The George Washington University
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Maritime Simulation Model of San Francisco Bay

Modeling Overview

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1. INTRODUCTION

The maritime systems simulation exposure assessment is the first step of an overall probabilistic risk assessment methodology. The goal of the simulation is to reconstruct the maritime transportation system (MTS) and, through the simulation of that system, count specific vessel interactions and the conditions under which these interactions occur. Thus the simulation is designed to estimate the system exposure to various maritime conditions. By adding more information as part of the simulation, more specific details of vessel interactions may be captured. For the San Francisco (SF) Bay simulation, attributes of vessel type, location, wind speed, wind direction and visibility state were used to characterize the types of vessel interactions.

The exposure results obtained with the MTS simulation can be combined in follow on steps with a conditional accident probability model and an accident damage model for an overall estimate of MTS accident risk. Thus, the MTS simulation results presented herein do not portray a full probabilistic risk analysis in terms of accidents per year and should not be interpreted as such. The results of the MTS simulation alone, however, do give an initial indication of where the high accident risk spikes may occur by illustrating MTS exposure. Specifically, accident risk for a specific type of vessel interaction is proportional to the exposure (i.e. number of occurrences) to that interaction. Hence, an interaction with high exposure involving high-occupancy high-speed passenger vessels should be of concern (particularly in restricted visibility) as vessel collisions of this nature are most likely to result in a mass casualty event.

The remainder of this document describes the methodology behind the maritime simulation model.

2. THE SIMULATION: VESSEL MOVEMENT

The background map of the maritime simulation model for the San Francisco Bay area (see Figure 1) was constructed from NOAA electronic charts which were converted to bit maps for use with the simulation program.

The simulation approach is based on the premise that exposure (and thus risk) is a dynamic property of the MTS. Harrald et al. (1992) discuss the need for dynamic modeling in the assessment of risk in the maritime area. The MTS risk at any given time is the summation of the risk posed by each of the vessels in the system. As vessels pass through the MTS, the system changes with time, thus changing the level of exposure (and risk) in the MTS. To be able to estimate the system risk of the MTS over time, a model must capture the dynamic nature of the transportation system. Such a model allows for the examination of modifications to the present system through simulation rather than disruption of the actual MTS. These modifications may represent proposed risk interventions that change the dynamics of the MTS. This ability is a major benefit when studying systems in which accidents have the potential to lead to mass casualty events.

2.1. Modeling Ferry Traffic

Ferry movements for the base case simulation were obtained from ferry schedules collected from ferry operators for the years 1998-2001. The ferry routes configurations for the base case simulation and proposed expansions were obtained from the URS Corporation (see Figure 2). This map was spliced into the bitmap of the San Francisco Bay area in order to insure proper placement of the routes. In all, 18 ferry routes were considered for the base case simulation and up to 64 ferry routes for the proposed expansion (referred to as *alternative* 1). The cruising speed of each ferry class was used as a constant speed for each ferry along its route when underway. The ferries slow down when leaving and entering dock and also slow down in conditions involving restricted visibility. This behavior is reflected in the simulation.

For each of the three future alternatives, denoted alternatives 1 through 3, the routes for the ferries follow the maps created for each alternative supplied by URS Corporation, while their schedules follow the spreadsheets supplied. If there were any discrepancies between the two, the spreadsheet was used as the master.

The ferry schedules were edited to match the routes in the maritime simulation. Figure 4 provides a snapshot of the resulting table used in the maritime simulation. Microsoft Visual Basic for Applications programs were written to create arrivals databases suitable for the simulation program.

2.2. Modeling Other Vessel Traffic

Usually, traffic arrival/departure data are used to construct probability distributions for vessel inter-arrival times and these distributions are then used to simulate vessel arrivals and transits in the system. However, the presense of the San Francisco Vessel Traffic System (SF VTS) eliminated the need for this approach. Data on date, time, and transits for 6000 routes for up to 26 different vessel types were obtained from the VTS for the 1998-2001 period. Way point data obtained from the SF VTS was used in conjunction with the bit map of the San Francisco Bay area to produce the total vessel transit picture. Figure 3 illustrates an example of the routes of a particul class of vessels. Again average vessel speeds for each class are maintained durring transits with the exception of vessels slowing down in restricted visibility conditions. Average vessel speed information was obtained through personal communication with SF Bar Pilots.

2.3. Modeling Special Events

The USCG supplied their Marine Event List for over 1000 special events for the year 2001. Figure 6 provides a snapshot of the data. Due to time and budget constraints only the main type of special event was modeled in the maritime simulation, i.e. 828 scheduled regattas. The data on regatta times and areas were obtained from the USCG data. Initially 260 different regatta locations were identified. Through discussions with the SF VTS this number was reduced to 32 locations. Finally, these 32 events were reduced to 13 main regatta areas provided in the Table 1. Information regarding 828 regatta events in the year 2001 was collapsed using these 13 locations. Regattas were modeled by blocking the defined areas (see Figure 7) during the times and dates for the regattas and then randomly moving the assigned number of participating vessels within each area.

Table 1. Collapsed Regatta Locations in Maritime Simulation Model

Regatta Locations
SF City Front
Berkeley Circle
Raccoon Strait/Richardson Bay
Knox
Estuary
South Bay
Treasure Island
Southampton
Central Bay
North Bay
San Pablo Bay
Carquinez
Horseshoe Bay

3. THE SIMULATION: WEATHER

The weather modeling at this stage consists of a model for wind speed, wind direction and visibility. For the purposes of weather modeling, the San Francisco Bay area was divided into five regions; Golden Gate, Port Chicago, Redwood City, Richmond, and Alameda (see Figure 8).

3.1. Modeling Wind Speed and Direction

Hourly wind speed and direction data was recorded via NOAA buoys for the period 1998-2001 at the five locations. Thus, as with vessel movements, these values did not have to be simulated but merely replicated.

3.2. Modeling Visibility

Visibility data is not regularly gathered and thus a visibility modeled had to be developed. Initially, the visibility model of Sanderson (1982) was used. This model utilizes differences between water temperature and dew point to predict restricted visibility. The original model visibility is defined as good if it is greater than or equal to 0.6 miles and bad otherwise. Rather than using this definition we adhere to the rules of the road definition of restricted visibility (i.e. vessel operators are required to use their fog signals).

To calibrate the visibility model in terms of the percentage of times restricted visibility conditions occur within the locations Golden Gate, San Pablo Bay, South Bay and Grizzly Bay, information from the Coast Pilot was used combined with results from an expert judgment elicitation technique called the Analytical Hierarchy Process (AHP) (see e.g., Saaty (1980) and Vargas (1990)). The AHP utilizes a series of paired comparisons questions. Each questionnaire consists of six questions of a similar format. Figure 9 provides an example of the questionnaire format.

