INTERNATIONAL COUNCIL FOR
THE EXPLORATION OF THE SEA

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Fish Capture Committee

# A PRELIMINARY STUDY ON THE LANDINGS CAPACITY OF STERN FREEZER TRAWLERS.

by

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## Contents

## Abstract.

This paper deals with several models for the calculation of the yearly attainable landings of stern freezer trawlers, using technical input variables like the volume of the fishholds and the freezing rate and operational variables like a continuity factor for the process of freezing blocks of fish, a factor describing the stowage of the cargo in the holds, the duration of the voyage to and from the fishing grounds and the amount of days the vessel is in port for unloading the cargo and for maintenance and repair.
**The process of filling the boat is modelled as a continuous flow determined by the freezing operation.** The process of searching the fish and capturing the fish with a trawl is not described. It is assumed, that through the use of adequate buffer storage these processes may be separated and treated indepently. The effect of the different variables on the total landings attainable is analysed. A sensitivity analysis indicates, that the capacity and continuity of the freezing process are the most important variables followed by the volume of the fishholds and the fillingcoefficient of these holds. The time lost at steaming and in port are also important, but to a lesser degree. No attempt has been undertaken to find the optimum values, as these depend on economic criteria, that still have to be worked out. It should be emphasised, that the figures given are theoretical ones, not validated yet by a comparison with true figures of landings obtained over a year. **The models are aimed to determine the relative influence of the major parameters and not to predict actual annual catches.** Further study is needed to develop a model, that can be used to quantify and predict fishing operations of new vessels in the preliminary stage of design.


## 1. Introduction.

The problem of matching fleet capacities to existing quota regimes is of growing importance. It is generally accepted, that over-capacity exists in many fisheries. Todays fishermen are confronted with a vast set of rules and regulations, ranging from operational restrictions like allowed days at sea, to technical constraints like mesh or even gear size and towing power restrictions. In many mixed species fisheries additional requirements on the amount of by-catch are given. Administrative requirements also grow rapidly and so are inspections by national and international authorities. In this complex situation a fisherman still has to find his way to make a living.
The design and operation of fishing vessels must therefore be aimed at an optimal economic performance within these constraints. The fishing industry responds to this situation by putting more emphasis on landing a product of a higher value by improving the quality or further refinements on board and by constantly aiming at a decrease in operational costs. In the Dutch trawler fishery this leads to an increase in ship dimensions. The vessels are probably not designed for a fishing operation alone. They can also be put into freezing fish and transportation service.

## 2. Vessel type and characteristics.

TABLE 1 summarizes the principal dimensions and technical data of sterntrawlers added to the Dutch fleet since 1980.
**The essential characteristics of this type of vessel are :**
- Two decks.
- Superstructure and machinery room placed aft.
- Closed stern without a ramp.
- A relatively short deck for gear handling.
- Two independent net drums.
- A number of refrigirated seawater storage tanks below the gear handling deck.
- A large battery of plate freezers.
- A number of large insulated fishholds.

A few examples are given in Figures 1 and 2 on the next pages :

