# Analysis of Vessel Traffic in Tokyo Bay Observed by New Remote Radar Network System

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**Abstract**

Since 2000, the authors have been developing remote radar network system to observe the vessel traffic in Tokyo Bay. In December 2002, the first operational remote radar station was set at the National Defense Academy in Yokosuka, and vessel traffic observation was started. However, it was impossible to perform accurate observation in the northern part of Tokyo Bay by this Yokosuka radar station only.
In September 2003, the second remote radar station and AIS receiving station were installed at Higashi Ogishima in Kawasaki. This second radar enabled us to carry out accurate observation in that area. Both radars can be remotely controlled from the monitoring station in Tokyo University of Marine Science and Technology. On September 30 and October 1, 2003, the vessel traffic observation was carried out using both radars. Combining radar images observed by both radars, the ships' tracks were taken and the dangerous ships were extracted by using SJ value and Bumper Model. The time changes of dangerous ship density in some areas in Tokyo Bay and utilization ratio of the traffic routes were also investigated. In addition, analyzing the AIS date received at Kawasaki station, the positions and speed vectors of the ships equipped with AIS were shown.

## 1. Introduction

In Tokyo Bay having the narrow traffic routes and congested vessel traffic, complete grasp of the traffic characteristics is very important to improve the safety of navigation. The authors have developed the remote radar network system to observe the vessel traffic in Tokyo Bay [(1), (2), (3)]. Some softwares for analyzing vessel traffic such as tracking of ship's positions, determination of ship's size, animation of ships' movements, superposition of successive radar images, display of ships' tracks, calculation of ship's speed distribution, extraction of the dangerous ship encounters, etc. have been also developed.
However, it was impossible to grasp the vessel traffic flow of entire Tokyo Bay only by one remote radar station sited in Yokosuka. In order to cover wider area of Tokyo Bay, the second remote radar station was set at Higashi Ogishima in Kawasaki in September 2003. With the second radar station, the vessel traffic conditions from Kannon Zaki to Keiyo Sea Berth could be displayed in real-time on the monitor screen at the monitoring station in Tokyo University of Marine Science and Technology. Additionally, the AIS receiving station was installed at Kawasaki radar station, and the positions and the speed vectors of the ships equipped with AIS were observed.
A method to estimate the ship's length by measuring the size of blip of the ship on radar screen was proposed in the last study [(2), (3)]. This method was also applied to the data observed at Kawasaki radar station, and the regression formula between the ship's length and the size of blip of the ship on radar screen was established.
Using the ship's track and ship's length data obtained by this remote radar network system, the traffic characteristics in Tokyo Bay were analyzed.

## 2. Remote radar network system for traffic observation

The remote radar network system is composed of the monitoring station in Maritime Transport Joint Research Center of the Tokyo University of Marine Science and Technology and two radar stations, respectively installed at the National Defense Academy in Yokosuka and at the warehouse in Higashi Ogishima in Kawasaki. In the following text, the radar station at National Defense Academy is called "Yokosuka Station", and the radar station at the warehouse in Higashi Ogishima is called "Kawasaki Station". With these two radar stations, the vessel traffic from Kannon Zaki to Keiyo Sea Berth can be observed. The AIS receiving station (made by JRC) was installed near the radar antenna at Kawasaki Station, which enabled us to get the static/dynamic information from the ships equipped with AIS. The radar antenna of Kawasaki Station and the AIS transponder are shown in Fig.1.

Concerning the data transmission, constant Internet access via ADSL has been adopted between Yokosuka Station and the monitoring station, but constant Internet access via optical communication line has been utilized between Kawasaki Station and the monitoring station. The AIS receiving station in Kawasaki Station has used the same optical communication line as the radar to transfer AIS data to the monitoring station. In Fig.2, a configuration of this new radar network system for observing vessel traffic in Tokyo Bay is shown.

Fig.3 shows radar images on the screen of the communication controller of the monitoring station in Tokyo University of Marine Science and Technology.

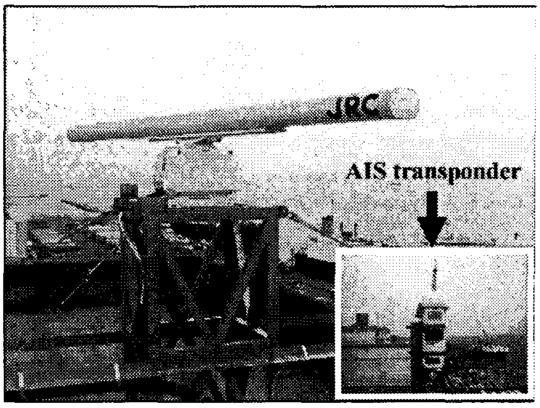



Fig.1 Radar antenna and AIS transponder set on the rooftop of the warehouse in Higashi Ogishima in Kawasaki

