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Summary Sheet

The Comprehensive Evacuation Planing Model in Case of Emergency

Summary

Keywords: VRP; optimal path; Tyson polygon; Time-varying curve; Time-varying curve

Contents

1   Introduction

1.1   Background

Changes in global ocean temperature will cause various marine lives to migrate. When the temperature varies too great, these animals can no longer survive and they will migrate to more suitable habitats.

herring and mackerel are very important pelagic fish in the Scottish fisheries. herring is widely distributed throughout the Northeast Atlantic, while mackerel is mostly distributed in the North and West Seas. They are located in the deep water during the day and move towards the surface at dusk and spread over a wide area.

It has been suggested that observed spatial variation in mackerel fisheries, extending over several hundreds of kilometers, is reflective of climate-driven changes in mackerel migration patterns.

In recent years, with the global ocean temperature rising, the distribution of these populations has changed dramatically. However, the geographic population shift may seriously affect the disrupt the livelihood of the smaller Scottish Fisheries companies who depend on these ocean-dwelling species.

1.2   Problem Restatement

In order to develop the Scottish fishing industries steadily, we need to analyze the characteristics, requirements, and interactions of herring and mackerel

1. How does the location of herring and mackerel change according to temperature

2. What are the best case, worse case and most likely time about small fishing companies based on the rate

3. Whether these small fishing companies should change the way they operate, what is the best way to run a small fishing company

4. What will happen if a certain percentage of fishery enters the territorial seas of another country

5. What solutions will improve the future business prospects of fishermen

1.3   Our Work

2   Assumptions

To simplify our problems, we make the following basic assumptions, each of which is properly justified.

- Assumed that the fishing time of Scottish vessels negligible

- Assumed that the ship travels in a straight line and its sailing route is from the port to the center of the position of fish.

- Supposed that the salaries of crews in Scotland are equal to the average wage of the British people, at 7 pounds per hour.

- Supposed that large size ferries in Scotland generally have 20 crew members and small Scottish ships generally have 8 crew members.

- Assumed that the maximum catch per vessel of a small Scottish company is 10 percent of its own weight

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3   List of Notation

Table 1: The List of Notation

Symbol	Meaning
L	The length of the Scottish vessels
B	The width of the Scottish vessels
D	The height of the Scottish vessels
W	The weight of the Scottish vessels
d	The waterline length of the Scottish vessels
l	Length between perpendiculars
v	The average velocity of the Scottish vessels
P	The average power of the Scottish vessels
P_0	The average power of small Scottish vessels
V	The displacement of the Scottish vessels
V_o	The volume of the fuel consumption
A_1	Total purchase cost of a Scottish vessel
A_2	Total salary of a crew member
A_3	Total fuel cost of a Scottish vessel
A	total cost of a Scottish vessel
A	total cost of a Scottish vessel
A_e	Extra cost for one voyage.

c_1	The purchase cost of a Scottish vessel per hour
c_2	The salary of a crew member per hour
c_3	The fuel cost of a Scottish vessel per hour
T_1	The time spent in fishing of a Scottish vessel
T_2	Fish preservation time at ambient temperature
S	The distance sailed of a Scottish vessel
a	Fish density ratio
k	Unit fixed cost of the ship
r_o	Fuel consumption ratio
E	The earnings of herrings and mackerels
E_0	The small Scottish vessel's earnings of herrings and mackerels
E_1	The earnings of herrings
E_2	The earnings of mackerels
p_1	The price of herrings
p_2	The price of mackerels
n_1	The number of crew in large size ferries
n_2	The number of crew in small size ferries

4   The fish accumutation model

4.1   basic idea

Below, we are going to find the trend of the yearly change and demonstrate a monthly correct and a reference expression of the spatial distribution to reach the prediction of the temperature after years, then find the relationship between temperature and the density of fishes, and finally obtain the change of fish accumulation area over time.

4.2   The varying temperature model

The changing of the sea surface temperature(SST) can be regarded as a short-term monthly average temperature change, a long-term yearly average temperature change from a time perspective; and a spatial distribution from geographical perspective. We separate those changing trend by analyzing the data from project ERSST which contains 1deg resolution data from 1981 to 2010 and 2deg data from 1854 to 2020. Specificly, we use the long-term data to predicte the yearly change, and use high resolution data to be the begining of long-term prediction as well as to analyze the spatial distribution and the monthly change. The area we analyze lies in W15.5 to E13.5 and N46.5 to N65.5.