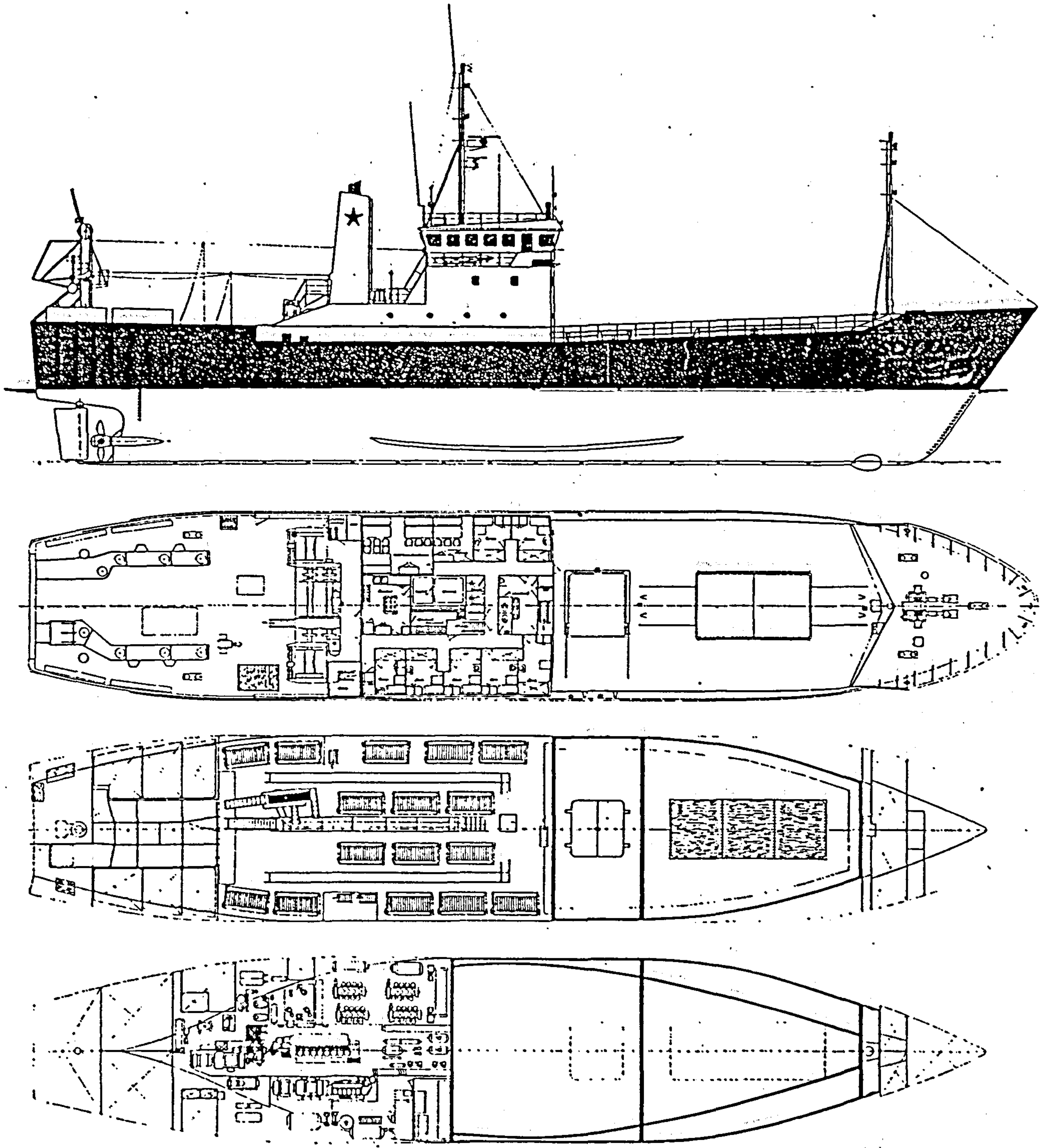


**Figure 1 : Example of a Dutch stern freezer trawler, designed in 1980.**

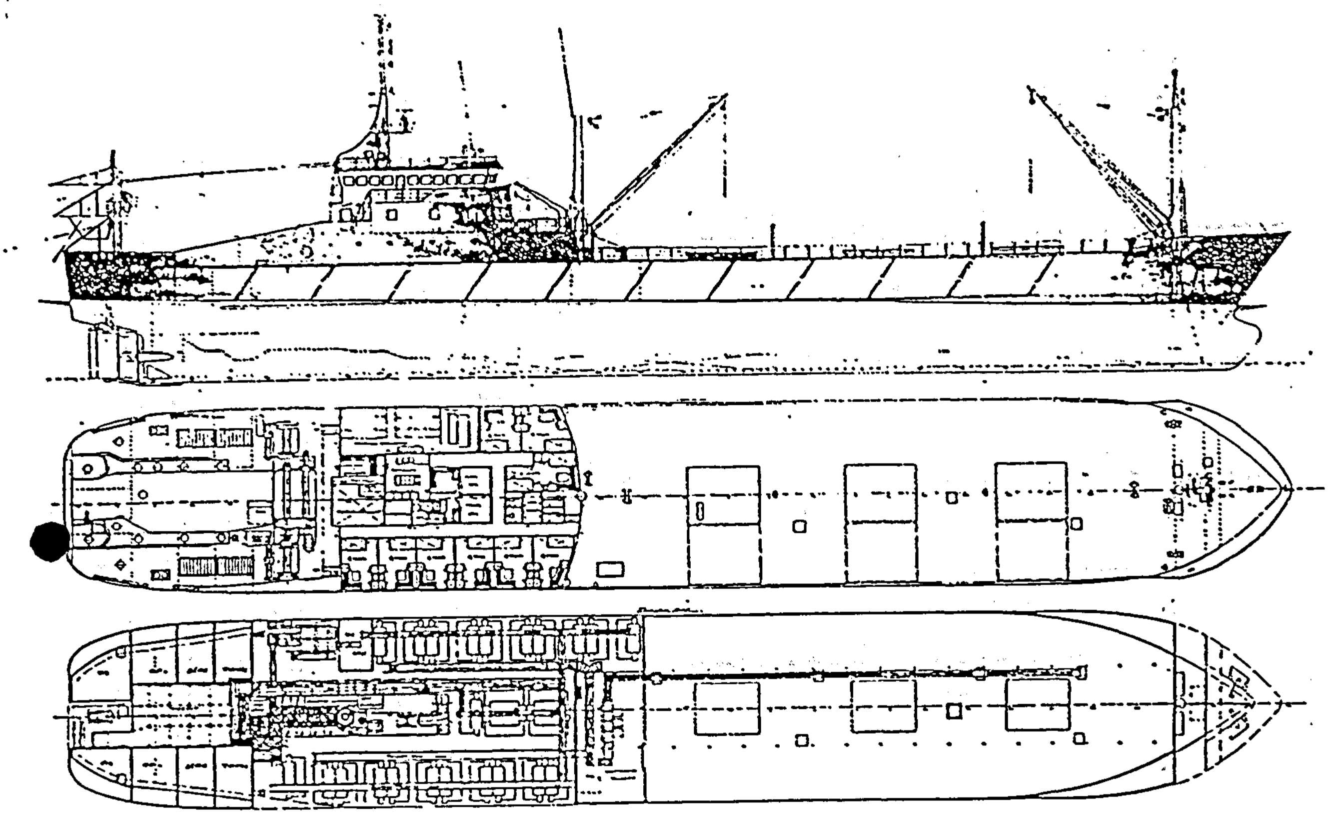


**Figure 2 : Dutch stern freezer trawler, built in 1984.**

## 3. Trends in vessel design.

Most significant are the raise in fishhold volume, along with the principal ship dimensions, the raise in freezing capacity and installed power of the main engines. Similarly the size of midwater trawls has grown rapidly over the last decade. This trend has been magnified by the increase in mesh size in this type of net from 20 cm. at the beginning to 28.80 m. today. Some net designers expect the 10000 meshes (of 20 cm.) circumference trawl within the next couple of years.[4]
The latest developments are the use of pallets when stowing frozen blocks of fish, a reduction in the size of the packing unit with horizontal plate freezers and the growing use of filleting machines. Unloading procedures, done with conveyor belts by hand for many years, are recently changed as well. The most modern ships have a large door in the side through which forktrucks can unload the vessel. This procedure implies storage on pallets. Apparently the speed of operation has been given higher priority over cargo space. Personnel costs will also be lower with less manual labour.
The quality of the landed fish has recently been improved in some boats by pumping the fish directly from the RSW-storage tanks to the plate freezers, without the former intermediate storage in a fish bin. Using this bin caused the fish to warm up after beiing cooled down in the tanks and prior to the freezing process. This implied a waste of energy and unneccessary deterioration of the fish quality. The use of fish pumps to transfer fish from the cod-end of the trawl to the RSW-tanks has been tried in commercial practise several times, but did not break through has resulted in the Dutch fisheries due to handling difficulties. The traditional method using a halfing becket and the lazy decky.and repeating the filling of the cod-end and heaving onboard is still commonly used. This method is tied to the closed stern construction and is aimed at higher quality by reducing the load on the fish while hauling in. Another result is the relatively light construction of the trawls. One recently built trawler, the "Tetman Hette" (KW-20) is equipped with a stern ramp, but also allows the traditional hauling procedure.

## 4. Performance Models.

### 4.1 Background.

Models of trawler operations and corresponding economic performance can become very complex. Detailed simulation models date back from as early as 1968.The model described here predicts the merits of the economies of scale, leading to best performance for the largests units.[1]
The process of catching fish has been studied and described by many scientists. Trost [2] and Förster [3] found the input process of Markovian type, a specific type of stochastic processes for which the state at any time depends only on the previous state and not on the sequence of states before that. In other words the process has no memory, or given the present state, the future of the system can be predicted. The arrival of **m** schools of fish in the region of a net within the time interval **t** can be described by a **Poisson** Process. The probability density function for this type of process follows from :

$$P(X(t) = m) = \frac{(\lambda t)^m}{m!} \cdot e^{-\lambda t} \qquad \text{; with} \qquad P(t) = 1 - e^{-\lambda t}$$

The time between events is negative-exponentially distributed with mean and variance equal to **1/λt.** The time-interval between arrivals of schools can be described with the **negative-exponential distribution P(t),** a distribution tied to the Poisson process. This implies, that these arrivals should be independent of one another. These characteristics are vital in modelling the complete process of search and capture, for which a digital simulation model is yet being made at RIVO.
More simple **deterministic** models can be used to appraise the influence of the major parameters on the landing capacity of stern trawlers. This serves as an aid to the simulation model. Parameters of lesser influence can be left out or simplified.

The problem in general can be defined as **to determine the influence of the design variables on the overall economic operational performance.**

A further extension will be to find the <u>optimum set</u> of decision variables, which will not be dealt with in this paper.

A *vessel owner* will be interested in questions like :

- How big should the boat be?
- How many plate freezers should be installed?
- What engine power should be taken?
- How big should the fuel oil tanks be?
- What is the influence of the distance to the fishing grounds on the landing capacity?
- What is the influence of the duration of the period in port?
- How critical is a continuous operation of the freezing plant?
- Which configuration will lead to maximum profits for the trawling company?

whereas a *fisheries manager* may be interested in questions like :

- What level of effort in terms of number of boats, their size and power will lead to a stable exploitation, with maximum benefits to the fishing community or society as a whole of a particular fish stock?
- What size of net or meshsize used will ensure a stable exploitation pattern?

A *combined question* with both views in mind could be like :

- Given certain limiting regulations in terms of fishing time, total landings allowed, fishing areas, safety regulations, limitations to the dimensions of fishing gear etc., what will then be the optimum vessel and configuration?

**4.2 Description of the first model.**
In the EXCEL-spreadsheet programme, running on a Macintosh personal computer the following model has been set up with the next variables, refered to as **fleetcapmodel**. The complete set of formulae is given in the appendix **fleetcapmodeltext.**
The table below gives the major variables and the value range:

| variable | unit | value range : |
|---|---|---|
| fisholdcap(acity) | m3 | 5000 to 10000 step 500 |
| freezing rate | ton/24 hrs | 100 to 500 step 25 |
| pack unit vol | m3 | 0.02916 |
| unit pack weight | kgf | 22.0 and 23.5 |
| fillingcoeff(icient) | % | 0.5 to 1.0 step 0.1 |
| steaming time | days | 3, 6, 12 |
| port delay | days | 5, 7, 10 |
| workdaytotal | days | 355 |
| noworkdays | days | 10 |
| freezingpercentage | % | 0.5 to 1.0 step 0.1 |

This model is a **deterministic** straightforward calculation method to estimate the total landings of a vessel of given technical and operational characteristics. Any variability in catches or stochastic elements are not considered.
**The basic premise is that the skipper of the trawler manages to keep the freezing plant in continuous operation all the time.**
In the real world situation this will not always be the case, but the buffer storage space of the RSW-tanks will not cause a strong deviation from this premise. It is unrealistic to assume a 100% operation and not to allow for disturbances. To model the overall effect the variable **freezingpercentage** has been introduced. A 90 % value describes the situation where the freezers are in operation 90 % of the time.

The starting point in the model forms the total volume of the fish holds, expressed in the variable **fishholdcap** The vessel can not be filled over the maximum capacity of her holds. Fish is frozen and packed into carton boxes of a specific size.
In our model the size taken by one box is 540*540*100 mm. at the exterior (= 0.02916 m3). Due to the discrete nature of this cargo in contrast for instance with fluids or grain, the total number of boxes will not be equal to the total holdvolume divided by the volume of one box. In actual fact this number will be smaller and this is expressed in the variable **fillingcoefficient.** Fish boxes vary in weight depending on the size distribution and species involved. Therefore the variable **unit pack weight** has been introduced. Typical values range from 19.0 to 20.0 kgf. for mackerel up to 23.5 kgf. for herring. The weight in tons of 1000 kgf per m3 of the cargo is expressed by the **stowfactor** according to the formula :

**stowfactor = fillingcoefficient * unit_pack_weight / (1000 * pack_unit_vol)**

Multiplication of this stowfactor with the fishholdcapacity or fishholdvolume leads to the total weight of the cargo (**cargoweight**):

**cargoweight = fisholdcap * stowfactor**

Another point of certainty is the total amount of workdays per year. The vessels go to sea on the 2-nd of January mostly and will at the latest be back in port from their last trip a few days before Christmas. These definite days of inactivity are given in the variable **noworkdays**.
The distribution of days at sea and days in port for unloading and repair and maintenance depend on the amount of trips a boat will undertake during the year.

Fishing trips follow a cyclic pattern. The vessel has to steam to the fishing grounds, starts fishing once arrived at a suitable spot and will continue to fish either at the same spot or when catches drop at another position. When her holds are adequately filled, the boat will return to the home port to unload. This sequence may be interrupted for several reasons like waiting for weather improvement (dodging), shifting to other grounds where catch rates are assumed to be higher, aiming at other target species when market prices are unfavourable or quotas nearly reached. Even a stop of the fishing operation to buy fish and freeze it without having to catch it (klondyking) may be a profitable strategy. All these possible interruptions are not taken into account in this model, but the effect can be presented by changing the freezing percentage and determining the influence of this variable.

In a normal fishing operation the time to fill the fishholds can be calculated as follows:

**holdfillingtime = ROUND(cargoweight / (freezing_rate * freezingpercentage) ; 0 )**

The time unit in this model is a day of 24 hours. Other units may be considered. In fact this is done later in the second and the third model. With an assumption of the time needed to reach the fishing grounds and to travel back to the home port the total duration of a fishing trip follows from :

**trip duration = steaming_time + holdfillingtime**

The total amount of fishing trips to be made per year follows from :

**tripnumber = ROUND(workdaytotal / (trip_duration + port_delay) ; 0 )**

where **port_delay** stands for the amount of days after each trip necessary to unload the fish and refit the vessel for the next trip.
Maintenaince and repair jobs are mostly done in this short interval. The effect of port delays can be determined by variation of the variable **port_delay**. As this number must be an integer value, the EXCEL-function **ROUND(..)** is used to round the number to the whole integer.
This means, that a value of 12.4 will become 12 and 12.5 and up will become 13.
**This feature of the model introduces a deviation from reality.** In a second version a better formulation has been found. The total amount of frozen fish landed per year can be determined from :

**landings1 = tripnumber * cargoweight**

Any over- or underestimate of the number of trips per year will cause a deviation in the landings.

## 4.3 Model verification.

**A verified model is one that behaves as intended by its designer.**
The simplest method is to vary the input data and look at the result on the output and intermediate values. In our case negative numbers of fishing trips or negative landings would imply errors in the formulation of the model. Such errors are clear to recognise and may be due to simple mistakes. It is more difficult to detect errors, that are not so obvious. Generally the process of model verification is a continuous one, every new alteration should also be verified.

### 4.4 Model validation.

**A validated model is one that has been proven to be a reasonable description of the real world system it is meant to represent.**
A usual technique of validation is to use existing historical data and compare model results with the outcome of the real system over that period. In this case the model would be valid if landings reported by existing vessels would be of similar magnitude. A problem is, that this model does not describe the actual operations of fishing vessels, but only will give possible values of landings, depending on assumptions about the operational profile. Their may be many reasons, that a real ship does not come up with similar numbers, like a forced period of inactivity.
**Future models will be aimed at a more precise description of the real world system.**
Like the verification of a model, its validation is an iterative activity, coming back in the different phases of development.

