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THE DEVELOPMENT OF SYSTEMS FOR EXPLOITING DISTANT-WATER FISHERIES

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The world catch of fish is expected to double in the next two decades, and investment in new fishing vessels will be at a rate equivalent to some hundreds of millions of sterling a year. A substantial proportion of this investment will be in ocean-going factory vessels, mother-ships and freezer trawlers. These types of vessel have been developed in Europe over the last sixteen years and the authors describe current vessel types and trends.

Recent technical development has been directed to a large extent towards greater productivity in terms of capital and labour employed, and towards minimizing fatigue, danger and discomfort; among recent and current projects are transfer of catches at sea, mechanization of fish gutting and of handling of nets, and elimination of watch-keeping staff in the engine rooms of vessels with complex propulsive and auxiliary machinery, making voyages of several weeks involving several distinct operating regimes, and during which there is frequent manoeuvring. Expeditions comprising a mother-ship and catchers are already employed in some fisheries and for very distant fisheries, e.g. the Antarctic, the use of nuclear-powered depot-ships remaining on the grounds for the entire four years between surveys is envisaged.

The design of distant-water fishing vessels, and the methods and equipment employed on board, are much influenced by market requirements, including consumer preferences. Operations analysis is increasingly used to help identify the most effective and economically efficient fishing unit (single vessels or fleets) for exploiting a given fishery. The possibility of forming a mathematical model of a fishery, as an instrument for guiding further development and management of operations, is put forward. This is a natural objective arising out of the increasingly deliberate systems approach imposed by the large capital investment required for deep sea fishing and the growing number of options that technical development is making available to management.

INTRODUCTION

Economic and Historical

The growing intensity of exploitation of the marine fisheries is indicated by the fact that the world catch has more than doubled in the last sixteen years. The natural consequence of this rapid development of the fisheries has been the necessity of extending operations to fishing grounds very distant from the traditional ports of landing. This has meant changes in methods and consequent development of new types of fishing vessel. The basic condition of successful exploitation of the fish stocks on the distant ocean fishing grounds is the availability of sufficiently powerful means of preserving the catch on board for a considerable period of time: the traditional deep sea fishing vessel designed for carriage of wet fish in crushed ice could not fulfil this role.

To those not familiar with the recent rapid expansion and equally rapid technical development of the fisheries, it may be surprising that there exists such a vessel as the Russian *Vostok,* a mother-ship and floating factory of over 40 000 tons which carries fourteen glass-reinforced plastic, powered catching vessels, each of 70 tons, on board. In the last sixteen years several hundred freezer trawlers and factory trawlers have been built in Europe and Japan, costing from £½ million to well over £1 million each, as well as mother-ships, factory vessels and refrigerated fish transporters of up to 15 000 tons and more.

The biggest user of these types of vessel is the Soviet Union. Other nations employing substantial numbers of modern vessels in the distant-water fisheries of the North or South Atlantic, or both, include France, East Germany, West Germany, Italy, Poland, Portugal, Spain, Japan and the United Kingdom. Comprehensive statistics on the size of national fleets and on recent building are not available, but Appendix I analyses new construction in various European countries in 1965–67 as noted in one trade journal.[1] The distant-water fleet of the United Kingdom now includes over thirty modern freezer trawlers and factory vessels of the stern-fishing, shelter-deck type, each roughly as productive as two of the older single-deck, side-fishing trawlers, using ice as a means of preservation, of which there are still some 150 in the British distant-water fleet. The Polish fleet includes 57 freezer and factory trawlers and two mother-ships of 10 000 tons each.

The factory trawler and freezer trawler were first developed in Britain, but the Russians and other European nations have been the leaders in their construction and use on the grand scale. They have also pioneered the practical application of means of transferring catches at sea and the use of mother-ships. This development was due in part to

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the fall in catch rates experienced in the Barents Sea in the late 1950s and early 1960s; of the two nations mainly concerned, the Russian response was to build mother-ships to allow the existing catchers to be used on more distant grounds; the British was to implement more rapidly the replacement of the existing vessels by freezer trawlers, each freezer trawler operating independently.

As a result of her building programme, which has given extensive employment in Western European shipyards as well as in the Eastern bloc, Russia has risen in the last sixteen years from being a relatively insignificant power in world fisheries to being the fourth biggest fishing nation in the world, and probably second only to Japan in landings of marine fish and fish products for human consumption. The massive post-war entry of Russia, Poland and other nations into the deep sea fisheries was due to the relative rapidity with which it is possible to expand the production of high-grade protein food by exploitation of the sea, as compared with development of agriculture; moreover, in spite of the capital investment involved, the costs of production of protein from the sea can be much lower than from the land, although to take advantage of this, it may be necessary to bring about changes in consumer habits and preferences.

Most of the major fishing nations, apart from the Americans and the British, have increased their production in recent years. It is generally recognized that no nation will ever again be able to afford to neglect the sea as a source of food. The world catch is expected by some experts to have doubled again by the early 1980s. The rate of investment will be several hundred million pounds sterling a year, of which a substantial proportion will be represented by ocean-going vessels of the kind referred to in this paper.

For those nations that fished the North Atlantic and Arctic before the recent rapid increase in exploitation, one problem is to reconcile declining rates of catch with rising costs, in a situation where increased prices are possible only to the extent that the customer is willing to pay for better quality or greater convenience, and where the prices of competing foodstuffs have remained steady or have actually fallen.[2] It is recognized that only by a programme of vigorous technical development in both catching and marketing will such nations be able to afford in future to reap their share of the more and more valuable harvest of the seas.

TECHNICAL DEVELOPMENT

Vessel Types

Sixteen years ago the typical ocean-going fishing vessel was still a very simple, single-decked ship, usually less than 200 ft in overall length, built in a small, specialist shipyard at a cost not much exceeding £100 000, and bearing unmistakable signs of her sailing-smack ancestry. There are still many vessels of this type in service, even in the Russian fleets, operating either independently or as catchers for mother-ships. The conditions for successful freezing and cold storage of fish, and for manufacture of high grade fish meal from offal and unwanted species, were worked out at the Torry Research Station in Aberdeen, Scotland, in the 1930s and 1940s. Practical methods of quick-freezing fish were developed in the U.S.A. and Britain; automatic machine tools for recovering the edible flesh of fish in the form of fillets were developed in Germany. These systems were combined in the first commercially-practicable factory trawler, built in Scotland in 1953.[3] Because of the space demanded by the fish-working machinery and the large crew required on the factory deck, this ship had to be much bigger than conventional deep sea trawler. This in turn, imposed the necessity of large holds, because the high costs had to be matched by high earnings, and there was therefore a strong incentive towards voyages of long duration in order to achieve a high proportion of time on the fishing grounds. The concept of the large shelter-deck stern-ramp trawler was developed by Burney and Lochridge to reconcile these factors.

The last review of fishing vessel design presented to this Institute was just over ten years ago.[4] The authors confined themselves for the most part to the traditional type of vessel, although they did put forward a scheme for freezing the early part of the catch in order to improve the economics of operation; stern trawlers were mentioned only briefly. It is to be doubted whether any more long range side-fishing single-decked trawlers will ever be built, even though the capital cost of the equivalent stern-fishers may be higher. The reasons for this are the greater comfort afforded the crew and the greater ease with which the stern trawler lends itself to mechanization of the handling of the net and, most important, to factory operations. The advantages of the stern trawler are discussed at length in the proceedings[5] of an international conference on stern trawling held in the United Kingdom in 1963. Recent accounts of distant-water fishing vessel development are those by Kamensky[6] and Kamensky and Terentiew.[7] Fishing vessel types produced in Poland have also been described.[8] The authors therefore feel it unnecessary to provide detailed descriptions of vessels in this paper, but they have listed in Appendix II the technical characteristics of three typical modern British-built deep sea trawlers and three of the most successful standard types designed and built in Poland.