4.2.1 The yearly change prediction model

From the Long's previous work[4],we know that the major factor of the yearly SST change is related to the concentration of carbon dioxide, which affact SST's retard growth model. By analyzing the yearly avarage SST of the entired area, we found an obviously increasing trend especially after 1980s. However, that model is more precise on a time scale of hundreds of years, and we found a quadratic model is more accurate to predicte the temperature on a time scale over years, fitting the rising segment of the logistic curve, especially with the concider that the concentration of carbon dioxide are only dramatic growth in recent decades and affect the retard growth model.
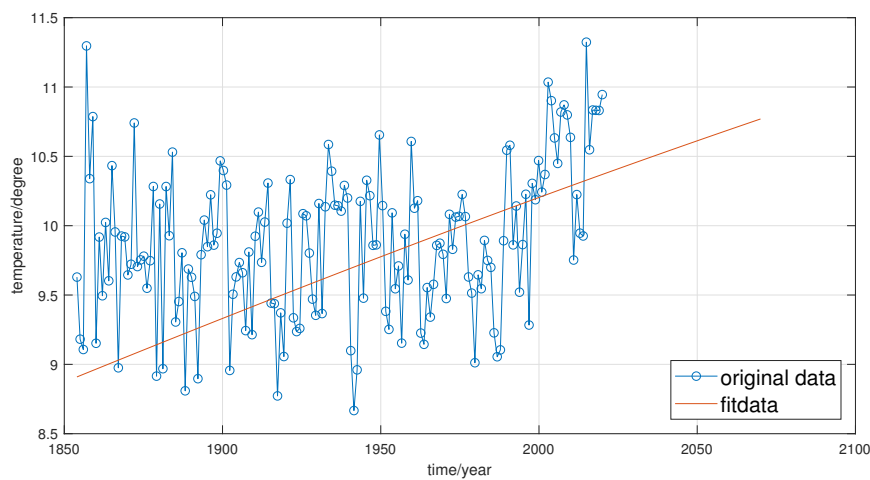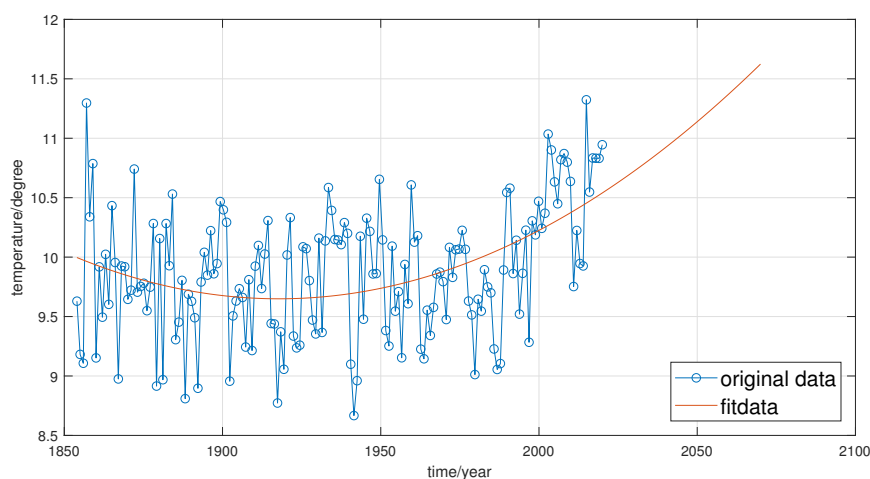


Figure 1: using logistic model

Figure 2: using quadratic model

4.2.2 Monthly correct of the prediction

The monthly or even dayly rate of SST change is much stronger than the rate of yearly SST change and is important to the analysis of the fishes distrbution. In our model, we assume that the monthly change has a central value related to its annual avarage temperature. We also assume that the monthly change are determined by the seasonal change and independent of the factors which affect the yrarly change of avachange temperature. Then we are going to use the predicted annual avarage temperature above and add a monthly correction to get the actual temperature accurate to month. A long-term dayly avarage and a spatial avarage are made based on SST data from 1981 to 2010 in the area we Analyzed. Since the seasonal change of temperature are mostly related to the rotation of the earth, it is convenience to suppose this change has a trigonometric form. And we find the monthly correction is:

$$T(t) = 3.3598\sin(-0.0184t + 0.5921\pi) + 0.1382 + T_{annual} \tag{1}$$

where T_{annual} is the annual avarage temperature, and t is days ranging from 1 to 365. To simplicity the representation, our further work are still using the annual avarage temperature, which as actually close to the temperature in spring and fall, as the beginning of the yearly prediction model. The affect of the seasonal change will be considered in the profit model, which will be discussed in later section.
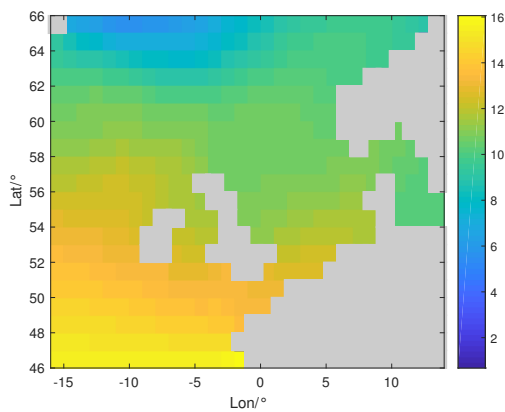
(a) spatial temperature distribution
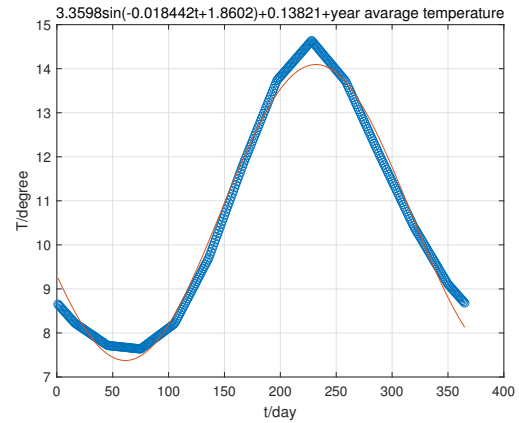