### 4.5 Development of refinements to the first model.

The first model, using formula **landings1** can not be regarded as very realistic as broken values are rounded off to integers. The effect of this can be seen in Figure 5 where for some combinations of fishhold volume and freezing rate the yearly landings are declining against ones expectation. This is not a valid respresentation of the real system. The formula **landings2** has therefore been introduced as follows: (see **fleetcapmodeltext**)

**landings2 = integerpart_tripnr * cargoweight + restlanding**

By working out a **restlanding** and assuming an equal duration of the fishing trips for the majority of the year a better value will be obtained.

**restlanding = MIN((shorttripdays - steaming_time) * freezing_rate * freezingpercentage ; cargoweight)**

The duration of the last trip before the end of the year is given in the variable **shorttripdays** as follows:

**shorttripdays = workdaytotal - integerpart_tripnr * (trip_duration + port_delay)**

If a year is taken as 365 days and an amount of days is assumed for the boat to be inactive, (noworkdays = 10), the total amount of workdays can be found from substraction: ( in this case 355 days)

**workdaytotal = yeartotaldays - noworkdays.**

When the number of days left for the last trip is very small however, it is not realistic to assume that the boat will go out to sea. In normal practise one will attempt to extend the last trip and bring along some more cargo. This is not modelled here.

To see the effect of the formula **landings1** the real-value of tripnumber has been worked out in :

**tripnumber_unc = workdaytotal / (trip_duration + port_delay)**

and the integer part in :

**integerpart_tripnr = INT(workdaytotal / (trip_duration + port_delay))**

The number of days spend at sea and in port follow from:

**seadays = integerpart_tripnr * trip_duration + shorttripdays**
**portdays = integerpart_tripnr * port_delay + noworkdays**

Figures 3 and 4 depict the amount of fish to be landed on the basis of formula **landings2** for several values of the freezing rate, varying from 100 tons/day to 425 tons/day and a fishholdvolume ranging from 5000 up to 10000 m3. The results suggest some combinations to be less favourable than others. **A further investigation proves this being caused by rounding off errors in the formula and by negative values that occured for the restlanding.**

**fig.:3 Yearly landings2 as function of fishhold volume and freezing rate.**

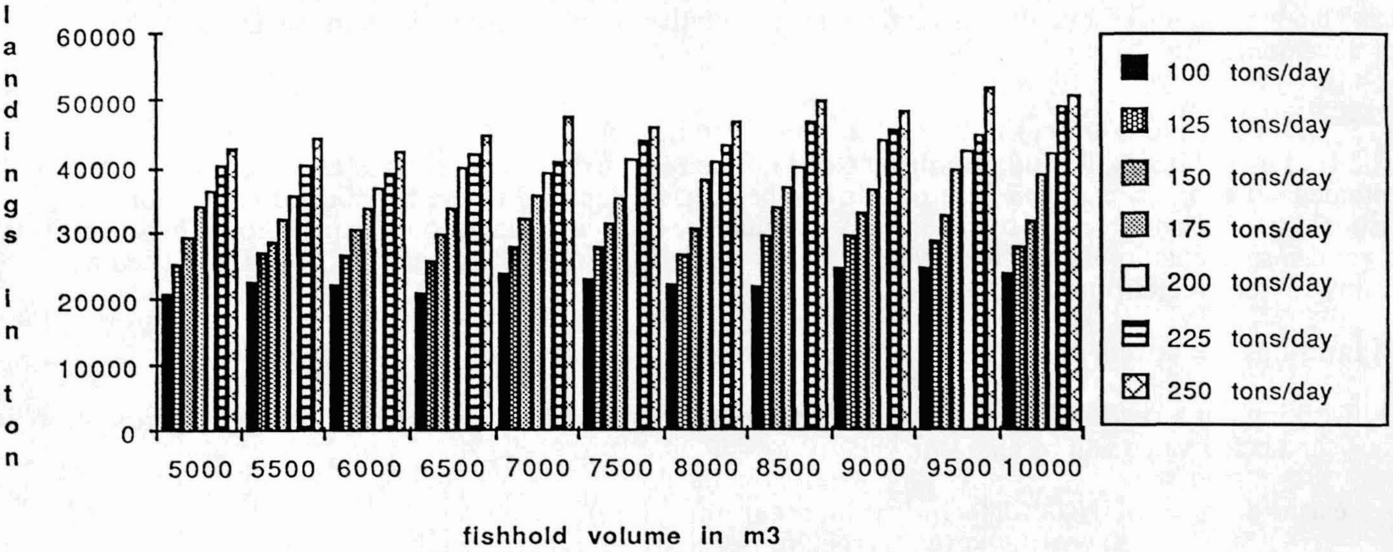
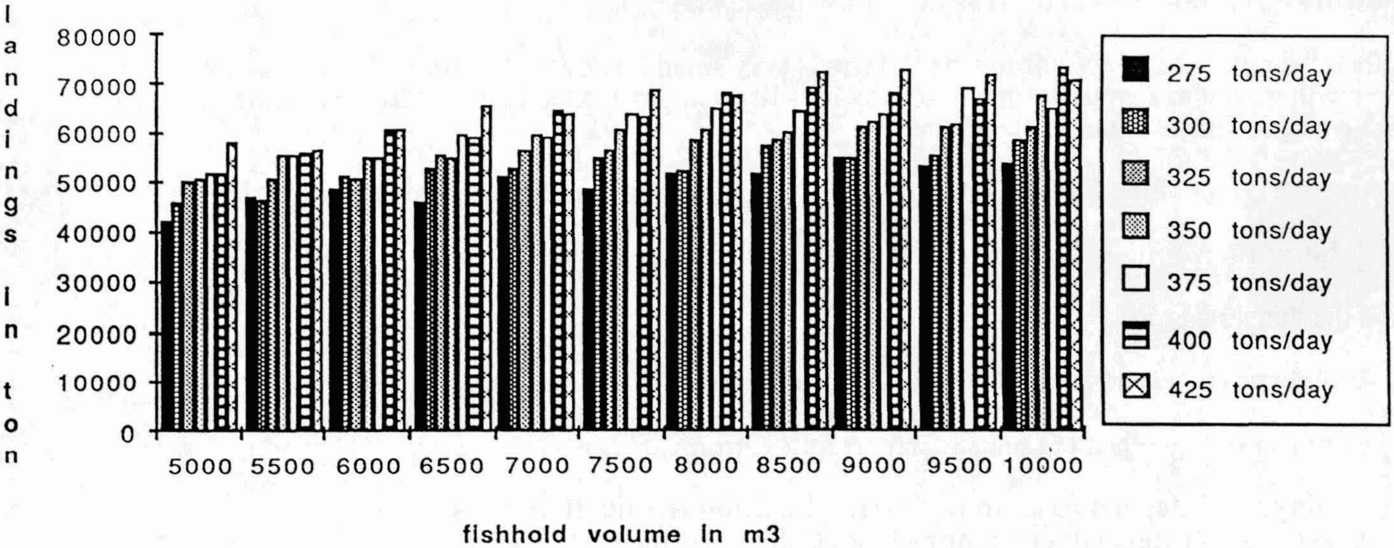



**fig.:4 Yearly landings2 as function of fishhold volume and freezing rate.**



When working with the formula **landings2** the dependency of the total yearly landings on the fishhold volume and the freezing rate becomes more smoothed without the downward slopes found in Figure 5 with **landings1**, as can be seen in Figure 6.
The effect of increasing the freezing rate seems to be stronger than the one resulting from increasing the fishhold volume, especially at the lower freezing rates. At the high rates an increase in fishhold volume leads to substantial rises in yearly landings.

fig.: 5 Yearly landingcapacity(1) of stern freezer trawlers
Upw = 22.0 kgf. Steaming time = 3 days
Port delay = 7 days
Holdfilling = 80 % Freezing = 90 %

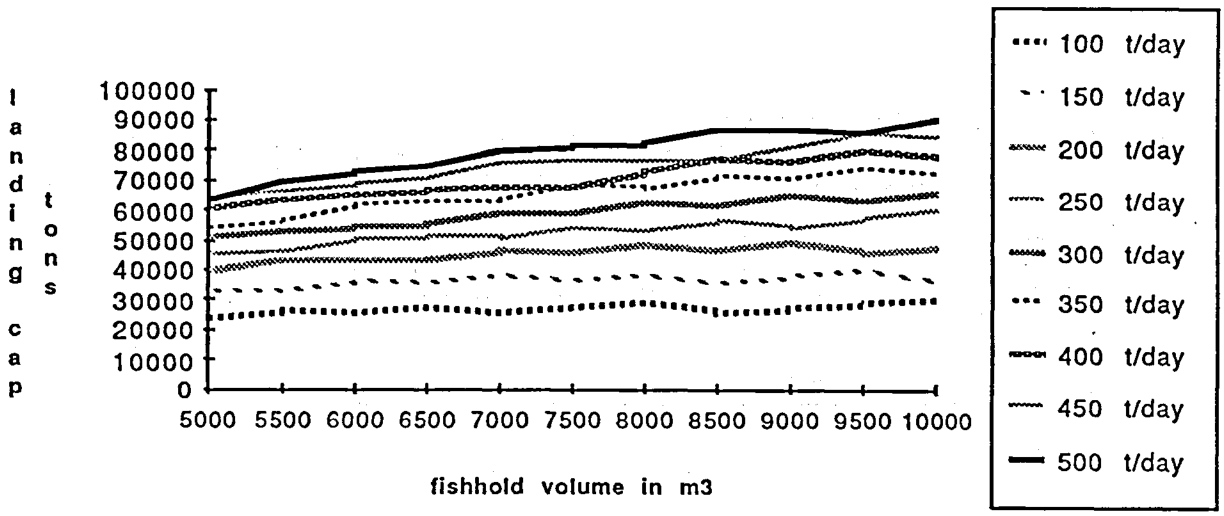
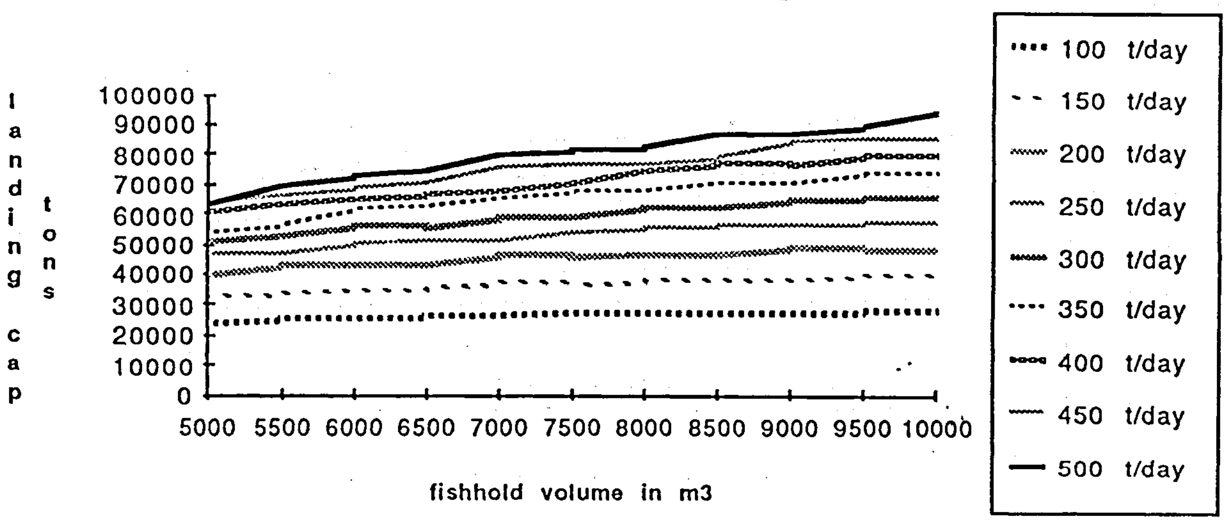