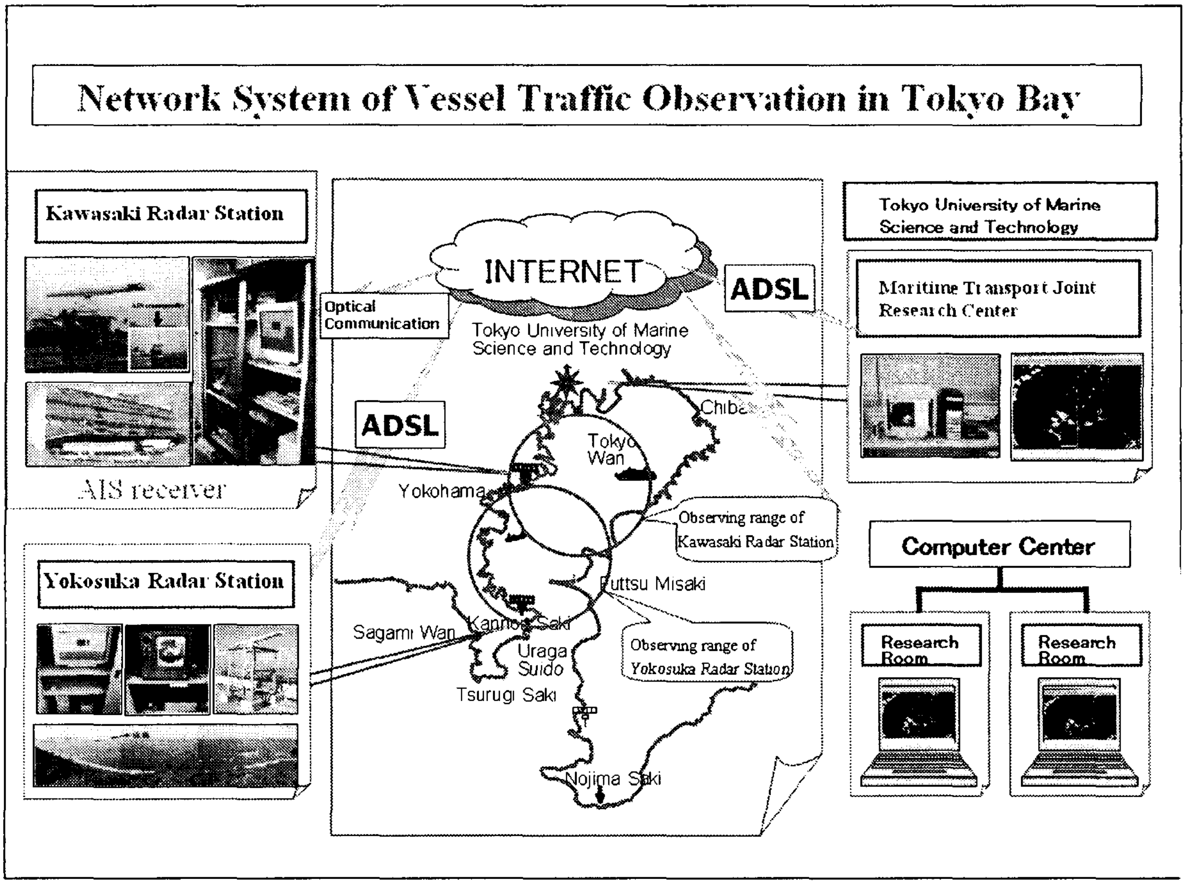



Fig.2 Configuration of new radar network system for observing vessel traffic in Tokyo Bay

The left figure shows the radar image from Yokosuka Station, and the right figure shows the radar image received Kawasaki Station. To start, adjust and end the operation of both radar stations are feasible on the screen of communication controller in the monitoring station. The adjusting function is comprised of radar image control functions (gain, FTC, STC, sweep/scan correlation, etc.) and data communication functions (image quality, compression ratio, etc.).
The transmitted radar image is indicated on screen of communication controller of the monitoring station so as to know the traffic situation of Tokyo Bay in real time, meanwhile it is entirely possible to record the radar image and AIS data to analyze them later.

