CE 505

APPLIED STOCHASTIC ANALYSIS AND MODELING

TERM PROJECT

‘OPTIMIZATION OF THE WAITING TIME FOR THE SHIPS ENTERING THE STRAIT OF ISTANBUL’

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INTRODUCTION

The huge number of passages makes the Strait of Istanbul very vulnerable to the accidents. And this dense traffic and considerable number of casualties has been our motivation to analyze the problem.

Since these passages cannot be prevented or limited due to the international regulations, the only solution is to minimize the risk of accidents. Our approach considers the problem from only one point of view, namely the optimum waiting time for the ships entering the strait, but nevertheless the results are useful and valuable Also this analysis can easily be broadened to more complex cases.

OBJECTIVE & PROBLEM DEFINITION

The object of this project is to determine a numerical value for waiting time for the ships passing the strait of Istanbul, for a desired level of risk.
Two ships entering the strait are considered. The ships are assumed to have arrived the entrance of the waterway at the same time, which is not always the case. The passage is referred as *safe* if the lagging ship cannot catch up with the first ship within the strait. The term *risk* refers to the probability that the second ship catches up with the first ship, which has entered the strait just before, within the strait. Also the ships are assumed to have constants speed during the passage.

We also want to minimize the waiting time, because historical data shows that the ships waiting at the south and north entrances of the strait also cause accidents in those regions, so we modeled our analysis such that the second ship catches up with the first ship just at the exit, so that both the safe passage and minimum waiting time criteria are satisfied.

In order to perform the analysis we needed the passage time data for the ships which was obtained from "Ahırkapı Deniz Kontrol İstasyonuDue to the legal problems we could have the data only for passages on 20-05-2002, so we assume that this data representative of the whole. But although the outcomes are dependent on the data, the model is independent of the data available, so if better data is available in the future larger data samples may be input to the model to get more accurate results.

Table 1 shows a piece of the data we had. The whole original data can be seen in the appendix .We had data for 71 southbound passages and 59 northbound passages.

Table 1 Data sample

SAMPLE DATA FROM "AHIRKAPI DENİZ TRAFİK KONTROL İSTASYONU"

SHIP NO	GRT	NRT	L (m)	LOAD	LOAD (TON)	ARRIVAL TIME	ENTRANCE TIME	EXIT TIME	PASSAGE TIME (min)
1	1202	687	71	KAĞIT	1000	6 5	6 35	7 45	70
2	38613	20204	228	H.PETROL	60100	6 25	6 55	8 25	90
3	3079	1206	85	YOLCU	187	6 35	7 5	8 30	85
4	44239	29042	248	H.PETROL	82269	7 40	8 10	9 40	90
5	1941	1053	87	SAÇ	2975	7 50	8 20	9 50	90
6	11315	6871	147	FOSFAT	17000	8 0	8 30	9 59	89
7	14453	7511	170	KONT	11232	8 10	8 40	9 55	75
8	2576	1195	107	A.FOSFAT	3188	8 25	8 55	9 55	60
9	2660	798	75	BOŞ		8 35	9 5	10 45	100
10	39605	17728	229	F.OIL	60000	8 55	9 25	11 0	95

The problem may be visualized on the following figure:

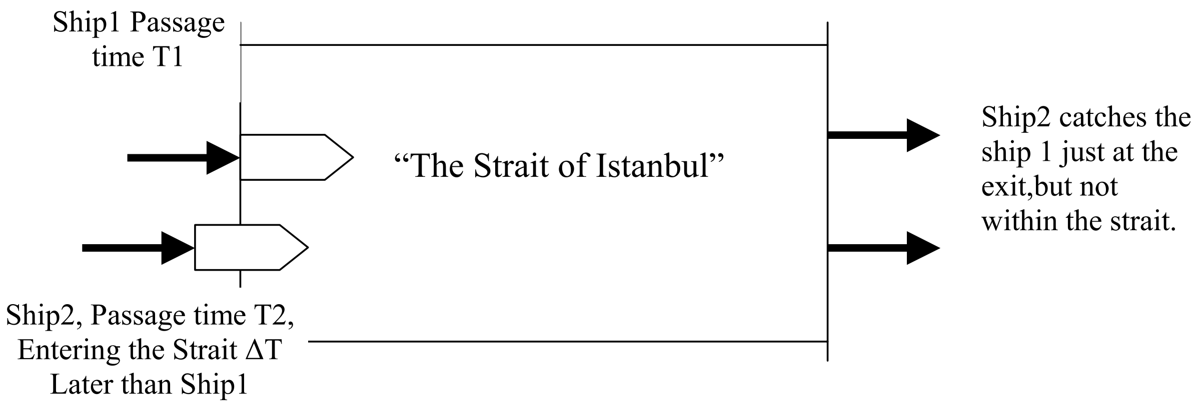

Figure 1 VISUALIZATION OF PROBLEM

SOLUTION METHOD

DEFINITIONS

T : Passage duration

T_1 : Passage duration of ship 1

T_2 : Passage duration of ship 2

ΔT : $T_1 - T_2$: waiting time between ship 1 and ship 2

$\Delta T < T_1 - T_2$: Risky waiting time, catch-up within the strait is possible

α: Risk parameter for a given waiting time,

f(t) : Probability density function of the passage time,T

g(t1,t2) : Joint probability density function for T1 and T2

DATA INTERPRETATION

The analysis is performed seperately for North-to-South passages and South-to-North passages. There are differences in passage times because the southbound passages are slower due to the currents from Blacksea to Marmara.The range for southbound passages is 60 to 120 minutes with a mean passage time of 92 minutes, and the range for northbound passages is from 70 minutes to 235 minutes with a mean passage time of 122 minutes.