fig.: 6 Yearly landingcapacity(2) of stern freezer trawlers
Upw = 22.0 kgf. Steaming time = 3 days
Port delay = 7 days
Holdfilling = 80 % Freezing = 90 %



Figures 7, 8 and 9 depict the dependency of the total **landings2** per year on the fillingcoefficient of the fishhold and the freezing percentage, which is a measure of the continuity of the process. 100% means the freezers are in operation all of the time and 50% means half the time.
A standard case has been chosen with 6500 m3 holdvolume, 3 days of steaming time and 7 days of port delay after each voyage. The influence becomes stronger with rising freezing-rate values.

fig.: 7 Dependency of total landings per year of fillingcoefficien with operational % of freezing
holdcap: 6500 m3; freezing rate: 150 t/day; Upw: 22 kgf.
steaming time: 3d; port delay: 7d.

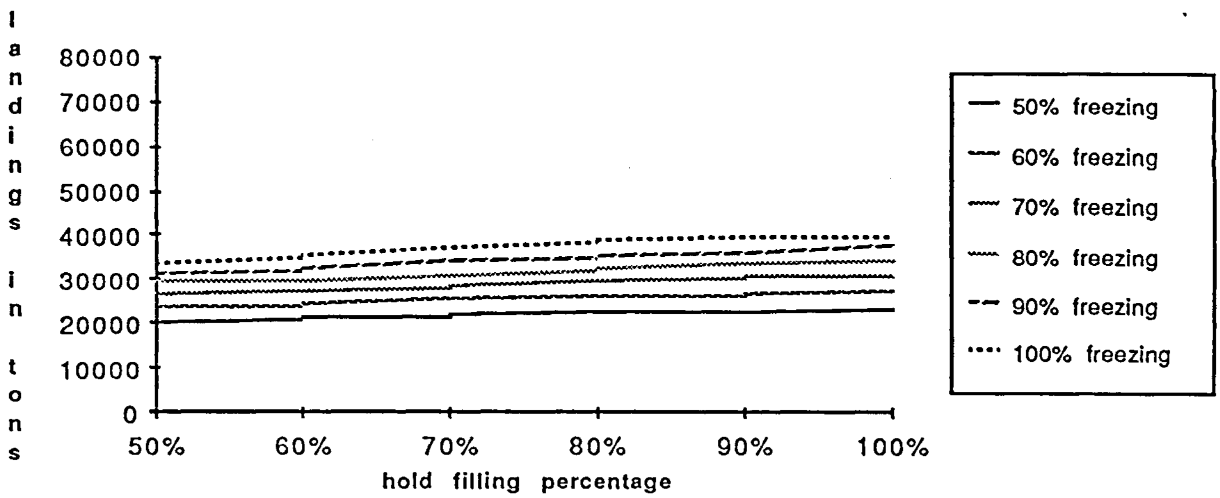



fig.: 8 Dependency of total landings per year of fillingcoefficien with operational % of freezing
holdcap: 6500 m3; freezing rate: 250 t/day; Upw: 22 kgf.
steaming time: 3d; port delay: 7d.

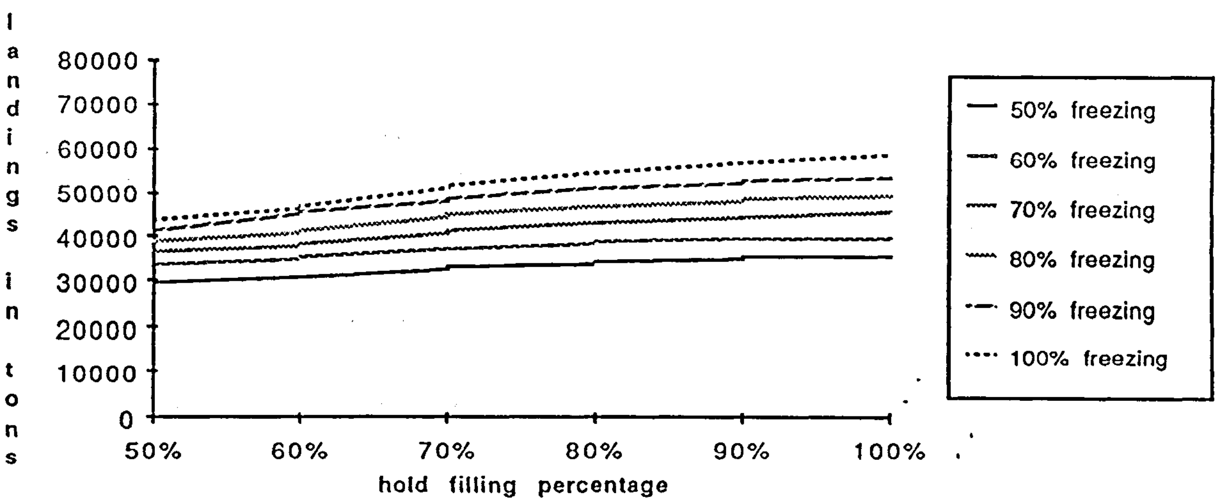
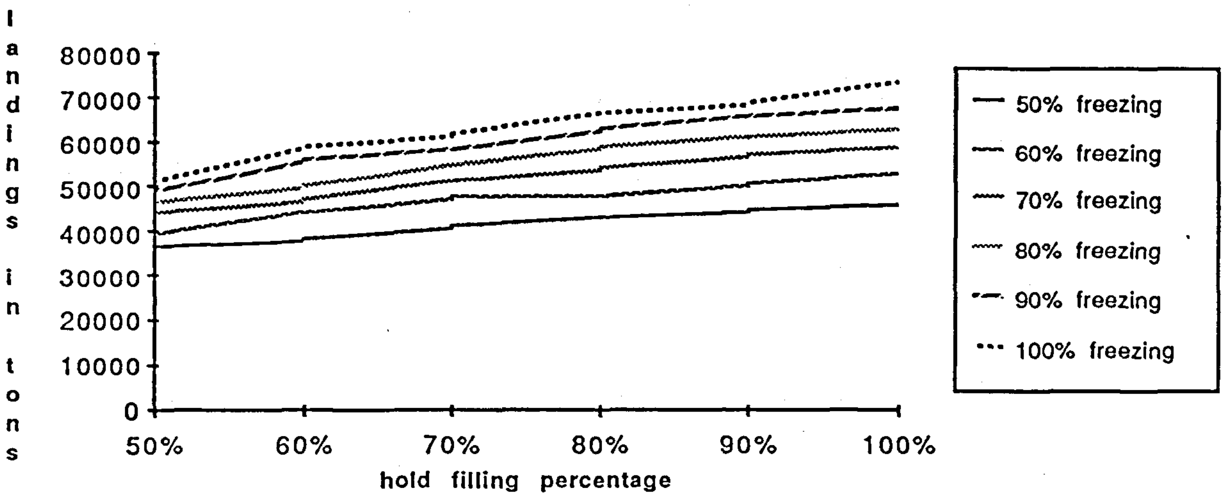
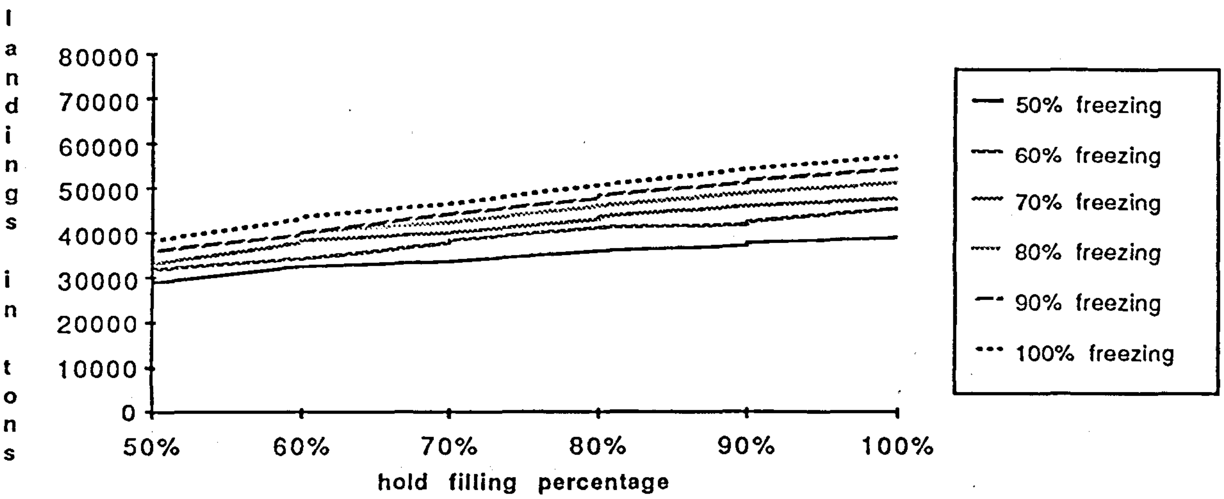


fig.: 9 Dependency of total landings per year of fillingcoefficien with operational % of freezing
holdcap: 6500 m3; freezing rate: 350 t/day; Upw: 22 kgf.
steaming time: 3d; port delay: 7d.