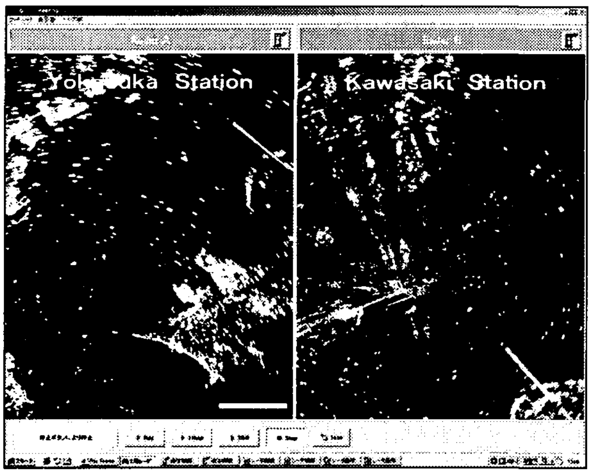



Fig.3 Screen of communication controller of the monitoring station

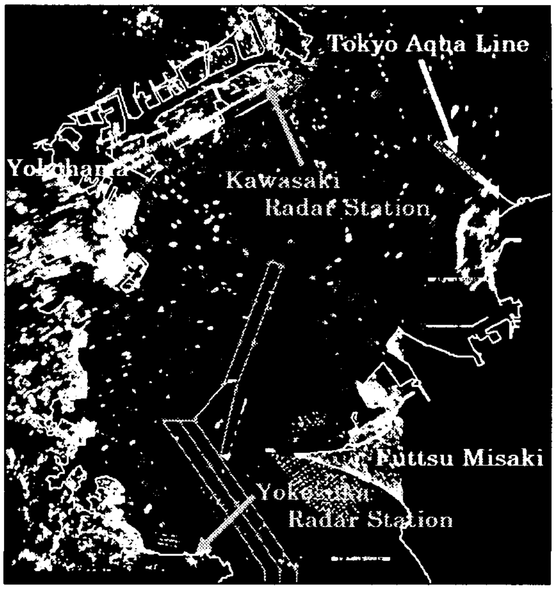



Fig.4 Composite radar image (14:20 on Sep. 30, 2003)

## 3. Vessel traffic observation in Tokyo Bay

### 3.1 Obtaining the composite radar image and ships' tracks

Operating two radar stations simultaneously, the radar observations were carried out on Sep.30 and Oct.1, 2003. The radar off-center function was used for the observations, and radar image data were recorded every minute with a 6-mile range.
A composite radar image was produced by combining two radar images from Yokosuka Station and Kawasaki Station. Then coastlines, buoys and traffic routes were taken from the chart and superposed on the composite radar image. Fig.4 shows the composite radar image at 14:20 on Sep.30, 2003 with coastlines, buoys and traffic routes. From this figure, we can observe sea area from Kannon Zaki to Keiyo Sea Berth in Tokyo Bay.

Applying the developed software in traffic analysis, the ships' tracks in Tokyo Bay were obtained and these are shown in Fig.5 for 06:00 - 09:00 on Oct.1, 2003. The boundary of images from Kawasaki Station and Yokosuka Station is located to the north of the exit of Nakanose Traffic Route (near the buoy of "Off Port of Kisarazu"). It can be seen from Fig.5 that since the ships' tracks are smooth at that boundary, two radar images were accurately combined. Clearly, it can be found in Fig.5 that vessels' tracks converge to Uraga Suido Southbound Lane from many ports in Tokyo Bay.

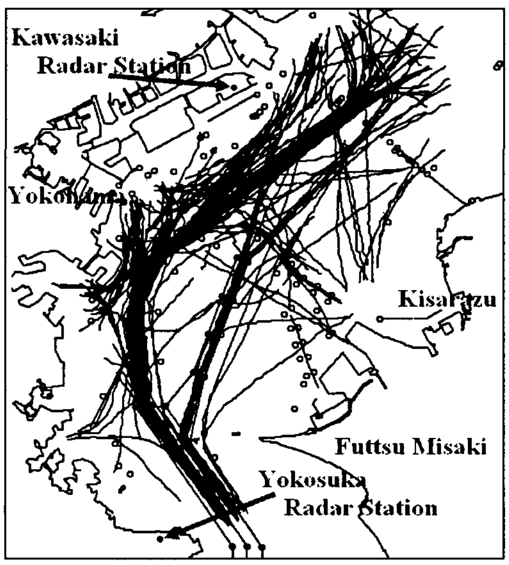


Fig.5 Tracks of ships observed by two radar stations (16:00 to 19:00 on Oct.1, 2003)

### 3.2 Estimating the ship's length

In this section, the method for estimating the ship's length based on the blip size of the ship on radar screen is explained. In the last study, by comparing the blip size of the ship on radar screen with the ship's length obtained by visual observation, the method to estimate the ship's length was proposed. In order to estimate the ship's length from radar image observed by Kawasaki Station, the regression formula was derived as follows.

First, setting the radar parameters of Yokosuka Station (gain, STC, FTC and so on) to the same values as those in the last study, the ship's images were observed every one minute. Then, the relation between blip size of the ship and distance from Yokosuka Station was investigated while the ship's positions were located between 4 miles and 6 miles from Yokosuka Station, and the first-order regression formula was derived by the least mean square method. Using this regression formula, the blip size at 5miles from Yokosuka Station was calculated. Then the ship's length was estimated based on the second-order regression formula mentioned in the last study.

Secondly, when the same ship was shown on the radar screen of Kasawaki Station, the relation between blip size of the ship and distance from Kawasaki Station was investigated while the ship's positions were located between 3 miles and 5 miles from Kawasaki Station, and the first-order regression formula was calculated by the least mean square method. Using this regression formula, the blip size at 4 miles from Kawasaki Station was calculated. An example of this procedure is shown in Fig.6 for the ship of 116 meters LOA observed by Kawasaki Station.

