# Study on Automatic Collision Avoidance System and Method for Evaluating Collision Avoidance Manoeuvring Results


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## Goals of Study

- Development of an automatic collision avoidance system for unmanned Autonomous ships (Remote maneuvering)
- Development of evaluation method of automatic collision avoidance maneuvering results

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# CONCEPT OF AUTOMATIC COLLISION AVOIDANCE MANOEUVRING

## Strategic Collision Avoidance Manoeuvring

- ***Ship manoeuvring which minimizes the economic loss, constantly selects a low-risk course from an early stage and reduces the encounter situation where the manoeuvring load is high***

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# CONCEPT OF AUTOMATIC COLLISION AVOIDANCE MANOEUVRING

## Strategic Collision Avoidance Manoeuvring

- *There are many ambiguous expressions in the current COLREGs (ex Action by stand-on vessel, she shall take such action as will best aid to avoid collision)*
- *Therefore, the desirable automatic system takes action to reduce the risk before the "Conduct of Vessels In Sight of Another" defined by the COLREGs is applied.*
- *It should be avoided that the rules of "Action by stand-on vessel" apply*

***Conduct of vessels in sight of one another***

***Rule 17 Action by stand-on vessel***

***…… The vessel required to keep her course and speed finds herself so close that collision cannot be avoided by the action of the give-way vessel alone, she shall take such action as will best aid to avoid collision***

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# CONCEPT OF AUTOMATIC COLLISION AVOIDANCE MANOEUVRING

## Strategic Collision Avoidance Manoeuvring

- *Developed an automatic collision avoidance system considering the realization of strategic collision avoidance manoeuvring*

  *A method of altering her course or changing her speed to reduce the risk before rules defined by CORLEGs is applied*

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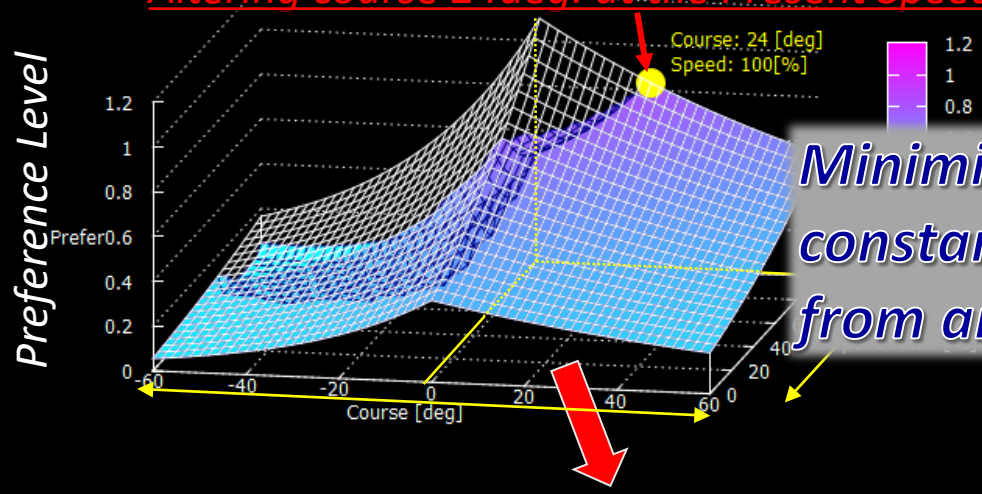
# CONCEPT OF AUTOMATIC COLLISION AVOIDANCE MANOEUVRING

## Model of Automatic Collision Avoidance Manoeuvring

Highest $Ev(X_{ij})$

Altering course 24deg. at the Present Speed




**Closing situation**

Target Ship
Loa 175m, 12kts

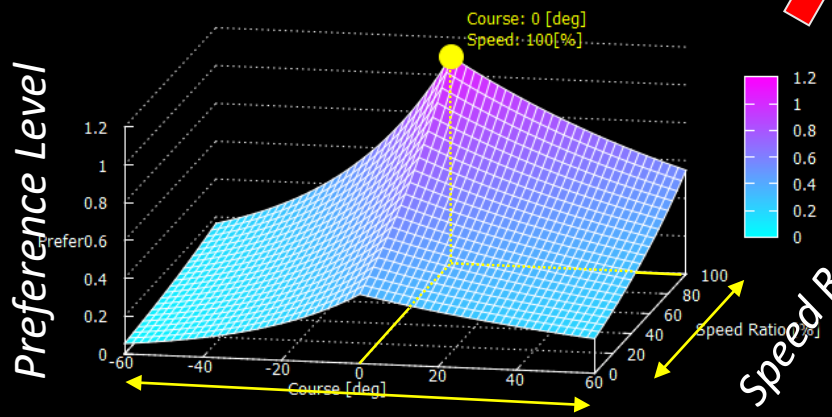
*Minimizes the economic loss, constantly selects a low-risk course from an early stage*

Loa 175m, 12kts

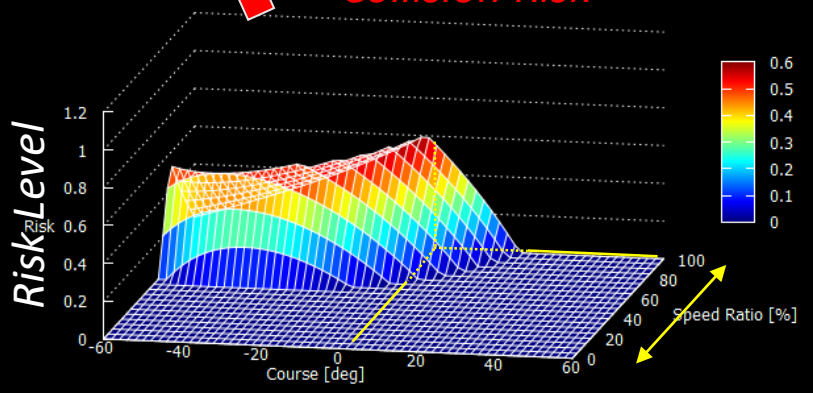
Preference of Manoeuvre
(Minimizes the economic loss)

$$Ev(X_{i,j}) = Pb(X_{i,j}) - \alpha \cdot \max\{R(X_{i,j})\}$$

Collision Risk




Speed Reduction Ratio (j)

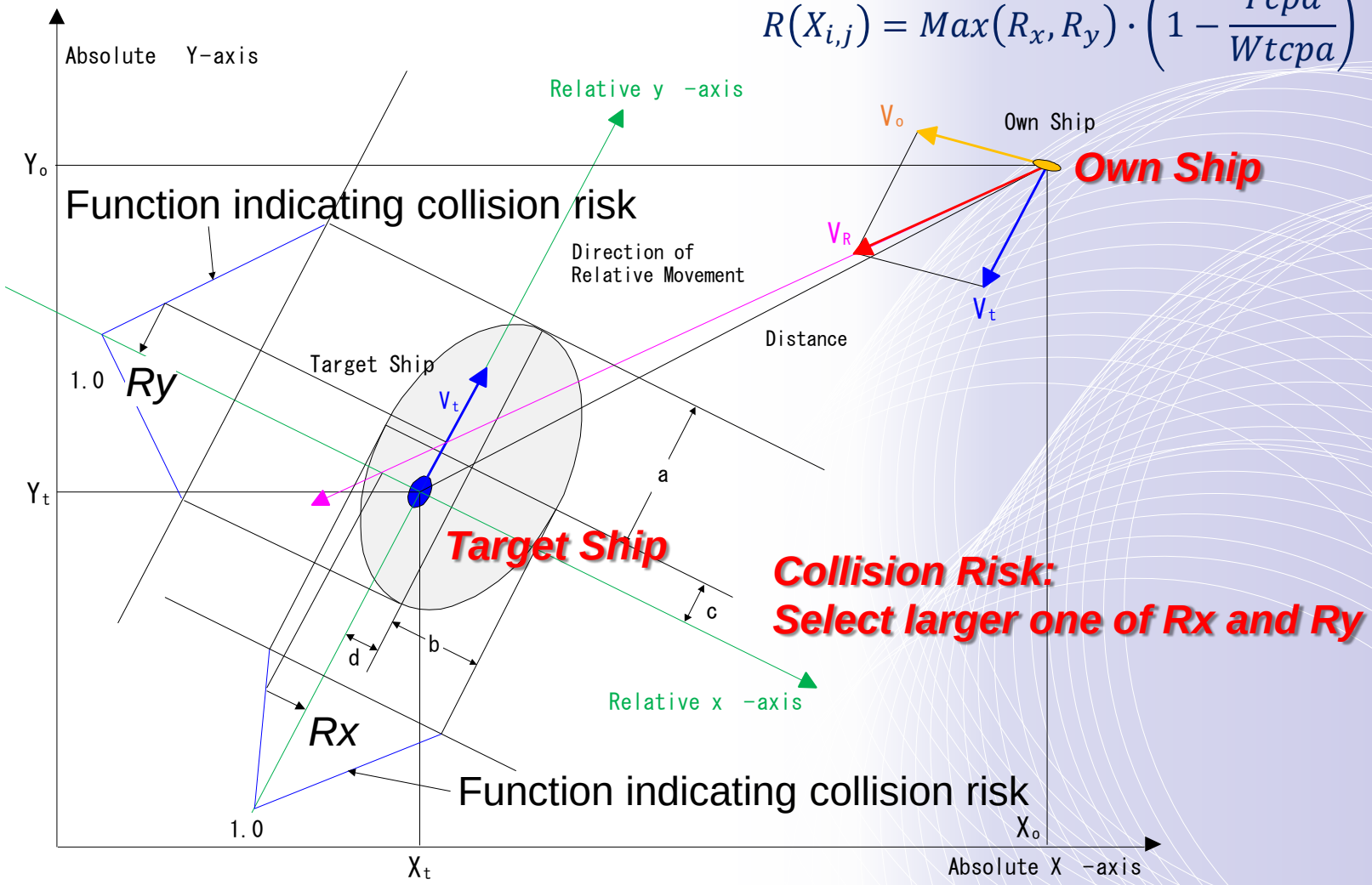



Altering Co. Port 60deg. to Stb'd 60 deg. (i)

# CONCEPT OF AUTOMATIC COLLISION AVOIDANCE MANOEUVRING

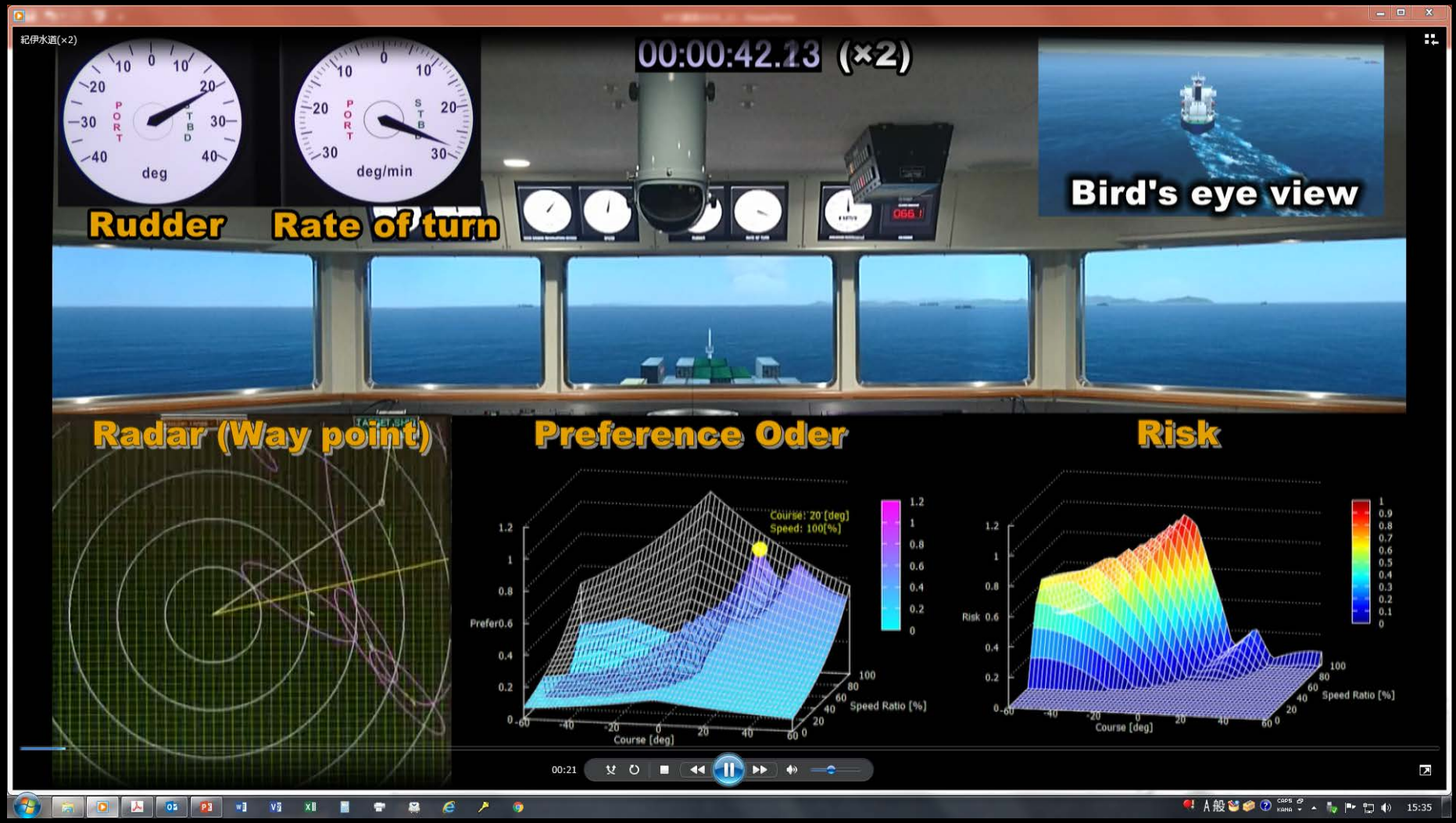
## How to calculate the collision risk by using exclusive area

$$R(X_{i,j}) = Max(R_x, R_y) \cdot \left(1 - \frac{Tcpa}{Wtcpa}\right)$$




**Collision Risk:**
**Select larger one of Rx and Ry**

# CONCEPT OF AUTOMATIC COLLISION AVOIDANCE MANOEUVRING




× 2　　× 20

# EVALUATION METHOD OF AUTOMATIC COLLISION AVOIDANCE MANOEUVRING RESULTS

## Towards level certification of automatic collision avoidance system

- **The desirable automatic collision avoidance system should reduce the risk before rules defined by CORLEGs is applied**