(b) monthly changing and fit

4.2.3 Spatial distribution model

During the work above, we make a spatial avarage of the data,but we are also intersted in the spatial distribution of the SST. From jansen's work[3], the SST of a given location in Scottish area are strongly related to the distance between that place and the continental shelf. In our model, we assume that those dependencies of distance can be converted into the dependencies of longitude and latitude. We

also assume this distribution is damping from the mean temperature value of the area at a given time, which offers a way to predict the future's SST distrbution based on the predicted value of annual avarage SST. The equation we obtain is:

$$T(t) = -0.34\sqrt{(Lon + 14.08)^2 + (Lat + 104.87)^2} + T_{annual} + 55.65 \qquad (2)$$

where T_{annual} is the annual avarage temperature.
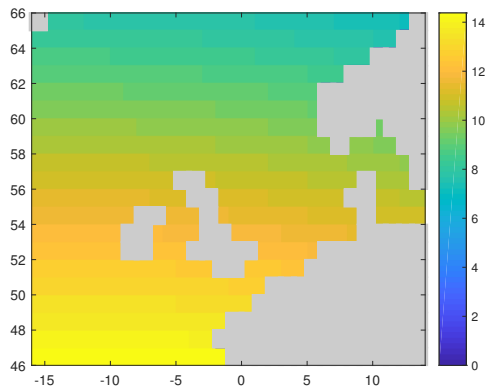
(c) fit of the spatial temperature distribution
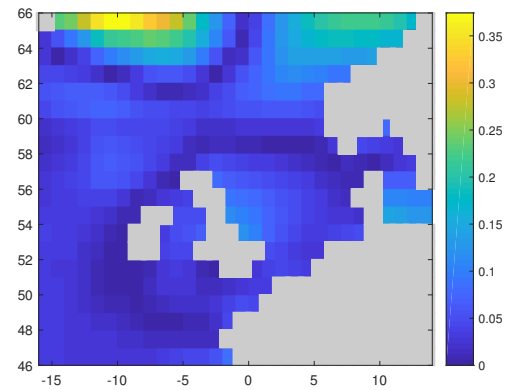
(d) relative error of fit

However, in order to reduce the error, we will not use that analytical method, but based on the original spatial distribution data which we used to get this analytical representation.

4.3   The fish-temperature model

As we known, fish need the proper habitat to service, and temperature play an important role in multiply of fish, such as the mackerel population is found further upstream in warmer waters as the current cools through winter[3]. In our previous predictions, the increase of SST because global warming is obvious, so we take fisheries data from The International Council for the Exploration of the Sea(ICES) and make a comparison.

According to the graph, we can tell that besides fisheries productivity growth and some statistical gaps, the density of fish is particularly relevant to SST. So we use Pearson correlation coefficient to correlation analysis.

Table 2: The result of correlation analysis

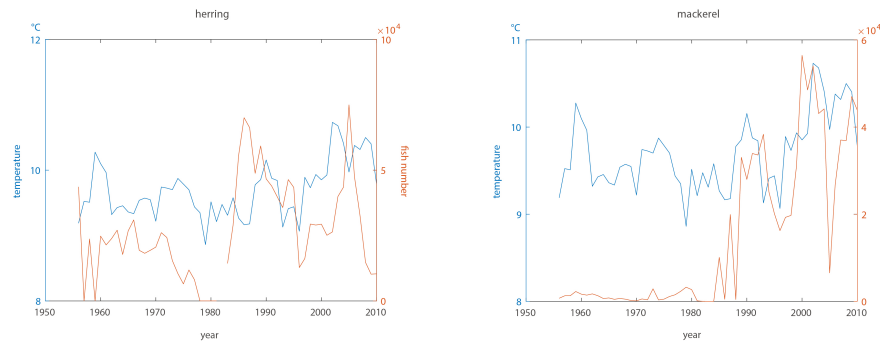| result	herring	mackerel
r	0.4637	0.5463

Figure 3: Comparison graph

So it's highly correlative. Then we use them to fitting the Gaussian distribution, and get the desired relationship between temperature and fish density.
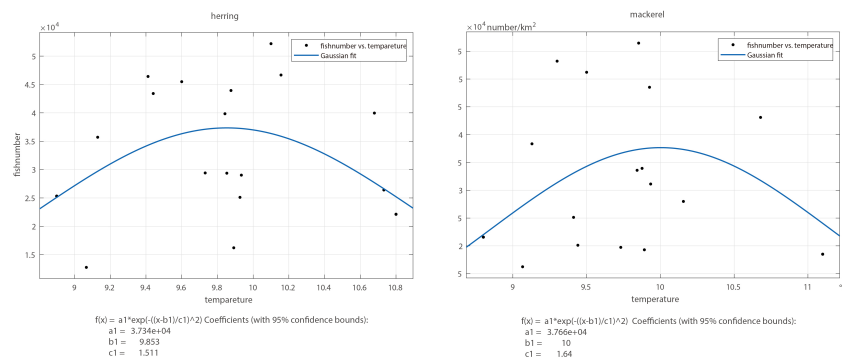

Figure 4: Fitting result

4.4 The prediction of fish accumutation distribution

We have obtained the relationship between fish density and temperature as well as the basic model to caculate the temperature distribution in the future. The following figure are going to reveal the sea surface temperature distribution and fish accumulation area in the current and after 10,25,50 years.