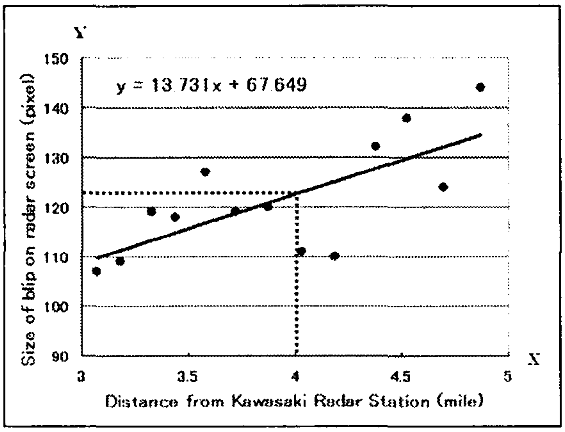



Fig.6 Size of blip on radar screen versus distance from Kawasaki radar station

Calculating blip sizes of many ships at 4 miles from Kawasaki Station by regression formulae, the relation between ship's length and blip size of the ship at 4 miles from Kawasaki Station was investigated as shown in Fig.7. From the second order regression formula in Fig.7, the ship's length can be estimated using blip size of the ship at 4 miles from Kawasaki Station.

In this estimating method, since blip size of the ship at a fixed distance from the radar station (i.e. 5 miles from Yokosuka Station and 4 miles from Kawasaki Station) is statistically estimated by regression formula, it can be said that ship's length can be estimated with high accuracy.

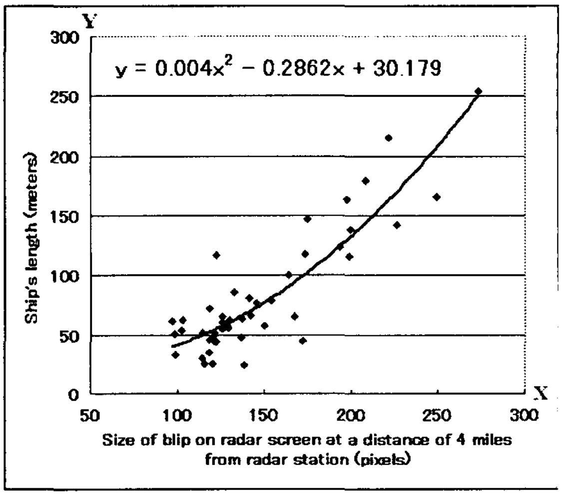



Fig.7 Ship's length versus size of blip on radar screen at a distance of 4 miles from Kawasaki radar station

## 4. Vessel traffic characteristics in Tokyo Bay

### 4.1 Extracting dangerous encounter situation observed by two radar stations

Based on the radar data obtained by two radar stations, dangerous encounter situation having collision risk were extracted for the morning and evening time zones. The SJ value (Subjective Judgment value) and the Bumper Model were used to judge the dangerous encounter situation.

If SJ value of own ship or target ship becomes less than −1, both ships are judged as the dangerous encounter situation. In addition, if the bumpers of own ship and target ship overlap each other, both ships are judged as the dangerous encounter situation; in this case, both ships are regarded as the dangerous ships by Bumper Model even if they are also judged as dangerous encounter situation by SJ value.

The positions of dangerous encounter situation in Tokyo Bay during 06:00 – 09:00 on Oct.1, 2003 are shown in Fig.8, in which △, ○, and + marks indicate the position of dangerous ship in head-on, crossing and overtaking encounter judged by SJ value. The □ mark expresses the position of dangerous ship judged by Bumper Model. It is clear that in Nakanose and Uraga Suido Traffic Route, there are many dangerous encounter situation judged by Bumper Model because many ships navigate to the same direction with short distance between them. In the area off Yokohama, since the ships entering Yokohama area meet the southbound ships from Tokyo area, there are many dangerous ships in crossing encounters judged by SJ value.

Fig.8 Positions of dangerous encounter situation (06:00 - 09:00, Oct. 1, 2003)

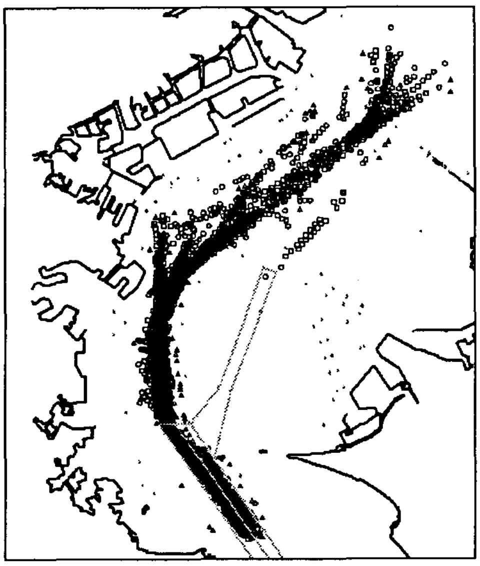


Fig.9 Positions of dangerous encounter situation (16:00 - 19:00, Sep. 30, 2003)

The positions of dangerous encounter situation in Tokyo Bay during 16:00 – 19:00 on Sep.30, 2003 are shown in Fig.9. In this time zone, since many ships usually were going out from Tokyo Bay, there are many dangerous encounter situation in the area where southbound ships navigate. It can be seen that there are few dangerous encounter situation in Nakanose Traffic Route.

