETS  FSANO  FENGS  FRCCS  FREXS  FFLOR  FSDAB  FLING  FPCOC  FBLKC
FRCKF  FCCNP  PKSHP  SPKOC  SPKKC  SPKSC  BRSHP  BRCCB  BRKCB  BRSCB  PACFF
PACSH  PACCC  PACKC  PACSC  SEALC  SLCOV  SLPET  SLSND  SLENG  SLROC  SLREX
SLFLN  SLDAB  SLLIN  SLPAC  SLBLK  SLRKF  SLOCN  SLSHP  SLOCW  SLOCM  SLKCM
SLSCM  SLCHK  SLCOH           .
PACKED
MAXIMIZE
CONSTRAINTS 76
000000000000000000000000000000000000000000000000000000000000++++++++++++++++
FORMAT
(I3.I4,F10.2)
READ INPUT
* OBJECTIVE FUNCTION
  0   1  -168.
  0   2  -290.
  0   3  -270.
```

```
0   4  -250.
0   5  -230.
0   6  -220.
0   7  -135.
0   8  -230.
0   9  -160.
0  10  -150.
0  11  -137.
0  12  -155.
0  13  -155.
0  14  -230.
0  15  -550.
0  16  -2900.
0  17  -1300.
0  18  -1530.
0  19  -1250.
0  20  -1.19
0  21  -0.40
0  22  -0.81
0  23  -0.13
0  24  -0.13
0  25  -3.36
0  26  -0.23
0  27  -0.23
0  28  -9.79
0  29  -10.01
0  30  -0.56
0  31  -0.54
0  32  -0.61
0  33  -0.61
0  34  -118.6
0  35  -73.4
0  36  -73.4
0  37  -139.1
0  38  -100.9
0  39  -89.7
0  40  -89.7
0  41  -89.7
0  42  -28.8
0  43  -31.0
0  44  -32.4
0  45  -31.0
0  46  -73.4
0  47  -36.0
0  48  -365.0
0  49  -357.0
0  50  -357.0
0  51  -26.14
0  52  -29.41
0  53  -21.44
0  54  -46.79
0  55  -1.22
0  56  -11.03
0  57  -25.73
0  58  -19.79
0  59  -19.79
0  60  -4.04
0  61  1300.
0  62  1750.
0  63  1550.
0  64  1370.
0  65  1650.
0  66  1170.
0  67  1250.
0  68  1170.
0  69  1000.
0  70  1000.
0  71  790.
0  72  850.
0  73  800.
0  74  2200.
0  75  850.
0  76  3560.
0  77  3500.
0  78  3500.
0  79  2980.
0  80  2290.
*TRF1
 1   1  -1.
 1   2  -1.
 1   3  -1.
 1   4  -1.
 1   5  -1.
 1   6  -1.
 1   7  -1.
 1   8  -1.
 1   9  -1.
 1  10  -1.
 1  11  -1.
 1  12  -1.
 1  13  -1.
 1  20  1.
 1   0  0.
*TRF2
 2  14  -1.
 2  22  1.
 2   0  0.
*TRF3
 3  15  -1.
 3  21  1.
 3   0  0.
*TRF4
 4  16  -1.
 4  23  1.
 4   0  0.
*TRF5
 5  17  -1.
 5  24  1.
 5   0  0.
*TRF6
 6  18  -1.
 6  19  -1.
 6  25  1.
 6   0  0.
*TRF7
 7  20  -1.
 7  26  1.
 7   0  0.
*TRF8
 8  21  -1.
 8  28  1.
 8   0  0.
*TRF9
 9  22  -1.
 9  27  1.
 9   0  0.
*TRF10
 10  23  -1.
 10  32  1.
 10   0  0.
*TRF11
 11  24  -1.
 11  33  1.
 11   0  0.
*TRF12
 12  18  -1.
 12  79  1.111
 12   0  0.
*TRF13
 13  19  -1.
 13  80  1.111
 13   0  0.
*TRF14
 14   1  -1.
 14  34  3.448
 14   0  0.
*TRF15
 15   2  -1.
 15  35  3.077
 15   0  0.
*TRF16
 16   3  -1.
 16  36  3.077
 16   0  0.
*TRF17
 17   4  -1.
 17  37  3.704
 17   0  0.
*TRF18
 18   5  -1.
 18  38  3.333
 18   0  0.
*TRF19
 19   6  -1.
 19  39  2.500
 19   0  0.
*TRF20
 20   7  -1.
 20  40  4.545
 20   0  0.
*TRF21
 21   8  -1.
 21  41  2.500
 21   0  0.
*TRF22
 22   9  -1.
 22  42  3.333
 22   0  0.
*TRF23
 23  10  -1.
 23  43  3.571
 23   0  0.
*TRF24
 24  11  -1.
 24  44  3.333
 24   0  0.
*TRF25
 25  12  -1.
 25  45  3.333
```