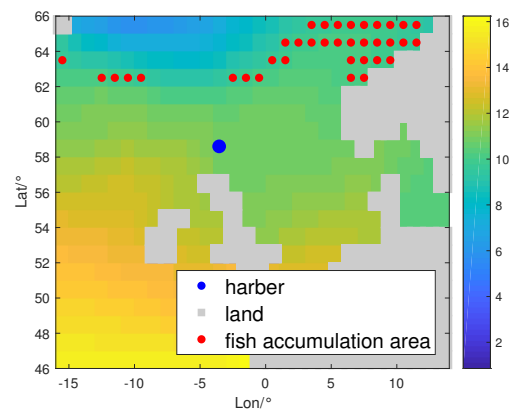# 5 The Demand Distribution Model

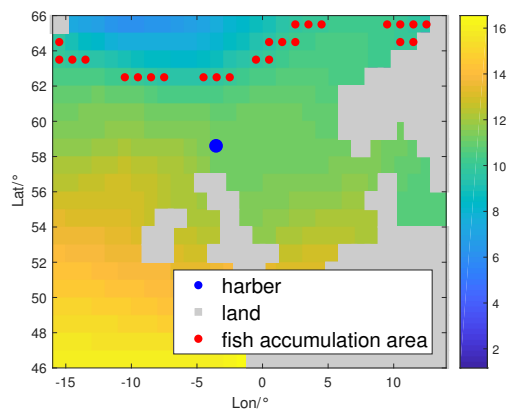Table 3: The range dimension ratios of trawlers

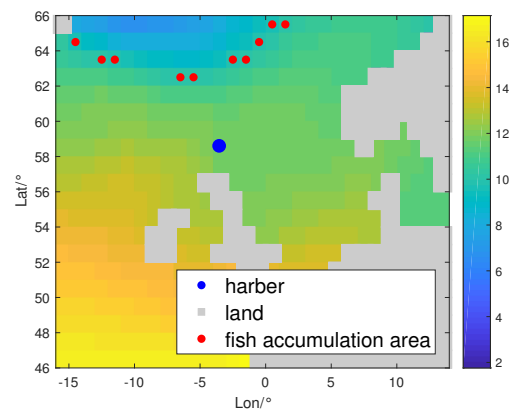| parameter	L/B	B/d	D/d
Range of steel materials	3.93-5.00	2.38-3.65	1.19-1.38
Range of wood materials	3.19-4.53	2.61-4.67	1.06-1.44
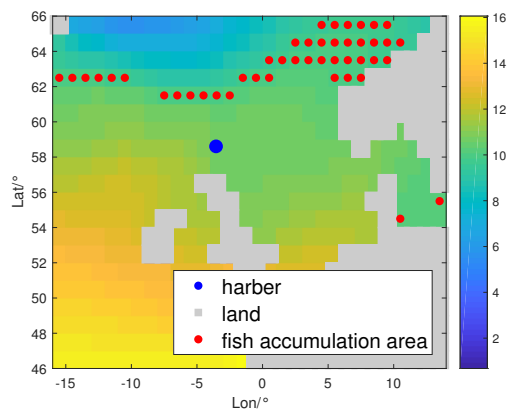
(a) fish accumulation areas after 0 years

(b) fish accumulation areas after 10 years

(c) fish accumulation areas after 25 years

(d) fish accumulation areas after 50 years

As can be seen from the 2016 Scottish Marine Statistics (Table 3), most of the Scottish vessels that capture herring and mackerel are larger than 40 meters in length. Figure 6 is the structural model of the ship. We simplified the structure of the ship to a rectangular parallelepiped, and the relationship between its length, width, and height is shown in Table 3. We assume that the length of the Scottish vessels in small company is about 40 meters, the width is one quarter of its length, the height of the waterline is one twelfth of the length, and the length between the perpendiculars is equal to the length of the boat.

From Table 4, it is estimated that the average power of a 40-meter-long Scottish vessel is 4000 kilowatt and. the average tonnage is about 1300 tonnes. The speed and flight time are calculated from the speed-related formula.

Table 4: The prices of two species : 2012 to 2016

Year	2012	2013	2014	2015	2016	average
Herring (pound per tonne)	565	408	308	369	665	463
Mackerel (pound per tonne)	1034	979	832	664	895	880.8
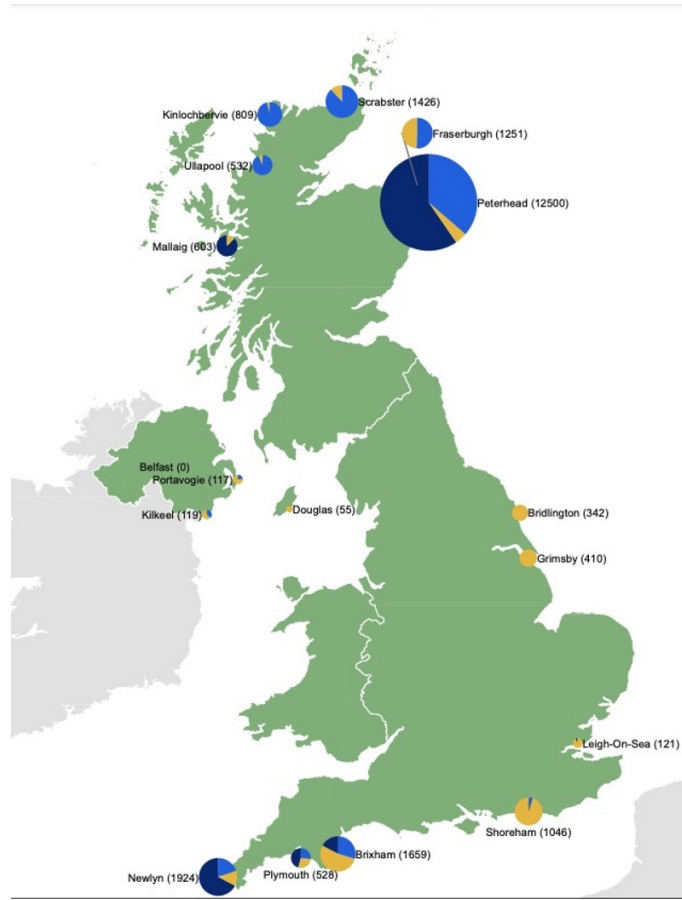
Figure 5: English Harbor Division