### 4.2 Extracting dangerous ships observed by one radar station

Based on 1,120 tracks of the ships observed by Yokosuka Station from 19:50 on Jan.9 to 19:49 on Jan.10, 2003 (Fig.10), the dangerous ships were extracted and time change of dangerous ship density was investigated in 6 areas of Tokyo Bay.

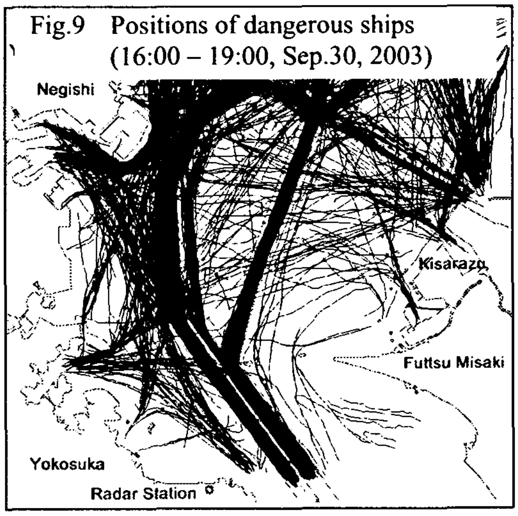



Fig.10 Ship's tracks observed by Yokosuka radar station (19:50 on Jan.9 –19:49 on Jan.10, 2003)

As shown in Fig.11, the observation area of Tokyo Bay was divided into 6 areas (the offing of Yokohama, the west of Nakanose, Nakanose Traffic Route, the north of the exit of Nakanose Traffic Route, Uraga Suido Northbound Lane and Uraga Suido Southbound Lane). In each area, the dangerous ships were extracted by using the SJ value and the Bumper Model at every one minute, and average number of dangerous ships per hour was calculated. Then dividing that the mean value of dangerous ships by the area (km$^2$) of each area, dangerous ship density (DSD) (ships/km$^2$) was calculated.

Fig.12 shows a change with time of DSD in the offing of Yokohama (Area 1) and the west of Nakanose (Area 2). In Fig.12, ▲, ●, ◆ marks indicate DSD in head-on, crossing and overtaking encounters judged by SJ value, and ■ mark indicates DSD judged by Bumper Model. From Fig.12, both of these areas

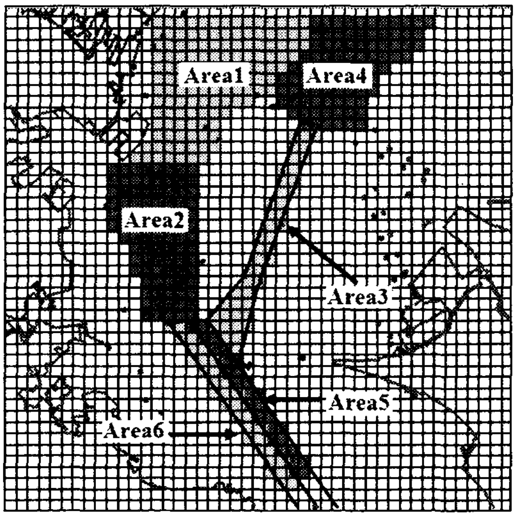



Fig.11 Areas for investigating dangerous ship density

have high DSD in crossing encounter and high DSD judged by Bumper Model. This is because the ships navigating southward from Tokyo area meet the ships entering/leaving Yokohama and Negishi areas. The DSD in head-on and overtaking encounters are low in these areas. In the west of Nakanose, DSD judged by Bumper Model is high in the evening, which indicates the concentration of the ships to Uraga Suido Southbound Lane.

Next, Fig.13 shows time change of DSD in Nakanose Traffic Route (Area 3) and the north of the exit of Nakanose Traffic Route (Area 4). Since the vessels navigate very closely each other in the traffic route, DSD judged by Bumper model becomes high in all time zones, specially in the morning when many vessels navigate in Nakanose Traffic Route. Since many ships navigate at a speed of about 12 knots in Nakanose Traffic Route, DSD in head-on and overtaking encounters are extremely low. In the north of the exit of Nakamose Traffic Route, the vessels disperse for the Tokyo, Kawasaki-Yokohama and Kisarazu, so DSD judged by Bumper model is lower than that in Nakanose Traffic Route. However, since ships heading for Kawasaki-Yokohama have dangerous crossing encounters with the southbound ships from Tokyo, and ships heading for Tokyo have also dangerous crossing encounters with ships leaving Kisarazu, DSD in crossing encounter by SJ value becomes high.