An expert was asked to compare pairwise the percentage of time in these locations that vessels operate in restricted visibility (i.e. are required to use their fog signal). If, for example and in the expert's opinion, the percentage of time that that vessels operate in restricted visibility in **GOLDEN GATE** is 6 times more frequent in the **THIRD QUARTER** of the year **(July, August and September)** than in **SAN PABLO BAY** the expert provides the answer using an X as indicated on the scale in Figure 8. The experts used were 7 operators from the SF VTS and 5 SF Bar Pilots with extensive experience throughout the SF Bay Area. Figure 10 below demonstrates remarkable agreement between the VTS Operators and the SF Bar Pilots regarding visibility conditions at Golden Gate over the four quarters in the year. The green dotted line indicates the percentages that were used in the maritime simulation model.

Figure 11 below indicates some level of disagreement regarding visibility conditions in the first quarter of the year. In particular, differences are observed for San Pablo Bay and Grizzly Bay. In the latter case the information of the SF Bar Pilots was chosen rather than the information of VTS Operators as the Pilots experience restricted visibility conditions in a direct manner.

The locations for visibility were defined using again a block model. Figure 12 below identifies the different visibility locations used in the maritime simulation model. To reduce the number of questions that we needed to ask in the questionnaires, restricted visibility percentage for Alameda were derived as averages from the locations Golden Gate, San Pablo Bay and South Bay. This averaging combined with the location definition was used to model the phenomenon of channel fog observed in Golden Gate. Figure 13 provides the results for the location Golden Gate for the year 2000 utilizing the visibility model above. Similar results were developed for the locations South Bay, San Pablo Bay, Grizzly Bay and Alameda.

4. THE SIMULATION: INTERACTION COUNTING MODEL

The simulation itself does not indicate how often each possible situation occurs. A snapshot of the simulation is taken every minute and the interactions observed are recorded in an event database. This data recording process is coded into the simulation program itself. To count interactions between ferries and other vessels (including other ferries) are considered. Figure 14 shows a snapshot of San Francisco Bay in the simulation. Moving boats are represented by the triangles. Which pairs of ferries could be considered an interaction? This depends on the time until the vessels meet and the type of interaction. Any vessel within a half a mile is counted as an interaction. If a vessel is more than half a mile away and in addition is more than five minutes away from crossing the ferry track, it is not counted as an interaction. If a vessel is within five minutes of crossing the ferry track and in addition this crossing occurs within 1 nautical mile in front of the ferry or within half a mile behind the ferry, the vessel is counted as an interactions. This counting model is based on Closest Point of Approach (CPA) type arguments and stems from the considerations that a ferry captain will make when considering interactions with other vessels. For example, vessels close in at different speeds, thus in evaluating a situation involving other vessels, a captain is interested in which will arrive first, not necessarily which is closest. Experts with maritime experience outside the ferry service and a group of ferry captains from the Washington State Ferry Service provided input for this methodology.

4.1. Defining Types of Interaction

Figure 15 shows the various types of interactions as defined by the course for the other vessel in relation to the ferry. If the other vessel is moving in the opposite direction from the ferry then it will be a meeting situation. If the other vessel is moving in the same direction as the ferry, it will be an overtaking situation (this means the other vessel is moving faster than the ferry). If the vessel is coming from either side and crossing the path of the ferry, in front or behind, then it will be a crossing situation.

4.2. Recording Vessel and Waterway Attributes

The snapshot of the simulation at a specific time is analyzed to determine whether an interaction is occurring. For each interaction determined, the information about vessel type, type of interaction and the weather conditions of the interaction are recorded. Each interaction is recorded in an interaction database. The factors recorded for each interaction are risk factors that may be utilized in a follow-on probabilistic risk assessment that includes estimation of the probability of a triggering incidents as well as the probability of accidents.

5. REFERENCES

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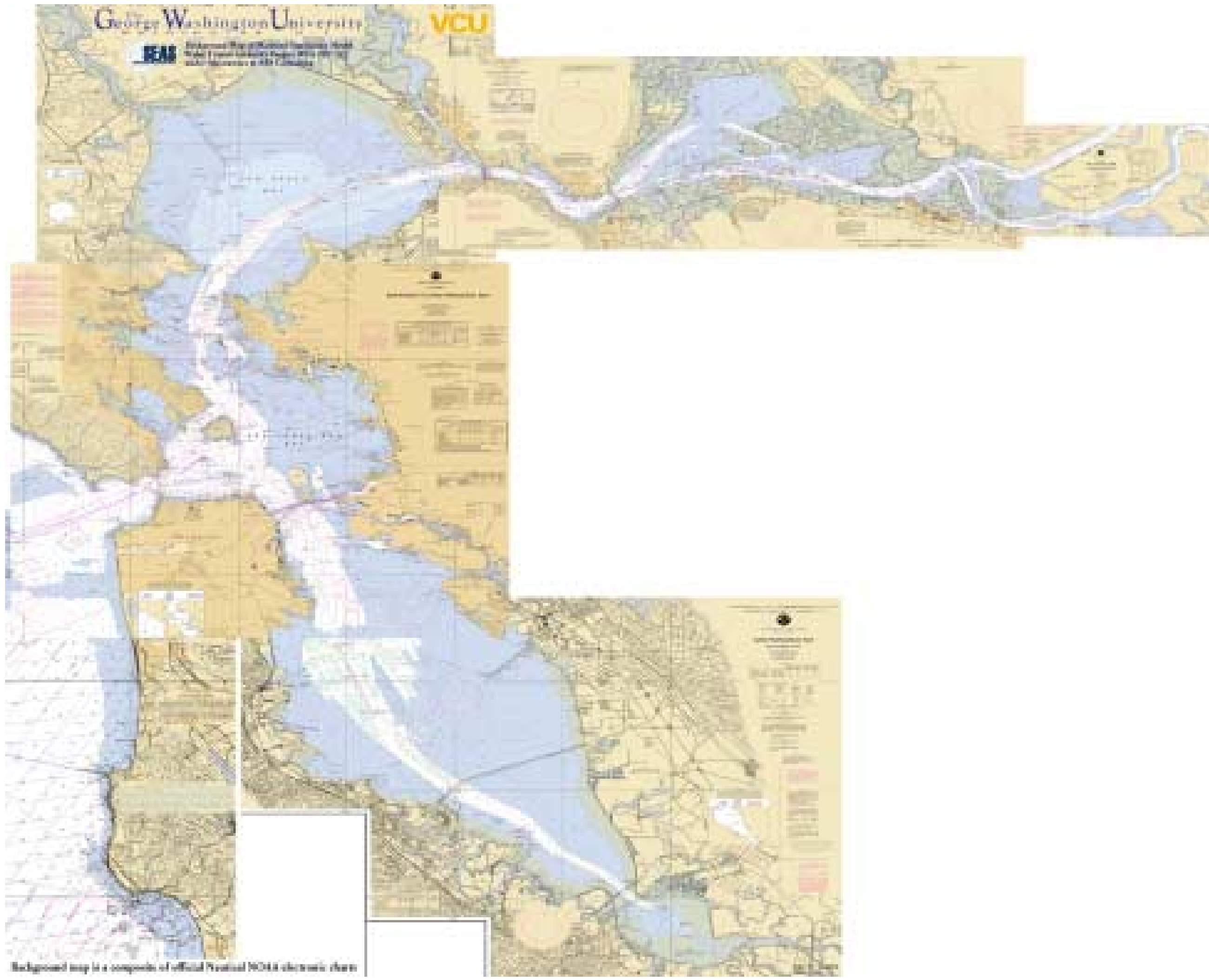