The effect of a change in the fisholdcapacity can be seen from Figures 9 and 10. Figure 9 gives the total attainable landings for the case with 6500 m3 fishholds and Figure 10 for 4000 m3. The values drop substantially, caused by the greater number of trips in the last case with more time lost in travelling to and from the fishing grounds. The differences, dependent on the freezingpercentage, decline with a smaller holdvolume.

fig.: 10 Dependency of total landings2 per year of fillingcoefficient witl operational % of freezing
holdcap: 4000 m3; freezing rate: 350 t/day; Upw: 22 kgf.
steaming time: 3d; port delay: 7d.




The effect of changing the steaming time and the port delay can be seen in Figure 11a. Of course more delay means a reduction in the total landing capacity, but this effect is strongest when steaming short distances. The steaming time has a dramatic influence, especially when the port delay times are low. Three days of added steaming time per trip cause a decrease of appr. 10000 tons with port delays of one week.

**Apparently the time factor is of crucial importance which is easy to understand.**
Port delays and steaming are inproductive in terms of fishing.
Notable is the zig-zagging behaviour of the curves in the region of longer voyages. In some cases a longer delay in port leads to higher landings, a feature of the model that seems contradictory to the expectation.

fig.: 11a Yearly landings2 of stern freezer trawlers as a function of steaming time and port delay. (restlanding not cut off below 0)
Holdcap = 6500 m3; freezing rate = 350 t/day; Upw = 22.0 kgf.
80 % Holdfilling; 90 % Freezing

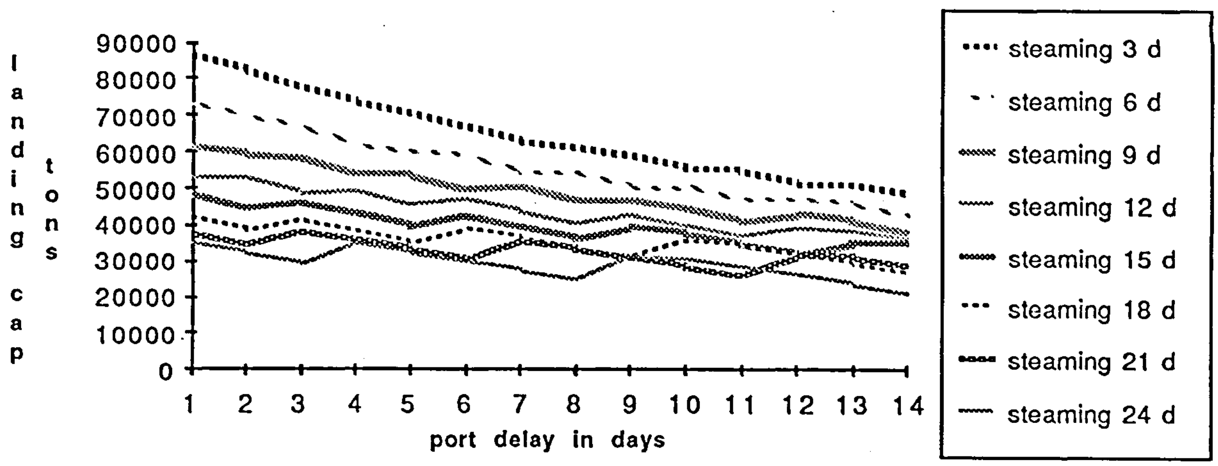
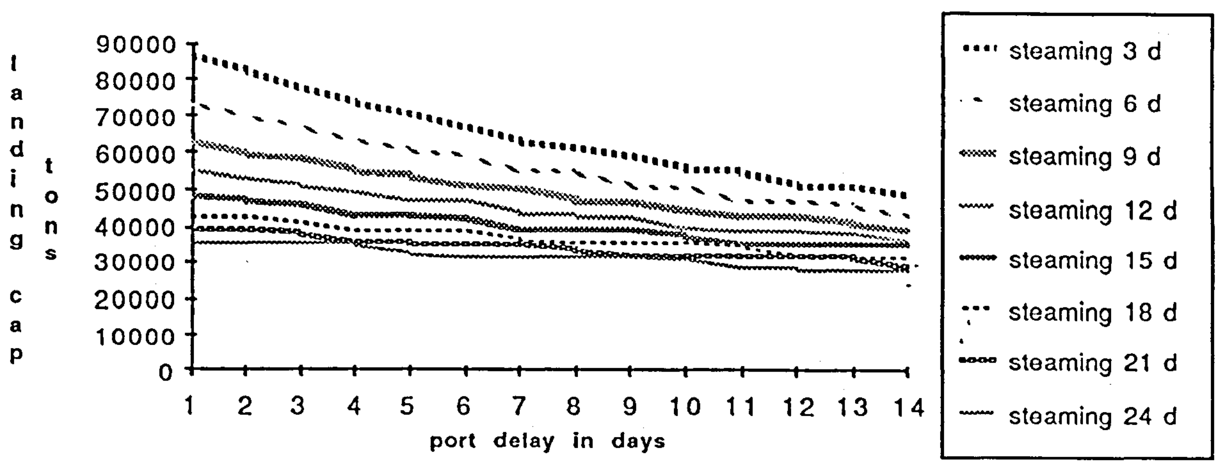



fig.11b : Yearly landings2 of stern freezer trawlers as a function of steaming time and port delay.
Holdcap = 6500 m3; freezing rate = 350 t/day; Upw = 22.0 kgf.
80 % Holdfilling; 90 % Freezing



A closer look at the formula for the restlanding reveals the answer to this problem.

**restlanding = MIN((shorttripdays - steaming_time)
* freezing_rate * freezingpercentage ; cargoweight)**

when the steaming time needed is longer than the amount of days left for another trip the restlanding becomes negative, which of course is highly unfeasible.
The following formula cuts the restlanding off to 0 in this case:

**restlanding = MAX( 0 ; (MIN((shorttripdays - steaming_time)
* freezing_rate * freezingpercentage ; cargoweight)))**

This is a more realistic behaviour of the model. In these cases the vessel could not even get to the fishing grounds and return, let alone do some fishing.
The result of this smoothing can be seen in Figure 11b on the previous page, where especially for the longer voyages a better picture is obtained.

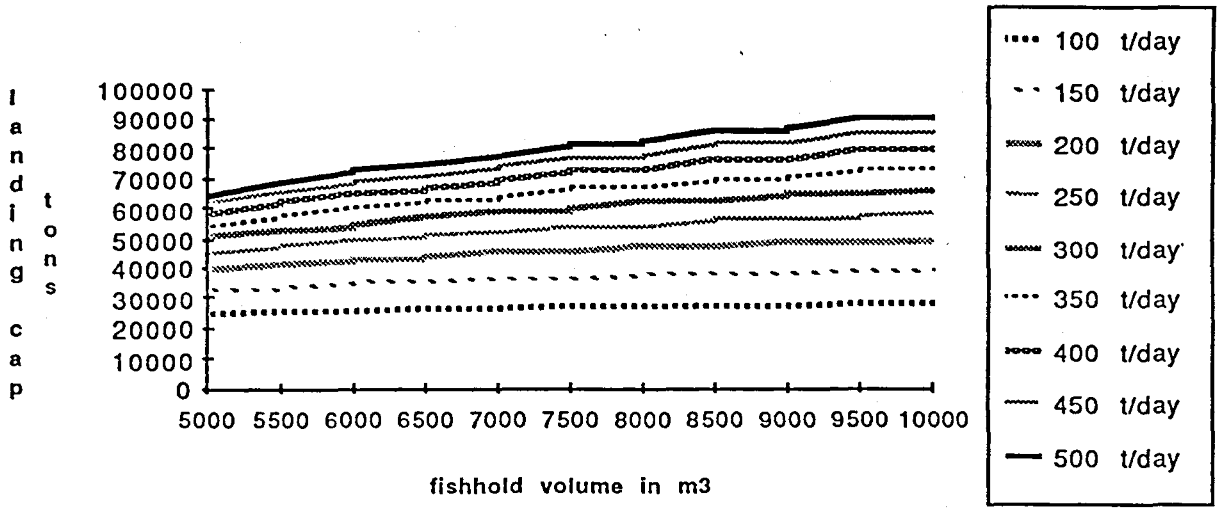
### 4.6 Sensitivity Analysis.

A sensitivity study on the variables has been undertaken for several cases. The results are given in TABLE 2 : **Fleetcapmod.var.89.**
The purpose of this approach is to determine the variables with the strongest influence.
For case A with a freezing rate of 350 tons/day the effect of a 10% increase in the freezing rate and the freezing percentage seem to have the strongest effect. The times needed for steaming and port delay play a lesser role with such a minor increase, but these may easily rise to higher levels. The fisholdcapacity and the fillingcoefficient have an influence in between. However this picture does not result for case B with a freezing rate of 250 tons/day, a fact that indicates caution when generalising such a conclusion. When using a rate of 150 tons/day (case C), the same tendency as found for the first case appears. This result is odd and could have been an effect of the formulation of the model and not represent a physical phenomena. It appeared to be the case, that favourable and unfavourable combinations of freezing rate and fishhold volume would exist.
Rounding off to full days of 24 hours may not be very precise. A way to find out is to alter the model to a smaller time-unit, leading to smaller rounding off errors.

### 4.7 Development of the second model.

**The model has been converted to hours instead of days as the time-unit.** The formulae are given in the appendix FLEETCAPMOD.89.TEXT. Figure 12 shows the attainable landings, when calculated on an hourly basis. Some of the ripples of Figure 6 have been smoothed, but the overall effect is rather small. The curves in Figure 12 show a more regular pattern. The suggestion of unfavourable combinations of fishhold volume and freezing rate does not seem to hold ground, but may be interpreted as a feature of the previous model.

fig.: 12 Yearly landingcapacity(3) of stern freezer trawlers.
Upw = 22.0 kgf. Steaming time = 3 days
Port delay = 7 days
Holdfilling = 80 % Freezing = 90 %




## 4.8 Development of the third model.

When studying the second model more carefully it was found, that a raise in unit pack weight causes the holdfillingtime to increase, due to the higher stowfactor and therefore the increased cargoweight. The result is that the number of trips declines. The explanation of this behaviour is that the filling is done according to weight and not according to volume by working out the fillingtime as a function of the freezing rate in tons per day. This is only realistic if a heavier fish species leads to a longer time needed to freeze the blocks of fish.