Means of quick freezing such fish as cod in the whole, gutted form in slabs of 100 lb (50 kg), so eliminating the need to carry filleting machines and large factory crews, were developed at the Torry Research Station and subjected to successful practical trial in 1956.[9] Vessels so equipped are designated freezer trawlers, to distinguish them from the factory trawlers producing frozen fillets.

Factory trawlers are equiped to produce not only frozen blocks of fillet but also fish meal processed from fish waste and offal, and fish oil obtained from cod livers. The production of fillets necessitates gutting and beheading of fish by machine or by hand, then cutting and skinning of fillets by machine. Sometimes it also necessitates the removal of the remaining fish bones and membranes, and a search for parasites. The crews of these ships can number from 60 to 100 men, and the endeavours to create satisfactory living conditions for the seamen staying at sea for 60 to 90 days influence the size of the ships and necessitate a high standard of accommodation and other amenities. As a result of the application of such fish processing plant as beheading, filleting, and skinning machines, the factory trawlers are forced to operate only on such fishing grounds where the fish species that can be handled by the fish processing machines on board are abundant.

The freezer trawlers land for the most part whole frozen fish, gutted and sometimes beheaded, destined mainly to be thawed and further processed on shore. Thus the freezer trawlers have greater flexibility as they can fish wherever there is fish catchable by trawl. They are especially suited for operation in African waters where a variety of fish for human consumption can be found. British freezer trawlers designed for the North West Atlantic carry only 24 to 26 men, as compared with the 60 to 100 of the large factory trawler.

In both freezer trawlers and factory trawlers, good practice requires quick-freezing in air blast or plate contact freezers and subsequent storage at −20°F (−30°C), and there are many other requirements connected with the processes of *rigor mortis*, autolytic and bacterial spoilage which must be adhered to in design and operation of the processing deck if a good quality product is to be obtained.

In the past few years a third type of vessel for autonomous fishing on distant ocean fishing grounds has been developed: the canning factory trawler, provided with a full set of machines and equipment for canning of various fish species and for fish meal and oil processing from fish waste and offal. Existing vessels of this type have been designed to remain on the fishing grounds even longer than the factory trawlers or freezer trawlers. For the crews the prolonged voyages are less attractive, but, on the other hand, on a vessel of the canning factory trawler size, 6000 tons and upwards, it is possible to create better living conditions than on the previously described types of vessel.

With their integrated systems of propulsive, auxiliary and deck machinery, their sophisticated electronics and specialized equipment for gutting, filleting, quick freezing or canning and storing the catch, modern distant-water fishing vessels are among the most complex ships afloat. This is reflected in the fact that their cost per displacement ton is twenty or thirty times that of a medium-sized tanker or bulk carrier.

The predecessor of the modern mother-ship was the Portuguese, American or Canadian schooner with dories. Factory mother-ships employing open dories as catchers were used by the British in the North West Atlantic nearly forty years ago; the Russians and Japanese also have long experience of this type of operation. Mother-ships serving fleets of trawlers are, however, of very recent introduction, and in the Atlantic are confined to the Eastern European fleets. These mother-ships can process wet fish received from catchers into frozen fillets, frozen gutted and beheaded fish, or canned fish. They can also produce fish meal and oil.

Following the introduction of the mother-ships, it was necessary to develop a new type of vessel to catch the fish and to deliver it as a raw material for processing: this new type is comparatively small, with holds adapted to store the catches for only a few days, in order to limit cost. For the same reason, their crews must be as small as possible. Thus, extensive mechanization and automation are fully justified.

To ensure good catches on various fishing grounds, the catcher vessels must be adapted to use bottom trawls, pelagic trawls and purse seines.

The classic deep sea side trawler had been developed by the customary slow, evolutionary methods familiar throughout the history of shipbuilding. With small ships performing complex operations in such a hostile and unknown environment as the North Atlantic, this may be the safest and surest method of development, but it does not provide a sufficient technical basis for implementing rapid changes when these are dictated by economic circumstances. The building of large, sophisticated and costly shelter-deck stern trawlers and other new types of catcher exposed the lack of knowledge—in engineering terms—about what the vessels and their equipment had to do; about rates of catch and other statistics on fishing operations from hour to hour and day to day; and about the environment in which the ships and their equipment had to work and the treatment to which they were subjected. This indeed was true of all fishing vessels, if not of ships in general.

For these reasons, the British White Fish Authority in 1963 mounted a series of technical investigations on board commercial fishing vessels in operational conditions, in support of a programme of engineering development. This work is continuing and similar work is now in progress in Iceland, the Netherlands, the U.S.S.R. and Poland.

Performance Measurement

In the fishing vessel, the problem of measuring performance in operational conditions is much complicated by the severe motion, the sometimes long voyages, and the variety and variability of complex manoeuvres and operations carried out on the fishing grounds. An effective attack had to wait upon successful adaptation of aircraft instrumentation techniques by Bennett,[10] further adapted for use in conjunction with small data loggers by Hearn.[11]

Of particular interest is the method adopted to measure propeller shaft thrust and torque, bearing in mind that many of these ships are driven by direct-coupled Diesels with large torque fluctuations, that voyages may last nine weeks or more, and that there are operating regimes when the power developed is only half of the maximum available, or even less. The method involves the application of foil-type resistance strain gauge circuits, by the methods pioneered by the National Physical Laboratory, to short lengths of hollow-bored high-grade steel shafting, inserted in the length of the intermediate shafting. These insert shafts are made in duplicate and are removable for direct recalibration. Propeller shafts from 3 to 15-in in diameter have been instrumented in this way.[12]

The simplest type of information produced by such work has been that serving to provide direct guidance to owners and designers on the selection of power of main engines (especially in multi-engine installations) and of ship's service generators; also on the specification of the power and torque of winches and so on.[13, 14] The use of data loggers has allowed techno-economic design decisions to be made on a statistical basis, e.g. the proportion of all occasions when a 210-ft stern trawler will need more than 1100 hp to be able to shoot the trawl (because of bad weather) can be stated.

A more advanced example of the use of performance measurements in operational conditions to optimize ship design has been presented to this Institute:[15] a combination of performance measurement, ship model work and economic analysis indicated to what extent it would pay owners to adopt c.p. propellers of larger diameter than had hitherto been employed in British stern freezer trawlers.

As well as refinements in the design of the vessels, trawl winches and other equipment, these investigations have produced changes in the techniques of using them that again have led to reductions in cost or savings in time.[16] One example again concerns c.p. propellers. In order to facilitate the most effective and economic operation of vessels fitted with such propellers, a method has been worked out in Poland, based upon the measurements taken during a normal trip of the factory trawler *Kastor,* whereby the optimum propeller pitch can be selected in face of changing weather conditions and the varying towing load imposed by the fishing gear.[17]

In one series of investigations carried out in British vessels in order to investigate the design and performance of trawl winches and propellers, it was found necessary to develop a method of measuring tension in the warps used to tow the trawl; this has resulted in a valuable additional fishing aid: the warp tension meter. This gives warning that the trawl has come fast on an obstruction before too much damage is done, it allows more intelligent handling of the winch and winch brakes, it gives a check on whether the trawl is towing square and indicates certain kinds of damage, and it is the only means of setting towing power correctly when the ship's speed over the ground is affected by surface winds or currents.