Table 5: The information about Scottish registered vessels

vessel length (metres)	<=10	10-12	12-15	15-24	24-40	>=40
Herring (tonnes)	0	0	0	7	1505	63031
Mackerel (tonnes)	811	0	0	42	3802	183831
Average tonnage (tonnes)	4	13	22	110	273	1748
Average age (year)	26	33	29	31	28	17
Average engine power (kW)	57	127	190	325	641	4327

$$\begin{cases} v = 1.84 \times \left(\frac{P}{V}\right)^{0.237} \times \sqrt{l} \\ l = L \approx 40 \\ P = 4000 \\ V = L \times B \times d = \frac{1}{48 \times L^3} \end{cases} \tag{3}$$

$$T = \frac{S}{v} \tag{4}$$

$$A_1 = c_1 \times T_1 \tag{5}$$

$$A_2 = c_2 \times T_1 \times n_1 \tag{6}$$

$$A_3 = c_3 \times T_1 \tag{7}$$

$$A = A_1 + A_2 + A_3 + A_e \tag{8}$$

Where:

A_1 represents the average working cost per hour of the large Scottish vessel.As a Scottish vessel with a length of 40 meters, the purchase price is approximately 44,000 pounds, the number of days of operation is 180 days per year, and the daily working time is 13 hours.

A_2 is the cost that the small company need to pay about 20 crew members during a voyage

A_e is a fixed cost of about 20,000 pounds for a small sailing company in Scotland, including depreciation fees for fishing boats, fishing nets, hook fees, port fees, and loss costs during the off-season.

$$\begin{cases} E_1 = 1300 \times 10\% \times a_1 \times p_1 \\ E_2 = 1300 \times 10\% \times a_2 \times p_2 \\ E = \frac{a_1 \times p_1}{a_1 \times p_1 + a_2 \times p_2} \times E_1 + \frac{a_2 \times p_2}{a_1 \times p_1 + a_2 \times p_2} \times E_2 \end{cases} \tag{9}$$

The weighted average prices and the proportion of density in different regions of herring and mackerel is used to calculate the earnings of small Scottish companies during a voyage.

Since no refrigerant fishing, in order to ensure fresh fish, the return time of Scottish vessel must be shorter than the fresh-keeping period of the fish

$$\frac{T_1}{2} \leq T_2 \tag{10}$$

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time is crucial [8, 9].
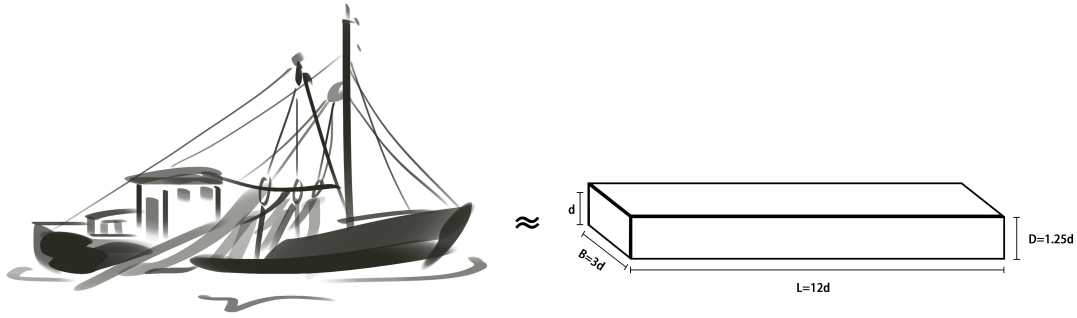
as is shown in Figure 8.

Figure 6: The model of a ship

6 the spatial profit distribution model

We have obtained the predicted fish density distribution in last section, and after the work above we can caculate the net profit by the sailing cost, the gross profit from fishing, and a constant cost appears on every yoyage.