Figure 1. Background Bitmap of San Francisco Bay Maritime Simulation Model

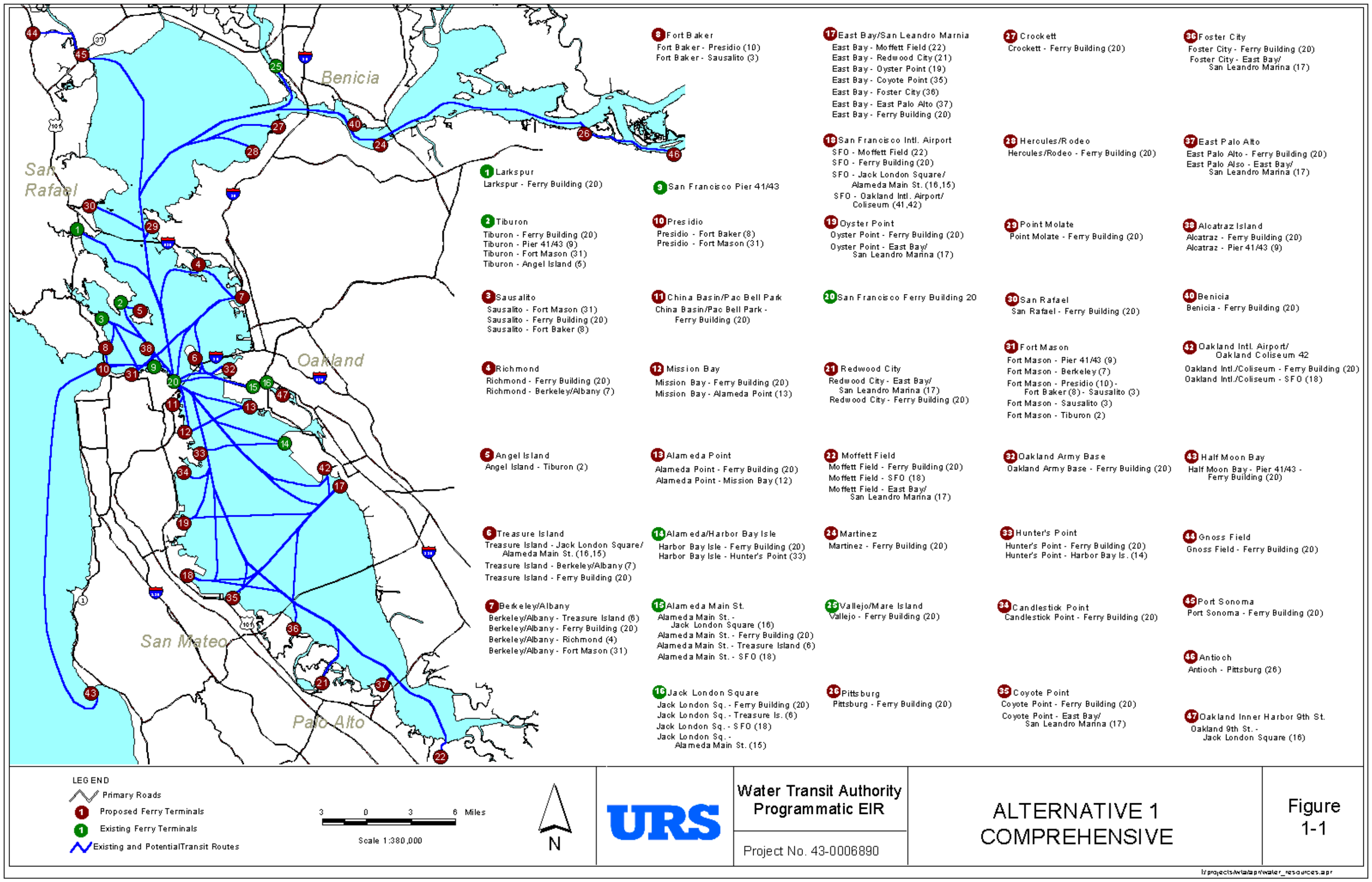

Figure 2. Current and Future Ferry Route Configuration from the URS Corporation

			Alternative 3 - Enhanced (Existing) Water Transit System									
								-----------------------------------Weekdays -----------------------				
						Per Trip		*Per Day- Minutes*		*In Minutes*		
		Vessel	**Speed**	**Headways**		**Sailing**	**Idle**	**Sailing**	**Idle**	**Deadhead**	**Weekday**	**Weekday**
Corridor	**Route**	**Type**	**(Knots)**	**Weekdays**	**Vessels**	**Time**	**Time**	**Time**	**Time**	**Time**	**Trips**	**Service Hrs**
Transbay	Vallejo - SF	350+	35	15	8	53.8	6.2	6459	741	40	120	128
	Alameda Point-Mission Bay-SF	149	25	15	4	28.8	1.2	3456	144	60	120	60
	Oakland - SF	149	25	15	4	24.0	6.0	2880	720	60	120	60
	Harbor Bay - SF	149	25	15	4	25.2	4.8	3024	576	60	120	60
	Subtotal Transbay Corridor				*20*							*308*
Golden	Sausalito-San Francisco	149	25	30	2	20.4	9.6	1224	576	30	60	30
Gate	Tiburon-San Francisco	149	25	30	2	20.4	9.6	1224	576	30	60	30
	Larkspur-San Francisco	350+	35	15	6	31.8	13.2	3812	1588	30	120	90
	Subtotal Golden Gate Corridor				*10*							*150*
GGNRA	Alcatraz	200	25	60	1	8.4	6.6	134	106	15	16	10
Service												
	Subtotal GGNRA Service				*1*							*10*
	TOTAL SYSTEM				**31**			**22,213**	**5,027**	**325**	**736**	**468**
DATE:	9-Apr-02											
	alternative 3~rev											

Figure 3. Example of Ferry Schedules for Alternative 3 supplied by the URS Corporation