**Therefore ……**

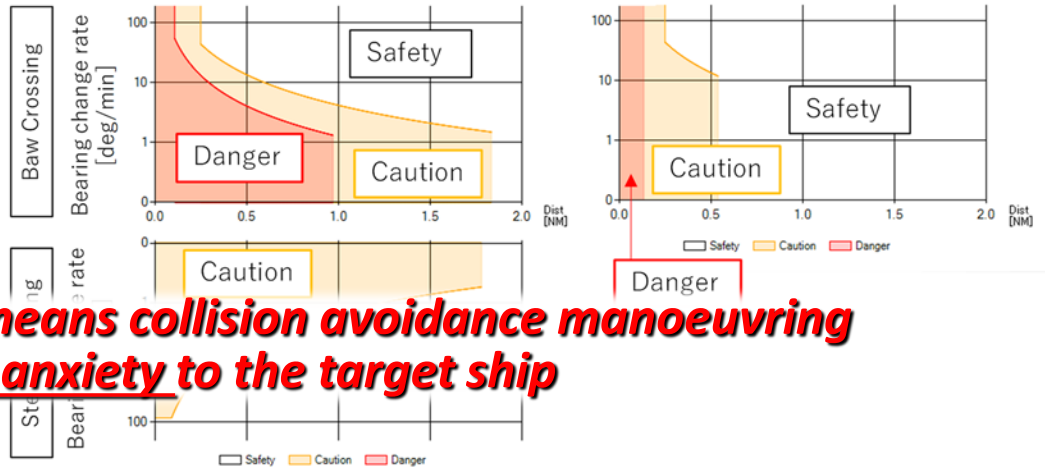
# EVALUATION METHOD OF AUTOMATIC COLLISION AVOIDANCE MANOEUVRING RESULTS

## Towards level certification of automatic collision avoidance system

Evaluation by
"Relative distance" and
"Bearing change rate"

Three areas are defined according to the [illegible] situation with ot[illegible]

【Head-on / Crossing from Starboard 】 【Same-way 】




**Safety area →** ***It means collision avoidance manoeuvring that dose not give anxiety to the target ship***

**Unacceptable area**

"Danger area"

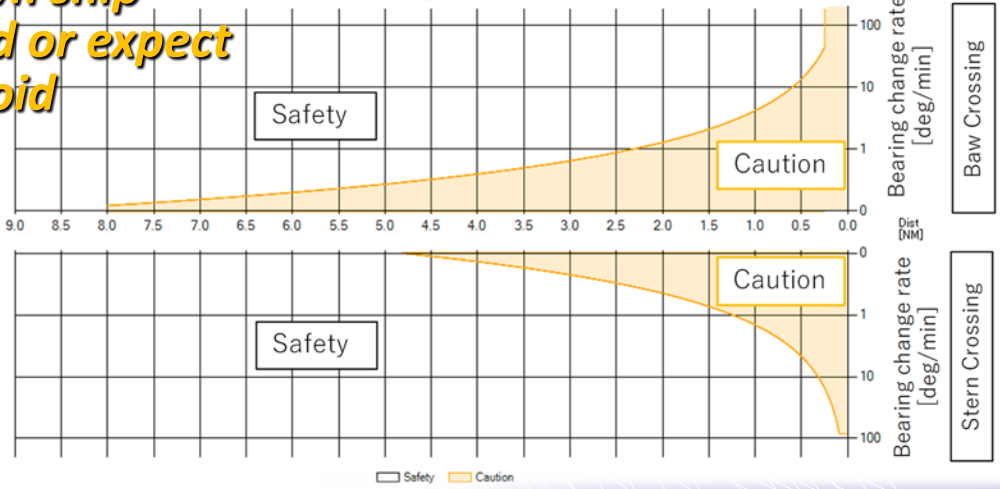
"Caution area"

"Safety area"

**The area where own ship commence to avoid or expect another ship to avoid**

**Acceptable area**

【Crossing from Port 】




It was formulated in an experiment in which 12 captains and pilots participated

Total Number of data reached approx. 30,000 points

# Automatic collision avoidance manoeuvring that dose not give anxiety to the target ship

**Not give anxiety**

**Give anxiety**

2.3 miles

2.3 miles

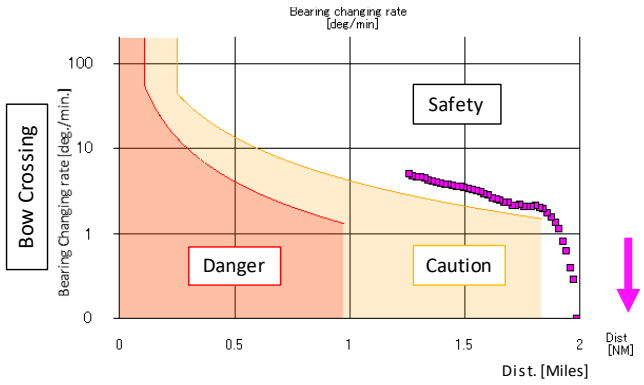
**View from Own Ship**

Time

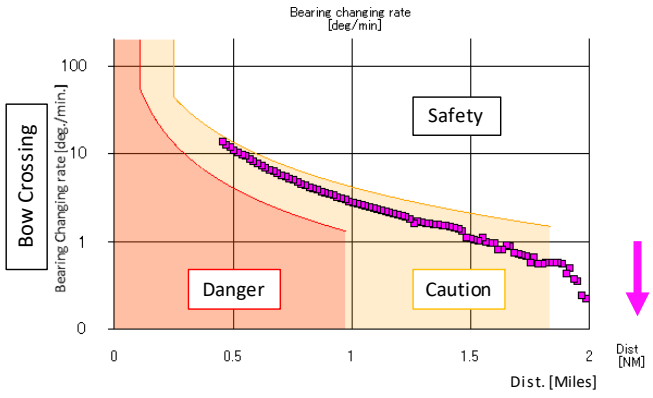
0:00

**View from Target Ship**

[Head-on / Crossing Situation]




[Head-on / Crossing Situation]

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# Automatic collision avoidance manoeuvring that dose not give anxiety to the target ship

**Not give anxiety**

**Give anxiety**

2.1 miles

2.1 miles

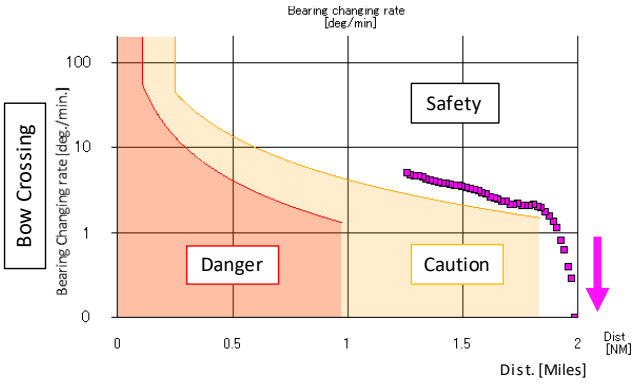
**View from Own Ship**

Time

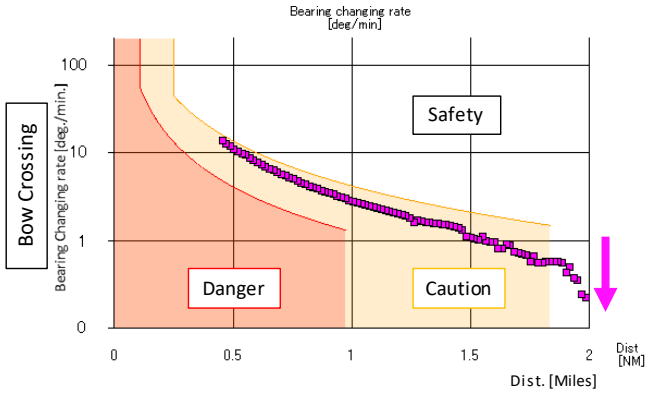
0:30

**View from Target Ship**

[Head-on / Crossing Situation]




[Head-on / Crossing Situation]

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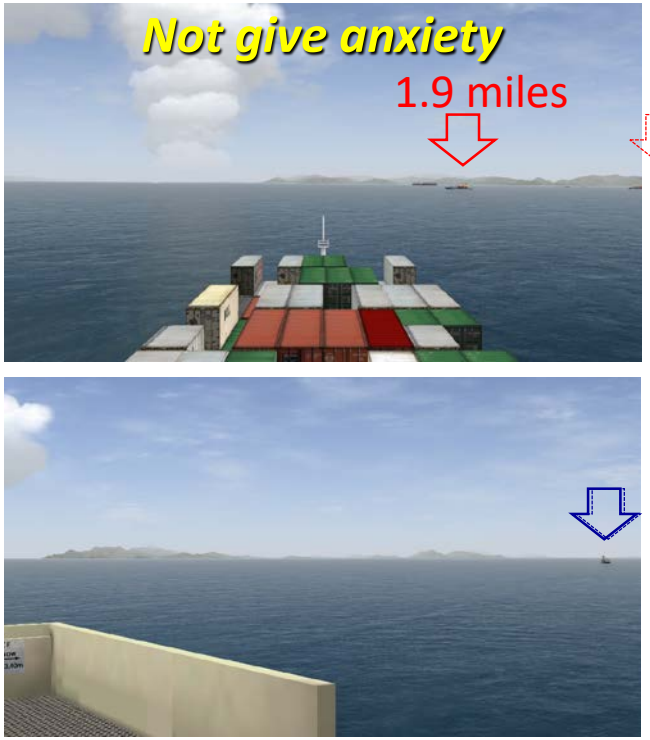
# Automatic collision avoidance manoeuvring that dose not give anxiety to the target ship

**View from Own Ship**

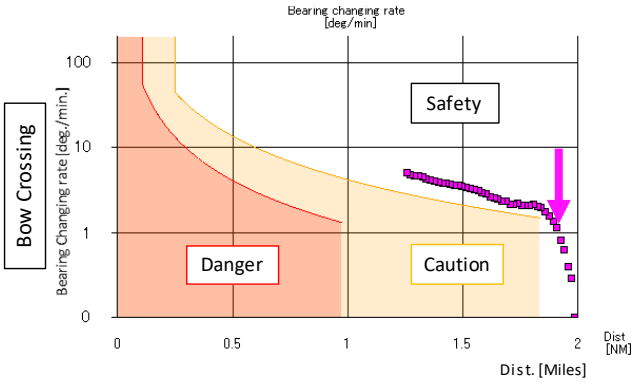
**View from Target Ship**



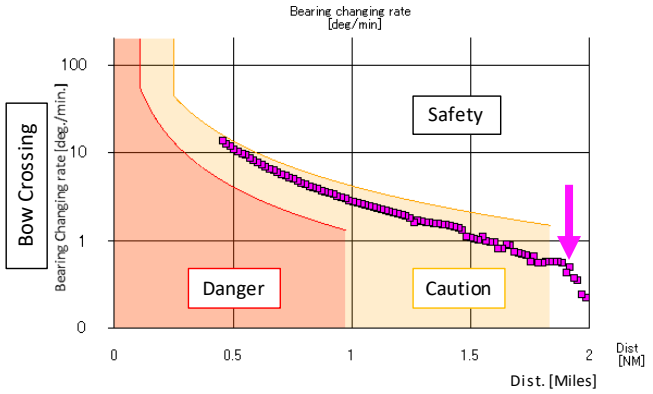


Time
1:00

[Head-on / Crossing Situation]




[Head-on / Crossing Situation]

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# Automatic collision avoidance manoeuvring that dose not give anxiety to the target ship