7 The Comprehensive Evacuation Planning Model

$$v = 1.84 \times \ (\frac{P}{V})^{0.237} \times \sqrt{l} \tag{11}$$
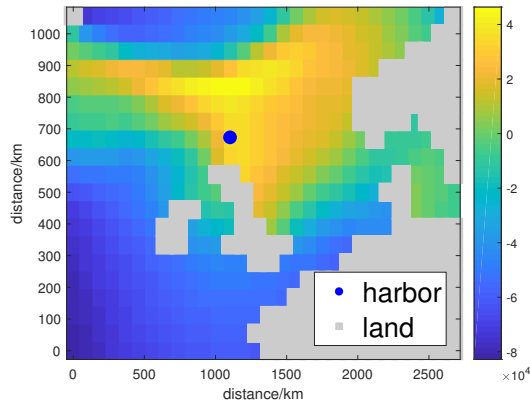
$$\begin{cases} P_0 = P \times (1 - 0.2) \\ P = 25.278 \times L - 169.31 \end{cases} \tag{12}$$

$$V = L \times B \times \ d = \frac{1}{48 \times L^3} \tag{13}$$
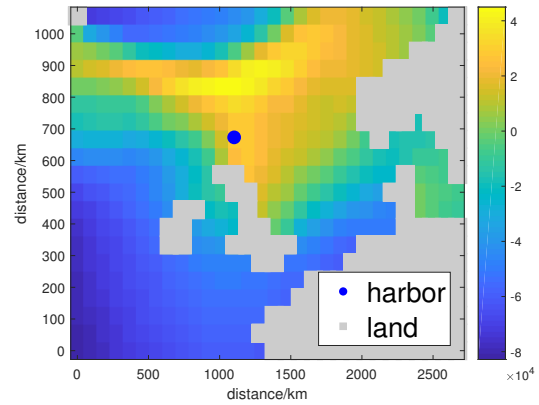
$$l = L \approx 40 \tag{14}$$

$$T_1 = \frac{S}{v} \tag{15}$$

$$\begin{cases} A_1 = k_1 \times T_1 \times L \\ A_2 = c_4 \times T_1 \times n_1 \\ A_3 = c_3 \times T_1 \\ A = A_1 + A_2 + A_3 + A_e \end{cases} \tag{16}$$

(a) spatial net profit distribution after 0 years

(b) spatial net profit distribution after 10 years
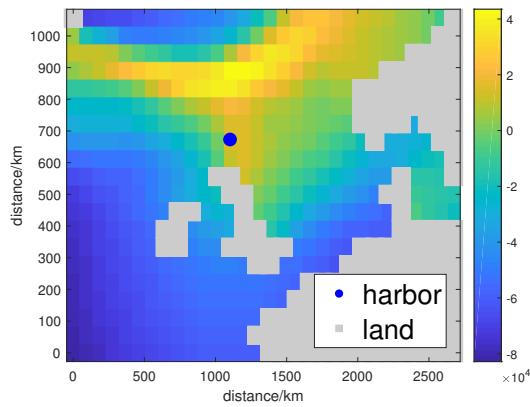
(c) spatial net profit distribution after 25 years
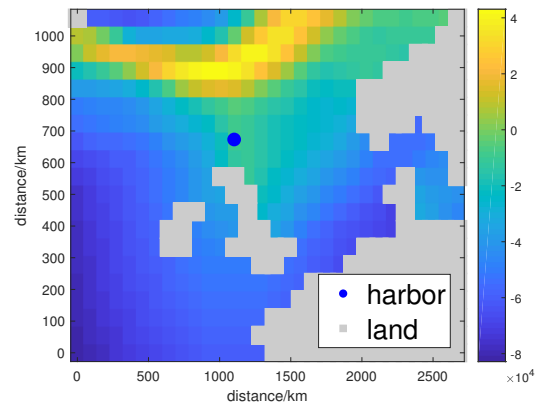
(d) spatial net profit distribution after 50 years

$$\begin{cases} E = 12.441 \times L - 130.82 \\ E_1 = E \times 10\% \times a_1 \times p_1 \\ E_2 = E \times 10\% \times a_2 \times p_2 \\ E = \frac{a_1 \times p_1}{a_1 \times p_1 + a_2 \times p_2} \times E_1 + \frac{a_2 \times p_2}{a_1 \times p_1 + a_2 \times p_2} \times E_2 \end{cases} \tag{17}$$

8   The Comprehensive Evacuation Planning Model

8.1   Model Preparation

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VRP [1, 2] generally defined as: on a range of clients point (location known or can be estimated) in satisfying certain constraints (such as the demand for goods,