Route	From	To	Weekday Every	Weekend Every	From	To	Hours	Vessel Type
F28	Vallejo	Ferry Building	15	30	6:00	21:00	15	7
F7	Ferry Building	Pier 41	15	30	7:00	22:00	15	7
F21	Pier 41	Vallejo	15	30	6:20	21:20	15	7
A3	Alameda Point	Mission Bay	15	15	6:00	21:00	15	8
A37	Mission Bay	Alameda Point	15	30	6:00	21:00	15	8
F14	Oakland	Alameda	15	15	6:00	21:00	15	8
F1	Alameda	Ferry Building	15	15	6:10	21:10	15	8
F7	Ferry Building	Pier 41	15	15	6:30	21:30	15	8
F18	Pier 41	Ferry Building	15	15	6:00	21:00	15	8
F4	Ferry Building	Alameda	15	15	6:15	21:15	15	8
F2	Alameda	Oakland	15	15	6:35	21:35	15	8
F5	Ferry Building	Harbor Bay	15	30	6:00	21:00	15	8
F10	Harbor Bay	Ferry Building	15	30	6:00	21:00	15	8
F23	Sausalito	San Francisco	30	60	6:00	21:00	15	8
F25	San Francisco	Sausalito	30	60	6:00	21:00	15	8
F26	Tiburon	Ferry Building	30	60	6:00	21:00	15	8
F8	Ferry Building	Tiburon	30	60	6:00	21:00	15	8
F22	Larkspur	Ferry Building	15	30	6:00	21:00	15	7
F13	Ferry Building	Larkspur	15	30	6:00	21:00	15	7

Figure 4. Snapshot of Table of Ferry Schedules in Maritime Simulation

Figure 5. Vessel Routes for LPG Vessels

EVENT NUMBER	EVENT	LOCATION	Sailing_Area	DATE	Start_Time	End_Time
SF-01-348	TYC BROTHERS-SISTERS	NORTH BAY #16	11	4-Jul-01	12:00	17:00
SF-01-406	TYC H.O. LIND #3-4	NORTH BAY/ #16	11	21-Jul-01	12:00	17:00
SF-01-678	TYC DOUBLE HANDED RACE	NORTH BAY/#16	11	13-Oct-01	12:00	17:00
SF-01-425	TYC BEHRENS #5-6	NORTH BAY/#16	11	28-Jul-01	12:00	17:00
SF-01-544	TYC BEHRENS #7-8	NORTH BAY/#16	11	25-Aug-01	12:00	17:00
SF-01-320	TYC H.O. LIND #2	NORTH BAY #16	11	23-Jun-01	13:00	17:00
SF-01-202	TYC H.O. LIND #1	NORTH BAY/ #16	11	19-May-01	13:00	17:00
SF-01-246	TYC FRIDAY NIGHT #3	NORTH BAY #16	11	1-Jun-01	18:00	21:00
SF-01-292	TYC FRIDAY NIGHT #4	NORTH BAY/ #16	11	15-Jun-01	18:00	21:00
SF-01-340	TYC FRIDAY NIGHT #5	NORTH BAY/ #16	11	29-Jun-01	18:00	21:00
SF-01-378	TYC FRIDAY NIGHT #6	NORTH BAY/ #16	11	13-Jul-01	18:00	21:00
SF-01-420	TYC FRIDAY NIGHT #7	NORTH BAY/ #16	11	27-Jul-01	18:00	21:00
SF-01-149	TYC FRIDAY NIGHT #1	NORTH BAY/#16	11	27-Apr-01	18:00	21:00
SF-01-470	TYC FRIDAY NIGHT #8	NORTH BAY/#16	11	10-Aug-01	18:00	21:00
SF-01-536	TYC FRIDAY #9	NORTH BAY/#16	11	24-Aug-01	18:00	21:00
SF-01-997	Bay Race	Benicia Yacht Club	13	27-Oct-01	9:00	11:00
SF-01-1011	Get Out the Vote	Pier One S.F.	1	3-Nov-01	10:00	11:00
SF-01-647	CYC TRITON NATIONALS	KNOX/ #6	5	28-Sep-01	11:00	13:00
SF-01-655	CYC TRITON NATIONALS	KNOX/ #6	5	29-Sep-01	11:00	13:00
SF-01-660	CYC TRITON NATIONALS	KNOX/ #6	5	30-Sep-01	11:00	13:00
SF-01-789	Opening Day on San Francisco Bay	Along Northern shore of San Francisco	1	29-Apr-01	10:00	14:00
SF-01-003	OYC SUNDAY BRUNCH SERIES	ESTUARY/ #9	6	7-Jan-01	11:00	14:30
SF-01-017	OYC SUNDAY BRUNCH SERIES	ESTUARY/ #9	6	21-Jan-01	11:00	14:30
SF-01-031	OYC SUNDAY BRUNCH SERIES	ESTUARY/ #9	6	4-Feb-01	12:30	14:30
SF-01-047	OYC SUNDAY BRUNCH SERIES	ESTUARY/ #9	6	18-Feb-01	12:30	14:30
SF-01-065	OYC SUNDAY BRUNCH SERIES	ESTUARY/ #9	6	4-Mar-01	12:30	14:30