Using the available data the distribution f(t) is obtained.The distribution of both T1 and T2 is assumed to be represented by f(t).And T1 and T2 are treated as independent random variables. Because the velocity and the passage time of the second ship does not depend on the same parameters for the first ship.

FINDING THE DISTRIBUTION AND PDF FOR T

Using the data for passage time T we have calculated the histograms and probability density functions for T. And T1 and T2 are also represented by the same distributions..The Calculations are done using matlab.

f(t) = f(t1) = f(t2)

The figures in the following pages following graphs show the histograms and pdfs seperately for both directions.

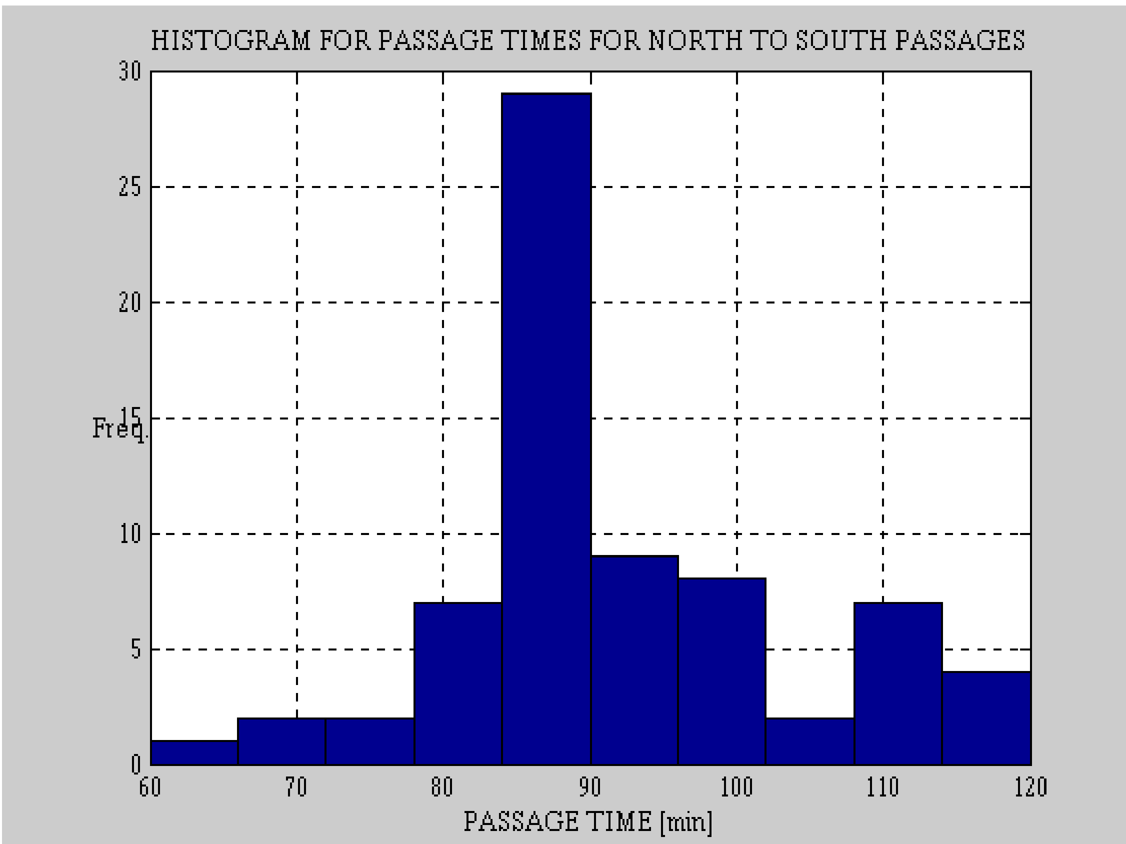