(e) the realationship between distance and net profit

(f) the elapsed time
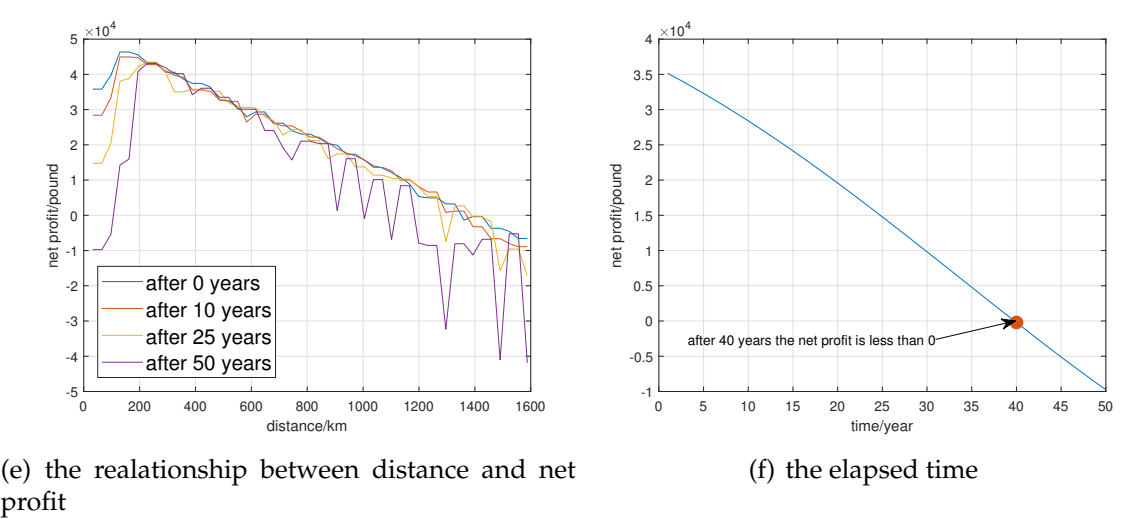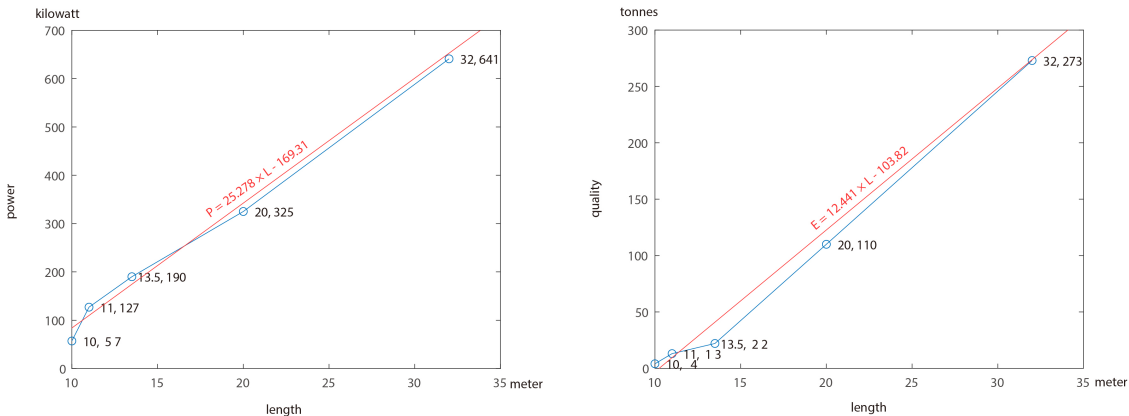
Figure 7:

Figure 8: The model of a ship

Table 6: The categories of hurricanes

Category	Maximum sustained winds	Potential damage
Category 5	≥ 250 km/h	Most of the buildings and detached houses were completely destroyed, and some houses were blown away completely.

the delivery time of delivery, the vehicle capacity constraints, etc.), reasonably arrange the vehicle distribution route, making the vehicle through them in an orderly way to achieve a certain goal (such as the shortest mileage and least cost,

least time, use as little as possible and so on). The representation of VPR can be seen in Figure 3.

Based on the traditional VRP, a comprehensive evacuation planning model is established to satisfy the constraint conditions:

- Time constraint: the total withdrawal time is the shortest in the case of meeting all the evacuees' needs and not violating the constraints;

- Risk constraint: minimum risk of meeting the minimum evacuation time;

- Carrying capacity constraint: the number of customers on each vehicle path is limited no more than a constant;

- Road afford ability constraint: the total carrying capacity on the road is not allowed to exceed the road capacity;

- Shelter capacity constraint: the total population in the shelter shall is not allowed to exceed the capacity limit;

- Priority relationship constraints: the more endangered areas have priority access;

- Path first constraint: after every vehicle completes its mission, records its shelter and the time to reach the sanctuary, preparing for the assignment of the next mission.

Before each task, we need to update the network node demand, shelter of residual capacity and the starting position of the vehicles, where each task should be according to the last mission at the end of the vehicle at the beginning of status to the caller, get the transport vehicles in the task.

8.2   Modeling

We now describe an optimization model that includes the assumptions of the previous section

The considered time horizon is denoted by T. This is not the evacuation time we are aiming for, but an upper bound on the evacuation time that is needed by our model. This quantity is used to build the time expanded network.

For public transportation we assume that there is already an established set of collection points, where evacuees gather for further transportation to shelters. For each collection point it is known how many people will appear at this point in each time step. We also given a set of possible shelter location. For each such location we are given the number of people W_j that this shelter can hold and additionally the parking space C_j available near this shelter.

The set of buses available for the public evacuation transit is denoted by B. For simplicity, we assume that all buses have the same capacity N_0 (however, different capacities can easily be included in our model). Besides all cars carry the same number of people.

Once the used shelter locations have been chosen, the public and private traffic will pour into the shelter. The private traffic is modeled as a dynamic network flow, the public traffic (the buses) as a dynamic multi commodity network flow. The private traffic is a single commodity whereas each bus is a commodity of its own. The flow of the buses has to be chosen such that all people that need public transportation can be brought to shelter locations while respecting the bus capacity. Both flows are chosen simultaneously in a system optimal way.

The total risk exposure is given by the sum of the risks of the individual arcs over all time steps. The risk of a single arc at a time step is given by the risk value of the arc multiplied with the number of people on this arc at this time step.