Lastly, Fig.14 shows time change of DSD in Uraga Suido Northbound Lane (Area 5) and Uraga Suido Southbound Lane (Area 6). Fig. 14 indicates that

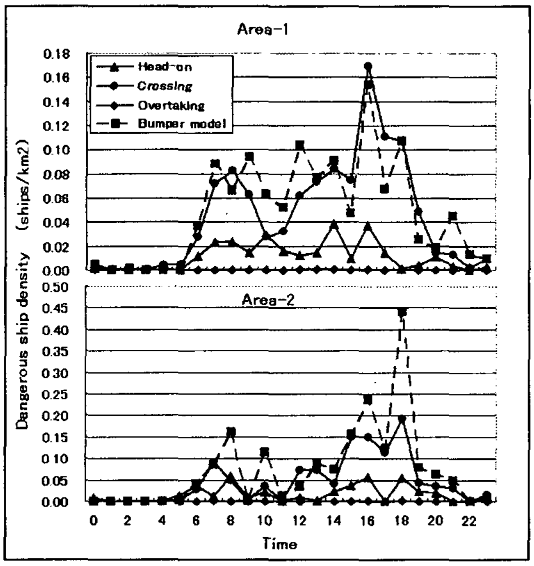



Fig.12 Change of dangerous ship density in Area 1 and Area 2

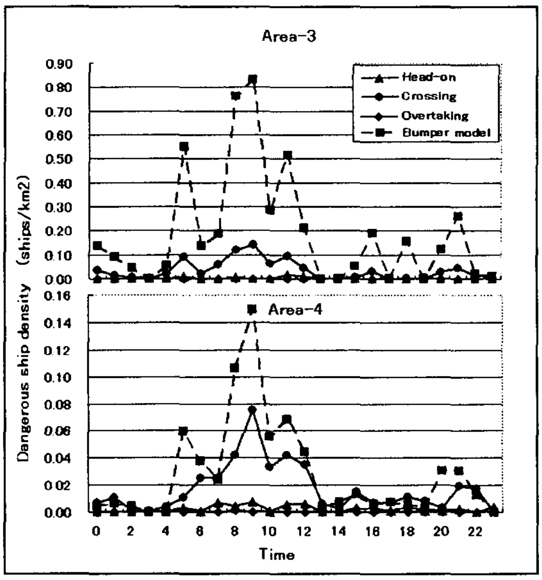
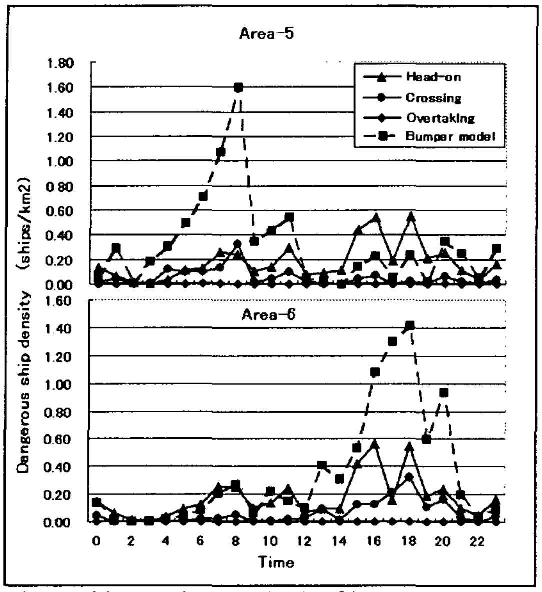



Fig.13 Change of dangerous ship density in Area 3 and Area 4

DSD judged by Bumper Model is high in Northbound Lane in the morning because of many ships entering Tokyo Bay, on the other hand, DSD is high in Southbound Lane in the evening because of many ships going out of Tokyo Bay. The DSD in head-on encounter by SJ value becomes high in both lanes in the morning and evening. This is because




the large ships navigate in both of lanes very closely.

Fig.14 Change of dangerous ship density in Area 5 and Area 6

### 4.3 Utilization ratio of traffic route

Traffic routes are crucial to the safety and efficiency of vessel traffic. However, since navigational area is restricted in the traffic route, the number of ships which can navigate in the traffic route at the same time is limited. So based on the Bumper Model, utilization ratios of Nakanose Traffic Route and Southbound and Northbound Lane of Uraga Suido Traffic Route were investigated using the vessel traffic data observed by Yokosuka Station from 19:50 on Jan.9 to 19:49 on Jan.10, 2003.

In Bumper Model, the shape of bumper is semiellipse having semimajor axis of 6.4L and semiminor axis of 1.6L in the front side of a ship, and semicircle having radius of 1.6L in the rear side of a ship, where L is the length of the ship. When the bumpers of own ship and target ship overlap, encounter is regarded as dangerous. The area of bumper is $6.4\pi L^2$, and utilization ratio of the traffic route is defined as follows.

$$\mathrm{UR} = \sum_{i=1}^{n} 6.4\pi L_i^2 / A \qquad (1)$$

where

UR : utilization ratio of traffic route
$A$ : area of traffic route
$L_i$ : length of i–th ship
$n$ : number of ships in the traffic route

The utilization ratio of traffic route represents the ratio of the sum of bumper areas of all ships in the traffic route to the area of traffic route.

The time change of utilization ratio (UR) of Nakanose Traffic Route is shown in Fig.15. The thin line indicates the instantaneous UR at intervals of one minute, whereas the bold line means UR averaged over one hour. Since many ships enter Tokyo Bay in the morning, the UR is high in the morning and instantaneous peak value is 44%.