Figure 2 HISTOGRAM FOR SOUTHBOUND PASSAGE TIME

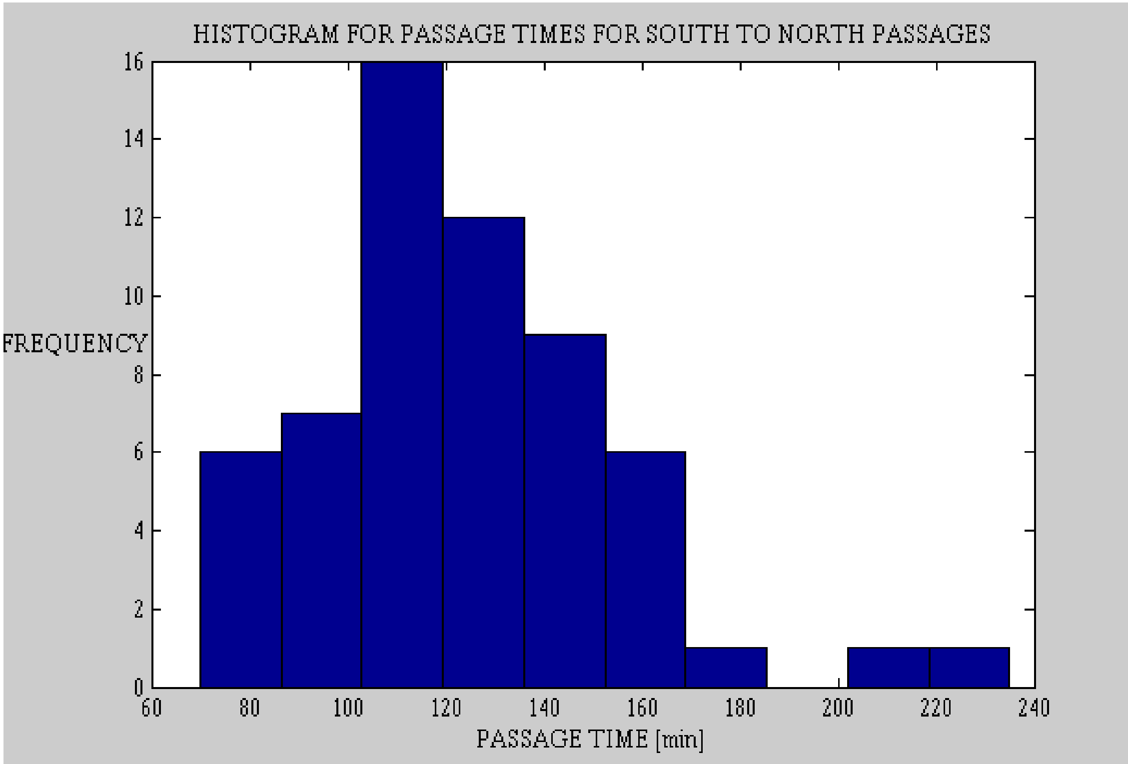

Figure 3 PDF FOR SOUTHBOUND PASSAGE TIME

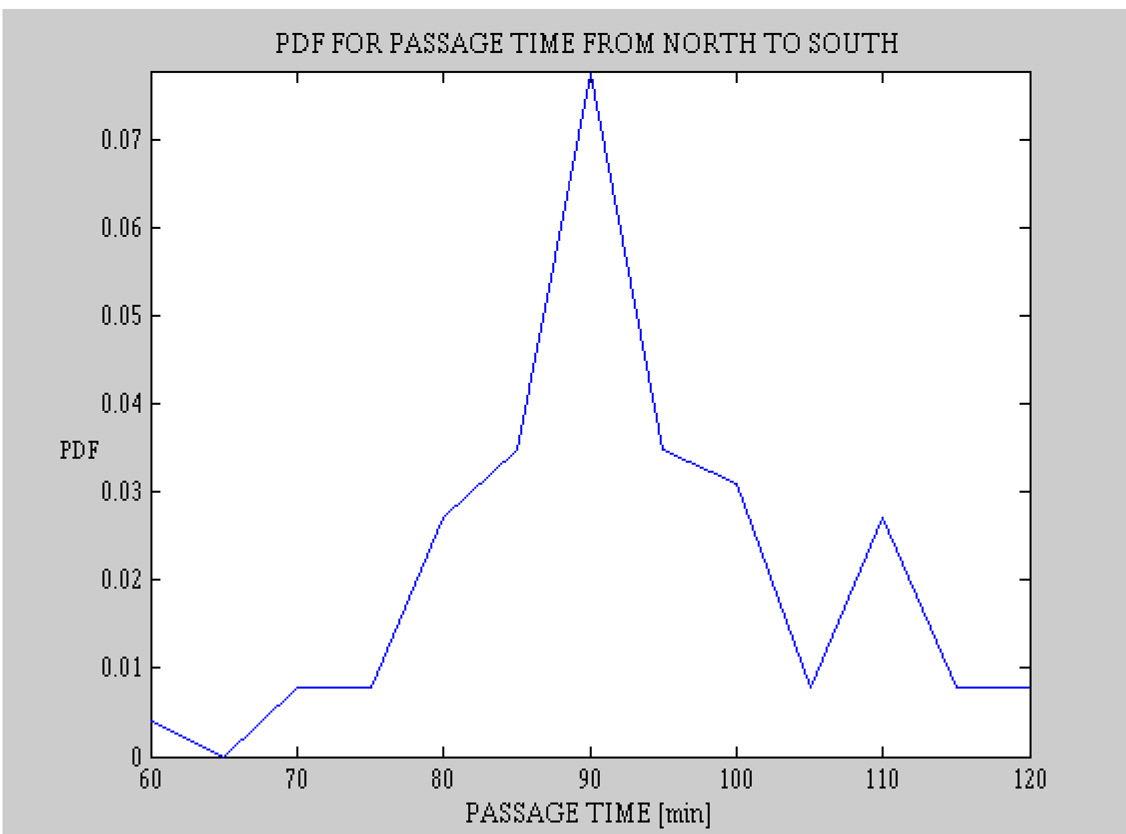

Figure 4 PDF FOR SOUTHBOUND PASSAGE TIME

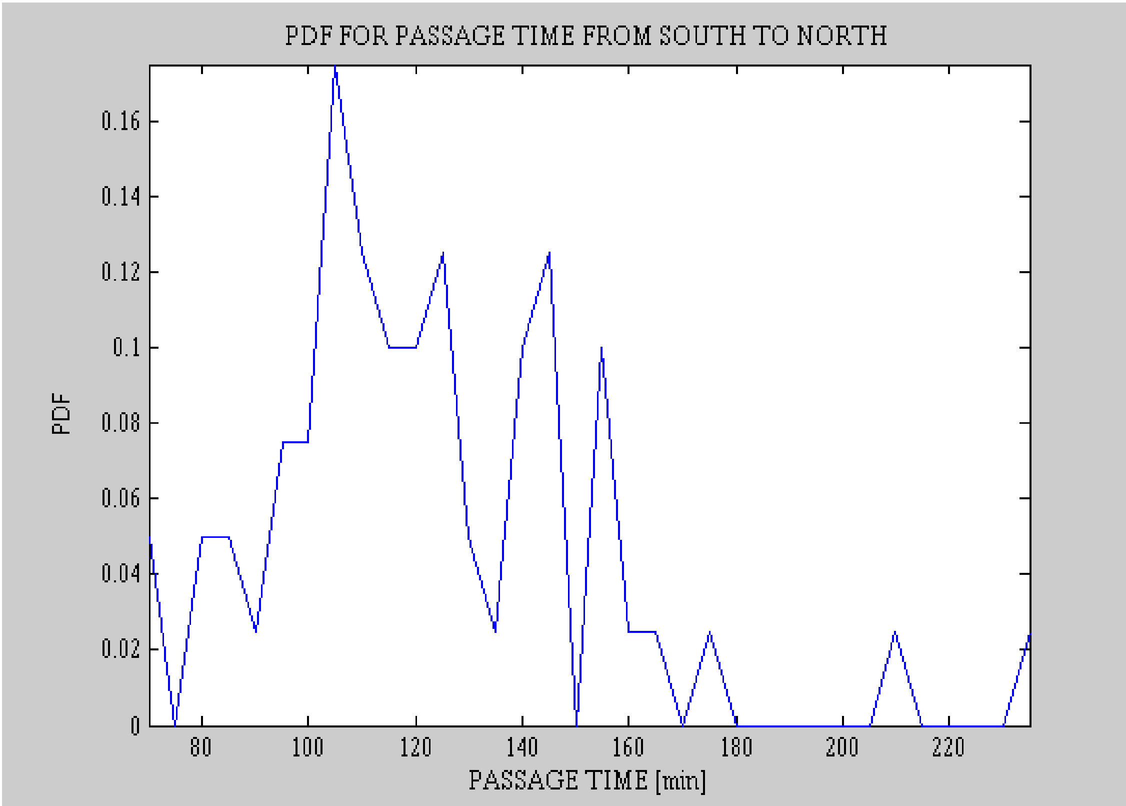

Figure 5 PDF FOR NORTHBOUND PASSAGE TIME

CALCULATING THE JOINT PROBABILITY DENSITY FUNCTIONS

Since $\Delta T = T_1 - T_2$, it depends on both the distribution of T1 and T2.So we have to calculate the joint probability density function for T1 and T2, g(t1,t2).

T1 and T2 are independent so:

g (t1,t2) = f (t1) x f (t2) = f (t)^2

The calculatıons are done in matlab and the three dimensional figures for jpdfs in boıth directions can be seen on the following pages.