Formulating these aspects mathematically, we propose the following multi-criteria mixed-integer programming model, which we call the Comprehensive Evacuation Problem (CEP)[5–7]

In this mixed integer program we use the following variables: δ_{ij} denotes traversal of arc (i,j) $\in$ A. x_{ij}^t denotes the spend time passing arc (i,j). r_{ij}^t denotes the risk factor passing arc (i,j) at time t. f_{ij}^t denotes the number of evacuees using cars passing arc (i,j) at time t. In contrast, g_{ij}^t denotes the number of evacuees using bus b to go from node i to node j at time t. η represents the jam factor, which depends on the magnitude of the hurricane, the location of the landing, and the average number of evacuees passing arc (i,j) at time t. B_{ij}^t denotes the number of bus driving on arc (i,j) at time t. In the same way, C_{ij}^t denotes the number of car driving on arc (i,j) at time t. P_j^t denotes the number of people in the j shelter at time t. r denotes the capacity factor.

$$\Delta \min(\Delta, R) \tag{18}$$

$$\Delta \geq (2n-1) \times \max\left(\sum_{(i,j)\in A} \sum_{t\in T} \delta_{ij}^t x_{ij}^t \right) + \Delta t \tag{19}$$

The objective (1) is to minimize the evacuation time Δ and the risk R ,These objectives are computed using constraints (2)-(4). Constraints (2) ensure that Δ is the maximal evacuation time. The risk R depends on the number of people passing a link. This relation is expressed in constraint (3)and(4).

In the equation (5), n means the number of journeys that the bus needs to transport, and the calculation should Integer plus one. Equation (8) - (10) is the road traffic that is used to constrain not to exceed its maximum capacity at time t.

When a hurricane is stronger, it may require a massive evacuation, that is,

to consider the interaction of the three states. The site selection, risk coefficient, road congestion, and site accommodation will be affected, we need to reset the influence parameters to get the minimum required time and the site situation again.

Optimization method: When the forecast hat hurricane level is high, we can arrange inland evacuation ahead, in the case of ensure the overall time is enough for the coastal areas to evacuate to the site of the corresponding time calculation.

Advantage: Inland remove first can reduce the road pressure; Coastal remove later can increase the economic benefit.Compare the results again and get the final optimization plan.

8.3   Model Solution

Based on the above model and the parameters involved in the model, the final evacuation time is obtained by programming, and the result is shown in the table below:

Table 7: The Evacuation time

Hurricane level	1	2	3	4	5	6
Evacuation time	11.4	18.2	24.28	33.6	47.8	49.6

As shown in the figure above, it is necessary to calculate the time required for a category 1- 5 hurricane, including the withdrawal time required for the optimization programme.

Because the evacuation and time of personnel also satisfied the curve of S type curve, it can be used to draw the time-varying personnel evacuation curve of hurricane from category 1 - 5, which can be seen in figure4.

On the basis of guarantee the safety of life, we put forward the optimization scheme, when hurricane prediction level too high, let let evacuated inland areas, in order to improve the economic benefit of coastal, and reduce economic loss. The maximum population density due to coastal areas, and abide by the S type curve evacuation rules.

Under the same Five - level hurricane conditions, the optimization scheme minimizes the economic loss under the conditions of increasing the cost of the smaller time. It has been proved that evacuating in the right time can get better effect, which has a positive effect on the subsequent development of evacuation plan.

9 Strengths and Weaknesses

9.1 Strengths

- The comprehensive evacuation planning model takes the shortest time and lowest risk and low economic losses as the total constraint conditions to get the optimal solution;

- The constraint conditions such as road carrying capacity and the capacity of escape points are considered in the comprehensive evacuation planning model;

- Determine the coverage scope by Thiessen polygon;

- Considering the demand distribution characteristics in the station nodes;

- In terms of model constraints, the shortest evacuation time is obtained for a 1-5 hurricane;

- Considering the economic benefit gap between inland and coastal areas, the optimal plan for economic loss is proposed;

- Analyze the extreme problems, propose solutions, and obtain the optimal solution through comprehensive consideration of evacuation time, evacuation risks and economic losses.

9.2 Weaknesses and Extensions

- Without considering the evacuation of the county itself;

- Without considering the refueling problem of cars and buses;

- Without considering the risk caused by large numbers of people in station nodes;

- Without considering other means of transportation, such as aircraft, railway, etc.;

- Without considering the subsequent material problems of the shelter.

Optimization method: When the forecast hat hurricane level is high, we can arrange inland evacuation ahead, in the case of ensure the overall time is enough for the coastal areas to evacuate to the site of the corresponding time calculation.

Advantage: Inland remove first can reduce the road pressure; Coastal remove later can increase the economic benefit. Compare the results again and get the final optimization plan.

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Appendices

Appendix A   First appendix

Aliquam lectus. Vivamus leo. Quisque ornare tellus ullamcorper nulla. Mauris porttitor pharetra tortor. Sed fringilla justo sed mauris. Mauris tellus. Sed non leo. Nullam elementum, magna in cursus sodales, augue est scelerisque sapien, venenatis congue nulla arcu et pede. Ut suscipit enim vel sapien. Donec congue. Maecenas urna mi, suscipit in, placerat ut, vestibulum ut, massa. Fusce ultrices nulla et nisl.

Here are simulation programmes we used in our model as follow.

Input matlab source:

Appendix B   Second appendix

some more text **Input C++ source:**