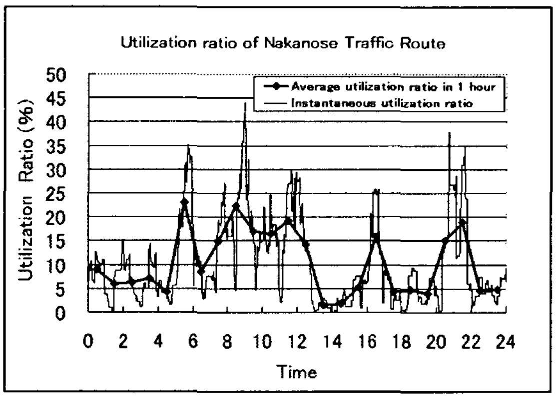



Fig.15 Change of utilization ratio of Nakanose Traffic Route (Jan.9 19:50 – Jan.10 19:49, 2003)

In Fig.16, the time change of UR of Uraga Suido Northbound Lane is shown. It can be seen that the change of UR is similar to Nakanose Traffic Route, that is, the UR is also high during the morning time. The peak value is 72%, which means almost three-quarters of the traffic route was occupied by the bumpers.

In Fig.17, the time change of UR of Uraga Suido Southbound Lane is shown. The change is contrary to Northbound Lane, and the peak value 47% appears in the evening.

Concerning the time change of UR of traffic routes in Tokyo Bay, the instantaneous UR varies largely and reaches about two times of UR averaged over one hour. This instantaneous UR is very useful to grasp the occupied condition of the traffic route by the ships, which cannot be represented by the traffic volume per hour.

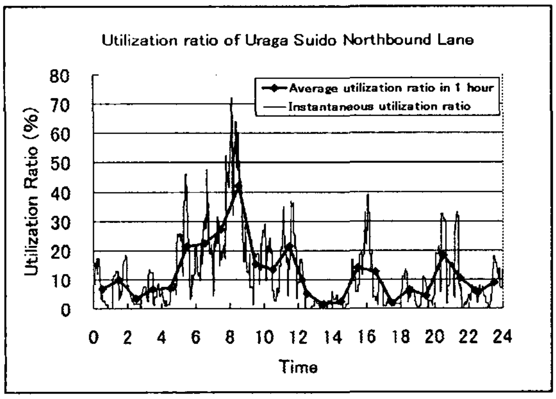



Fig.16 Change of utilization ratio of Uraga Suido Northbound Lane (Jan.9 19:50 – Jan.10 19:49, 2003)

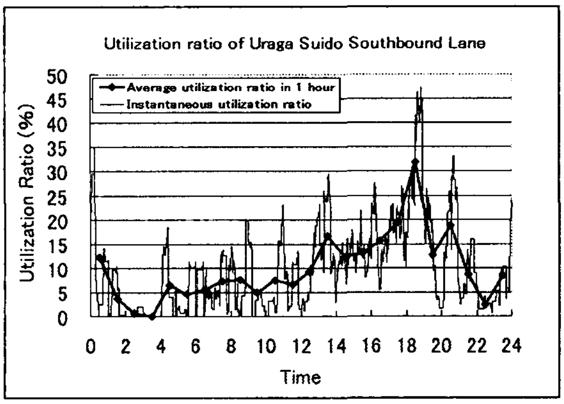



Fig.17 Change of utilization ratio of Uraga Suido Southbound Lane (Jan.9 19:50 – Jan.10 19:49, 2003)

## 5. Positions and speed vectors of ships equipped with AIS

The positions and speed vectors of ships equipped with AIS observed by AIS receiving station in Kawasaki are shown in Fig.18. The period of this observation is from 13:32 to 16:30 on Jan.16, 2004.
The radar observation of Tokyo West Passage, Tokyo East Passage and their approach area is impossible by Kawasaki Station because of the shadow of high buildings. The radar observation of the area to the south of Kannon Zaki is also impossible by Yokosuka Station because of the shadow of mountains. The AIS receiving station in Kawasaki can observe the vessel traffic in these radar shadow areas.
The southern limit of receiving AIS data is around Tsurugi Saki, depending on the height of AIS transponder on board the ship (Fig.19). In Fig.19, it can be seen that in the area to the south of Tsurugi Saki, AIS data could not be received by AIS receiving station because of high mountains in the Miura Peninsula.
This AIS receiving station will be a powerful tool to support radar observation by Yokosuka and Kawasaki stations.