```
 25   0  0.
*TRF26
 26  13  -1.
 26  46  3.333
 26   0  0.
*TRF27
 27  27  -1.
 27  29  1.
 27   0  0.
*TRF28
 28  28  -1.
 28  30  1.
 28  31  1.
 28   0  0.
*TRF29
 29  29  -1.
 29  47  4.762
 29   0  0.
*TRF30
 30  30  -1.
 30  75  1.111
 30   0  0.
*TRF31
 31  31  -1.
 31  48  4.000
 31   0  0.
*TRF32
 32  32  -1.
 32  49  2.564
 32   0  0.
*TRF33
 33  33  -1.
 33  50  2.703
 33   0  0.
*TRF34
 34  34  -1.
 34  35  -1.
 34  36  -1.
 34  37  -1.
 34  38  -1.
 34  39  -1.
 34  40  -1.
 34  41  -1.
 34  42  -1.
 34  43  -1.
 34  44  -1.
 34  45  -1.
 34  46  -1.
 34  55  1.
 34   0  0.
*TRF35
 35  47  -1.
 35  51  1.
 35   0  0.
*TRF36
 36  48  -1.
 36  52  1.
 36   0  0.
*TRF37
 37  49  -1.
 37  53  1.
 37   0  0.
*TRF38
 38  50  -1.
 38  54  1.
 38   0  0.
*TRF39
 39  51  -1.
 39  56  1.
 39   0  0.
*TRF40
 40  52  -1.
 40  57  1.
 40   0  0.
*TRF41
 41  53  -1.
 41  58  1.
 41   0  0.
*TRF42
 42  54  -1.
 42  59  1.
 42   0  0.
*TRF43
 43  34  -1.
 43  61  1.
 43   0  0.
*TRF44
 44  35  -1.
 44  62  1.
 44   0  0.
*TRF45
 45  36  -1.
 45  63  1.
 45   0  0.
*TRF46
 46  37  -1.
 46  64  1.
 46   0  0.
*TRF47
 47  38  -1.
 47  65  1.
 47   0  0.
*TRF48
 48  39  -1.
 48  66  1.
 48   0  0.
*TRF49
 49  40  -1.
 49  67  1.
 49   0  0.
*TRF50
 50  41  -1.
 50  68  1.
 50   0  0.
*TRF51
 51  42  -1.
 51  69  1.
 51   0  0.
*TRF52
 52  43  -1.
 52  70  1.
 52   0  0.
*TRF53
 53  44  -1.
 53  71  1.
 53   0  0.
```

```
*TRF54
 54  45  -1.
 54  72  1.
 54   0  0.
*TRF55
 55  46  -1.
 55  73  1.
 55   0  0.
*TRF56
 56  56  -1.
 56  57  -1.
 56  60  1.
 56   0  0.
*TRF57
 57  58  -1.
 57  77  1.
 57   0  0.
*TRF58
 58  59  -1.
 58  78  1.
 58   0  0.
*TRF59
 59  56  -1.
 59  74  1.
 59   0  0.
*TRF60
 60  57  -1.
 60  76  1.
 60   0  0.
*CONSTRAINTS DUE TO AVAILABLE RESOURCES
* UNLOADING LABOR FOR MAY
 61  20  0.295
 61  21  0.1
 61  22  0.2
 61  23  0.033
 61  24  0.033
 61   0  352.
* ROTARY WASHER CAPACITY FOR MAY
 62  26  0.2
 62   0  176.
* SORTING, BUTCHERING AND DEBACKING DUNGENESS CRAB LABOR FOR MAY
 63  28  2.43
 63   0  176.
* CRAB COOKER CAPACITY FOR MAY
 64  30  0.52
 64  31  0.28
 64  32  0.29
 64  33  0.28
 64   0  176.
* OEICF WASHER CAPACITY FOR MAY
 65  27  0.125
 65   0  176.
* LAITRAM FCA SHRIMP COOKER AND PEELER CAPACITY FOR MAY
 66  29  0.55
 66   0  374.
* FISH FILLETING LABOR FOR MAY
 67  34  29.4
 67  35  19.2
 67  36  18.2
 67  37  34.5
 67  38  25.
 67  39  22.2
 67  40  22.2
```

```
 67  41  22.2
 67  42  7.14
 67  43  7.69
 67  44  5.52
 67  45  7.69
 67  46  18.2
 67   0  3520.
* CRAB PICKING LABOR FOR MAY
 68  48  73.
 68  49  71.4
 68  50  71.4
 68   0  4400.
* SHRIMP PREPICKING LABOR FOR MAY
 69  47  10.
 69   0  1056.
* SALMON HANDLING LABOR FOR MAY
 70  25  0.833
 70   0  352.
* CONTINUOUS BRINER CAPACITY FOR MAY
 71  51  3.39
 71  52  3.81
 71  53  2.78
 71  54  6.06
 71   0  352.
* PACKAGING FISH FILLET LABOR FOR MAY
 72  55  0.316
 72   0  528.
* PACKAGING CRAB MEAT LABOR FOR MAY
 73  57  6.67
 73  58  5.13
 73  59  5.13
 73   0  176.
* PACKAGING SHRIMP MEAT LABOR FOR MAY
 74  56  2.86
 74   0  176.
* AUTOMATIC SEAMER CAPACITY FOR MAY
 75  60  1.
 75   0  176.
* COLD STORAGE CAPACITY FOR MAY
 76  61  1.
 76  62  1.
 76  63  1.
 76  64  1.
 76  65  1.
 76  66  1.
 76  67  1.
 76  68  1.
 76  69  1.
 76  70  1.
 76  71  1.
 76  72  1.
 76  73  1.
 76  74  1.
 76  75  1.
 76  76  1.
 76  77  1.
 76  78  1.
 76  79  1.
 76  80  1.
 76   0  610.

RNGOBJ
RNGRHS

PRINT
CHECK
OPTIMIZE
STOP
```

Source of Linear Programming Data

Type of Data	Source
1976 Cost of processing estimates (unloading, washing, de-icing, cooking, thawing, filleting, picking and shaking, brining, packaging, etc.)	O. S. U. Industrial Engineering studies (4), interviews with 8 seafood processors, labor union records (2), performance records of one plant, interviews with 3 equipment manufacturers.
1976 Wage rates	Plant manager, plant supervisor and floor lady of cooperating plants, and labor union records
1976 Electricity and water rates	Lincoln Public Utility District Office, and Water Department in Newport
1976 Plant facilities constraints or capacities	Plant manager, plant supervisor and floor lady of cooperating plant