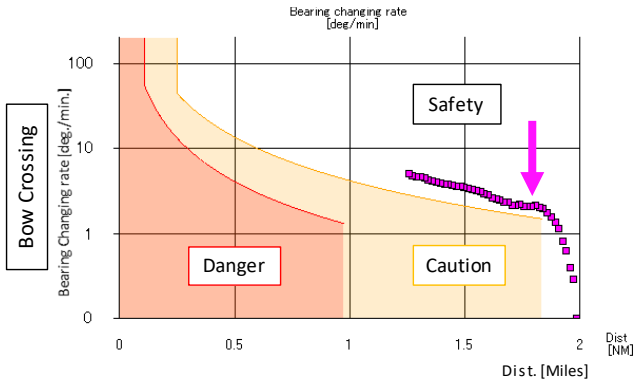
**View from Own Ship**

**View from Target Ship**

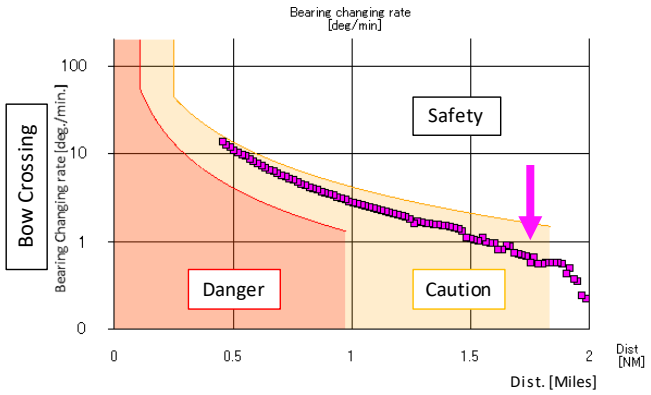


Time
1:30

[Head-on / Crossing Situation]




[Head-on / Crossing Situation]

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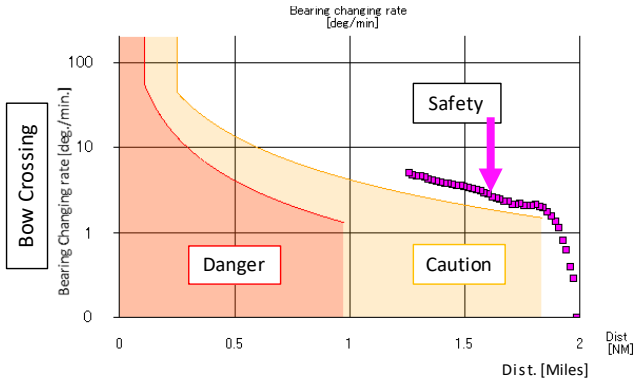
# Automatic collision avoidance manoeuvring that dose not give anxiety to the target ship

**View from Own Ship**

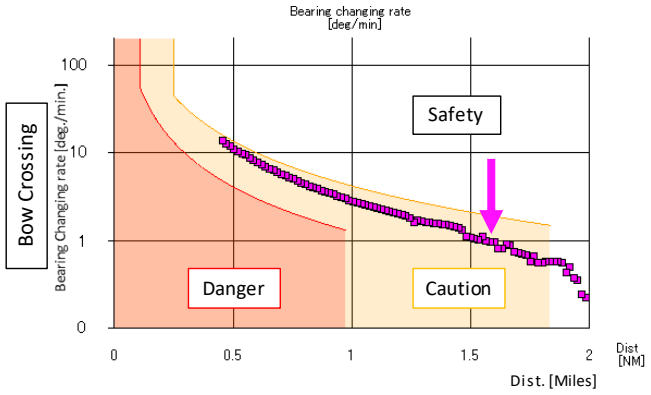
**View from Target Ship**


Time
2:00


[Head-on / Crossing Situation]




[Head-on / Crossing Situation]

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# Automatic collision avoidance manoeuvring that dose not give anxiety to the target ship

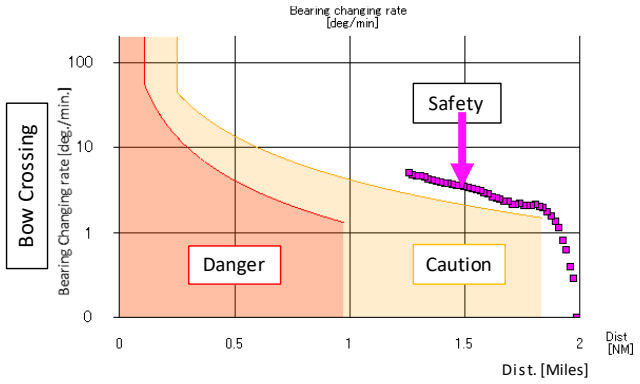
**View from Own Ship**

**View from Target Ship**

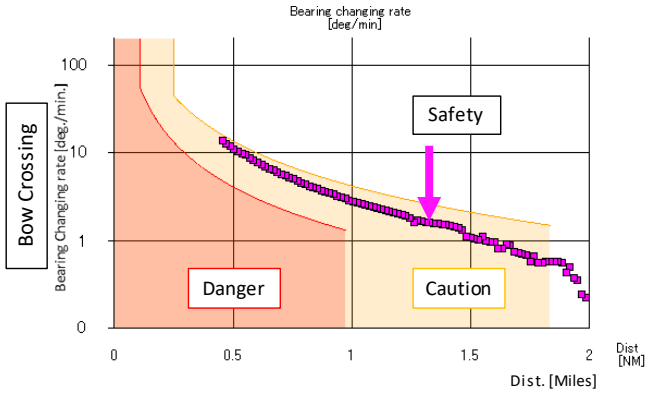


Time
2:30

[Head-on / Crossing Situation]




[Head-on / Crossing Situation]

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# Automatic collision avoidance manoeuvring that dose not give anxiety to the target ship

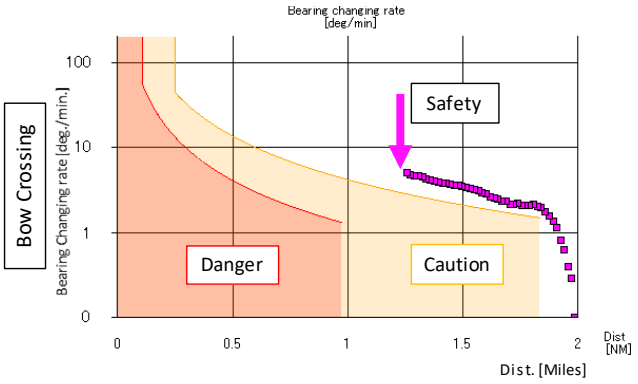
**View from Own Ship**

**View from Target Ship**

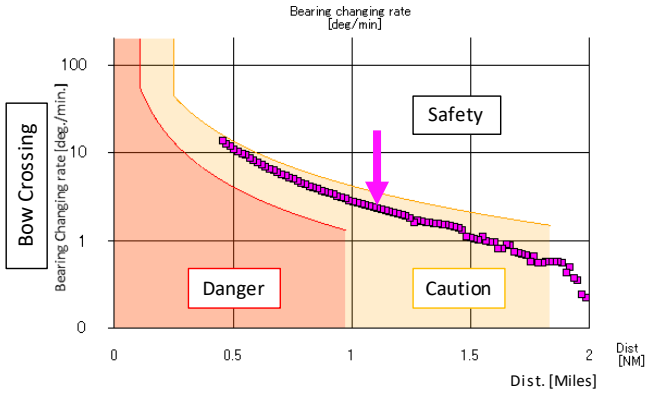


Time
3:00

[Head-on / Crossing Situation]




[Head-on / Crossing Situation]



# Automatic collision avoidance manoeuvring that dose not give anxiety to the target ship

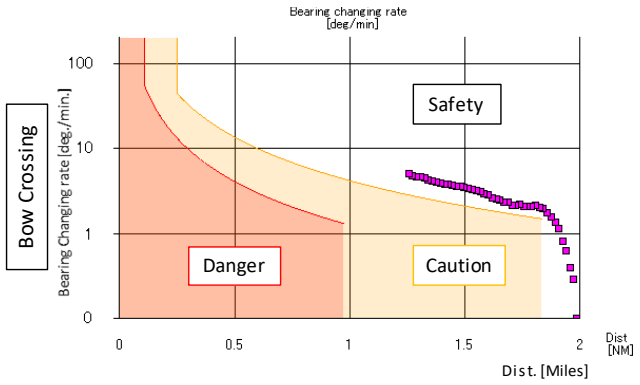
**View from Own Ship**

**View from Target Ship**

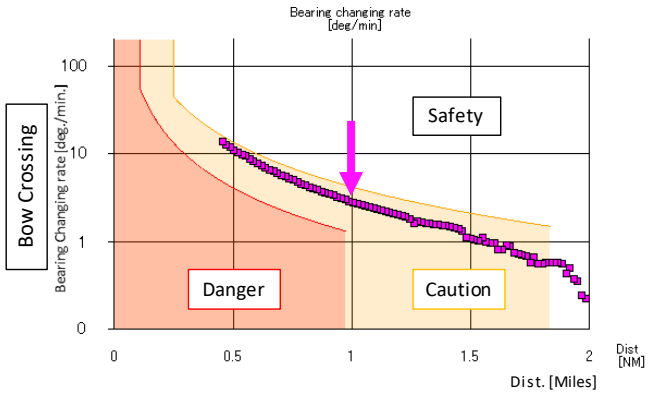


Time
3:30

[Head-on / Crossing Situation]




[Head-on / Crossing Situation]

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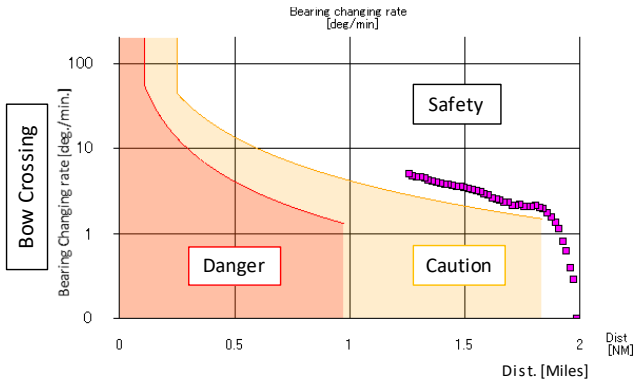
# Automatic collision avoidance manoeuvring that dose not give anxiety to the target ship

**View from Own Ship**

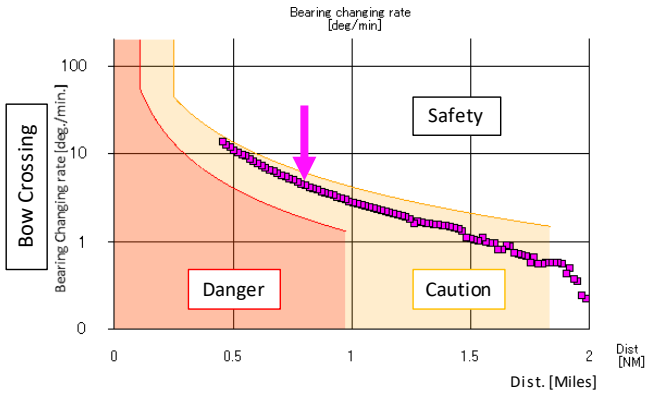
**View from Target Ship**


Time
4:00


[Head-on / Crossing Situation]




[Head-on / Crossing Situation]

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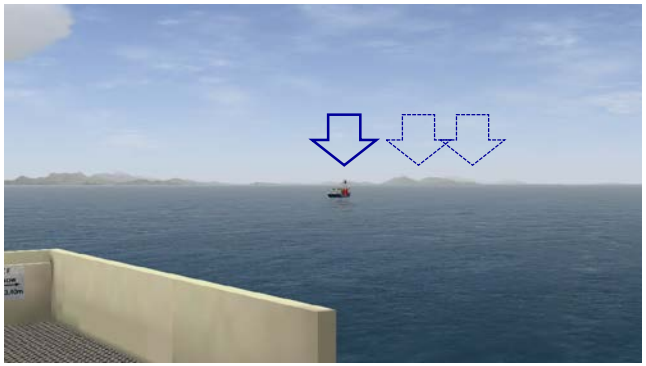
# Automatic collision avoidance manoeuvring that dose not give anxiety to the target ship

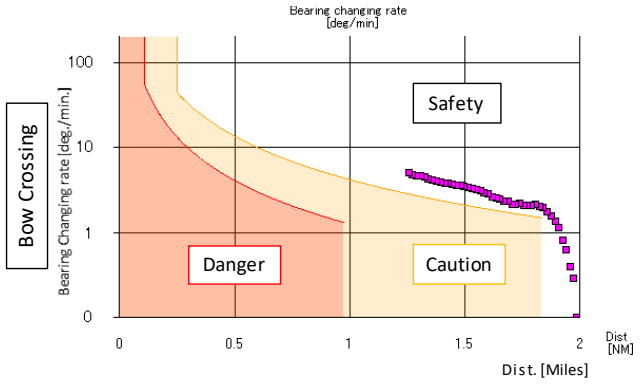
**View from Own Ship**

**View from Target Ship**

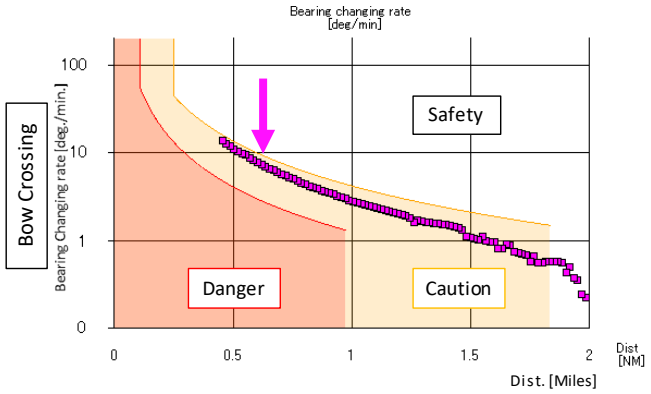



Time
4:30


[Head-on / Crossing Situation]