A third model **boatmodel3.89** has therefore been worked out with a holdfilling by volume instead of by weight and with a time unit of one hour to avoid rounding off errors. Several new variables are introduced like:

**nr. of freezers, nr of freezerstations, freezer cycletime**

The freezing rate is no longer an input variable, but will follow from :

**freezing hourrate = frostcapacity * nr of freezers**

with in tons per hour per freezer :

**frostcapacity = charges per day * chargeweight / 24**

where

**charges per day = ROUND(24 / freezer cycletime ; 0 )**

**chargeweight = nr of freezerstations * unit pack weight / 1000**

The number of packs delivered to the conveyor belts of the vessel per unit of time follow from :

**packing capacity = nr of freezerstations * (charges per day / 24) * nr of freezers * freezingpercentage**

Depending on the fillingcoefficient of the holds, the total number of packs in the cargo are determined by :

**totalpacknumber = cargovolume / pack unit volume**

The time needed to fill the fishholds can easily be calculated from:

**holdfillingshours = ROUND(totalpacknumber / packing capacity ; 0 )**

(If the time unit is taken as one hour, we can round off.)

Instead of restlanding the new variable restpacks has been introduced, following from:

**restpacks = MIN(totalpacknumber ; MAX( 0 ; (shorttriphours - steaming hours) * packing capacity))**

The function MAX ensures, that no negative values occur, which is of course nonsense, while MIN makes sure that the number of restpacks cannot exceed the total number that could be loaded in the fishholds, the **totalpacknumber.**

A restlanding can be worked out from:

**restlanding = MAX( 0 ; (MIN((shorttriphours - steaming hours) * freezing_hourrate * freezingpercentage;cargoweight)))**

or from, leading to the same result :

**restlanding = MAX( 0 ; (MIN(restpacks) * (unit pack weight / 1000); cargoweight)))**

This formula compares the restpacks, converted to a weight with the cargoweight attainable and picks out the total cargoweight if the restlanding may exceed this. In other words the last trip is broken off when the holds are filled.
**Filling is done by volume units, namely volume of packs, and not by weight in this model.**

The total attainable landings per year follow from, as before :

**landings = integerpart_tripnr * cargoweight + restlanding**

This formula can be compared to another, leading to the same amount of tons per year, but based on the total number of packs frozen over a whole year.
By working out the amount of packs of the normal trips as:

**trippacks = integerpart_tripnr * totalpacknumber**

and adding to the amount of packs frozen in the last trip, the restpacks, we find :

**yearlypacks = trippacks + restpacks**

This model has been compared with the previous ones and leads to slightly different answers. The complete model with all the formulae is given in **boatmodel3.89.formulae.** Due to rounding off the amount of shorttripdays may differ substantially, however. **It is therefore essential to work with an accurate time-unit and hours is definitely better than days.**

The total amount of packs landed over a year is given in Figure 13 and 14 dependent of the amount of plate freezers installed and the total volume of the fishholds, for a freezingrate of 90 % and a fillingcoefficient of 80 % and two different values for the steaming time necessary to reach the fishing grounds. The dependency of the landings of the number of plate freezers installed is slightly less than linear.

**Fig.:13 Total yearly packs landed as a function of the number of plate freezers installed. 6 d. steaming, 5 d. in port, U.p.w.= 23.5 kgf.**

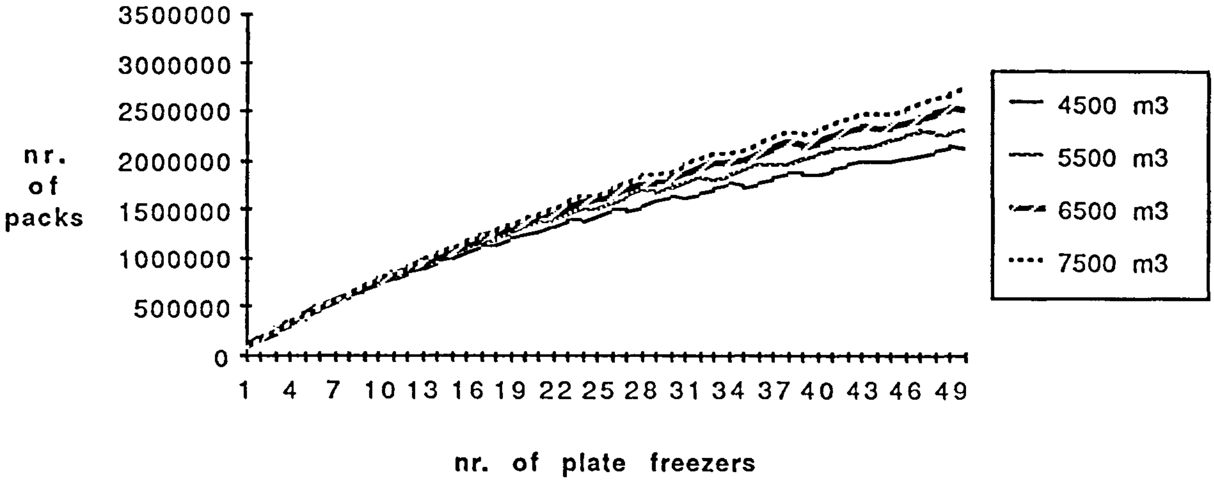
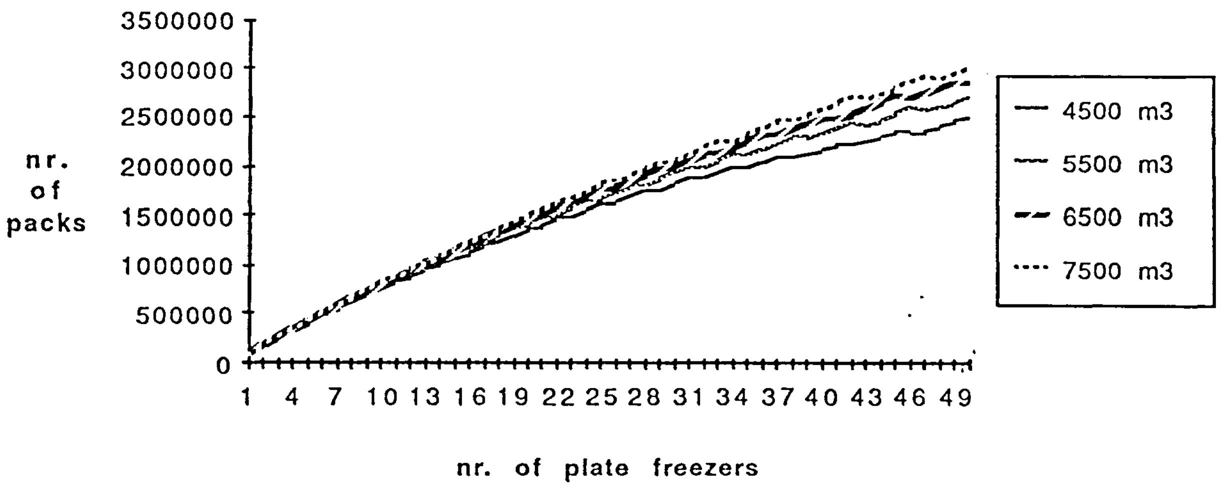



**Fig.:14 Total yearly packs landed as a function of the number of plate freezers installed. 3 d. steaming, 5 d. in port, U.p.w.= 23.5 kgf.**



## 5. Conclusions.

**The study is not completely finished and will be continued.** From the models given it can be deducted, that the freezing rate with the freezing percentage and the holdvolume with the fillingcoefficient are the most significant variables, followed by the steaming time and the port delay. **The answer to the question what the most economical solution is to catch a certain restricted amount of fish cannot be given from these models.** For this purpose, additions are needed with economic variables and it is intended to follow this line. A second improvement will be the introduction of stochastic elements in the model, as fishery is a strongly fluctuating operation. The trend in continuous growth in the scale of fishing vessels and gears clearly leads to augmented attainable landings per year and **the future challenge will be to determine the most economical effort input, that ensures long term stability without fish stock depletion.**

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BvM/BvM.

TABLE 2 : RESULTS OF SENSITIVITY ANALYSIS.

case A

| variable name | standard | added 10 % | landings1 | % growth | landings2 | % growth |
|---|---|---|---|---|---|---|
| fisholdcap | 6500 | 7150 | 56102 | 2.14% | 56102 | 2.14% |
| freezing rate | 350 | 385 | 58848 | 7.14% | 58848 | 7.14% |
| freezingpercentage | 0.9 | 0.99 | 58848 | 7.14% | 58848 | 7.14% |
| unit pack weight | 22 | 22.4 | 55923 | 1.82% | 55394 | 0.85% |
| fillingcoeff | 0.8 | 0.88 | 56102 | 2.14% | 56102 | 2.14% |
| steaming time | 6 | 6.6 | 54925 | 0.00% | 54925 | 0.00% |
| port delay | 7 | 7.7 | 54925 | 0.00% | 54925 | 0.00% |
| noworkdays | 10 | 11 | 54925 | 0.00% | 54925 | 0.00% |
| landings 1 | 54925 | | | | | |

case B

| variable name | standard | added 10 % | landings1 | % growth | landings2 | % growth |
|---|---|---|---|---|---|---|
| fisholdcap | 6500 | 7150 | 47471 | 0.83% | 47471 | 0.83% |
| freezing rate | 250 | 275 | 47078 | 0.00% | 47326 | 0.53% |
| freezingpercentage | 0.9 | 0.99 | 47078 | 0.00% | 47326 | 0.53% |
| unit pack weight | 22 | 22.4 | 43940 | -6.67% | 45740 | -2.84% |
| fillingcoeff | 0.8 | 0.88 | 47471 | 0.83% | 47471 | 0.83% |
| steaming time | 6 | 6.6 | 47078 | 0.00% | 45810 | -2.69% |
| port delay | 7 | 7.7 | 47078 | 0.00% | 45698 | -2.93% |
| noworkdays | 10 | 11 | 47078 | 0.00% | 47078 | 0.00% |
| landings 1 | 47078 | | | | | |

case C

| variable name | standard | added 10 % | landings1 | % growth | landings2 | % growth |
|---|---|---|---|---|---|---|
| fisholdcap | 6500 | 7150 | 34524 | 10.00% | 34524 | 4.18% |
| freezing rate | 150 | 165 | 35309 | 12.50% | 35309 | 6.54% |
| freezingpercentage | 0.9 | 0.99 | 35309 | 12.50% | 35309 | 6.54% |
| unit pack weight | 22 | 22.4 | 31956 | 1.82% | 32631 | -1.54% |
| fillingcoeff | 0.8 | 0.88 | 34524 | 10.00% | 34524 | 4.18% |
| steaming time | 6 | 6.6 | 31385 | 0.00% | 32411 | -2.20% |
| port delay | 7 | 7.7 | 31385 | 0.00% | 32384 | -2.28% |
| noworkdays | 10 | 11 | 31385 | 0.00% | 33005 | -0.41% |
| landings 1 | 31385 | | | | | |