Fishing Aids

Sixteen years ago the main tools available to the skipper in his tasks of finding and catching fish were experience, the radio telephone and the trawl itself. The warp tension meter is only one of several new tools. To provide more comprehensive information on conditions at the trawl (which may be on the sea bed at 200 fathoms (400 m) or more and over half-a-mile (1 km) behind the ship), both British and Russians have in an advanced stage of development acoustic telemetry systems for use in commercial fishing. One of many problems that had to be overcome in these developments was the interference caused by the propeller wake.

The use of similar but more sophisticated telemetry systems, and also of submersible vehicles and sector-scanning sonars, for research on the design of trawls, is now in its early stages. The result should be a better understanding of the behaviour of the trawl and of the fish; hitherto, development of better trawls has been a slow, costly business characterized by trial and error, intuitive guesses, and extreme caution arising from the cost of failure. Fisheries biologists are also beginning to study the behaviour of fish in their natural environment as a result of the availability of submersibles; a possible outcome of interest to the marine engineer is information on the reaction of fish to propeller noise, and to engine noise; this could affect future design of fishing vessels.

Bottom trawling is the dominant method of capture in the fisheries prosecuted by the type of vessel considered in this paper. Echo sounders are now available that can distinguish a single cod 14 in (35 cm) long at a depth of 200 fathoms (400 m) within 8 in (20 cm) of the bottom. The most advanced of these employs a narrow beam stabilized against the roll of the ship; even so, the information produced is not easy to interpret, although some progress towards automatic data-processing has already been made. Since forward-searching asdics are not yet technically feasible in the context of bottom trawling, and although searching for fish by echo sounder at speeds of 8 or 10 knots is beginning to be employed, the main method of searching is still to tow the trawl. One trawler with its gear down can search in a day an area of only about three square miles (8 km^2) and there is all of the Atlantic Continental shelf outside the fisheries limits to choose from. A desire for more effective searching may influence the selection of the fishing system, e.g. vessels operating independently or fleets. Use of reconnoitring vessels to help indicate the best deployment of the fleets is already practised by Eastern Europeans and by the Peruvians.[18]

The availability of various fishing aids makes it much more practicable to teach young trainee skippers some of the skills they need to possess. A simulator, similar in concept to those used for training aircraft pilots, comprising radar, echo sounder, direction finder, warp tension meters and telemetry displays; ship's log and displays of propulsive power and rev/min, is in course of design at the time of writing.

Ship-borne Computers

The possibility has just been indicated of processing echo-sounder information, and this might include means to indicate the probable size, species, course, speed and catchability of the targets. It has also been suggested that the course and speed of the ship could be automatically computed and controlled to effect interception of a moving shoal by the net. The Peruvians[18] already make use of synoptic information on current rates of catch of several vessels, and of the corresponding hydrographic and meteorological conditions, to control the deployment of the fleet. In the U.S.A., Bullis[19] and Alverson are now using land-based computers to study data collected over the last twenty years on hydrographic, meteorological and other factors and the movement, abundance and availability of various fish stocks, and are developing standardized exploratory fishing techniques that will lend themselves to statistical analysis. Operational Research mathematicians in Russia, Canada and elsewhere[20] are examining the possibilities of developing strategies to help the skipper decide when and where to move to another area, in the light of information on his own and other recent rates of catch and the current costs-and-earnings state of the voyage. British operational research workers have already evolved a decision-making process for one special case of this problem, viz. whether to refuel in Newfoundland or Greenland and return to the fishing ground or whether to go home partly empty. All of these possibilities, and also the availability of satellite navigational aids, suggest possible uses for ship-borne digital computers in large independent trawlers or in mother-ships.

Data-loggers are already installed in a few British freezer trawlers and in the Polish factory trawler, *Carina*. Digital computers intended primarily for scientific data-processing are to be installed in large trawler-type research vessels now on order for the Polish Sea Fisheries Institute and for the Marine Laboratory of the Department of Agriculture and Fisheries for Scotland, and the Fisheries Research Vessel, *Explorer* belonging to the latter establishment is already so equipped. A digital computer is to be installed in the commercial freezer trawler, *Saint Jasper* of Hull, already at sea. This computer forms part of the data-logging and control system for an experimental unmanned engine room, but the choice of a system using a general purpose digital computer, and the provision of redundant capacity in the computer, were done deliberately with the other possibilities, mentioned above, in mind.

Availability and Cost of Labour

Deep sea fishermen are already among the most highly paid workers in Poland and it has been predicted that in Canada, in the relatively near future, fishermen will have to be given an annual income about twice what they would enjoy as heavy labourers ashore. There has always been a scarcity of the most highly skilled fishermen in the British industry and the much higher labour productivity of the freezer trawlers as compared with the ships they replace (about 1·5 to 1) has barely allowed the industry to keep pace with the growing scarcity of recruits. This need to economize in scarce labour is common to most of the major fishing nations.

Saint Jasper, a freezer trawler of 231 ft length, o.a., and 1920 shp, has been equipped experimentally with facilities intended to eliminate watchkeeping crew from the engine room entirely. Vessels of this class carry five or six engine room crew and, depending upon the degree of sophistication finally decided upon, the system will eliminate two or three men; such systems are thereby expected to pay for themselves without putting a value on improved record keeping and maintenance or better control. The remaining engineer officers will be free to devote more time to servicing the growing complex of machinery on the factory and fishing decks. The equipment to be controlled includes a 1920 hp six-cylinder two-stroke Diesel engine using 400 sec Redwood No. 1 fuel driving a c.p. propeller at up to 235 rev/min, with shaft-driven generators for ship's services, also a standby generator and winch engine with hydraulic transmission and six refrigerating compressors serving the freezing plant and cold store, together with the usual pumps and other services. This equipment will be unmanned as regards control and manoeuvring 24 hours a day, on voyages of up to nine weeks to the North Atlantic and Arctic, with vertical accelerations, on passage, exceeding one gravity, and out-to-out rolling of 40° and more. In a vessel such as this, there are several operating regimes, and the fishing regime is characterized by frequent maneouvring, and wide fluctuations of the loads on propeller, winch and freezing plant.[15]

The data-logger in *Carina*, although not intended to reduce crew numbers, has proved very useful in facilitating control of the engine room and planning of maintenance.

On deck, there is a need to reduce labour and a desire to make the task of the remaining crew less uncomfortable, less dangerous and less fatiguing, on all classes of fishing vessel. In the deep sea trawl fisheries, the advent of the shelter-deck stern ramp trawler has gone far to improving conditions, to the extent that fishermen seem willing to stay at sea to a higher average age in the stern trawlers in spite of the long voyages and the high rates of catch. However, the advent of the stern trawler did not in itself bring about a reduction in size of crews. In British conditions, the number of men on the large comprehensively-equipped factory trawlers has been greater than that required to produce the same amount of fish by the older method; this comparison is of course unfair on three counts: the fish is processed to a higher degree, it is of better quality, and the ship can exploit more distant grounds. Nevertheless there are obvious incentives to reduce crews. This has been done, by the owners of some small factory trawlers, by installing a limited range and amount of equipment and accepting a higher probability of saturation of the processing system in times of good fishing. In some East German factory trawlers designed to catch and process herring exclusively, the flow of fish has been sufficiently mechanized and automated to bring the number of crew down to the same as in a freezer trawler. The British freezer trawlers have very high labour productivity, due to the use of the vertical plate freezer developed at the Torry Research Station,[21] and as noted already the number of crew is 24 to 26 as compared with 60 to 100 in a large factory trawler towing essentially the same sort of trawl. There is no doubt that, by development, a high degree of automation will ultimately be achieved in the flow of fish through the filleting lines, the packing lines and the freezers in factory trawlers; one such vessel, *Coriolanus*,[22] already has a crew of only 40. Choice of system is, of course, only partly governed by labour costs, and is discussed more fully later.