[Head-on / Crossing Situation]

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# Automatic collision avoidance manoeuvring that dose not give anxiety to the target ship

**Not give anxiety**

0.6 miles

**Give anxiety**

0.5 miles

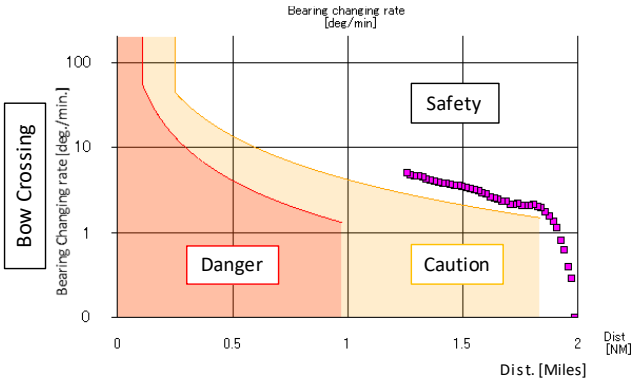
***View from Own Ship***

Time

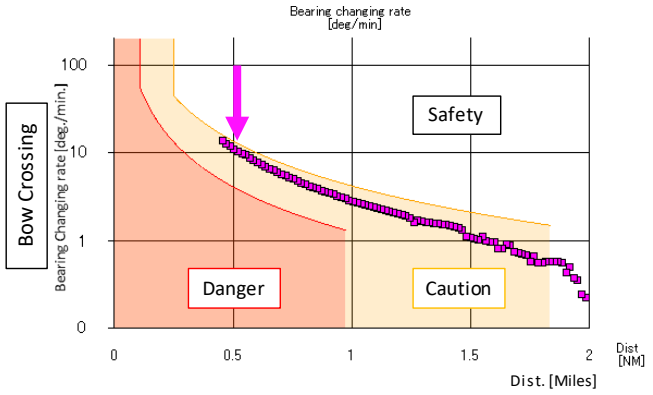
5:00

***View from Target Ship***

[Head-on / Crossing Situation]




[Head-on / Crossing Situation]

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# Automatic collision avoidance manoeuvring that dose not give anxiety to the target ship

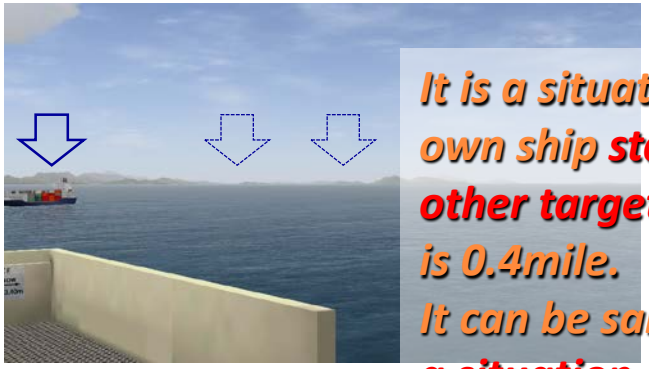
0.5 miles

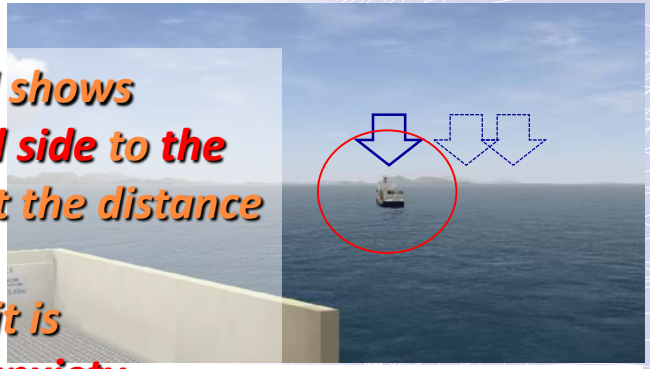
**View from Own Ship**



Time
5:30

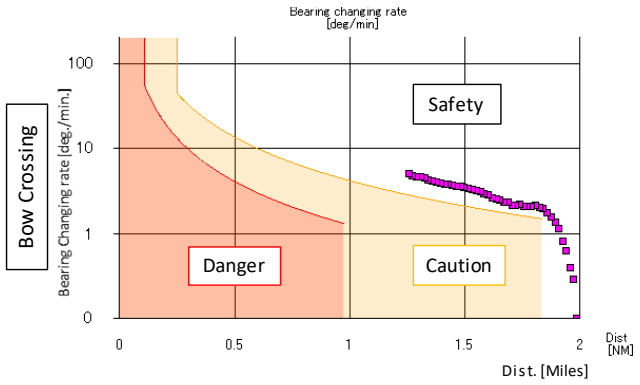
**View from Target Ship**



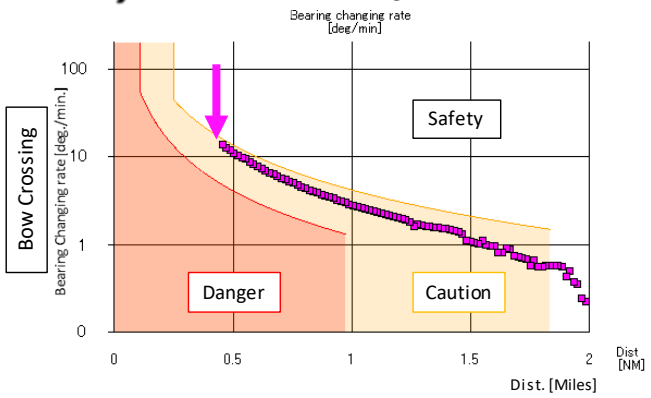


***It is a situation still shows own ship starboard side to the other target ship at the distance is 0.4mile. It can be said that it is a situation giving anxiety***

[Head-on / Crossing Situation]




[Head-on / Crossing Situation]

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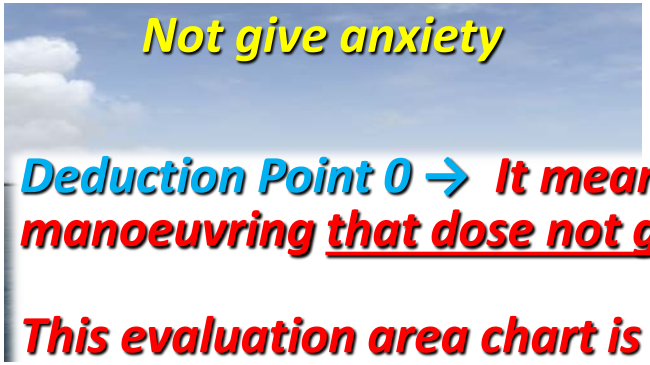
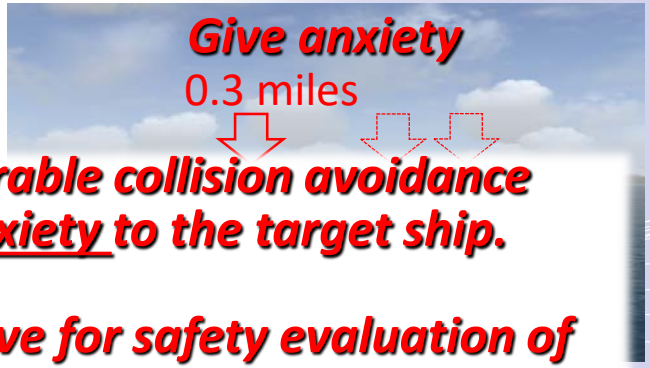
# Automatic collision avoidance manoeuvring that dose not give anxiety to the target ship

**View from Own Ship**




**Deduction Point 0 → It means desirable collision avoidance manoeuvring that dose not give anxiety to the target ship.**

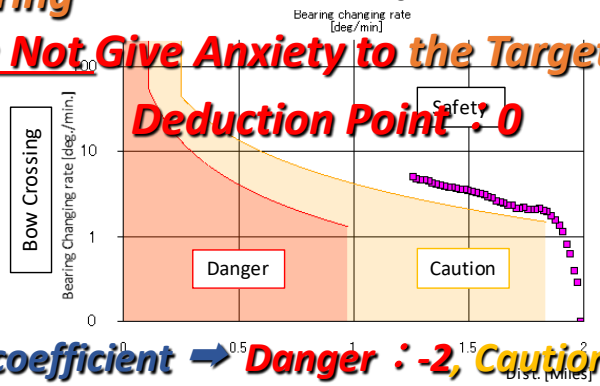
**This evaluation area chart is effective for safety evaluation of automatic collision avoidance systems.**

**View from Target Ship**

**though collision can be avoided ……**

**Manoeuvring that Dose Not Give Anxiety to the Target Ship**

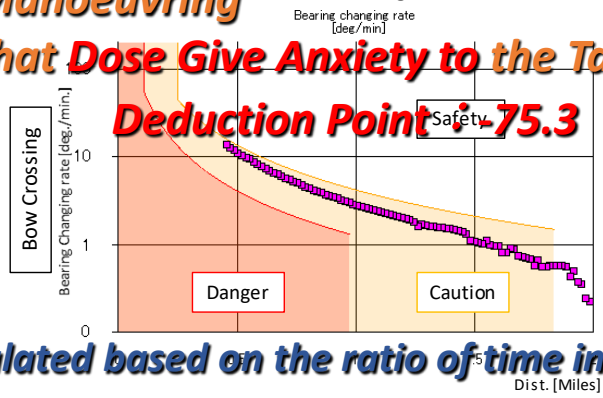
[Head-on / Crossing Situation]




**Deduction Point : 0**

**Manoeuvring that Dose Give Anxiety to the Target Ship**

[Head-on / Crossing Situation]



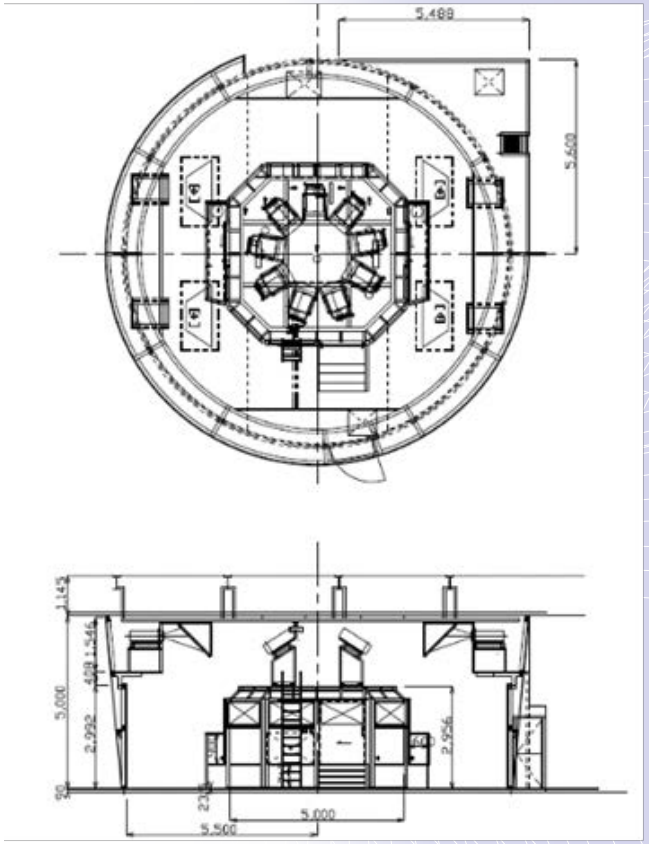

**Deduction Point : -75.3**

**Weighting coefficient → Danger : -2, Caution : -1 Calculated based on the ratio of time in the area**

# Comparison of Manoeuvring Results by Automatic Collision Avoidance System and Manoeuvring Result by Human

## Verification experiments using a full mission simulator

*Comparison of the maneuvering results of "Automatic Collision avoidance system" "Veteran captain“ and "Inexperienced Officer"*