Ships data stern freezer trawlers: 2/17/89

| ships ID | year | GT | NT | BRT | L o.a. | crew | L p.p. | B | GK |
|---|---|---|---|---|---|---|---|---|---|
| SCH-106 | 1980 | | 365 | 842 | 67.05 | 27 | 59.56 | 12.5 | ? |
| SCH-171A | 1981 | | 415.44 | 956.49 | 71.25 | 25 | 63.76 | 12.5 | 5.44 |
| SCH-33 | 1981 | 936.55 | 422.06 | | 71.25 | 26 | 63.76 | 12.5 | |
| KW-170 | 1981 | | 483.4 | 1079.4 | 71 | 29 | 63.8 | 13.25 | |
| KW-74 | 1982 | | 567.73 | 1178.5 | 78.2 | 26 | 73.35 | 13.25 | |
| KW-80 | 1982 | | 567.73 | 1178.5 | 78.22 | 26 | 71 | 13.27 | |
| SCH-303 | 1982 | | 485.77 | 1063.73 | 77.25 | 25 | 69.6 | 12.5 | 5.87 |
| KW-174 | 1983 | 3019 | 1269 | | 95.18 | | 88.17 | 14.5 | |
| SCH -72 | 1983 | 2610 | 1148 | | 88.13 | 27 | 81.5 | 14 | 6.45 |
| SCH-6 | 1984 | | | 2625 | 88.1 | ? | ? | 14 | ? |
| SCH-24 | 1984 | ? | ? | ? | 93.9 | 27 | 86.22 | 15 | ? |
| SCH-123 | 1984 | | | 3113 | 94 | ? | 86.22 | 15 | 6.75 |
| VL-70 | 1985 | | | | 97.75 | 32 | 90.31 | 14.5 | |
| KW-32 | 1986 | 2624 | 996 | | 90.2 | 32 | 83 | 13.5 | |
| SCH-21 | 1987 | | | | 101.71 | 30 | 93.89 | 15 | |
| SCH-171B | 1988 | | | | 113.97 | 39 | 107.71 | 17 | |
| KW-20 | 1988 | | | | 94 | 35 | 85 | 15.9 | |

| ships ID | T max. | T design | D upp deck | D fish deck | motor type | prop. ø | prop. type | HP inst | kW inst |
|---|---|---|---|---|---|---|---|---|---|
| SCH-106 | 4.75 | 4.75 | 8 | 4.95 | MaK 8M 453 AK | 2.8 | BERG | 2800 | 2060 |
| SCH-171A | 5.37 | 5.37 | 8 | 4.95 | Deutz SBV 6M 540 | 2.8 | BERG 710 H4 | 3600 | 2647 |
| SCH-33 | 5.23 | | 8 | 4.95 | MaK 8M 453 AK | 2.55 | | 3200 | 2355 |
| KW-170 | 5.15 | 5.13 | 8.35 | 5.2 | MaK SBV 9M 453 | 2.8 | SEFFLE | 3600 | 2700 |
| KW-74 | | | 8.35 | 5.2 | SWD 6 TM 410 | 3 | BERG 800 H4 | 4000 | 2940 |
| KW-80 | 5.15 | | 8.35 | 5.2 | SWD 6 TM 410 | 3 | BERG 800 H4 | 4000 | 2940 |
| SCH-303 | 5.37 | 5.37 | 8 | 5.5 | Deutz SBV 6M 540 | 2.8 | BERG? | 3600 | 2647 |
| KW-174 | 5.28 | | 8.6 | 5.4 | MaK SBV 6M 551 | | | 4350 | 3200 |
| SCH -72 | 6.108 | 5.8 | 9 | 6.2 | Deutz SBV 8M 540 | 3.2 | BERG 900H4 | 4400 | 3236 |
| SCH-6 | 6.1 | ? | 9 | ? | Deutz SBV 8M 540 | 3.2 | BERG 900H4 | 4400 | 3236 |
| SCH-24 | 6.1 | 5.8 | 9.4 | 6.2 | MaK SBV 8M 551 | 3.4 | BERG 900H4 | 5815 | 4268 |
| SCH-123 | 6.1 | 5.8 | 9.4 | | MaK SBV 8M 551 | 3.4 | BERG 900H4 | 5800 | 4266 |
| VL-70 | 5.6 | | 9 | 5.8 | Deutz SBV 6M | 3.6 | SEFFLE | 6662 | 4900 |
| KW-32 | 5.15 | | 8.35 | 5.2 | SWD 6TM410 | 3 | BERG 800H4 | 5058 | 3720 |
| SCH-21 | 6.1 | | 9.4 | 6.2 | MaK 8M551 | 3.4 | BERG 900H4 | 5803 | 4268 |
| SCH-171B | 7.06 | | 10.2 | 7 | Deutz SBV 16M 640 | 3.8 | BERG 1140H4 | 9546 | 7021 |
| KW-20 | 6.5 | | | 7.3 | Sulzer 8ZA 40/48 | | | 4400 | 3236 |

| ships ID | V trial | V service | d.w.t. | lightship | displacement | prop. rpm | V holds | Vcooltanks | D.O.+ H.O |
|---|---|---|---|---|---|---|---|---|---|
| SCH-106 | | 13.5 | 1100 | 1303 | 2873 | 230 | 1490 | 100 | 445 |
| SCH-171A | 17.2 | 13.5 | 1258 | 1275 | 2515 | 202.6 | 1840 | 100 | 452.2 |
| SCH-33 | | 13.5 | 1258 | | | 230 | 1667 | | 452.2 |
| KW-170 | ? | 14 | 1550 | | | 205 | 1950 | 200 | 600 |
| KW-74 | | 14 | 1750 | | | 198 | 2550 | 225 | |
| KW-80 | | 14 | 1750 | | | 198 | 2550 | 225 | 620 |
| SCH-303 | ? | 13.5 | 1522 | 1360 | 2882 | 202.6 | 2098 | 150 | 555 |
| KW-174 | | 14 | | | | | 4300 | 225 | 854 |
| SCH -72 | 15.6 | ? | 2701 | 1862 | 4563 | 185 | 3150 | 280 | 679 |
| SCH-6 | ? | ? | ? | ? | ? | 185 | 3040 | 262 | ? |
| SCH-24 | 18 | ? | ? | ? | ? | 175 | 3400 | 300 | 890 |
| SCH-123 | ? | ? | 2757 | 2123 | 4880 | | 3400 | 303 | 870 |
| VL-70 | | 15 | | | 2250 | | 4300 | 255 | 855 |
| KW-32 | | | 2350 | | | | 2950 | 235 | 755 |
| SCH-21 | 18 | | 3120 | | | 175 | 4456 | 300 | 994 |
| SCH-171B | 18 | | | | | 151.72 | 6500 | 505 | 1486 |
| KW-20 | | | | | | | 3200 | | |

| ships ID | ballast | nr. packs | freez. rate | nr. frosters |
|---|---|---|---|---|
| SCH-106 | 145 | ? | 100 | 16 |
| SCH-171A | 156 | ? | 100 | 16 |
| SCH-33 | 179.2 | 62000 | 100 | 16 |
| KW-170 | 140 | | 100 | 18 |
| KW-74 | 135 | | 125 | 20 |
| KW-80 | 135 | | 125 | 20 |
| SCH-303 | 161 | 60000 | 122 | 20 |
| KW-174 | | | 150 | |
| SCH -72 | 193 | 92000 | 165 | 26 |
| SCH-6 | ? | ? | 155 | 26 |
| SCH-24 | 240 | 105000 | 175 | 29 |
| SCH-123 | 238 | | 175 | 29 |
| VL-70 | | 120000 | 220 | 35 |
| KW-32 | | | 150 | 24 |
| SCH-21 | 240 | 117000 | 175 | |
| SCH-171B | 266 | 180000 | 253 | 33 |
| KW-20 | | | 150 | |

TABLE I

**INPUT VARIABLES :**
**fisholdcap**
**freezing rate**
**pack unit vol**
**unit pack weight**
**fillingcoef(ficient)**
**steaming time**
**port delay**
**noworkdays**
**freezingpercentage**

**FORMULAS :**

**trip duration**
=steaming_time+holdfillingtime

**holdfillingtime**
=ROUND(cargoweight/(freezing_rate*freezingpercentage);0)

**landings 1**
=tripnumber*cargoweight

**landings 2**
=integerpart_tripnr*cargoweight+restlanding

**restlanding**
=MAX(0;(MIN((shorttripdays-steaming_time)*freezing_rate*freezingpercentage;cargoweight)))

**tripnumber**
=ROUND(workdaytotal/(trip_duration+port_delay);0)

**stowfactor**
=fillingcoeff*unit_pack_weight/(1000*pack_unit_vol)

**tripnumber**
=ROUND(workdaytotal/(trip_duration+port_delay);0)

**cargoweight**
=fisholdcap*stowfactor

**workdaytotal**
=365-noworkdays

**tripnumber unc**
=workdaytotal/(trip_duration+port_delay)

**integerpart tripnr**
=INT(workdaytotal/(trip_duration+port_delay))

**shorttripdays**
=workdaytotal-integerpart_tripnr*(trip_duration+port_delay)

**seadays**
=integerpart_tripnr*trip_duration+shorttripdays

**portdays**
=integerpart_tripnr*port_delay+noworkdays

**yeartotaldays**
=seadays+portdays

**INPUT VARIABLES :**
**fisholdcap**
**freezing rate**
**freezingpercentage**
**pack unit vol**
**unit pack weight**
**fillingcoeff**
**steaming time**
**port delay**
**noworkhours**
**yeartotalhours**