Reduction of labour on the fishing deck is much nearer realization. The problem of handling the net is solved by fishing over a stern ramp or by using a powered net drum[23] or both. Automatic machine tools for eviscerating cod and similar species have come on the market in Western Germany and in Britain and are at present undergoing operational and economic assessment in the Russian, British and other fleets.[18]

Transfer of Catches

Polish expeditions employing mother-ships prosecute the herring fisheries of the North Sea, as do Russian expeditions, and both nations also operate mother-ships in the trawl fisheries of the North Atlantic and Arctic. In the United Kingdom there are proposals that trawlers not equipped to preserve their catches by freezing might fish alongside freezer trawlers or factory trawlers during seasons of slack fishing, and thus secure full utilization of the expensive processing plants. Or, in the less distant waters, several trawlers of the type depending on crushed ice as a means of preservation might transfer their catches to one of their number about to leave for the home port, and begin fishing again without the embarrassment of earlier-caught fish spoiling in their holds; this fleeting system, as it is called, would improve the quality of the landings or productivity or both. Forty years ago such a system was indeed in use by the English in the North Sea; the method of transfer was in boxes in open rowing boats, and the accident rate was high.

One modern method of transfer, the first to be used in commercial conditions in recent years, is for the fish taken aboard the catcher to be put in a net, similar to a cargo net; the receiving vessel floats a line down to the catcher and winches the net through the water. Another method is to pump the fish through a floating pipeline. Only in fine weather has it so far been found possible to bring the catchers alongside the mother-ships, using various types of floating fender and transferring the fish by pumps or by traditional derricks. Re-immersion of the fish in the sea, or pumping them, can cause accelerated spoilage and damage that are not acceptable in certain markets. Methods of temporary storage on board the catchers, such as in tanks of chilled sea water or rigid containers with ice, also need further development to be completely satisfactory, both operationally and otherwise. Recently, therefore, the White Fish Authority have been developing an improved system in which the catching vessel guts and washes the fish and stows them in ice in boxes, which are transferred by union purchase; the ships are separated by inflatable rubber fenders.[16, 24] This method has been subject to practical trial using commercial trawlers about 200 ft in overall length, off Iceland; the limiting wind force for bringing such ships together in the open sea using this type of fender is probably about Force 5 but, once moored together, transfer has on occasion continued as the wind increased to Force 7.

SYSTEMS ANALYSIS

The value of a programme of technical investigation in the field, to bring about refinement in design, ensure fitness-for-purpose, and thus improve costs and earnings, has already been noted. Thus choice of propulsive system—e.g. single large Diesel driving c.p. propeller and shaft generators, with or without gear-box, or multi-engine Diesel-electric, and if the latter, how many engines of what power; or, again, electric versus hydraulic winches, or choice of propeller diameter —can be guided in this way.[15, 17, 25] There are also, however, decisions to be made on the fundamental techno-economic parameters of the ship design: speed, hold capacity, fuel endurance and throughput of processing plant. The advent of freezing at sea removed the limitation formerly imposed by spoilage of the fish, which meant that the owner should make his choice within a relatively narrow range of length and horsepower; the main limit now is the maximum acceptable length of voyage.

When Burney and Lochridge designed the first factory trawler, *Fairtry*,[3] they had little or no real choice in the technology of processing then available, and they adopted a policy of providing equipment of sufficient variety and on a sufficient scale to make it highly improbable that fishing operations would be brought to a halt because the appropriate equipment was not available on board or was temporarily out of service. The economically viable size, speed, power and hold capacity of the ship were then determined by assessing likely costs and earnings; size was fixed at 240 ft length, b.p., and displacement and cost turned out to be roughly four times that of a conventional trawler of the day. The first series of factory trawlers built by the Russians were very similar to *Fairtry* in size, power and general concept. The West Germans subsequently built a series of stern-fishing factory trawlers of 200–220 ft length b.p., and of about half the cost, and this was the sort of size and cost chosen for the first generation of British freezer trawlers in 1961–64.

In the existing British stern trawler fleet, there is a wide range of size, speed, fuel endurance, throughput of freezing plant and capital cost; more especially, there is a wide range of variation of the ratios of these techno-economic parameters to what is probably the most important one of all: hold capacity. To achieve the maximum ratio of fishing time to time spent on passage, it is desirable to have a very large fish hold; however, the hold size may be limited by the maximum length of voyage acceptable to crews, or by the amount of investment capital available, or by the necessity of limiting the turnover capital tied up in the cargo carried on boad the ship. These early freezer trawlers were, of course, designed before results from the programme of technical investigation began to become available. Moreover, the owners and builders were preoccupied with gaining practical knowledge of building and operating these quite new types and sizes of vessel, involving new methods of handling the fishing gear and new methods of preserving the catch, and were concerned not to take too much risk by over-refining the design. The managers of the fishing industries of Eastern Europe have also been preoccupied, in their case with rapid expansion of their deep sea fleets. In both cases the task was to evolve systems that were workable, rather than to try and identify near-optimum designs. There is therefore good reason to suppose that at least some of the early designs, although operationally satisfactory, must be far from the techno-economic optimum that it was theoretically possible to achieve at the time they were designed.

Mathematical Models

The Ship Design and Research Centre of Union of Shipbuilding Industry and the British National Physical Laboratory were among the first to embark upon operations research with a view to optimizing the selection of techno-economical design parameters for fishing vessels, using digital computers. They were closely followed by the White Fish Authority, and more recently the Icelandic fisheries authorities have also established a small team of engineers and operational research mathematicians. In Poland, pioneering work by Swiecicki on speed and size of fishing vessels was followed by Bogucki and Majewski, who have developed a system of analysis that can be described as a stochastic model of a fishery for which the optimum ship speed, hold capacity, type and size of the processing plant and endurance can be determined.[26]

In the United Kingdom, the beginning of operations research in the fisheries can be seen in [9] and a techno-economic comparative analysis of a simple sort appears in [4]. Methods of optimizing the design of wet-fishing deep sea side trawlers were developed by Doust[27] and Hayes but these are suitable only for optimizing within the envelope of a very large number of existing designs. In the White Fish Authority, Haywood and his co-workers began by tackling the problem of choosing the optimum size of freezing plant in a trawler in terms of throughput and cost, in the face of violently fluctuating catches and various biological limitations on processing times and delays. The method employed was simulation, using probability data derived from detailed logs of fishing operations. This method has been extended to determining the optimum choice in a range of designs of freezer trawler of varying speed and hold capacity and the work has been described to this Institute.[28]

Other work in the field of operations research has been concerned with the scheduling of trawlers engaged in fleeting systems employing transfer of catches, and includes the evolution of decision rules for when to transfer. It is less easy to ensure that capital equipment and crews are employed to maximum effectiveness in fleeting systems than might at first appear: early mother-ship operations from Eastern Europe involved the catchers returning when the mother-ship was full, but continuous systems involving more than one mother-ship are now in operation. In the West Atlantic fishery, the Poles have recently introduced a system employing two mother-ships alternately, so as to keep one of them permanently present on the fishing grounds.