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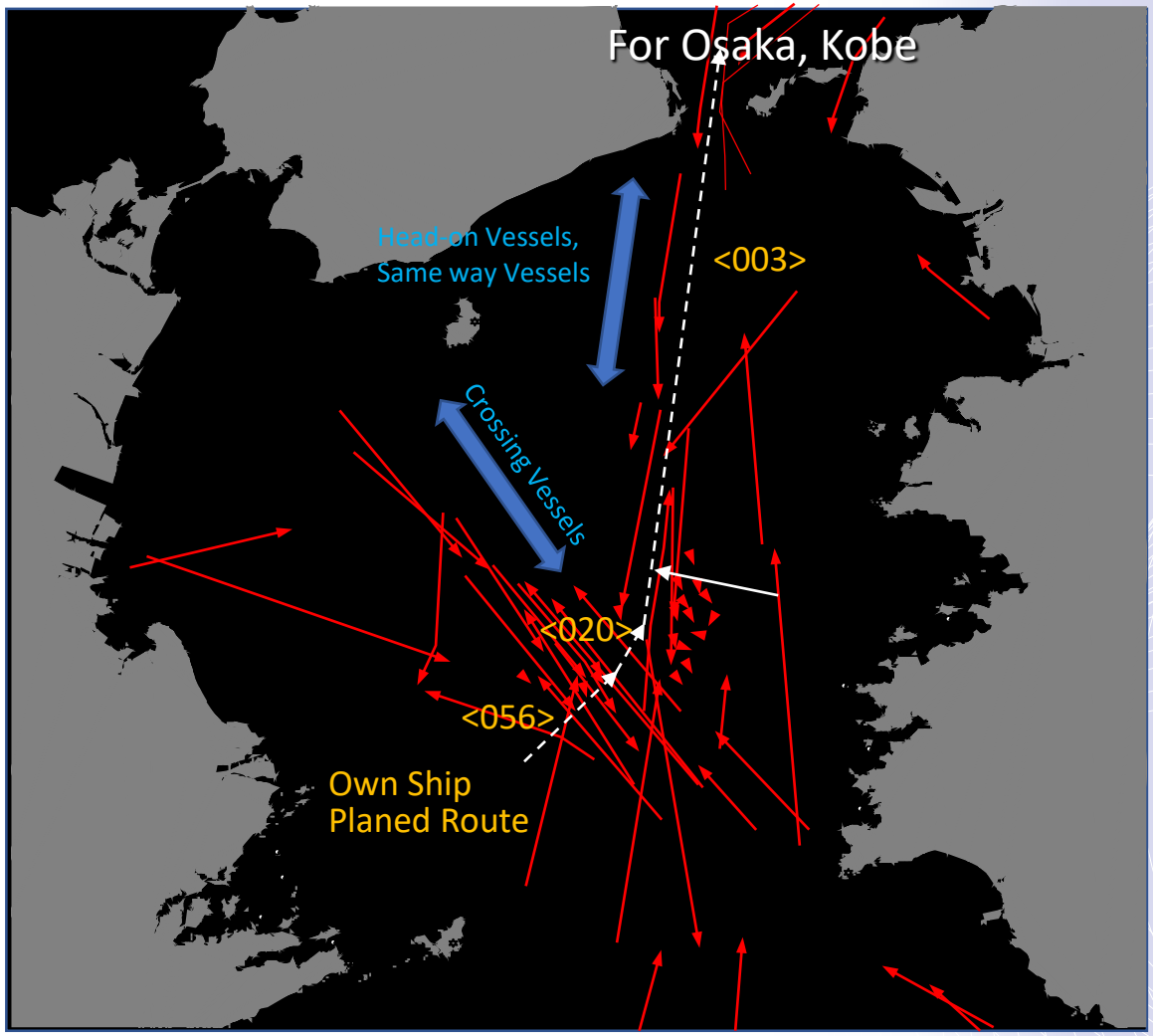
# Comparison of Manoeuvring Results by Automatic Collision Avoidance System and Manoeuvring Result by Human

## Experimental Scenario in Actual Congested Sea Area

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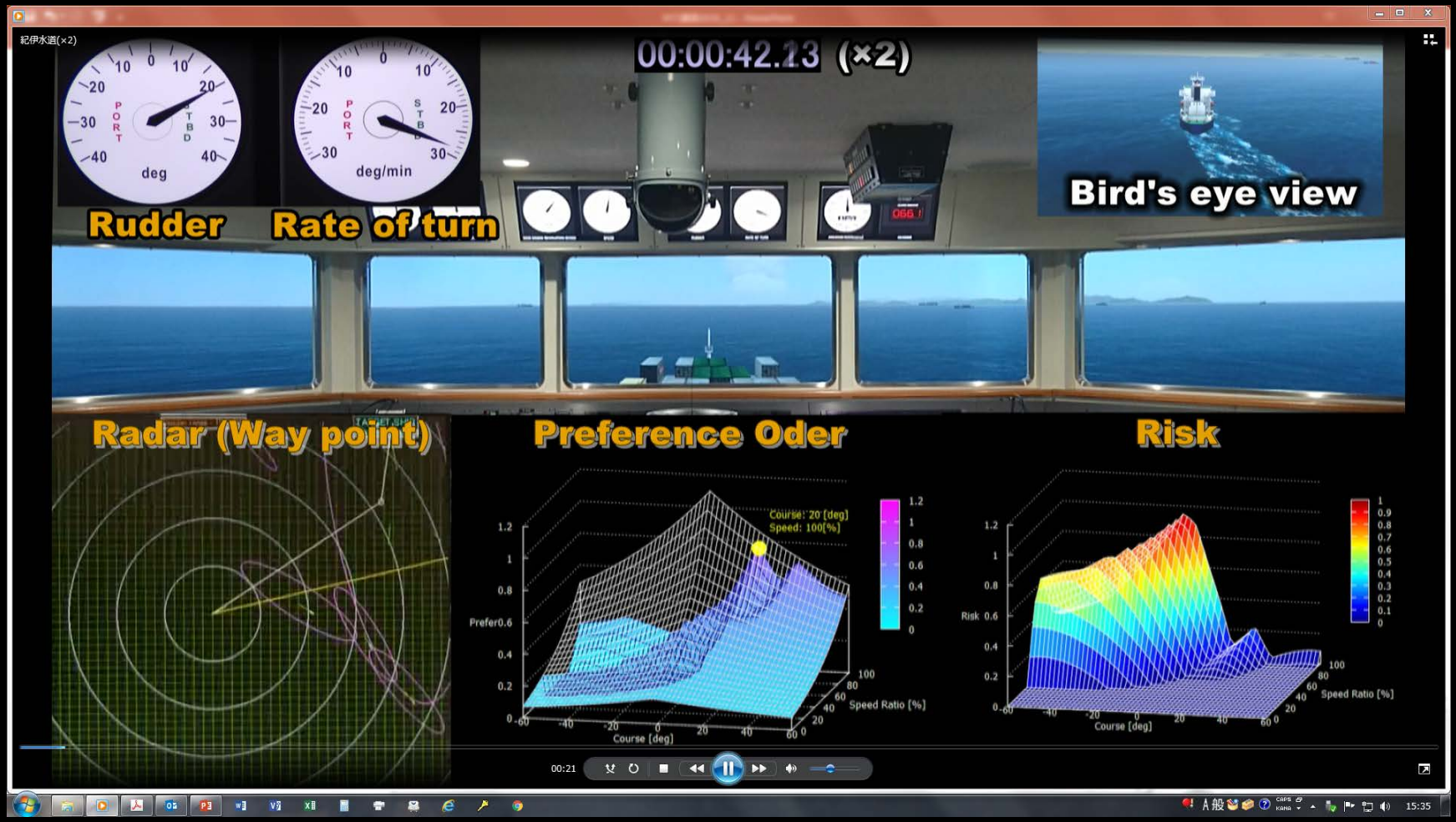
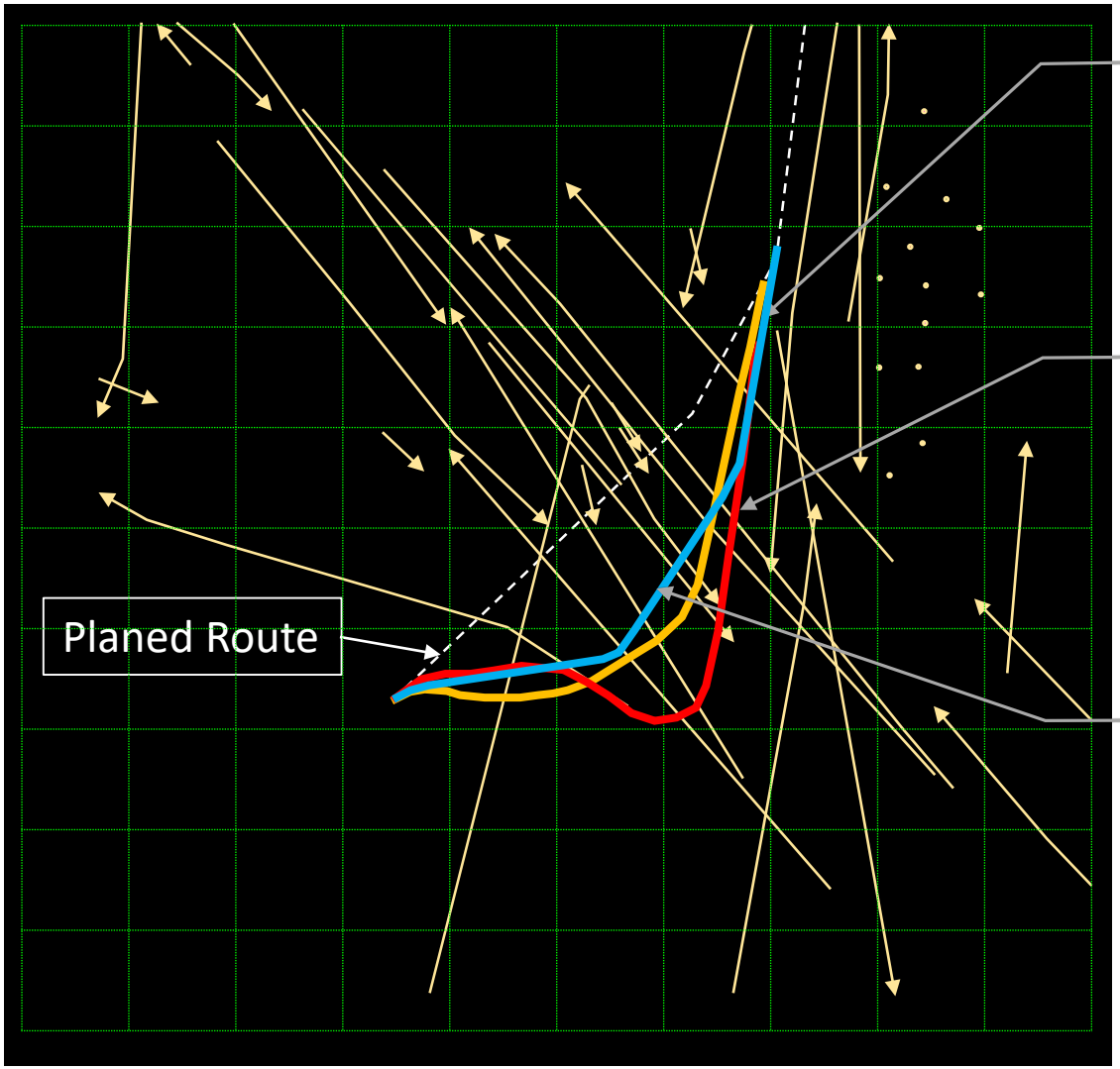
# Comparison of Manoeuvring Results by Automatic Collision Avoidance System and Manoeuvring Result by Human



# Comparison of Manoeuvring Results by Automatic Collision Avoidance System and Manoeuvring Result by Human

## Comparison by own ship's track chart




**Veteran Captain**

Performing a large course change to clearly show the intention

**Inexperienced Officer**

Judgment of avoidance is slightly delayed and enters caution area, and deviation from planned course is large

**Automatic System**

While ensuring a sufficient heading change that does not give anxiety to other ships, it seeks an optimal solution, so there is a slight deviation from the planned course compared to a veteran captain

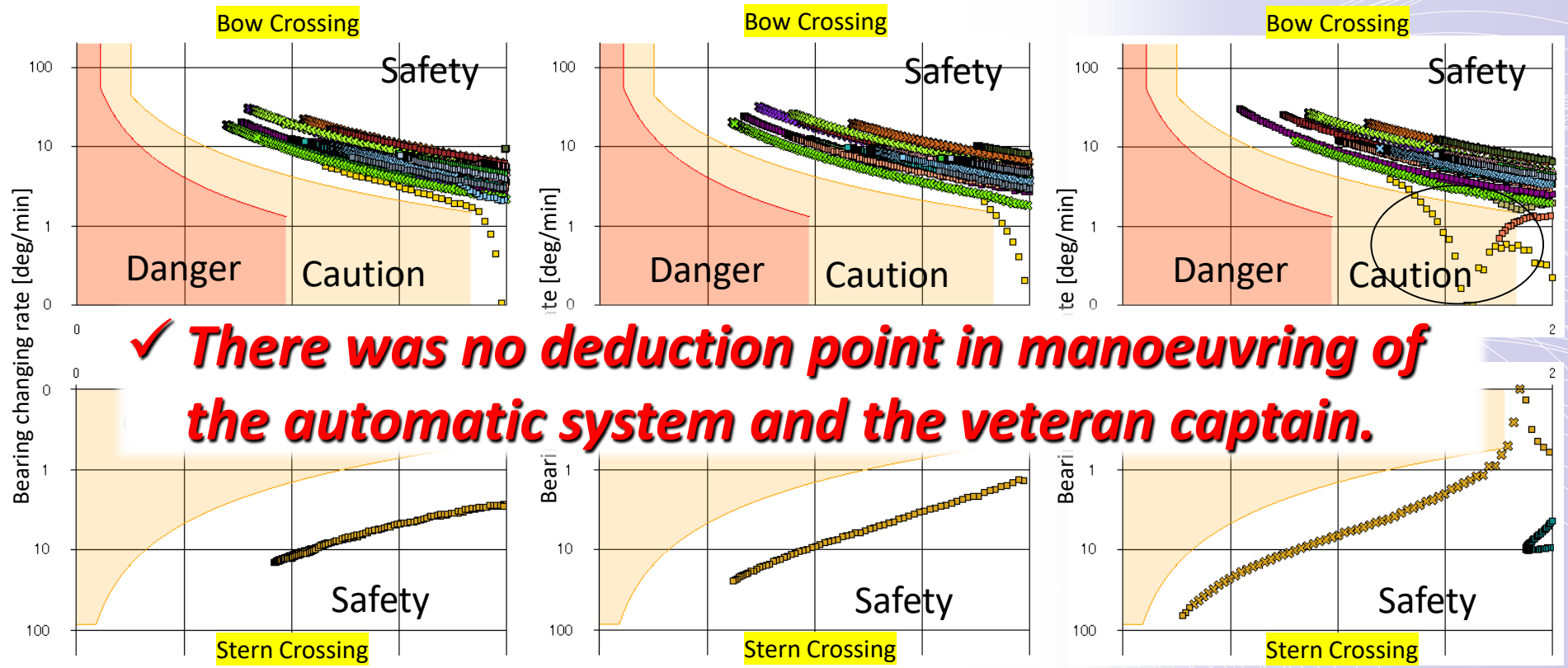
# Comparison of Manoeuvring Results by Automatic Collision Avoidance System and Manoeuvring Result by Human