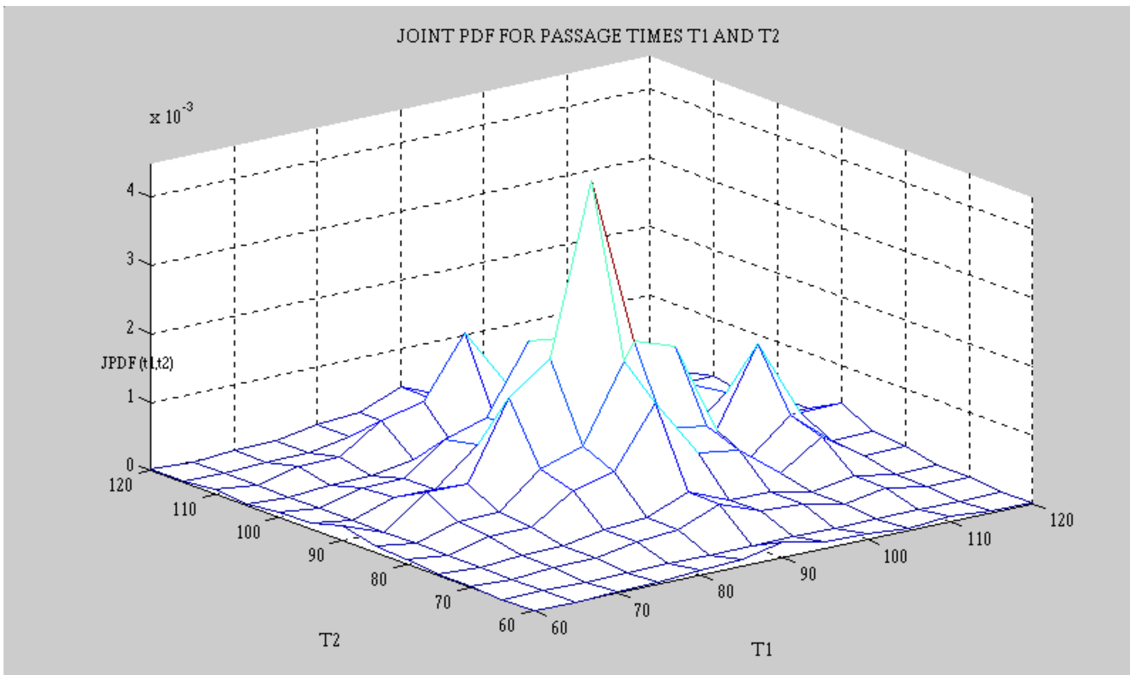

Figure 6 JPDF FOR T1 AND T2 FOR SOUTHBOUND PASSAGES

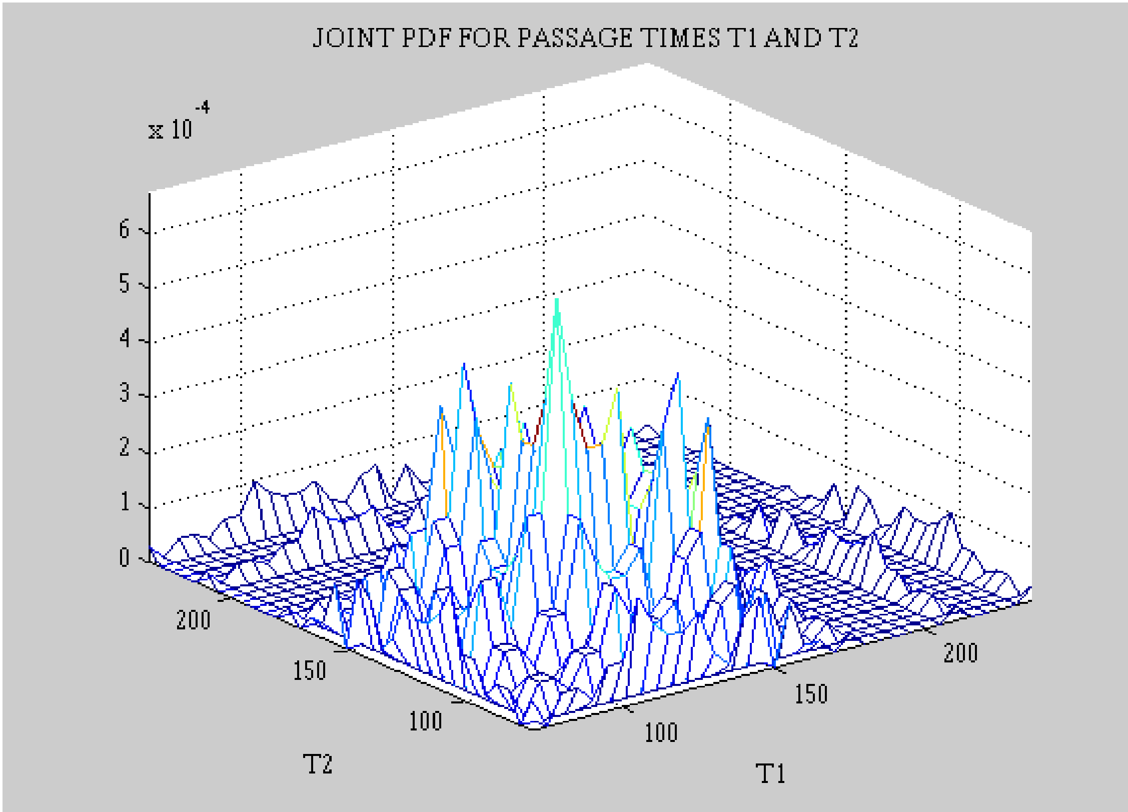

Figure 7 JPDF FOR T1 AND T2 FOR NORTHBOUND PASSAGES

CALCULATION OF THE RISK PARAMETER

The risk occurs when the waiting time assigned to the second ship is smaller than T1-T2. But whether the second ship will cathup with the first ship or not depend on their passage times T1 and T2. If the laggıng ship is slower than the first one (T2 >T1) then theres no risk,regardless of ΔT.

To calculate this risk we consider the cross section on the T1-T2 plane of the joınt probabaility density function.The risk is equal to the volume over the area defined as,Risky Zone, were cathing up may occur with a certain probability.
The cross section is visualised in the following figure.

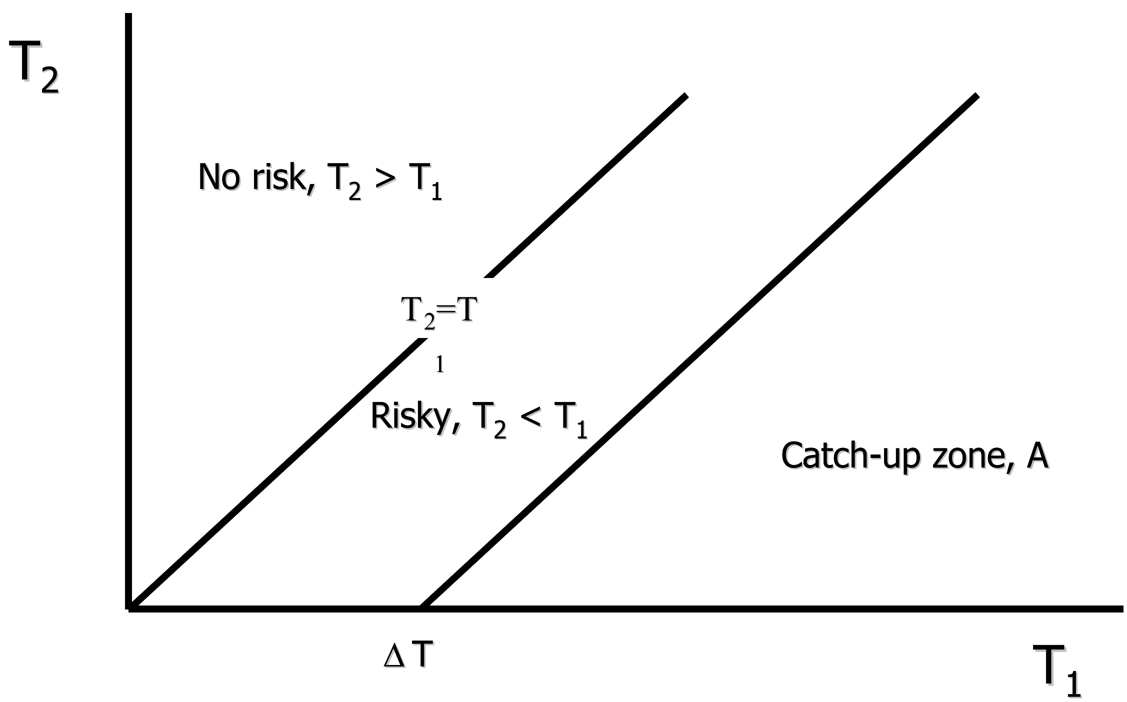

Figure 8 CROSSECTION REPRESENTATION OF JPDF

Since the distributions of T1 and T2 are identical their joint probability density function is symmetrical with respect to the T1=T2 axis.So if T1=T2, which means that waiting time, ΔT is zero,then the probability is just equal to the volume under the surface defined by g(t1,t2) and T1=T2 line on the T1-T2 plane.And this is just the half of the total volume. **So when ΔT=0, α should be 0.5**