In the use of these techniques to determine the optimum design of fishing vessels, one of the main problems is predicting the future trend of catch rates. The best that can be done at present is to postulate various outcomes, e.g. that catch rates of cod in the Davis Strait will reduce by five per cent per annum; or to examine how sensitive the final choice is to changes in catch rates. It is at least conceivable, however, that a mathematical model of the fishery will one day be possible. Mention has already been made of the work of Alverson and Bullis,[19] whereby hydrographic, meteorological and fishing data are stored with a view to studying movements and availability of stocks, and whereby systems of standardized exploratory fishing are being developed with a view to analysis and possible prediction of where good catches will occur within a given sea area. The mathematics of fish population dynamics has already been developed by Ricker and others and especially by Beverton and Holt.[29] Their models show how the size, of a fish stock, and the average size and yield of fish from it, are related to fishing effort, net mesh dimensions, and so on. Unfortunately, the absolute size of a stock is governed also by natural predation and mortality and by the success of spawning and the survival of the brood; given sufficient spawners one good brood-year can restore an ailing fishery, but the hydrographic and biological factors are not well understood. Neither are the interactions between species, and it is even difficult to distinguish which fisheries can be regarded as independent, closed systems and which cannot. Nevertheless, although it may be many decades before a good understanding of all these factors is reached, in the meantime it may be possible to begin to construct simulations or other types of model for entire fisheries, in much the same way as it is already possible to simulate the operations of a single trawler. The value of being able to predict the total catch, within certain limits of probability, would be that it might be possible to deploy the existing fleets in a nearer optimum way as judged in the light of the effort/yield equations of Beverton and Holt, and the costs of exploiting the various stocks. It should also be possible to decide on the optimum number and type of vessels in future building programmes.

Choice of System

The fishing vessel is, in fact, a component part of a complex economic process which, although with great difficulty, yet may be optimized. It is necessary to elaborate for this purpose a mathematical model in which the object of analysis is a fishing system, the characteristics and technical parameters of which are subordinate to definite economic goals. The model must also conform to the external constraints, namely, the conditions in which the system is to be operated. In view of the fact that, in practice, catch rates are subject to chance variation, the mathematical model of the fishery ought to be of the simulator type employing probability data and even the theory of games.

The studies already initiated in Great Britain and Poland in this field suggest that such a model can be worked out and that it may assist in finding the optimum technical solutions to prosecuting the distant-water fisheries and the best methods of operating them.

Various economic and operational criteria may be used to identify the "optimum" solution and it is likely that, in practice, several criteria will be employed in some sort of pre-determined preference ranking. A more serious difficulty, as will be seen from the section dealing with technical development, is that the number of options open to the management of an enterprise for fishing the distant waters, faced with selecting and specifying the system to be adopted, is quite bewildering, and as a result of technical development the number of options is growing. First there is the influence of marketing considerations, including the choice of method and degree of processing on board—fillet blocks, sea-frozen whole fish, canned products, etc.; this considerable number of options and sub-options is multiplied by the choice between independent individual vessels, rotational fleeting systems of catchers, mother-ships, and so on. Another sub-system already in operational use is the reefer ship used to carry fuel and other stores to the fishing grounds and to transport frozen fish products therefrom. Also there may be various operational options such as, for example, the practice of the Polish South Atlantic fleet of landing only every second or third voyage in Poland, the other catches being landed in African ports; a similar method of improving the ratio of fishing time to time spent on passage is employed in the North West Atlantic where every second voyage is landed in St. Pierre.

The most far reaching concept which may be used in operating very distant fishing grounds is to design a group of vessels, the nucleus of which would be a depot-ship staying permanently on the fishing grounds for the whole of the four-year period between surveys. The flotilla of catcher vessels to accompany the depot-ship would also remain permanently on the fishing grounds, while the fish products would be transported by reefer ships which would carry stores and provisions to the group and also allow the replacement of the depot-ship and catcher crews. In order to reduce the quantities of stores carried to the fishing grounds, a nuclear reactor deserves very serious consideration as the source of power for the depot-ship. It may also be advantageous to use fuel cells for the propulsion of the catcher vessels.

Under such circumstances, the depot-ship, together with the flotilla of catchers, would have to make a completely self-sufficient group. The depot-ship hull would have to be of a special form so as to constitute a sheltered berthing facility as well as a floating dock. In view of her great size and numerous crew, the depot-ship would provide not only normal port and repair base facilities but also very extensive amenities, equivalent to those available on shore. At the present time this seems to be a rather far-fetched project, nevertheless the results of the preliminary studies made by Polish naval architects point to the fact that it is fully practicable and justified from the viewpoint of economics.

Whatever the fate of this particular idea, it is conceivable that none of the existing combinations of various sub-systems may be the best choice for any of the managements concerned with exploiting the long-distance Atlantic fisheries. Thus, it is possible that a thorough systems analysis would suggest that there could be better systems than any now available. Research and development would then have to be devoted to producing any crucial sub-systems that do not yet exist. Such a thorough systems analysis has not yet been carried out. If it were it would have to take account of factors as yet only hinted at in this paper—those connected with the market. The main ones are choice of species and form of product.

Influence of the Market

The product of *Fairtry* and her successors is a block of frozen fillets weighing 14–50 lb (7–25 kg). The original outlet for these was the catering trade—hotels, restaurants, passenger ships. In Poland, when the expansion of the deep sea fleets began, there was a deliberate decision to build factory trawlers because markets for fillet blocks could most readily be created. In Western Germany, factory trawlers entered service at a higher rate than the marketing and distribution network for their kind of product was able to grow, and there was over-production of fillet blocks; this led to the development of blocks of fillets interleaved with plastic sheeting so that traditional fishmongers and small restaurants could sell individual frozen fillets. A new market came with the introduction of frozen fish fingers, the sea-frozen fillet block being sought as the raw material. Nevertheless the international market is still sensitive to over-production of fillet blocks both ashore and afloat. To make sea-frozen fillets suitable for a wider range of outlets requires practical solutions to be found for problems arising as a result of *post-mortem* processes, of which *rigor mortis* is the most obvious manifestation.

Sea-frozen whole fish as produced by freezer trawlers can be thawed and used for any purposes for which very fresh inshore fish is used, including smoked products and frozen consumer packs, and so it may command more outlets. At the same time, the freezer trawler may be more flexible than the factory trawler as regards choice of species and grounds, since, in the present state of the art, fish processing machinery can handle only a limited range of species. Thawing and further processing of sea-frozen whole fish are however best done in a central plant under close control, and so it is not surprising that the biggest development of the freezer trawler has been in England, a small country with a comprehensive and fast transport network and an existing trade in deep sea fish products. For the same reason, the British have developed faster than others the sale of prepackaged wet fish (produced from thawed sea-frozen fish or inshore fish). Freezing of whole fish at sea has, however, now been adopted in recently-built vessels in Germany and also in Poland, in order to ensure supplies of raw material for shore factories facing a decline in the inshore fisheries on which they formerly depended.

This discussion will serve to show that the choice of processing system to be installed in a distant-water trawler is not as straightforward as has been suggested by Heinsohn[5] and Kamensky,[6] among others. It is true that in the larger classes of factory trawler, the space occupied by filleting machines and extra crew is more than compensated for by the much smaller hold needed for fillet blocks than for blocks of whole (headless) fish, but it is not enough to make comparisons based on these factors even if numbers of crew are also taken into account. This is especially so when the catching of fish tends to be, in Western countries at any rate, a service to the marketing organization rather than a source of profit, owing to the free-entry, free-resource nature of deep sea fishing. Profits are associated with the marketing operation; the ship is only part of the system. In Eastern Europe, it has been possible to fix the prices of fish, relative to the prices of other foods, so that the fishing enterprise can operate economically.

Canning factory trawlers and mother-ships are already at sea, as noted earlier, and the possibility of producing, at sea, consumer packs of frozen fish cannot be ruled out. A system for rapid, accurate weighing on board a small ship in a seaway has now been developed.[30] Factory vessels already produce fish in the form of frozen mince for sausages, and this may presage a demand for bland, neutral protein to form the basis of a variety of manufactured foods. In this case, species may be less important than it is held to be at present. In any case there is evidence that, in certain circumstances, species is less important than the freshness of the fish, the "convenience" aspects and the way in which it is cooked and presented to the ultimate consumer.[16] The significance, or lack of significance, of species, is important, since preference for species can make a big difference to catch rate and to processing equipment, and also to the choice of fishing ground and hence to length of passage. On the other hand, flexibility as regards species preference would make fishing operations less sensitive to fluctuations in the abundance of the stocks of any one species.