## Relative distance and bearing change rate of all encounter vessels

**Automatic System**
**Deduction Point：0**

**Veteran Captain**
**Deduction Point：0**

**Inexperienced Officer**
**Deduction Point：-5.7**



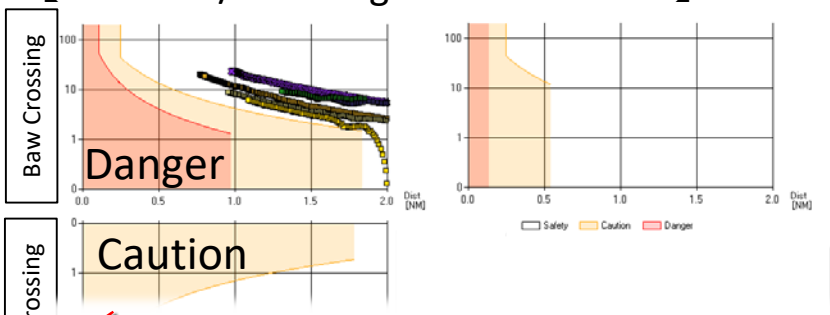

✓ **There was no deduction point in manoeuvring of the automatic system and the veteran captain.**

*Weighting coefficient ➡ Danger：-2, Caution：-1 Calculated based on the ratio of time in the area*

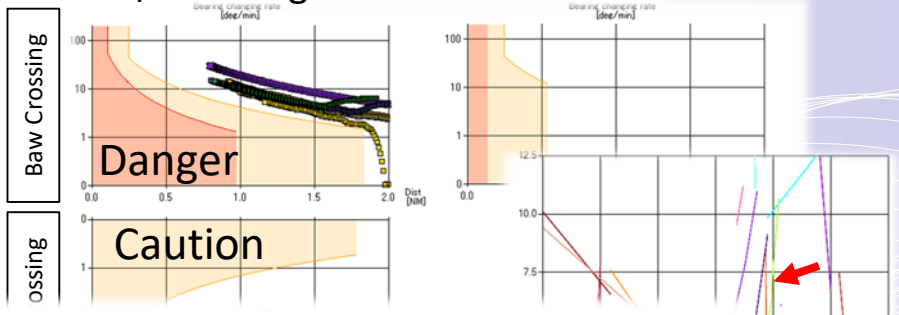
# Comparison of Manoeuvring Results by Automatic Collision Avoidance System and Manoeuvring Result by Human

## Relative distance and bearing change rate of all encounter vessels

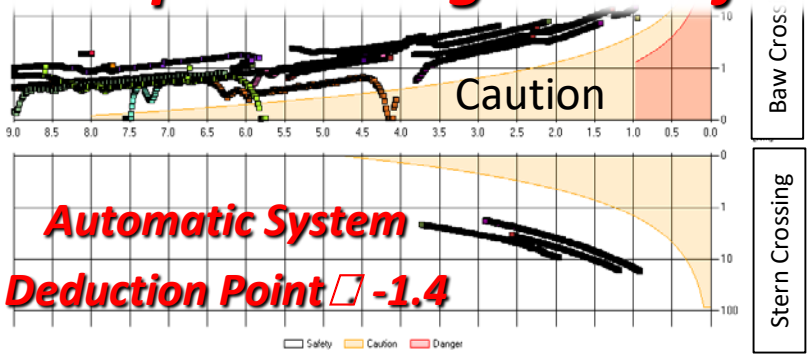
【Head-on / Crossing from Starboard 】




【Head-on / Crossing from Starboard 】

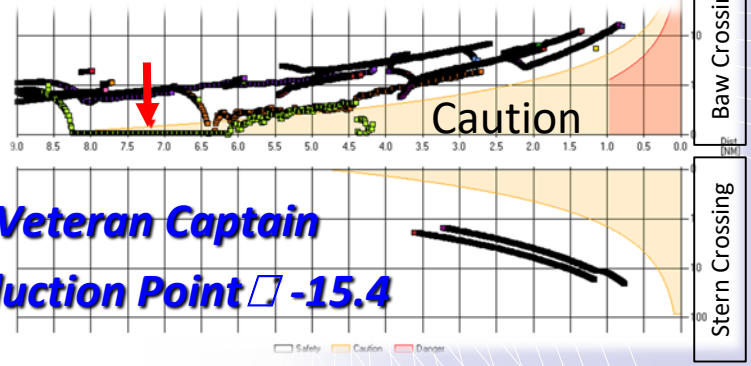



✓ **The system dose not calculate only immediate danger. Therefore the automatic system is better at preventing "lack of situational awareness"**




**Automatic System**

**Deduction Point：-1.4**

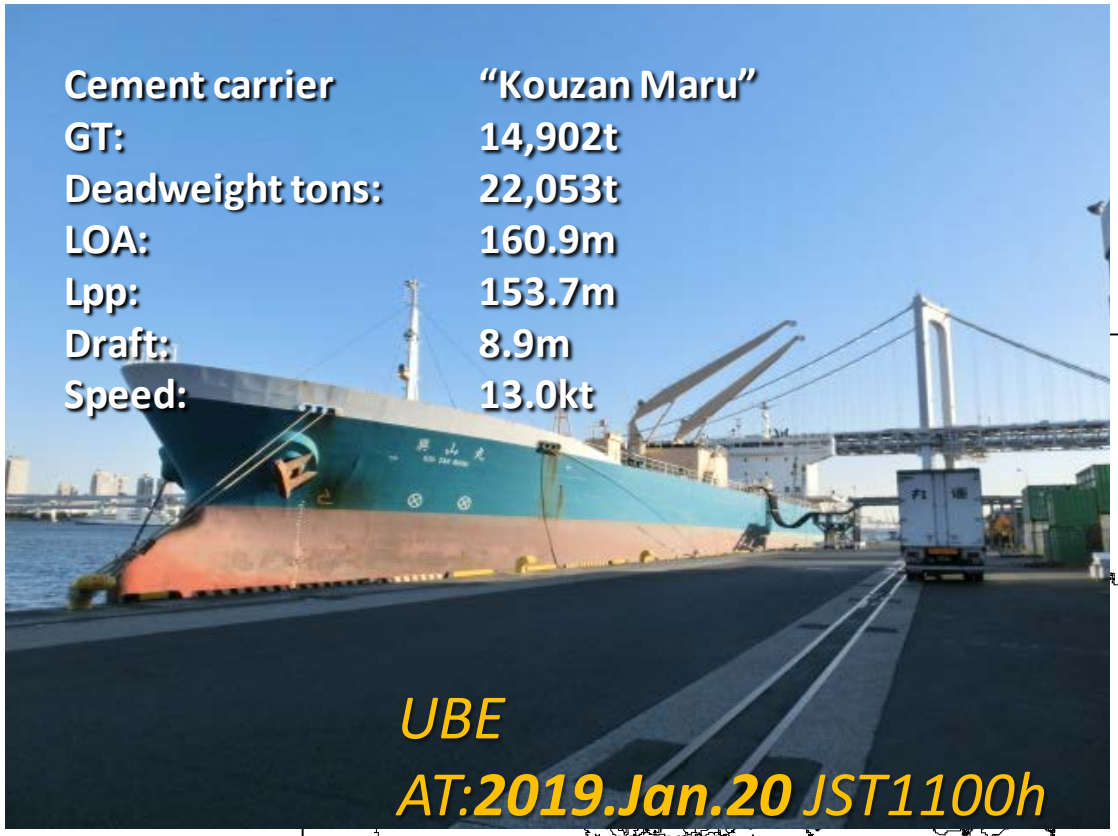



**Veteran Captain**

**Deduction Point：-15.4**

*Weighting coefficient ➡ Danger：-2, Caution：-1 Calculated based on the ratio of time in the area*

# Verification Experiment on Actual Ship





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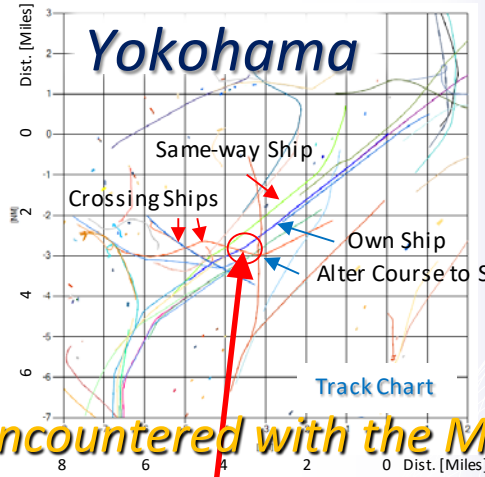
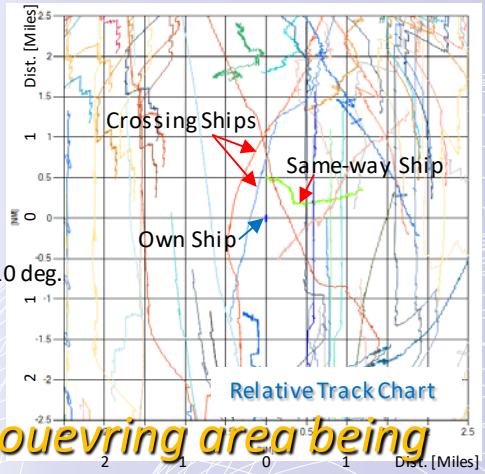
# Verification Experiment on Actual Ship

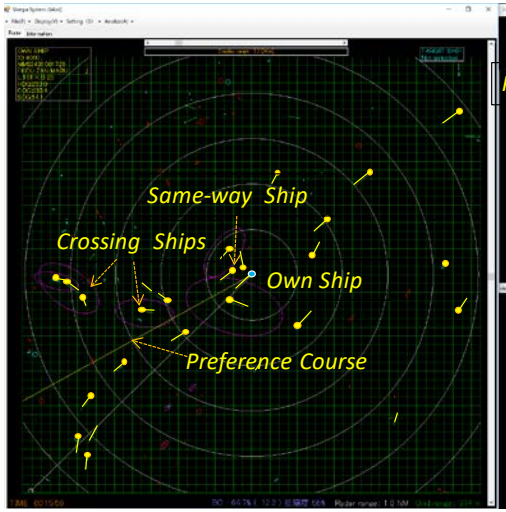
## Off the Coast of Yokohama Immediately after leaving Tokyo

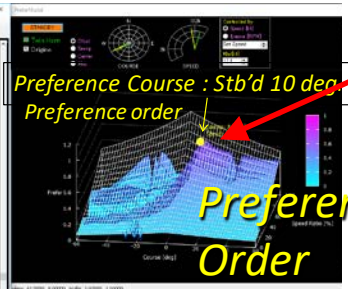
Crossing ships from Stb'd side are encountered with the Manouevring area being restricted by same-way ships

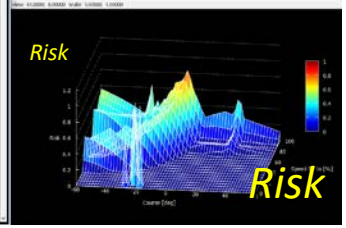



**Alter Course → Stb'd 10deg.**

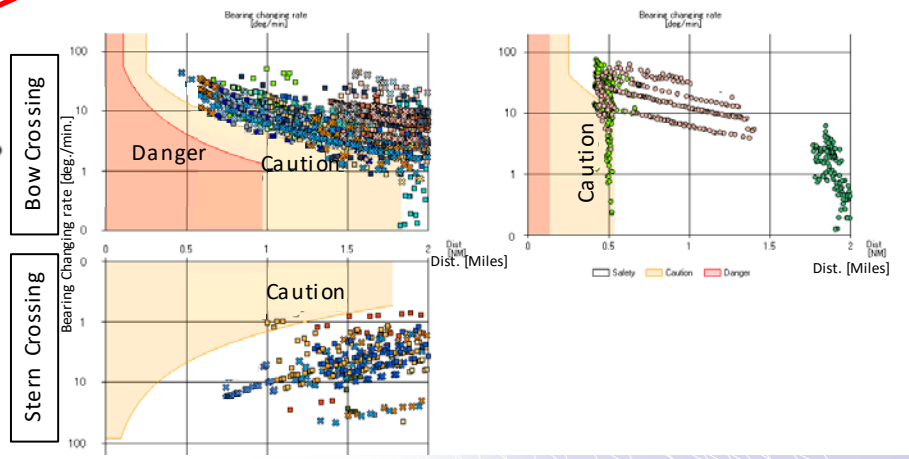



[Head-on / Crossing Situation]