**FORMULAS :**

**freezing hourrate**
=freezing_rate/24

**landings 1**
=tripnumber*cargoweight

**tripnumber**
=ROUND(workhourstotal/(trip_duration+port_delay_hours);0)

**stowfactor**
=fillingcoeff*unit_pack_weight/(1000*pack_unit_vol)

**tripnumber**
=ROUND(workhourstotal/(trip_duration+port_delay_hours);0)

**cargoweight**
=fisholdcap*stowfactor

**workhourstotal**
=8760-noworkhours

**tripnumber unc**
=workhourstotal/(trip_duration+port_delay_hours)

**steaming hours**
=steaming_time*24

**port delay hours**
=port_delay*24

**trip duration**
=steaming_hours+holdfillinghours

**holdfillinghours**
=ROUND(cargoweight/(freezing_hourrate*freezingpercentage);0)

**landings 3**
=integerpart_tripnr*cargoweight+restlanding

**landings 1**
=tripnumber*cargoweight

**restlanding**
=MAX(0;(MIN((shorttriphours-steaming_hours)*freezing_hourrate*freezingpercentage;cargoweight)))

**integerpart tripnr**
=INT(workhourstotal/(trip_duration+port_delay_hours))

**shorttriphours**
=workhourstotal-integerpart_tripnr*(trip_duration+port_delay_hours)

**seahours**
=integerpart_tripnr*trip_duration+shorttriphours

**porthours**
=integerpart_tripnr*port_delay+noworkhours

| MODEL OF ATTAINABLE LANDINGS PER YEAR OF STERN FREEZER TRAWLERS. | |
|---|---|
| =NOW() | =NOW() |

CONSTANTS :

| pack unit volume | unit pack weight |
|---|---|
| 0.02916 | 22 |

SHIP INPUT DATA :

| fisholdcap | nr of freezers |
|---|---|
| 6500 | 40 |

OPERATIONAL INPUT DATA :

| steaming time | port delay |
|---|---|
| 3 | 7 |

| fillingcoefficient | freezingpercentage |
|---|---|
| 0.7 | 0.9 |

CALCULATED QUANTITIES :

| freezing rate | freezing hourrate |
|---|---|
| =freezing hourrate*24 | =frostcapacity*nr of freezers |

| stowfactor | cargovolume |
|---|---|
| =fillingcoefficient*unit pack weight/(1000*pack unit volume) | =fisholdcap*fillingcoefficient |

| totalpacknumber | packing capacity |
|---|---|
| =cargovolume/(pack unit volume) | =nr of freezerstations*(charges per day/24)*nr of freezers*freezingpercentage |

| charges per day | chargeweight |
|---|---|
| =ROUND(24/freezer cycletime;0) | =nr of freezerstations*unit pack weight/1000 |

CALCULATED OPERATIONAL PROFILE :

| steaming hours | holdfillinghours |
|---|---|
| =steaming time*24 | =ROUND(totalpacknumber/packing capacity;0) |
| =A36/24 | =B36/24 |

| seahours | porthours |
|---|---|
| =integerpart tripnr*trip duration+shorttriphours | =integerpart tripnr*port delay hours+noworkhours |
| =A40/24 | =B40/24 |

| trip duration | tripnumber3 |
|---|---|
| =steaming hours+holdfillinghours | =ROUND(workhourstotal/(trip duration+port delay hours);0) |
| =A44/24 | |

| landings 1 | restpacks |
|---|---|
| =tripnumber*cargoweight | =MIN(totalpacknumber;MAX(0;(shorttriphours-steaming hours)*packing capacity)) |

| trippacks | yearlypacks |
|---|---|
| =integerpart tripnr*totalpacknumber | =trippacks+restpacks |
| =A51*unit pack weight/1000 | =B51*unit pack weight/1000 |

| | |
|---|---|
| nr_of_freezerstations | freezer_cycletime |
| 40 | 3.5 |

| |
|---|
| noworkdays |
| 10 |

| |
|---|
| cargoweight |
| =fisholdcap*stowfactor |

| |
|---|
| frostcapacity |
| =charges_per_day*chargeweight/24 |

| |
|---|
| chargevolume |
| =nr_of_freezerstations*pack_unit_volume |

| | | |
|---|---|---|
| port_delay_hours | shorttriphours | noworkhours |
| =port_delay*24 | =workhourstotal-integerpart_tripnr*(trip_duration+port_delay_hours) | =noworkdays*24 |
| =C36/24 | =D36/24 | =E36/24 |

| | | |
|---|---|---|
| yeartotalhours | workhourstotal | workdaytotal |
| 8760 | =8760-noworkhours | =D40/24 |
| =(seahours+porthours)/24 | | |

| | |
|---|---|
| tripnumber3_unc | integerpart_tripnr |
| =workhourstotal/(trip_duration+port_delay_hours) | =INT(workhourstotal/(trip_duration+port_delay_hours)) |

| | |
|---|---|
| restlanding3 | landings_3 |
| =MAX(0;(MIN((shorttriphours-steaming_hours)*freezing_hourrate*freezingpercentage;cargoweight))) | =integerpart_tripnr*cargoweight+restlanding3 |

MODEL OF ATTAINABLE LANDINGS PER YEAR OF STERN FREEZER TRAWLERS.

12-Apr-89 11:18:58 AM

CONSTANTS :

| pack unit volume | unit pack weight |
|---|---|
| 0.02916 m3 | 22.0 kgf |

SHIP INPUT DATA :

| fisholdcap | nr of freezers | nr of freezerstations | freezer cycletime |
|---|---|---|---|
| 6500 m3 | 24 | 40 | 3.5 hours |

OPERATIONAL INPUT DATA :

| steaming time | port delay | noworkdays |
|---|---|---|
| 3.0 days | 7.0 days | 10.0 days |

| fillingcoefficient | freezingpercentage |
|---|---|
| 0.7 | 0.9 |

CALCULATED QUANTITIES :

| freezing rate | freezing hourrate |
|---|---|
| 147.8 ton/day | 6.2 ton/hr |

| stowfactor | cargovolume | cargoweight |
|---|---|---|
| 0.5281 | 4550 m3 | 3433 ton |

| totalpacknumber | packing capacity | frostcapacity |
|---|---|---|
| 156036 | 252 packs/hr | 0.257 ton/hr.freezer |

| charges per day | chargeweight | chargevolume |
|---|---|---|
| 7 | 0.880 ton | 1.17 m3 |

CALCULATED OPERATIONAL PROFILE :

| steaming hours | holdfillinghours | port delay hours | shorttriphours | noworkhours |
|---|---|---|---|---|
| 72.0 hours | 619.0 hours | 168.0 hours | 789.0 hours | 240.0 hours |
| 3.0 days | 25.8 days | 7.0 days | 32.9 days | 10.0 days |

| seahours | porthours | yeartotalhours | workhourstotal | workdaytotal |
|---|---|---|---|---|
| 7008 hours | 1752 hours | 8760 hours | 8520 hours | 355.0 days |
| 292.0 days | 73.0 days | 365.0 days | | |

| trip duration | tripnumber3 | tripnumber3 unc | integerpart tripnr |
|---|---|---|---|
| 691.0 hours | 10 | 9.92 | 9 |
| 28.8 days | | | |

| landings 1 | restpacks | restlanding3 | landings 3 |
|---|---|---|---|
| 34328 ton | 156036 packs | 3433 ton | 34328 ton |

| trippacks | yearlypacks |
|---|---|
| 1404321 packs | 1560357 packs |
| 30895 ton | 34328 ton |

MODEL OF ATTAINABLE LANDINGS PER YEAR OF STERN FREEZER TRAWLERS.

12-Apr-89 11:21:05 AM

CONSTANTS :

| pack unit volume | unit pack weight |
|---|---|
| 0.02916 m3 | 22.0 kgf |

SHIP INPUT DATA :

| fisholdcap | nr of freezers | nr of freezerstations | freezer cycletime |
|---|---|---|---|
| 6500 m3 | 40 | 40 | 3.5 hours |

OPERATIONAL INPUT DATA :

| steaming time | port delay | noworkdays |
|---|---|---|
| 3.0 days | 7.0 days | 10.0 days |

| fillingcoefficient | freezingpercentage |
|---|---|
| 0.7 | 0.9 |

CALCULATED QUANTITIES :

| freezing rate | freezing hourrate |
|---|---|
| 246.4 ton/day | 10.3 ton/hr |

| stowfactor | cargovolume | cargoweight |
|---|---|---|
| 0.5281 | 4550 m3 | 3433 ton |

| totalpacknumber | packing capacity | frostcapacity |
|---|---|---|
| 156036 | 420 packs/hr | 0.257 ton/hr.freezer |

| charges per day | chargeweight | chargevolume |
|---|---|---|
| 7 | 0.880 ton | 1.17 m3 |

CALCULATED OPERATIONAL PROFILE :

| steaming hours | holdfillinghours | port delay hours | shorttriphours | noworkhours |
|---|---|---|---|---|
| 72.0 hours | 372.0 hours | 168.0 hours | 564.0 hours | 240.0 hours |
| 3.0 days | 15.5 days | 7.0 days | 23.5 days | 10.0 days |

| seahours | porthours | yeartotalhours | workhourstotal | workdaytotal |
|---|---|---|---|---|
| 6336 hours | 2424 hours | 8760 hours | 8520 hours | 355.0 days |
| 264.0 days | 101.0 days | 365.0 days | | |

| trip duration | tripnumber3 | tripnumber3 unc | integerpart tripnr |
|---|---|---|---|
| 444.0 hours | 14 | 13.92 | 13 |
| 18.5 days | | | |

| landings 1 | restpacks | restlanding3 | landings 3 |
|---|---|---|---|
| 48059 ton | 156036 packs | 3433 ton | 48059 ton |

| trippacks | yearlypacks |
|---|---|
| 2028464 packs | 2184499 packs |
| 44626 ton | 48059 ton |