Figure 6. Snapshot of Marine Event List for 2001

Figure 7. Example of Regatta Modeling

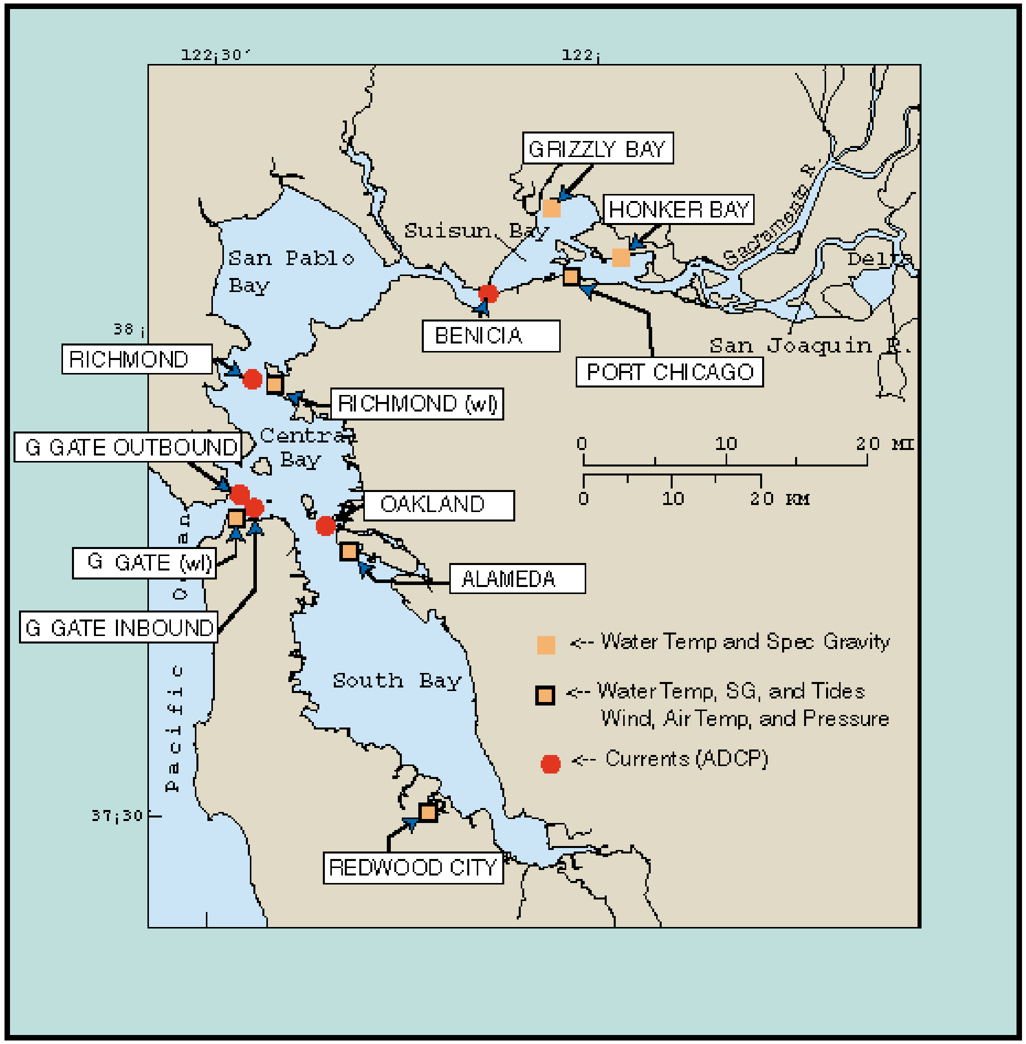

Figure 8. Weather Observation Stations in San Francisco Bay Area

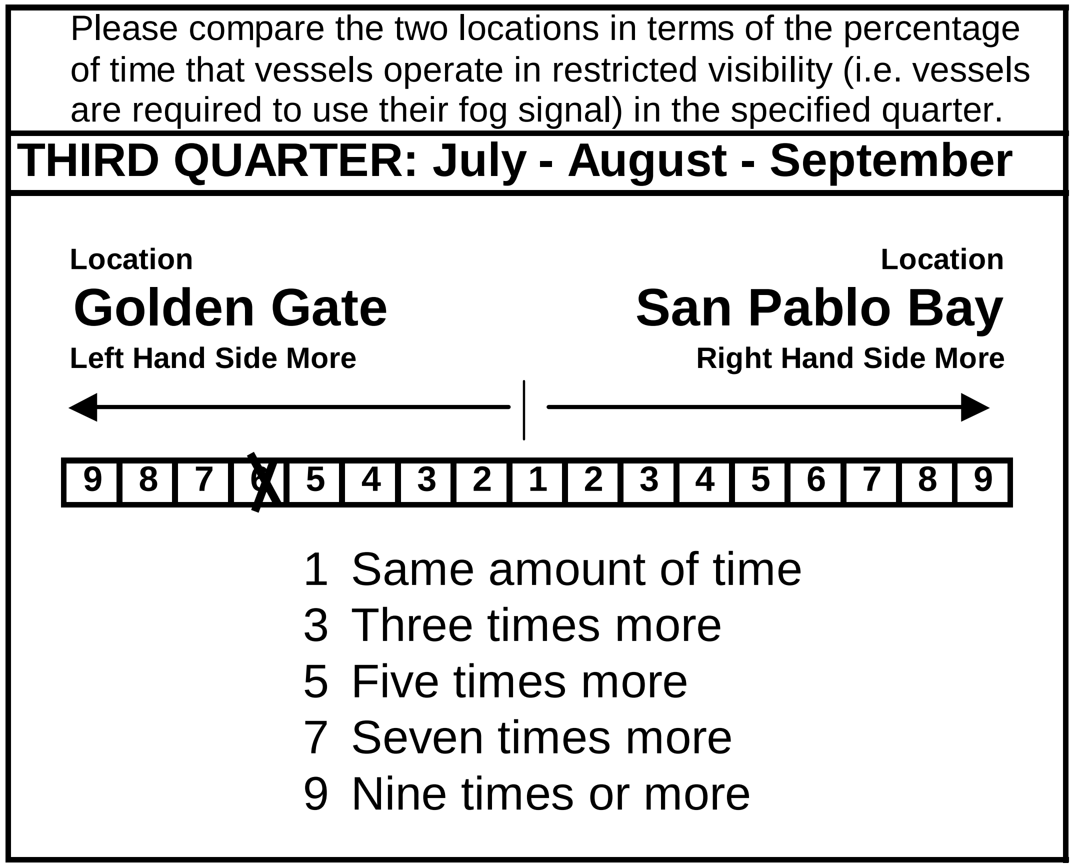

Figure 9. Example of Pairwise Comparison Question Format