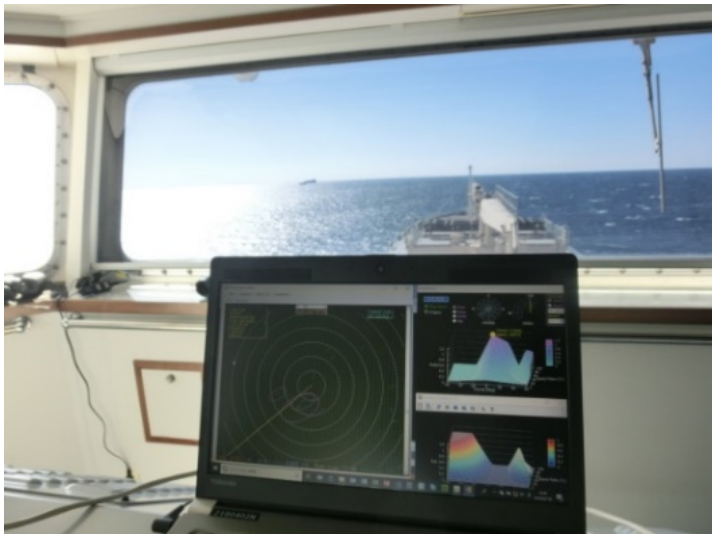
[Same-way Situation]

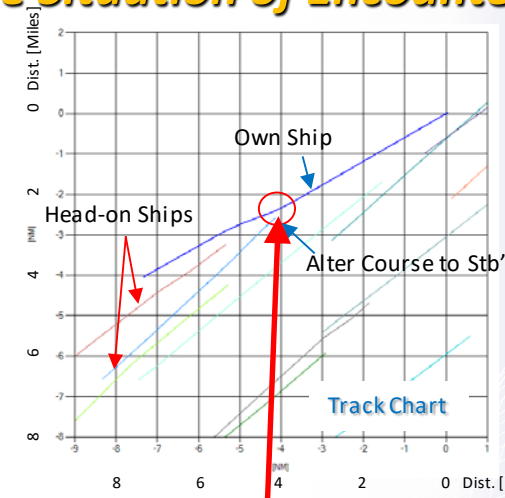


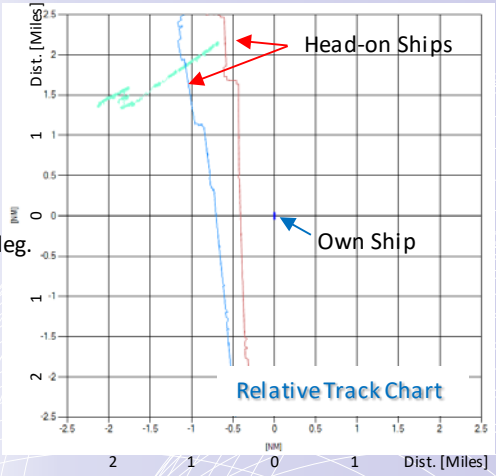
# Verification Experiment on Actual Ship

## Congested Water around Japan Coast

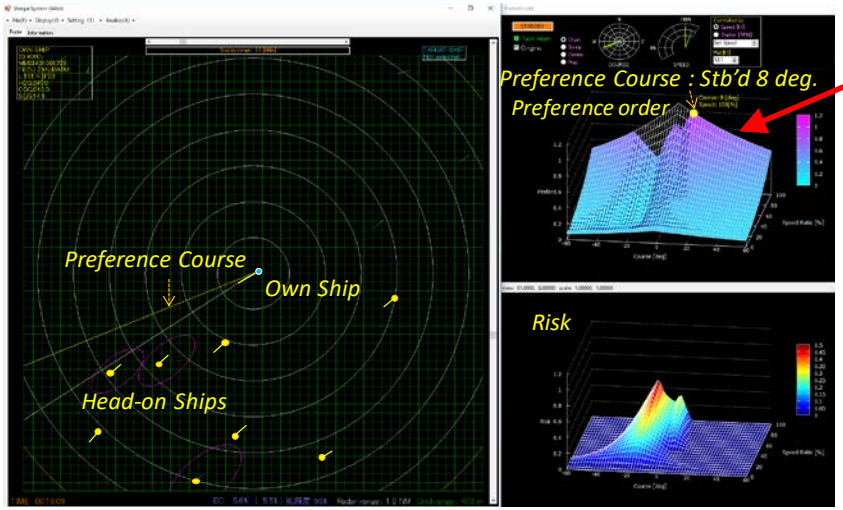
### In the Situation of Encounter with Head-on Ships

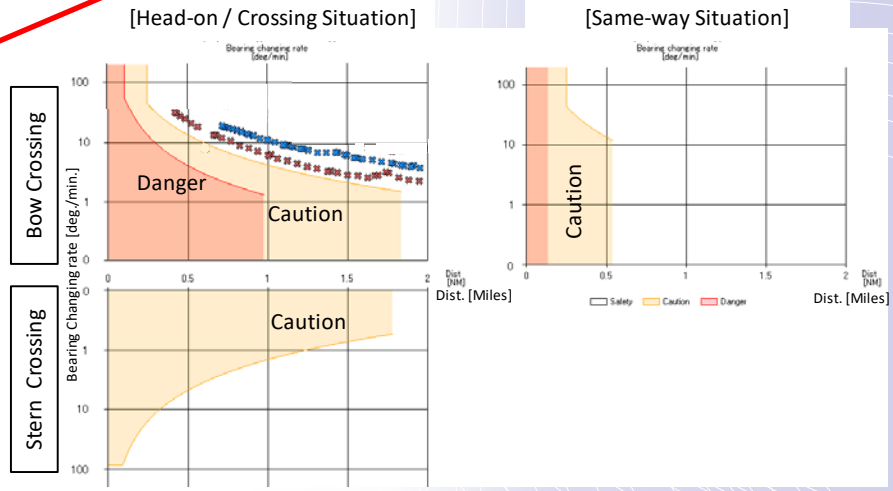





**Alter Course → Stb'd 8 deg.**



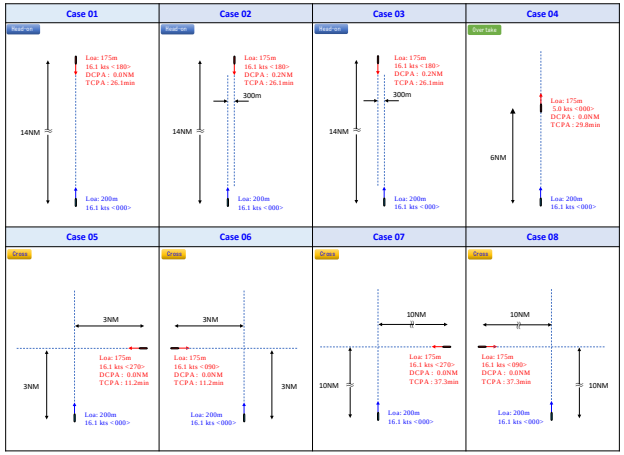
# Verification Experiment on Actual Ship

**Conducted the world's first Maritime Autonomous Surface Ships (MASS) trial performed in accordance with the IMO's Interim Guidelines for MASS** **Target Data: AIS + Radar TT**

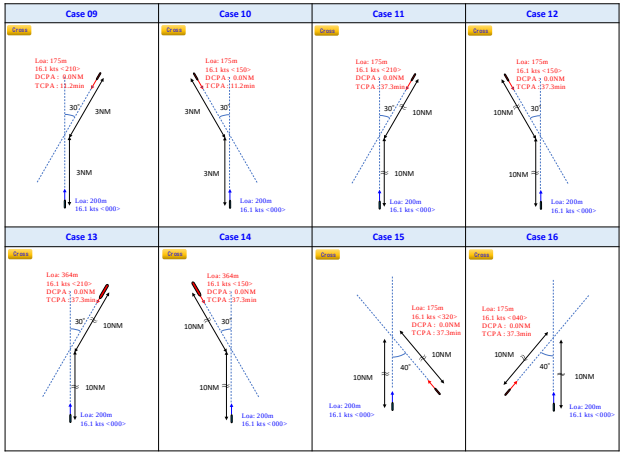

**"IRIS LEADER", a large NYK-operated PCTC having a gross tonnage of 70,826 tons, was navigated day and night using the Automatic Collision Avoidance System during the period from 14 to 19 September 2019 from Xinsha, China, to the port of Yokohama, Japan.** **(https://www.nyk.com/english/news/2019/20190930_01.html)**

# Conclusion

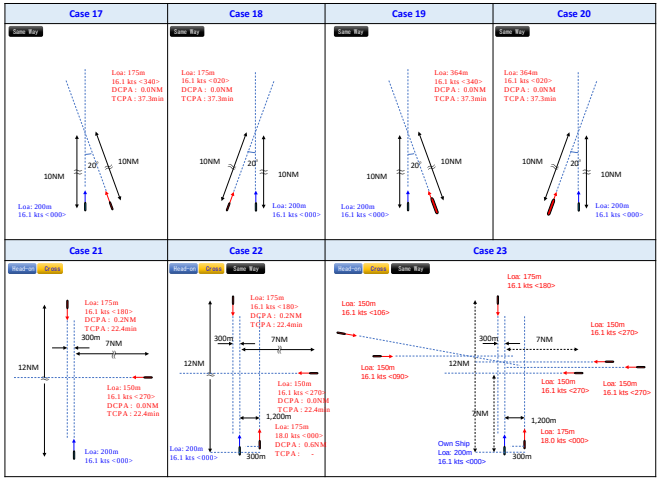
- ✓ *In order to carry out strategic collision avoidance manoeuvring, an automatic collision avoidance system constantly calculating optimal manoeuvring method was introduced.*
- ✓ *A system that evaluates the situation that entered "Danger area" and "Caution area" using the relative distance and bearing change rate with a deduction-based evaluation system was proposed.*
- ✓ *Validity verification of the developed automatic collision avoidance system was carried out compared to the manoeuvring results of veteran captain and officers.*
  *It was verified that the collision avoidance manoeuvring by the automatic collision avoidance system is almost equal to that by veteran captain.*
- ✓ *Verification experiments were successfully conducted to verify the effectiveness of the proposed automatic collision avoidance system on the actual ship navigating in congested waters..*