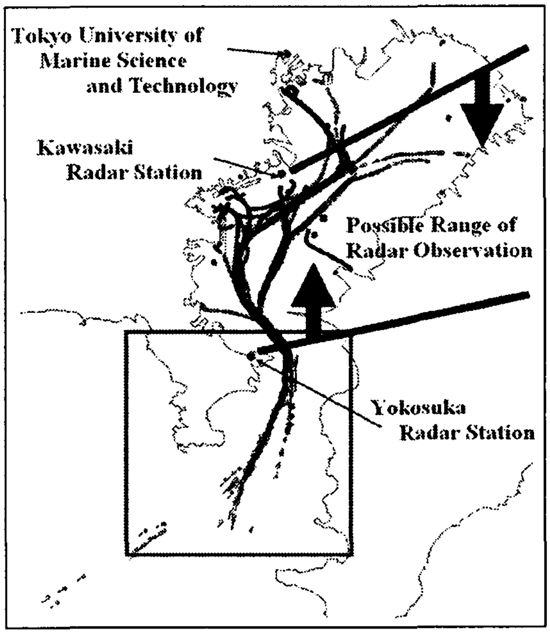



Fig.18 Positions and speed vectors of ships equipped with AIS observed by AIS receiving station in Kawasaki (Jan.16 13:32 – 16:30, 2004)

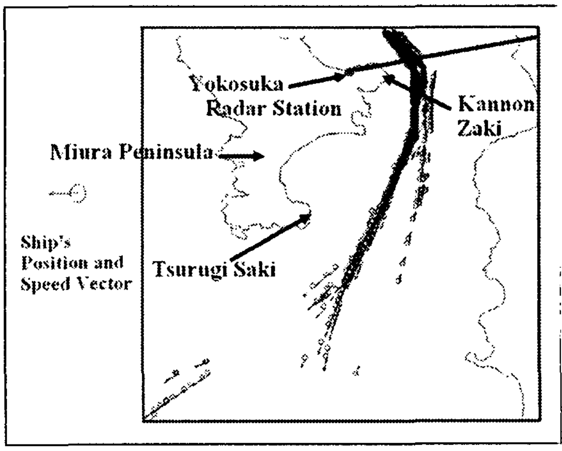



Fig.19 Positions and speed vectors of ships equipped with AIS navigating the south of Kannon Zaki

## 6. Conclusions

This study described the construction of remote radar network system for observing vessel traffic in Tokyo Bay. By adding the new Kawasaki radar station to Yokosuka radar station, the vessel traffic from Kannon Zaki to Keiyo Sea Berth could be accurately observed.

Using this system, traffic observations were carried out during 2 days from Sep.30 to Oct.1, 2003, and ships' tracks were obtained in wide area of Tokyo Bay. In addition to Yokosuka radar station, regression formula to estimate the ship's length from blip size of the ship on radar screen was derived for Kawasaki radar station. Thus estimating the length of the ship observed by only Kawasaki radar station became possible.

Furthermore, in the process of estimating ship's length, the method to accurately estimate the blip size of the ship on radar screen at a fixed distance from the radar station was developed. This method used many blips of the ship near the position of fixed distance to make the regression formula to estimate the blip size at the fixed distance.

Next, using the ship's track/length data obtained from radar observations, dangerous ships having collision risk were extracted by means of SJ value and Bumper Model. From the observation using two radars, dangerous ships during 3 hours in the morning and evening were extracted for wide area in Tokyo Bay from Kannon Zaki to Tokyo Bay Aqua Line. From the observation using one radar in Yokosuka (Jan.9 – Jan.10, 2003), time change of the dangerous ship density was calculated for 6 areas in Tokyo Bay.

The utilization ratio (UR) of traffic route was also defined as an index to show how much the traffic route is occupied by the bumpers of the ships. The time change of URs of Nakanose Traffic Route, Uraga Suido Northbound Lane and Uraga Suido Southbound Lane were shown.

The AIS receiving station was installed at Kawasaki radar station, which enabled us to get AIS data from the ships equipped with AIS transponder. From a short observation, positions and speed vectors of the ships equipped with AIS were shown, and it was found that this AIS receiving station could observe the vessel traffic where radar observation was impossible because of the shadow of the buildings and mountains.

For the further study, long-term vessel traffic observations covering wide area of Tokyo Bay will be carried out using two radars, and the vessel traffic characteristics will be thoroughly investigated. In order to analyze the huge observation data, automatic tracking system of ship's positions has to be developed.

In addition, comparing the ship's length estimated from the blip size on radar screen with actual length obtained from AIS, the accuracy of estimated ship's length will be evaluated.

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**References**

(1) Hagiwara, H., Ohtsu, K., Hayashi, S. and Shoji, R. (2002): Construction of Radar Network System for Observing Vessel Traffic in Tokyo Bay, Proceedings of 50th Academic Lectures of the Tokyo University of Mercantile Marine, pp.33-36.

(2) Shoji, R., Hagiwara, H., Ohtsu, K., Hayashi, S., and Namie, H. (2003): Study on Radar Network System for Observing Vessel Traffic in Tokyo Bay, The Journal of Japan Institute of Navigation (Vol.109), pp.69-78.

(3) Shoji, R., Hagiwara, H., Ohtsu, K., Hayashi, S., Namie, H., Liu, S., Okano, T. (2003): Development of New Radar Network System for Observing and Analyzing Vessel Traffic in Tokyo Bay, Proceedings of Asia Navigation Conference 2003, pp.67-74.