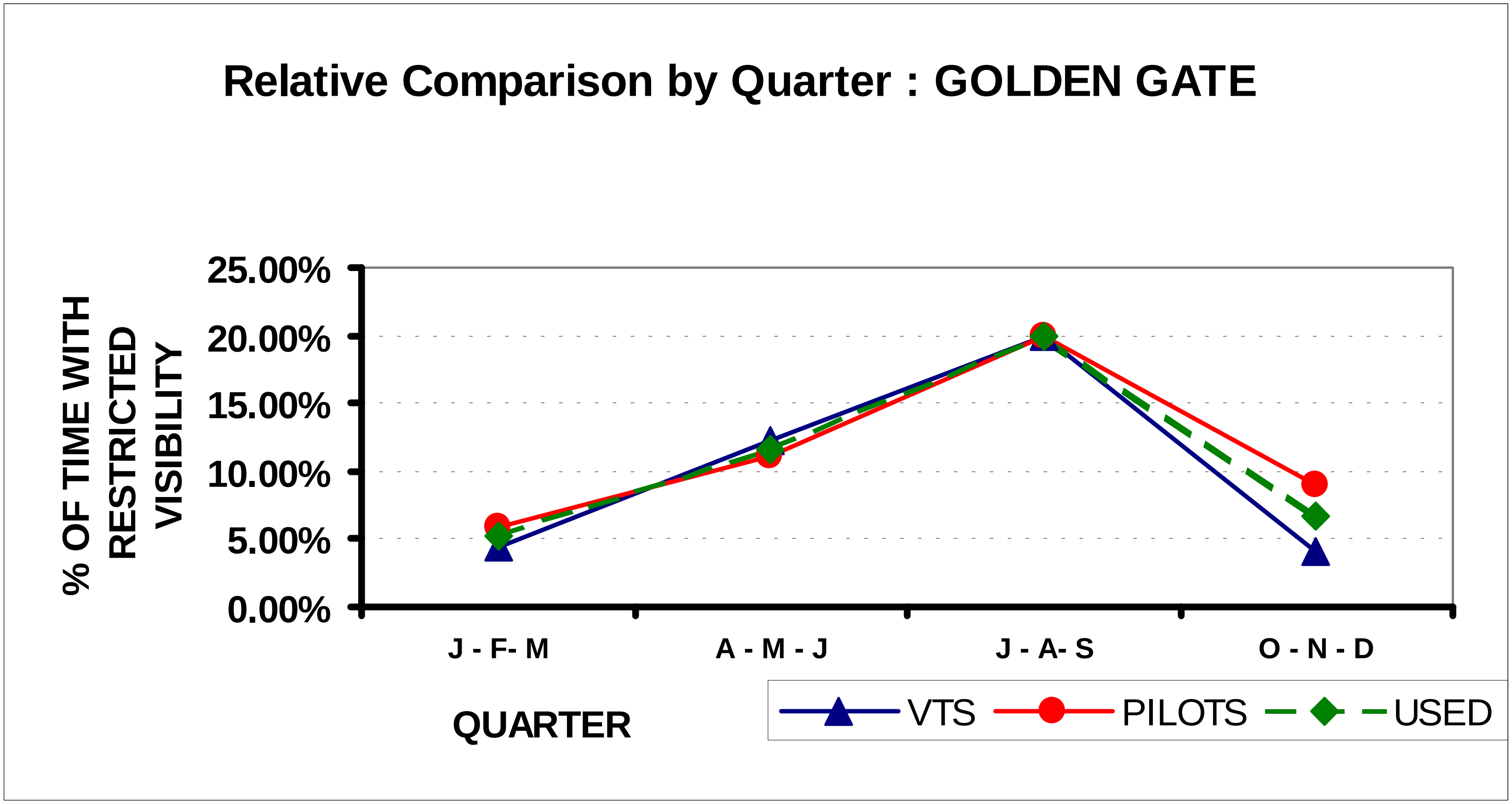

Figure 10. Results for Percentage of Time Restricted Visibility in the Location Golden Gate by Quarter

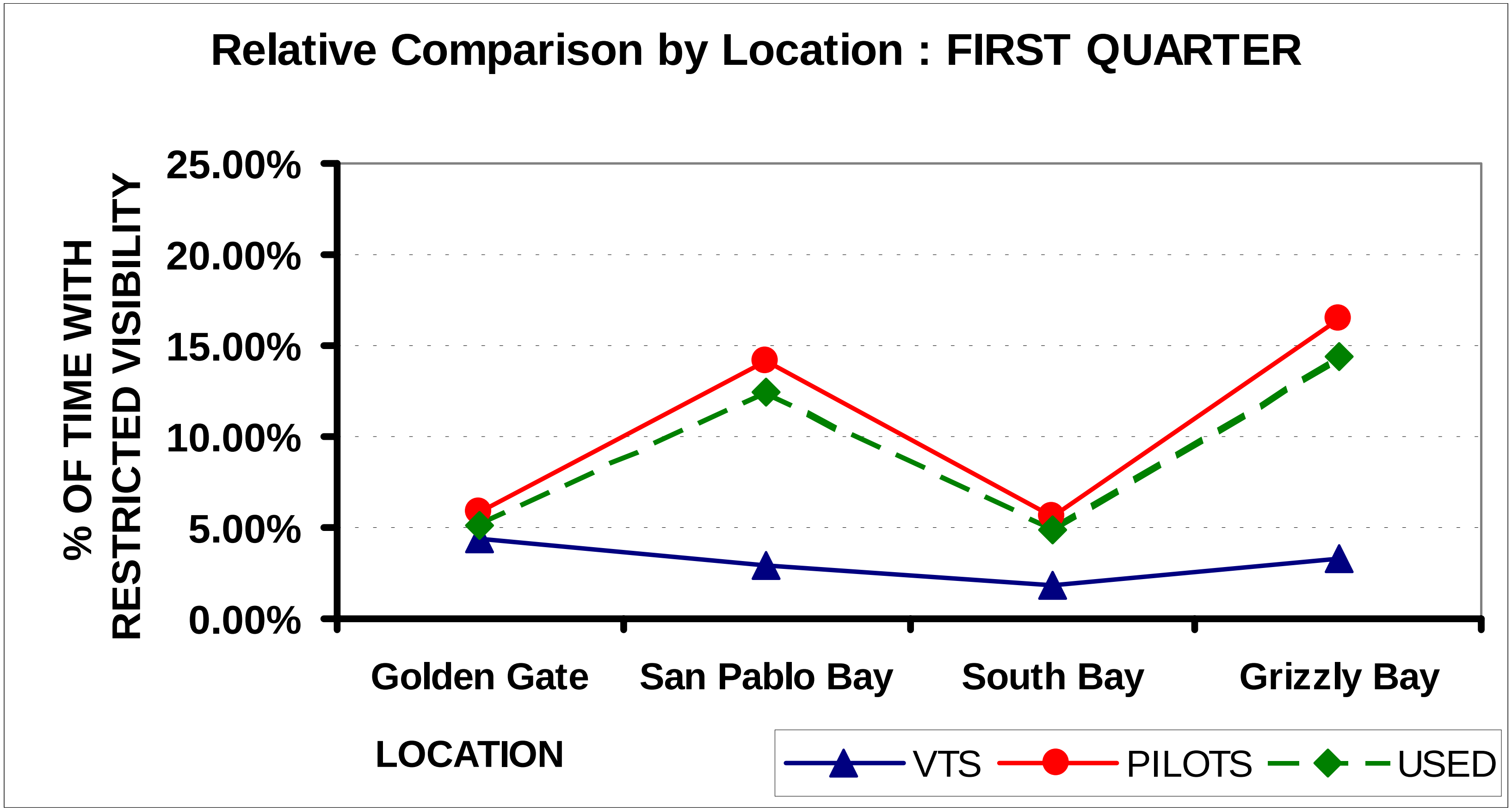

Figure 11. Results for Percentage of Time Restricted Visibility in the First Quarter of the Year by Location