It will be clear from the foregoing that correct choice of fishing system cannot be made without an overall systems analysis covering the entire operation from the sea bed to the consumer's plate. It cannot be assumed, however, that consumer preferences are fixed and unchanging. The management of the marketing side of the operation, therefore, can perhaps help, by influencing demand, to ensure that the main capital equipment of the enterprise, the vessels, are fully utilized in the face of seasonal and longer term fluctuations in supplies of various species, and that they can concentrate on species and sizes that represent the best relationship of costs to earnings.

One lesson, however, that the shipowner or the management of the fishing enterprise may well have to accept is that it is not their exclusive prerogative to specify the ships. Those responsible for marketing, by specifying the product they require, may have a noticeable influence on the choice of size, type and layout of the deep sea fishing vessel of the future.

CONCLUSION

Exploitation of the sea as a source of food is of growing importance to mankind. The predicted increase in the world catch of fish is very significant either in terms of food supplies or in terms of the number and value of the ships that will be required to catch them.

Any system of finding, catching and processing fish in the open sea of the North or South Atlantic, at a range of several thousand miles from the home port, and of bringing the catch home in good condition and in a form acceptable to the market, is bound to be very complex technologically. Nevertheless, or because of this, the number of options as regards choice of system is very large, and as a result of recent technical developments the number of options is growing. In these circumstances the correct choice of system is unlikely to be made unless management decisions are based upon proper analysis of accurate technical and operational data, including market requirements. The fishing industry is well on the way to evolving an overall systems approach of this kind.

REFERENCES

1) *Fishing News International, 1965, Vol. 1, No. 1 et seq.*
2) Hardie, C. M., Meek, C. I. M. and Eddie, G. C. 1968. "The Future of the Fishing Industry". *Fishing News,* Nos. 2862 and 2863.
3) Lochridge, W. 1956. "Mechanization in Fishing Vessels". *Trans. I.E.S.,* Vol. 99, p. 511.
4) Hunter, A. and Eddie, G. C. 1959. "Fishing Vessel Development". *Trans. I.Mar.E.,* Vol. 71, No. 6.
5) Heinsohn. 1963. "Stern Trawling". Proc. Conf., White Fish Authority.
6) Kamensky, E. 1968. "Operational Experience with Large Factory Trawlers and the Direction of their Further Development". Paper read Scientific Congress of Inrybprom, Leningrad, August.
7) Kamensky, E. and Terentiew. 1968. "Rybolovne Trawlery". *Sudostroenie, Leningrad.*
8) Bogucki, D. and Swiecicki, J. 1965. "New Trends in Construction of Polish Fishing Vessels". *Fishing News International,* Vol. 1, No. 4.
9) White Fish Authority. 1957. "Report on an Experiment into Freezing Fish at Sea". H.M.S.O.
10) Bennett, R. 1967. "The Performance of Fishing Vessels and Their Machinery". *Trans. I.E.S.,* Paper No. 1315.
11) Hearn, P. J. 1966. "Data Logging on Deep Sea Trawlers". Symposium on Electronics, Measurement and Control in Ships and Shipbuilding. Paper reprinted by B.S.R.A.

12) Bennett, R. and Hatfield, M. 1966. "Development of Strain Gauge Techniques for the Measurement of Propeller Shaft Torque in Distant-water Trawlers". *Jnl Strain Analysis,* Vo. 1, No. 2.
13) Hatfield, M. 1965. "Performance Measurements for Two Inshore Vessels". *Fishing Vessels of the World,* Vol. 3.
14) Bogucki, D. 1968. "Rozwazania nad doborem elementow zespolu statek-wlok". *Prace Morskiego Instytutu Rybackiego.* Vol. 14, Ser. B.
15) Bennett, R., Chaplin, P. D. and Kerr, N. M. 1968. "Controllable Pitch Propellers in Large Stern Trawlers". *Trans. I.Mar.E.,* Vol. 80, p. 257.
16) White Fish Authority. 1964 *et seq.* Annual Reports, H.M.S.O.
17) Brandowski, A. 1967. "Numerical Method for Optimizing the Work Parameters of the Vessel Propulsion Unit with a Controllable Pitch Propeller under Various Exploitation Conditions". Polytechnic Institute of Gdansk, Paper.
18) Valdez, P. 1968. Proceedings of Second F.A.O. Technical Conference on Fishery Research Craft (to be published).
19) Bullis, M. Bureau of Commercial Fisheries, Pascagoula (Personal Communication).
20) Dickie, Ll. M. 1968. "Distribution and Location of Bottom Fishing". Atlantic Fisheries Technological Conference, St. John's Newfoundland, Contribution to Discussion.
21) Eddie, G. C. and Yule, P. A. A. December, 1953. "A Vertical Plate Freezer for Whole Fish". *Modern Refrigeration,* Vol. 56, p. 441.
22) 1967. *"Coriolanus". Fishing News International,* Vol. 6, No. 6.
23) Bennett, R. 1968. "Some Recent Applications of Hydraulics to the Deck Machinery of British Fishing Vessels". Paper read to Scientific Congress of Inrybprom, Leningrad.
24) Bennett, R. August, 1968. "Report on Transfer of Fish at Sea". Scientific Congress of Inrybprom, Leningrad, Paper.
25) Bogucki, D. 1960. "Mathematical Criterion of Choice of the Vessel Machinery". Third Scientific Session of Shipping Industry, Gdansk. Paper.
26) Bogucki, D. and Majewski, W. 1966. "Method of Optimizing Parameters of Fishing Vessels by Medium of Multi-criterial Estimating System". Ship Design and Research Centre, Gdansk, Paper.
27) Doust, D. J. 1962. "Optimized Trawler Forms". *Trans. N.E.C.-I.E.S.,* Vol. 79, p. 95.
28) Chaplin, P. D. and Haywood, K. H. 1968. "Operational Research Applied to Stern Freezer Trawler Design". I.Mar.E. Conference, Paper.
29) Beverton, R. J. and Holt, S. J. 1957. "On the Dynamics of Exploited Fish Populations". Fishery Investigations London, Ser. 2, No. 19.
30) Allison, E. and White Fish Authority. British Patent Applications No. 18244/67 and No. 35457/67.