Here is the theoretical proof for the discussion above

Pr {catching-up with the strait} = $\iint_A f(T_1, T_2).dT_1.dT_2 = \alpha\%$

$$\iint f(T_1).f(T_2).dT_1.dT_2 = \alpha\% \quad ; \quad f(T_1, T_2) = f(T_1).f(T_2)$$

$$\int_{\Delta T}^{\infty} \int_{0}^{T_1-\Delta T} f(T_1).f(T_2).dT_2.dT_1 = \int_{\Delta T}^{\infty} f(T_1)\left[\int_{0}^{T_1-\Delta T} .f(T_2).dT\right]_2 .dT_1 = \alpha\%$$

where α is the risk parameter.

$$\int_{\Delta T}^{\infty} f(T_1)\left[\int_{0}^{T_1-\Delta T} .f(T_2).dT\right]_2 .dT_1 = \int_{0}^{\infty} f(T).F(T).dT \quad ; \quad f(T) = \frac{dF}{dT}$$

$$\int_{0}^{\infty} \frac{dF}{dT}.F(T).dT = \int_{0}^{1} dF.F = \left|\frac{F^2}{2}\right|_0^1 = \frac{1}{2}$$

Different waiting times, **ΔT**, are considered and corresponding probabilities for catching up within the strait are calculated.

To find the volume, a Matlab code is written which integrates the volumes above the grids included in the "Catch-up zone, A".The code may be seen in the appendix.

Then risk parameter, α versus waiting time **ΔT** is plotted. The results for passages in both directions are shown in the figures and tables on following pages. Since the data is recorded at 5 minutes sensitivity, ΔT also starts from zero and increases in five minute intervals.