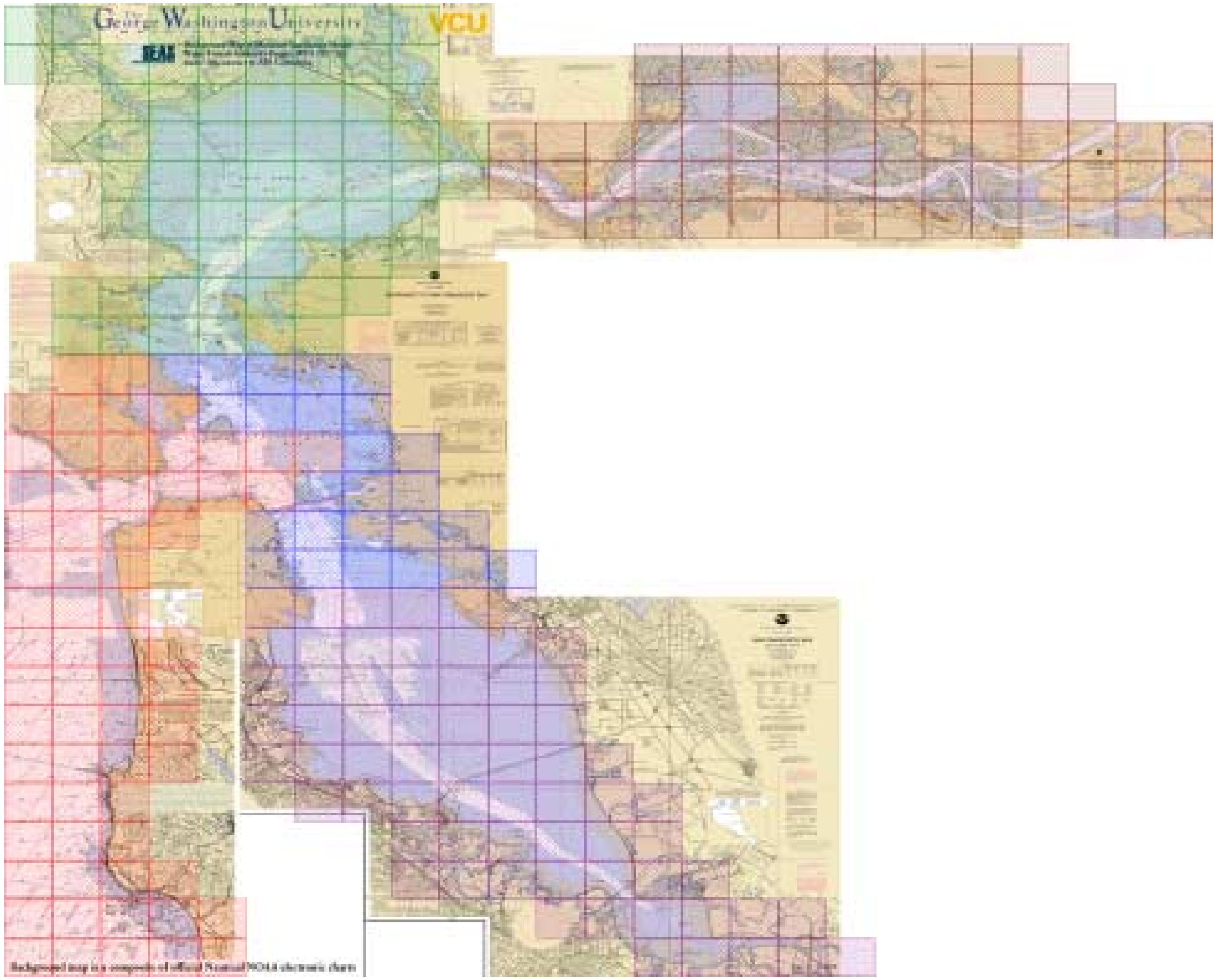

Figure 12. Definition of Visibility Locations

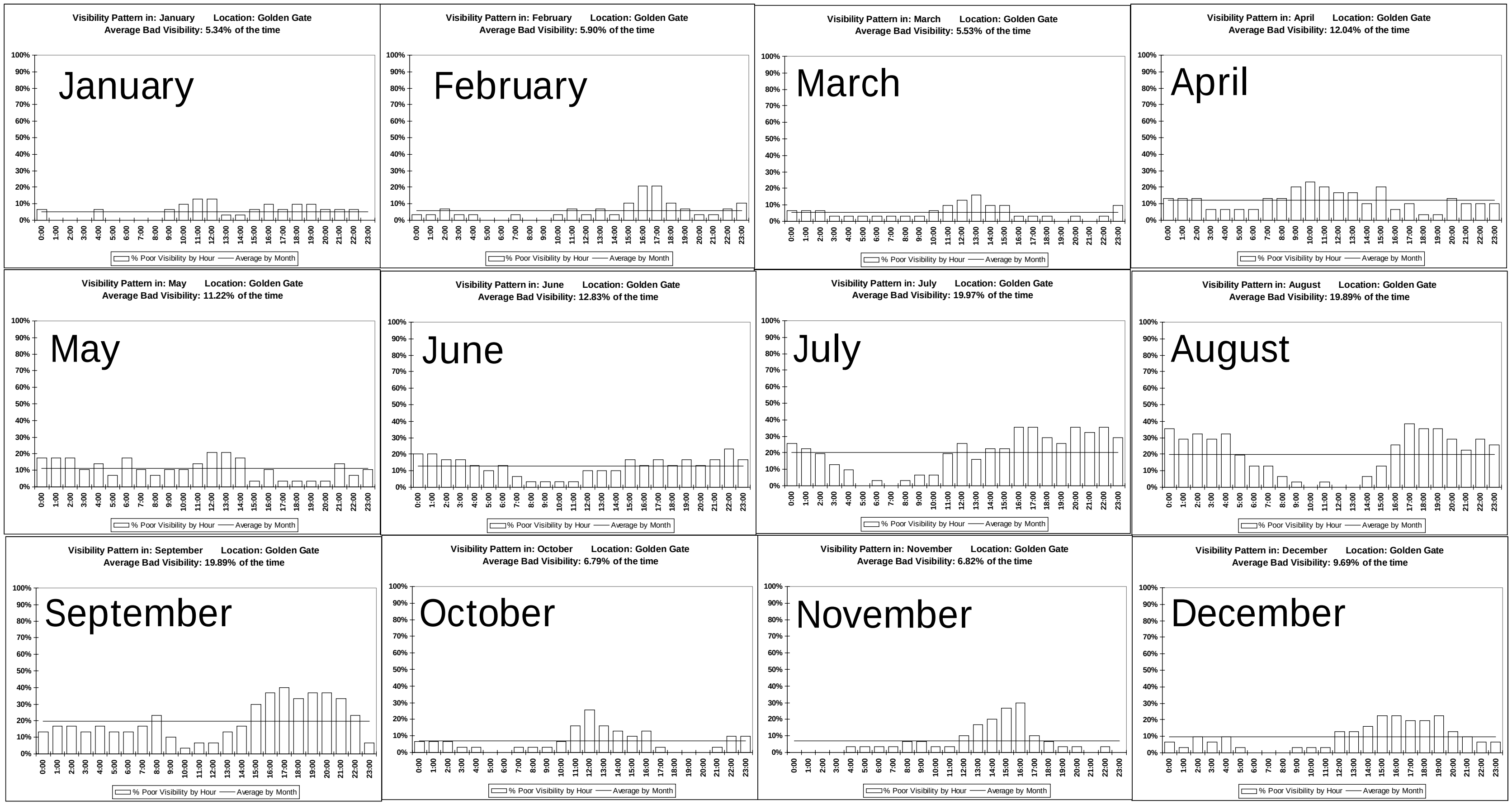

Figure 13. Hourly Percentages of Restricted Visibility for the Location Golden Gate by Month