Appendix I

FISHING VESSEL CONSTRUCTION IN SOME COUNTRIES OF EUROPE, 1965 1966 AND 1967[1]

Country of building		Factory/ freezer trawlers	Mother-ships	Other vessels over 140 ft	80–140 ft
Belgium	Home	1	—	3	4
	export	—	—	—	4
Denmark	Home	1	—	—	3
	export	—	—	—	4
France	Home	7	—	2	44
	export	7	—	—	48
W. Germany	Home	13	—	4	3
	export	2	1	2	7
Iceland	Home	—	—	1	1
	export	—	—	—	—
Italy	Home	6	—	18	3
	export	—	—	1	—
Netherlands	Home	2	2	5	11
	export	7	—	8	11
Norway	Home	5	—	17	73
	export	9	1	3	36
Poland	Home	20	1	—	20
	export	17	11	10	1
Spain	Home	29	—	17	31
	export	6	—	3	—
U.K.	Home	19	—	6	10
	export	3	—	8	1
TOTALS		154	16	108	315

Appendix II(a)

TYPICAL BRITISH FREEZER TRAWLERS

Name of ship	Year built	Length, o.a., ft	Gross registered tons	Service speed on passage, knots	SHP	Propeller, rev/min	Propulsion A, B, C, etc.	Fish hold capacity, ft	Freezer throughput, tons/day	No. of crew (total)
Marbella	1965	245 ft 6 in	1786	15	2100	204	A	30 000	37	26
Arctic Freebooter	1965	241 ft 7 in	1633	15	2100	275	B	27 000	40	26
Saint Jerome	1968	231 ft	1264	14	1920	225	E	32 000	31	29

A: Multi-engine Diesel-electric
B: Single Diesel, direct coupled to c.p. propeller, shaft-driven generators
C: Single Diesel, but with reduction gearing
D: Single Diesel, direct coupled to fixed propeller, separate auxiliaries
E: Single Diesel, direct coupled to c.p. propeller, separate auxiliaries

Appendix II(b)

STANDARD POLISH FISHING VESSEL DESIGNS IN COMMON USE

Name of ship	Year built	Length, o.a., ft	Gross registered tons	Service speed on passage, knots	SHP	Propeller, rev/min	Propulsion A, B, C, etc.	Fish hold capacity, ft	Freezer throughput, tons/day	No. of crew (total)
Carina factory trawler	1967	288 ft 4 in	3169	13	2420	175	C	55 000	30	103
Laskara freezer trawler	1968	247 ft 6 in	1890	13·5	2500	175	C	32 000	30	58
Pomorze mother-ship	1968	538 ft	13 872	14·2	7200	139	D	357 000	90	261

A: Multi-engine Diesel-electric
B: Single Diesel, direct coupled to c.p. propeller, shaft-driven generators
C: Single Diesel, but with reduction gearing
D: Single Diesel, direct coupled to fixed propeller, separate auxiliaries
E: Single Diesel, direct coupled to c.p. propeller, separate auxiliaries

FIG. 1—*A typical large steam trawler*

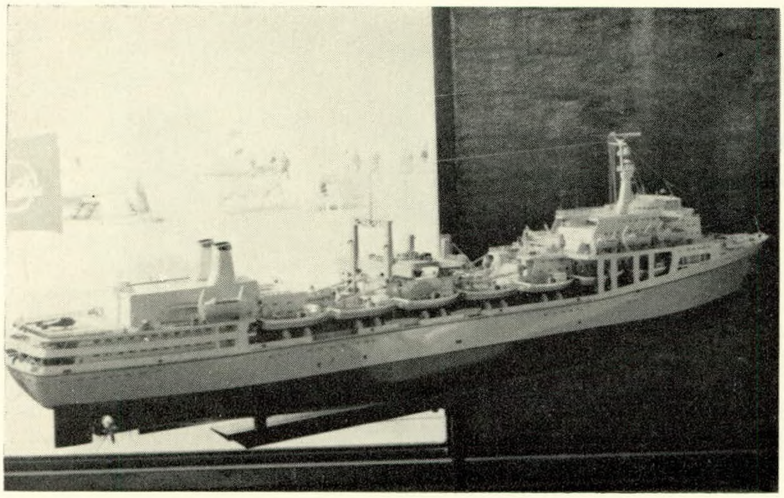
Photograph by courtesy of Mr. Peter Brady, Fleetwood.

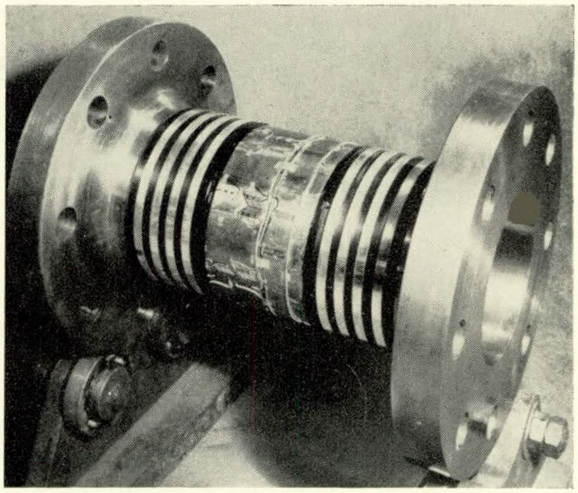
FIG. 2—Arctic Freebooter—*A modern freezer trawler (see Appendix IIa)*

Photograph by courtesy of Boyd Line Ltd.

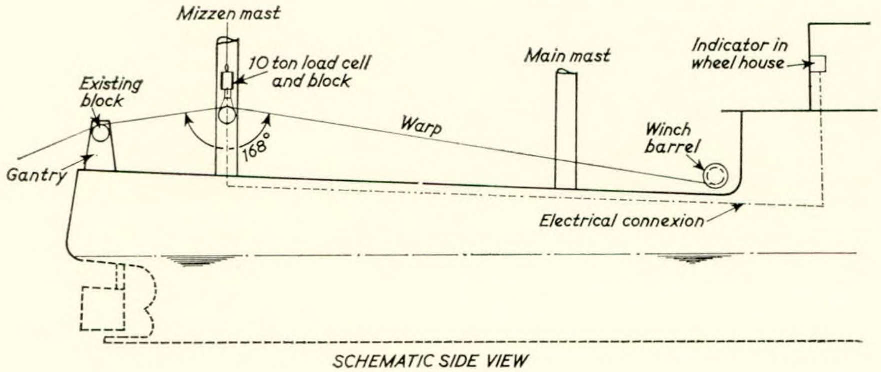
FIG. 3—*Factory trawler* Carina *(see Appendix IIb)*

FIG. 4—*Mother-ship* Pomorze *(see Appendix IIb)*





Photograph by courtesy of *World Fishing.*



ABOVE:

FIG. 5 *(left)—Model of mother-ship* Vostok*—45 000 tons*

FIG. 6 *(right)—Strain-gauged insert shaft for measuring propulsive thrust and power in commercial trawlers*

LEFT:

FIG. 7—*Layout of trawl warp load meter*

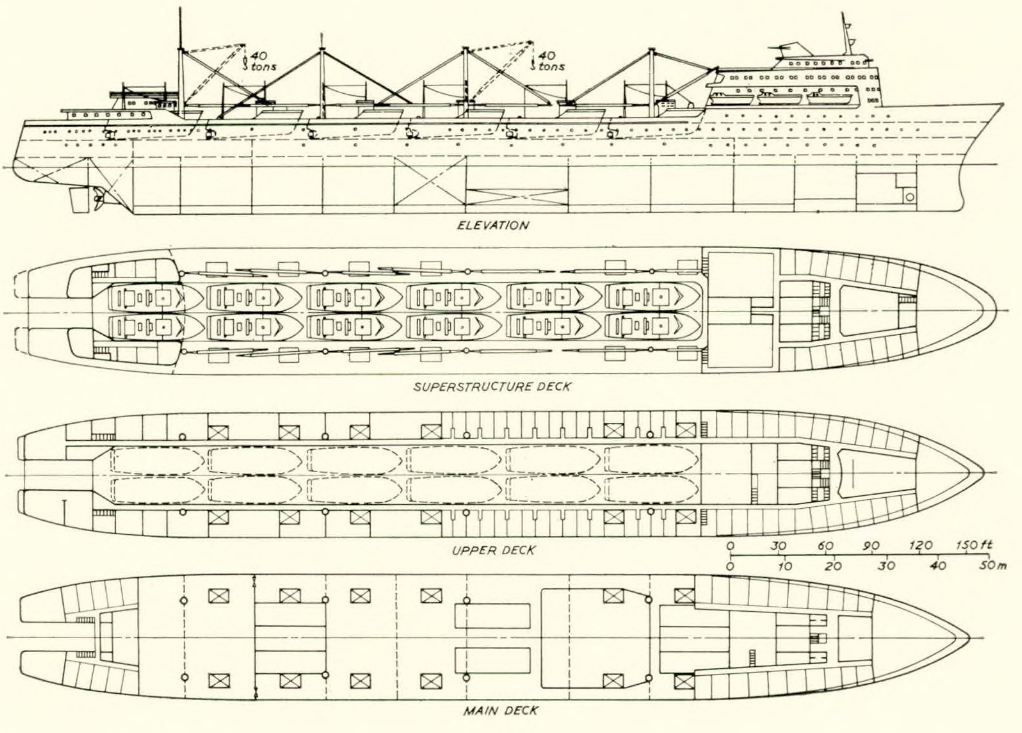


FIG. 8—*Proposed fish meal factory mother-ship*

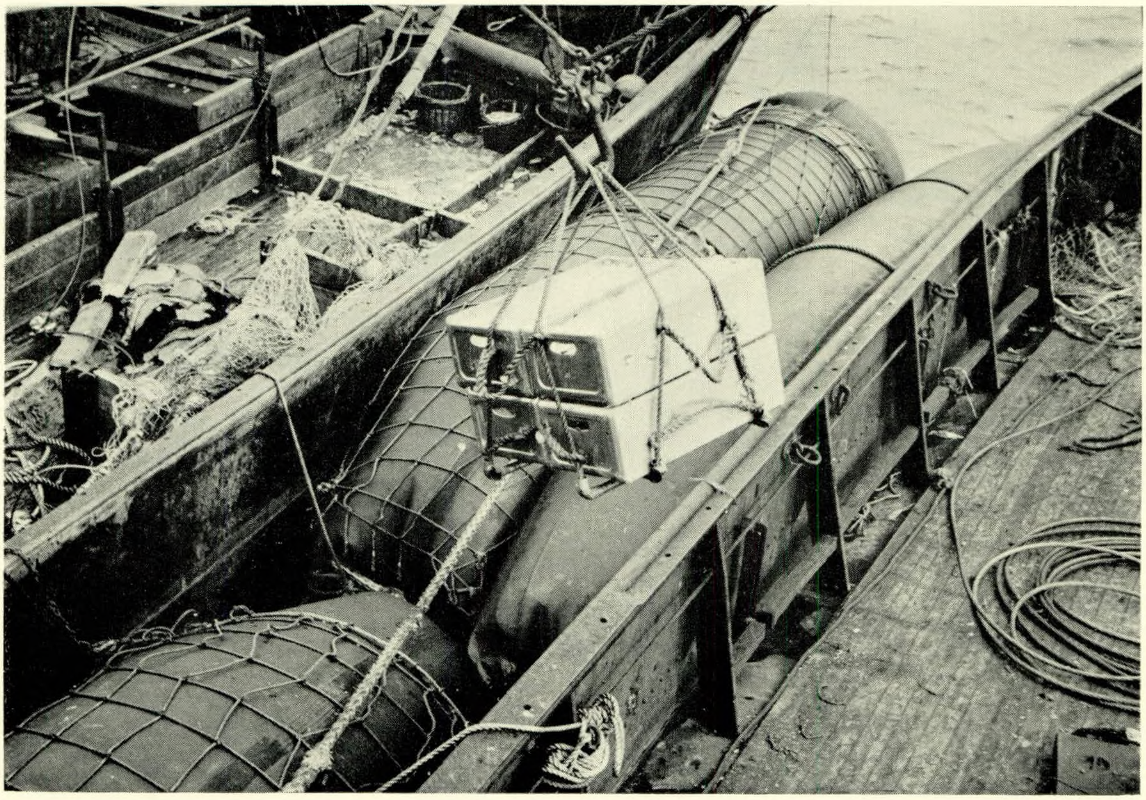


FIG. 9—*Trials of soft fendering system to facilitate transfer of catches between trawlers on the open sea*

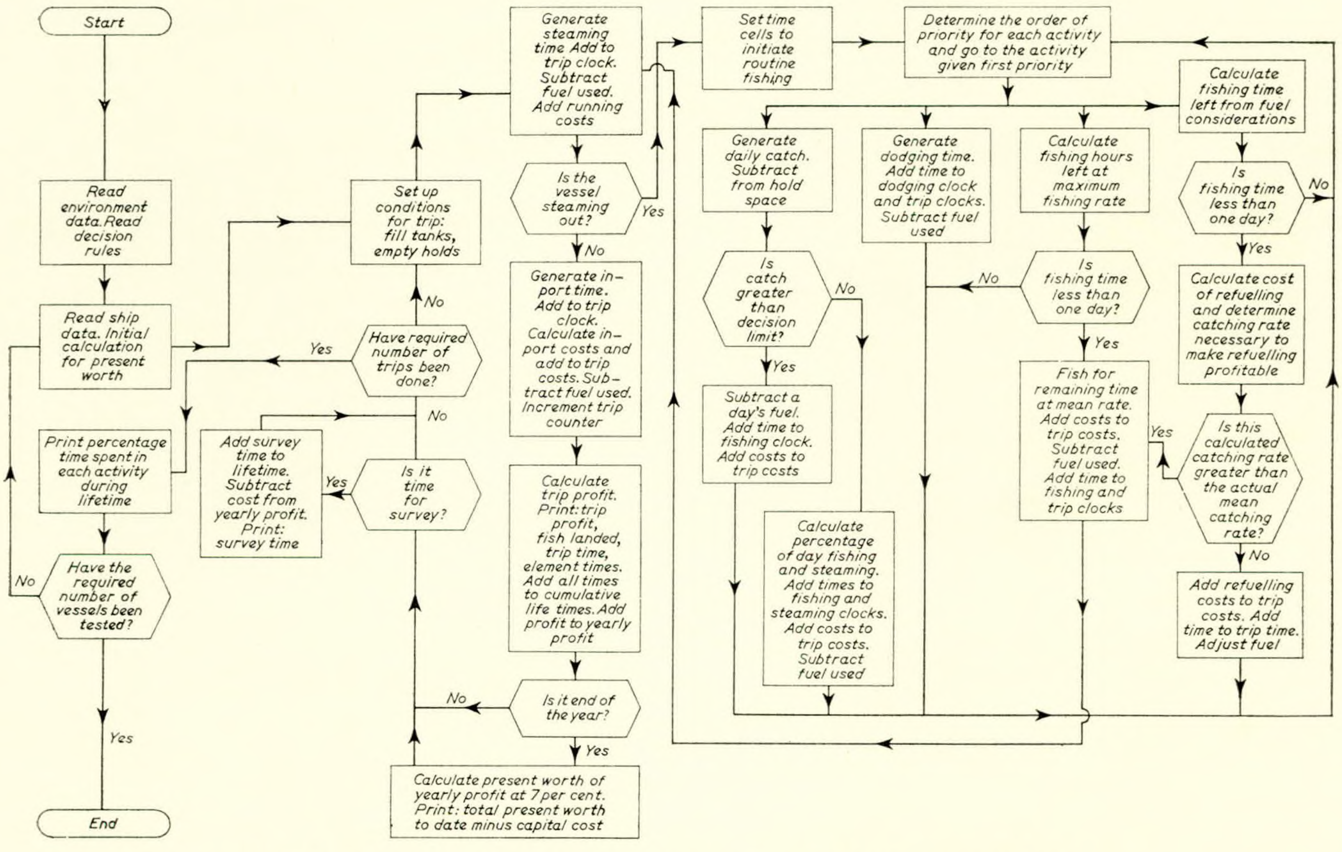


FIG. 10—*Computer simulation flow diagram in stern freezer trawler design*