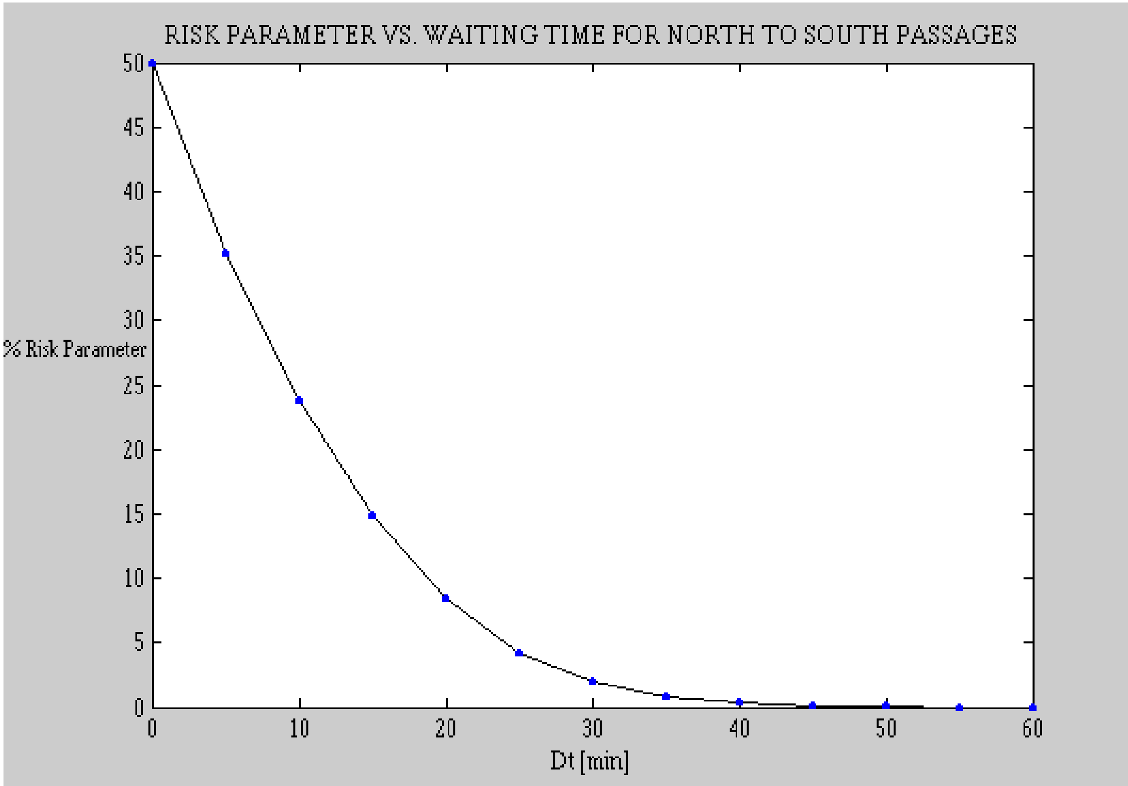

Figure 9 RISK PARAMETER VS WAITING TIME FOR SOUTHBOUND PASSAGES

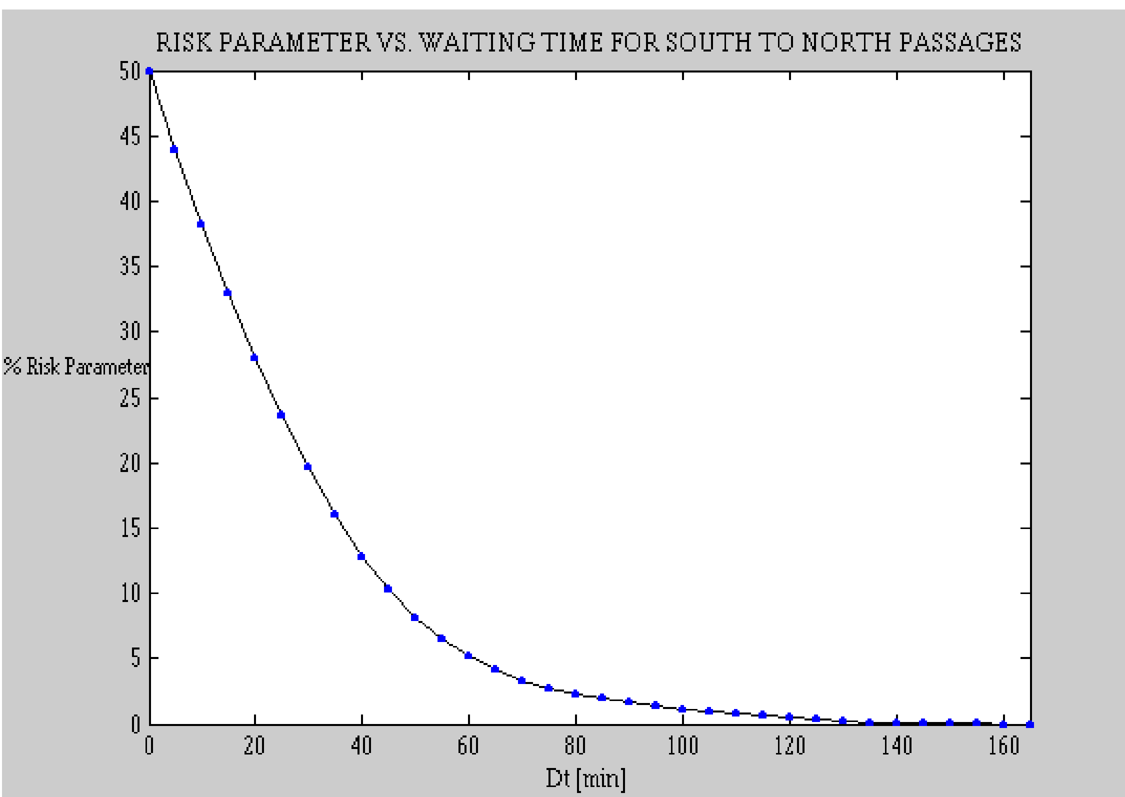

Figure 10 RISK PARAMETER VS WAITING TIME FOR NORTHBOUND PASSAGES

Table 2 RISK PARAMETER VS WAITING TIME (NORTHBOUND)

RISK PARAMETER VS WAITING TIME (NORTHBOUND PASSAGES)					
ΔT(min)	α(%)	ΔT(min)	α(%)	ΔT(min)	α(%)
0	50,00	55	6,50	110	0,74
5	43,97	60	5,17	115	0,60
10	38,29	65	4,11	120	0,45
15	32,90	70	3,31	125	0,30
20	28,03	75	2,75	130	0,19
25	23,65	80	2,33	135	0,12
30	19,59	85	1,96	140	0,08
35	15,94	90	1,67	145	0,05
40	12,86	95	1,42	150	0,03
45	10,30	100	1,17	155	0,01
50	8,18	105	0,93	160	0,00

Table 3 RISK PARAMETER VS WAITING TIME (SOUTHBOUND)

RISK PARAMETER VS WAITING TIME (SOUTHBOUND PASSAGES)	
ΔT(min)	**α(%)**
0	50,00
5	35,23
10	23,71
15	14,90
20	8,43
25	4,21
30	1,90
35	0,79
40	0,30
45	0,09
50	0,01
55	0,00
60	0,00

SECOND APPROACH

GETTING THE PDF FOR ΔT FROM $f(t_1, t_2)$ USING RANDOM VARIABLE TRANSFORMATION

$f(t_1) = f(t_2) = f(T)$

$f(t_1, t_2) \Rightarrow g(\Delta T, u)$

$\Delta T = t_1 - t_2$
$U = (t_1 + t_2)/2$

$T_1=h_2(\Delta T,U)$
$T_2=h_2(\Delta T,U)$

Then using above relations we can easily find that

$h_1=(\Delta T+2U)/2$ and $h_2= (2U-\Delta T)/2$

and

$$g(\Delta T,U) = f(t_1,t_2)\Big|_{\substack{t_1= h_1(\Delta T,U)\\ t_2=h_2(\Delta T,U)}} \times J$$

where,

$$J=\begin{vmatrix} dH_1/d\Delta T & dH_1/dU \\ dH_2/d\Delta T & dH_2/dU \end{vmatrix} = \begin{vmatrix} ½ & 1 \\ -½ & 1 \end{vmatrix} = 1$$

$g(\Delta T,U) = f((\Delta T+2U)/2 , (2U-\Delta T)/2)$

and from the above relations

$(\Delta T+2U)/2=t_1$ and $(2U-\Delta T)/2= t_2$

so we get

$g(\Delta T,U) = f(t_1, t_2)$!

and since the distribution of T1 and T2 are identical the integration turns back to the original pdf!
$g_{\Delta T} = f_T$

We did not rely on this analysis. The waiting time distribution which came out to be identical to the passage time distribution does not give us any clue to define a risk parameter using this distribution. And we could not find any theoretical mistake. So the previous analysis is considered as the solution to the problem.

CONCLUSION

The result of this analysis can be used by the controller in "Traffic Control Station" to assign waiting time values to the ships before they enter the strait. He just needs to decide how much risk shall be taken. But this analysis only takes the problem from one point of view and does not give any information about the traffic inside the strait, which may also cause accidents as we had in the previous days.

Also more accurate results would be be obtained if there had been more data available.

As expected the risk parameter came out to be 50 % when the waiting time is zero. This is reasonable because if the ships enter the strait at the same time, the probability that the second ship will pass the first one is 0.5, since they are assumed to have the same passage time distribution.