Case 01
Case 02
Case 03
Case 04
Case 05
Case 06
Case 07
Case 08

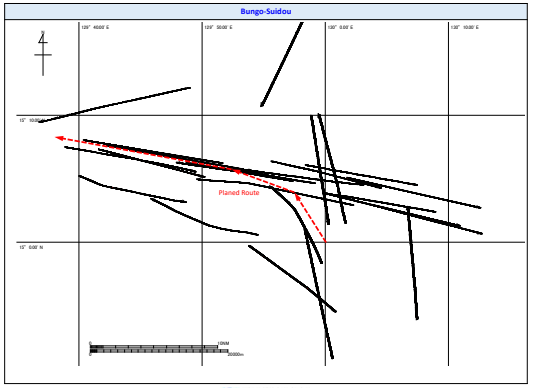
2

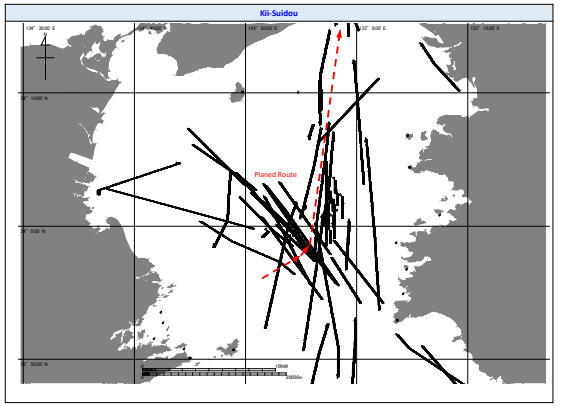

Case 09
Case 10
Case 11
Case 12
Case 13
Case 14
Case 15
Case 16

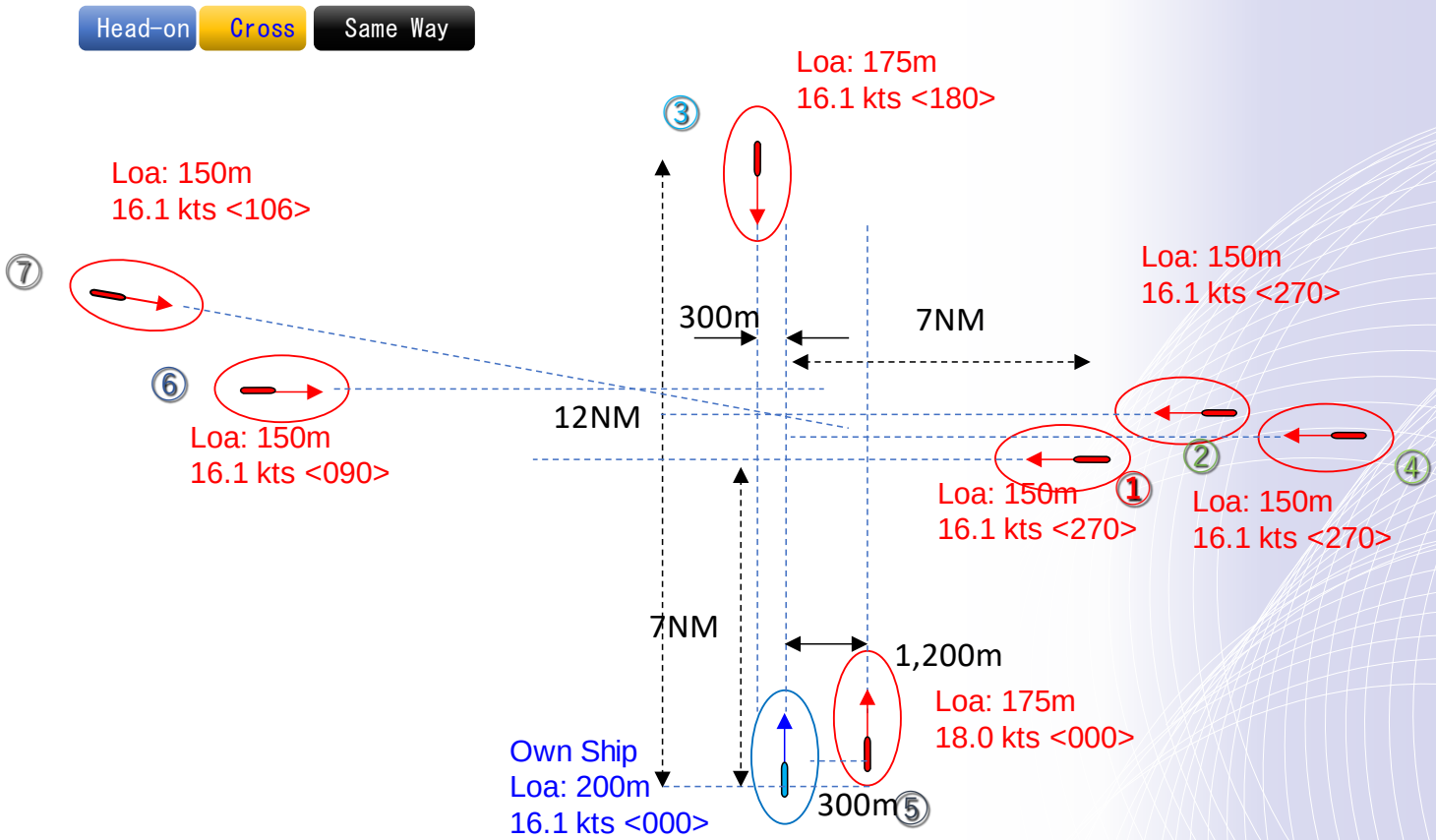
3

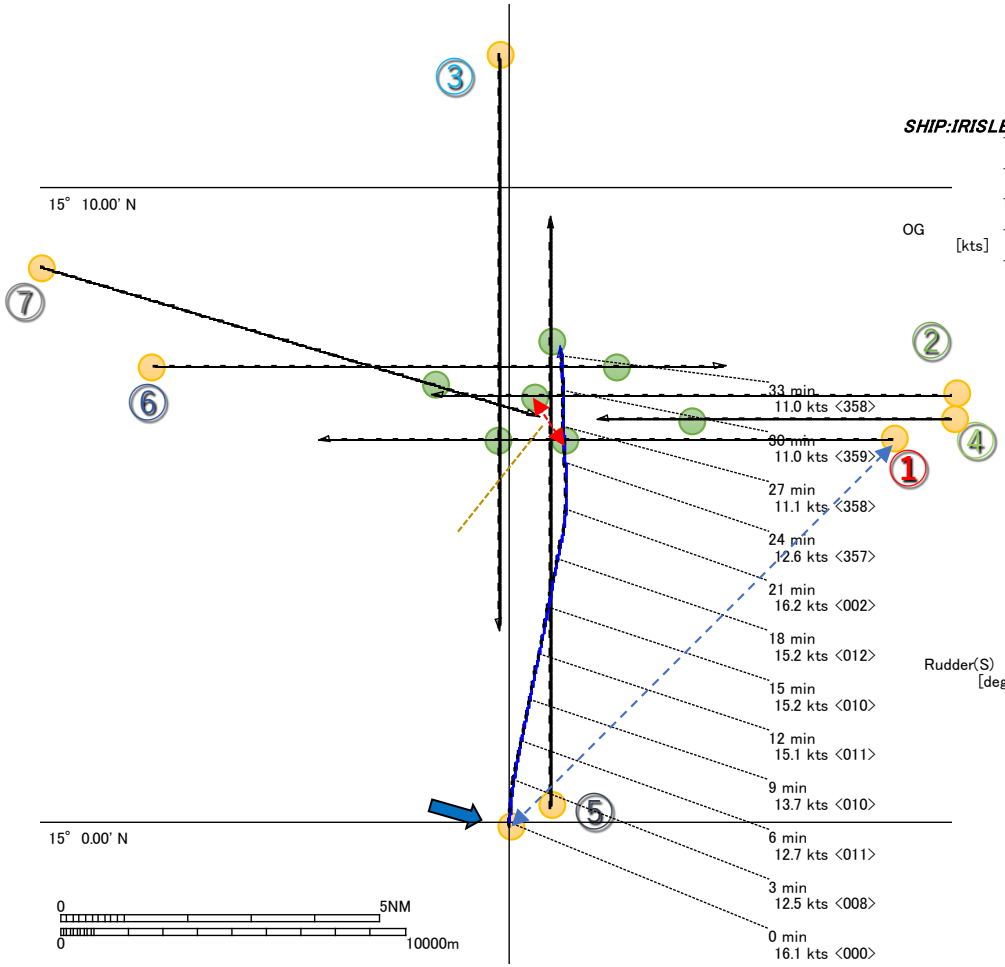

Case 17
Case 18
Case 19
Case 20
Case 21
Case 22
Case 23

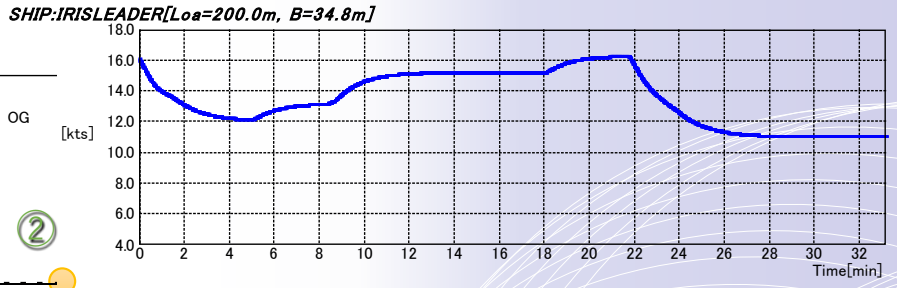
4


Bungo-Suidou
Planed Route

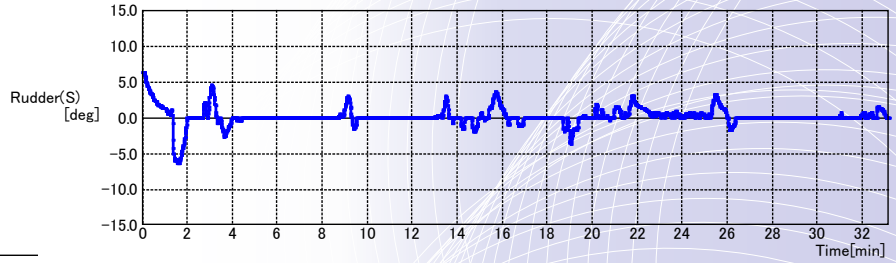

Kii-Suidou
Planed Route


Head-on
Cross
Same Way
Loa: 175m
16.1 kts <180>
③
Loa: 150m
16.1 kts <106>
⑦
300m
7NM
Loa: 150m
16.1 kts <270>
⑥
12NM
Loa: 150m
16.1 kts <090>
②
④
①
Loa: 150m
16.1 kts <270>
Loa: 150m
16.1 kts <270>
7NM
1,200m
Loa: 175m
18.0 kts <000>
Own Ship
Loa: 200m
16.1 kts <000>
300m
⑤

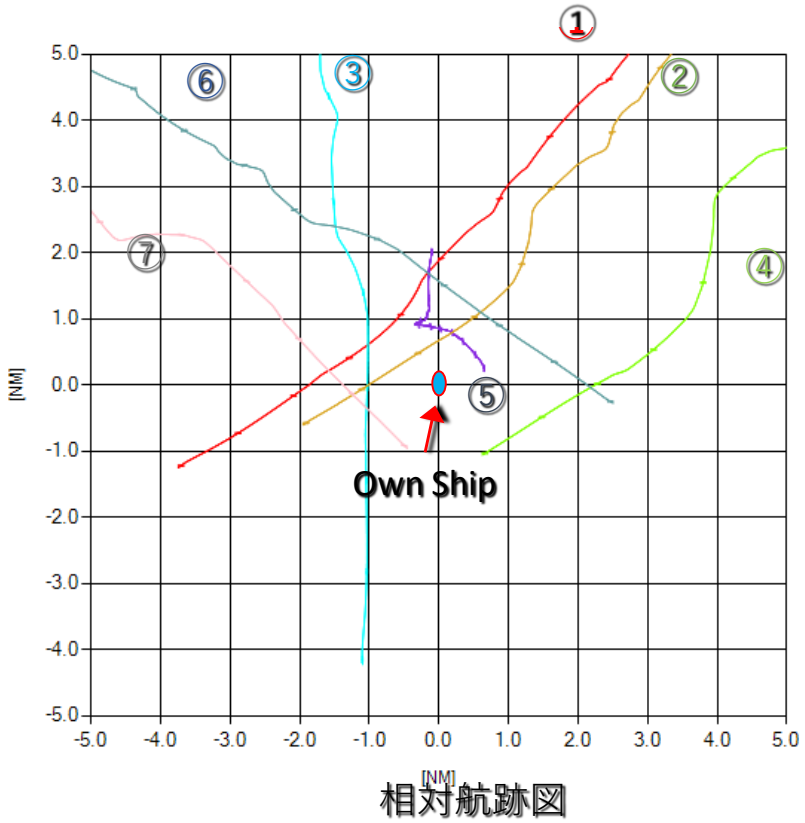


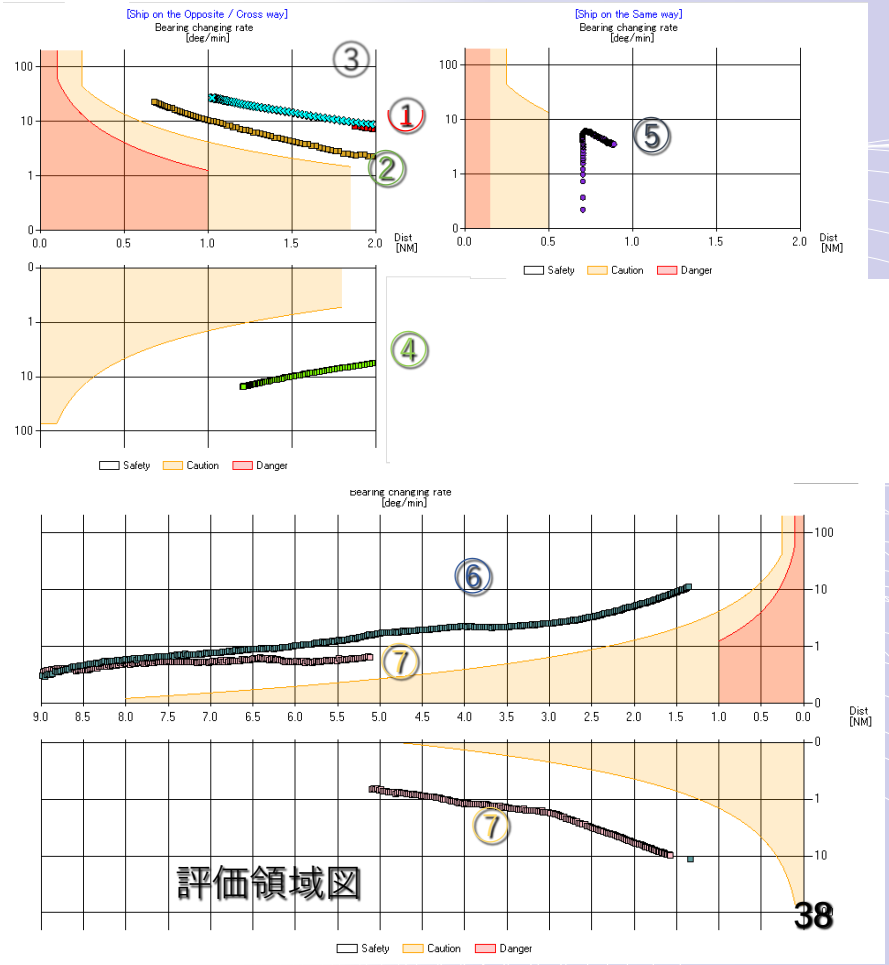

OG Speed [kts]




Rudder [deg.]


[NM]
Own Ship
[NM]

相対航跡図


[Ship on the Opposite / Cross way]
Bearing changing rate
[deg/min]
[Ship on the Same way]
Bearing changing rate
[deg/min]
Dist
[NM]
Safety
Caution
Danger
Bearing changing rate
[deg/min]
Dist
[NM]
Safety
Caution
Danger

評価領域図