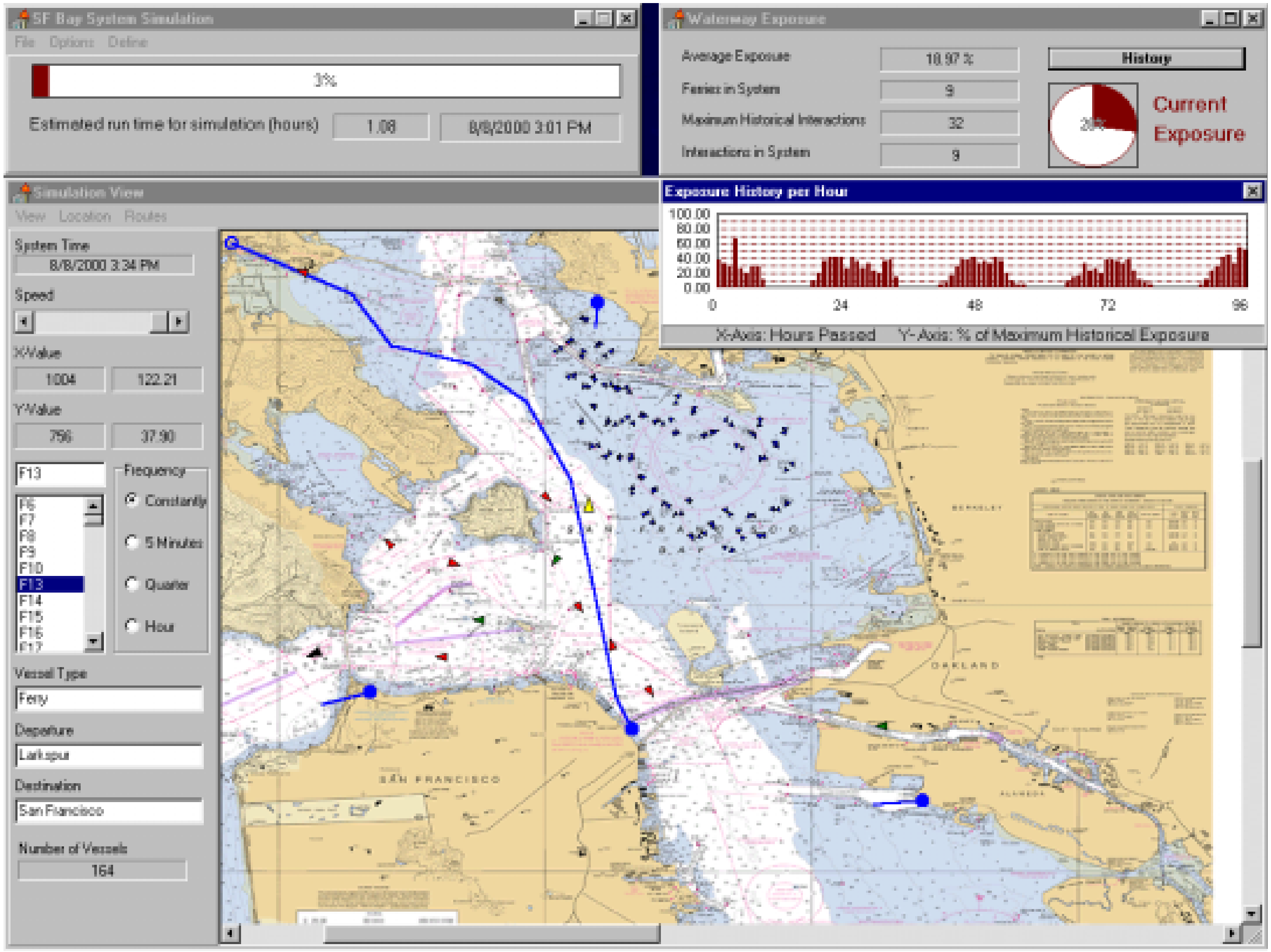

Figure 14. A Snapshot of the SF Bay Maritime Simulation Model

Interaction Counting Model - < 1/2 Mile

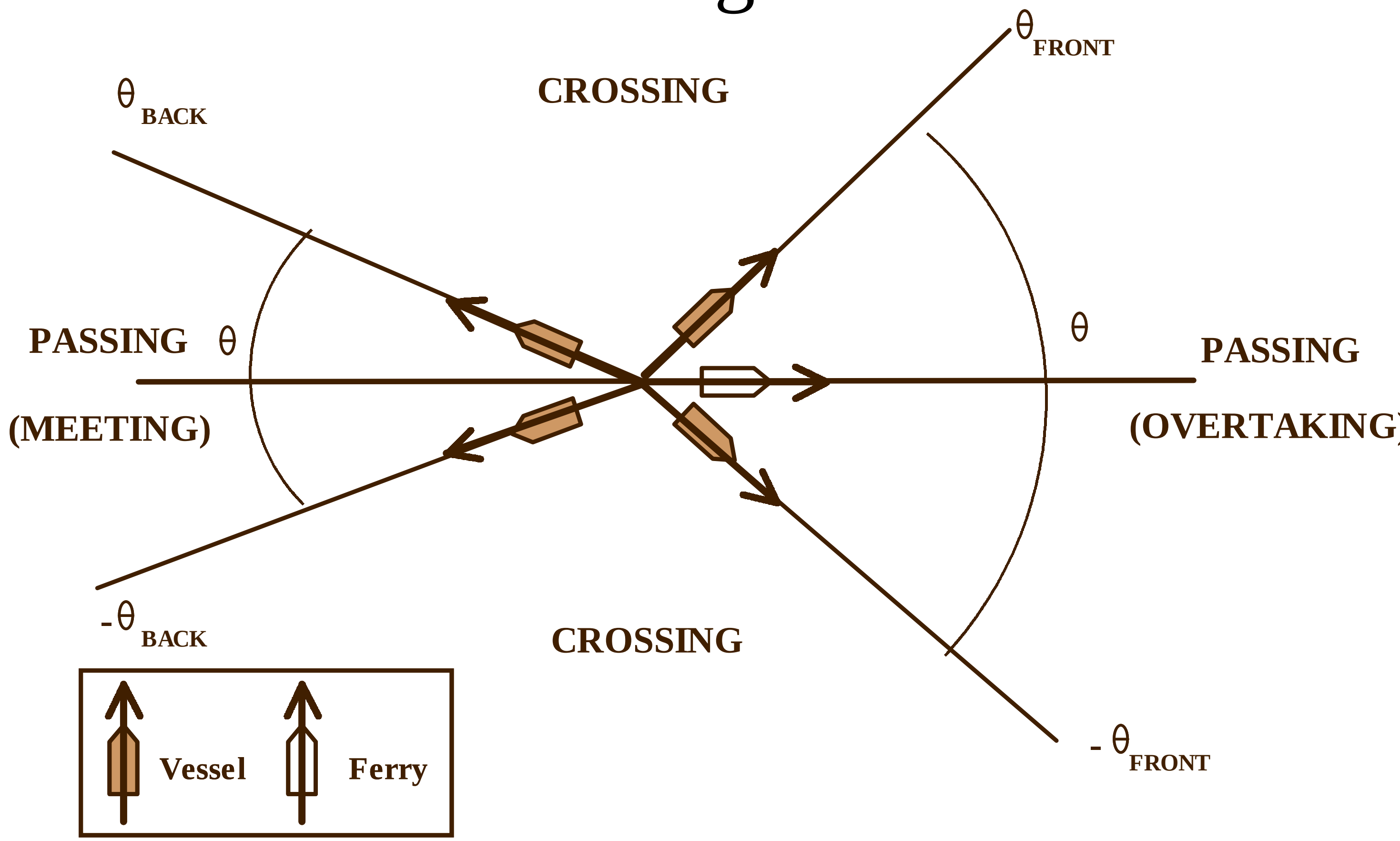

Figure 15. The Type of Interaction defined by Interacting Angle