Also if the risk taken should be less than 1% then fron the plots or tables we can easily conclude that:

For south-bound passages, when $\Delta T = 35$ $\alpha < 1\%$

For north-bound passages, when $\Delta T = 105$ $\alpha < 1\%$

APPENDICES

APPENDIX A: DATA USED IN CALCULATIONS

PASSAGE TIME DATA USED FOR SOUTHBOUND CALCULATIONS

(used as data1.dat in matlab code)

95 100 120 90 95 70 120 95 90 100 80 80 95 90 110 85 110 75 70 90 85 90 90 90
75 60 100 95 90 110 100 110 100 80 90 90 110 80 85 80 85 95 110 100 105 80 90
95 100 115 115 90 90 90 105 85 80 90 90 90 90 95 110 85 95 85 85 90 90 85 100

PASSAGE TIME DATA USED FOR NORTHBOUND CALCULATIONS

(used as data2.dat in matlab code)

70 70 80 80 85 85 90 95 95 95 100 100 100
105 105 105 105 105 105 105 110 110 110 110 110
115 115 115 115 120 120 120 120 125 125 125 125 125
130 130 135 140 140 140 140 145 145 145 145 145
155 155 155 155 160 165 175 210 235

APPENDIX B : MATLAB CODE

Below is the is the matlab code used in calculations:

```
clear all
close all
%Loading the passage time data%
load data2.dat
dx=5 %dx is the grid spacing used in the calculations%
T1=data2';
T2=data2;
T1=sort(T1);
T2=sort(T2);
x=min(T1) : dx : max(T1);
%histogram%
figure
HIST(T1);
title('HISTOGRAM FOR PASSAGE TIMES FOR SOUTH TO NORTH PASSAGES')
xlabel('PASSAGE TIME [min]')
ylabel('FREQUENCY')
A=HIST(T1,x);
%passage time distribution%
figure
plot(x,A);
axis([min(T1),max(T1),0,max(A)])
xlabel('PASSAGE TIME [min]')
ylabel('FREQUENCY')
title('PASSAGE TIME DISTRIBUTION FOR SOUTH TO NORTH PASSAGES')
%normalizing the distribution and getting the pdf%
ha=polyarea(x,A);
B=A/ha;
figure
plot(x,B);
axis([min(T1),max(T1),0,max(B)])
title('PDF FOR PASSAGE TIME FROM SOUTH TO NORTH')
xlabel('PASSAGE TIME [min]')
C=(B'*B); %c will vbe used to get the joint pdf%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%
%code for calculating the volume under the surface%
Dt=0 : dx : (length(x)-1)*dx;
for Dtind=1:length(Dt)-1; % Dt indice
    area(Dtind)=0;
    for i=1:length(x)-1
        for j=1:length(x)-1
            if i==j-Dtind % ucgen alani
                a1=C(i,j);
```

```
            a2=C(i,j+1);
            a3=C(i+1,j+1);
            a4=C(i+1,j);
            area(Dtind)=area(Dtind)+.5*(a1+a2+a3+a4)/4;
         elseif i<j-Dtind % karenin alani
            a1=C(i,j);
            a2=C(i,j+1);
            a3=C(i+1,j+1);
            a4=C(i+1,j);
            area(Dtind)=area(Dtind)+(a1+a2+a3+a4)/4;
         end
      end
   end
area(Dtind)=area(Dtind)*dx*dx;
end
area(Dtind+1)=0;
vol=2*area(1) %total area under the surface%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%
D=(B'*B)./vol; %normalizing to get the joint pdf%
figure
mesh(x,x,D)
title('JOINT PDF FOR PASSAGE TIMES T1 AND T2')
xlabel('T1'),ylabel('T2')
axis([min(x) max(x) min(x) max(x) 0 max(max(D))])
area=100*area./vol
figure
plot(Dt,area,'k',Dt,area,'b.')
Dt
area'
title('RISK PARAMETER VS. WAITING TIME FOR SOUTH TO NORTH PASSAGES')
axis([0 max(Dt) 0 max(area)])
ylabel('% Risk Parameter')
xlabel('Dt [min]')
```

APPENDIX C : STRAIT STATISTICS

Table 4 TOTAL FIGURES FOR THE STRAIT OF ISTANBUL 1995-2000

YEAR	Total	Used Pilot	SP report	Longer than 200m.	Over 500 GT	Direct Passed	Tankers
1995	46954	17772	9571	6491	40724	24325	-
1996	49952	20317	12777	7236	44636	23755	4248
1997	50942	19752	15503	6487	45849	24568	4303
1998	49304	18881	24432	1943	44829	24561	5142*
1999	47906	18424	30619	2168	44354	26323	4452
2000	48079	19209	38574	2203	44734	26858	4937

*This value includes all vessels carrying dangerous cargoes.

Table 5 CASUALTIES IN THE STRAIT OF ISTANBUL 1990-1999

YEARS	TOTAL PASS-AGES	COLLISIONS	ENG. BREAK DOWN	FIRE	STRAN-DING*	TOTAL
1990	N/A	N/A	N/A	N/A	N/A	**43**
1991	N/A	N/A	N/A	N/A	N/A	**49**
1992	N/A	N/A	N/A	N/A	N/A	**39**
1993	N/A	N/A	N/A	N/A	N/A	**25**
1994 (Before Reg.s)	N/A	N/A	N/A	N/A	N/A	**10**
1994 (After Reg.s)	N/A	N/A	N/A	N/A	N/A	**2**
1995	46954	4	-	-	0	**4**
1996	49952	2	-	-	5	**7**
1997	50942	2	-	-	9	**11**
1998	49304	3	-	-	8	**11**
1999	47906	4	3	3	6	**16**

*includes groundings