A Traffic Density Analysis of Proposed Ferry Service Expansions in San Francisco Bay Utilizing Maritime Simulation

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Introduction

• To relieve congestion on highways, the state of California is proposing to expand ferry operations on San Francisco (SF) Bay by
  - phasing in up to 100 ferries in addition to the 14 currently operating,
  - extending the hours of operation of the ferries,
  - increasing the number of crossings
  - employing some high-speed vessels.

San Francisco Bay Water Transit Authority (WTA) is tasked to investigate whether this can be done in a safe manner?
Three Future Ferry Service Scenarios

- Alternative 3: Enhanced Existing System (Least Aggressive Expansion)
- Alternative 2: Robust Water Transit System
- Alternative 1: Aggressive Water Transit System (Most Aggressive Expansion)

WTA asked us (GWU-VCU) to build a Maritime Simulation to help address the safety question.
Maritime System Simulation

1. Traffic Arrivals Simulation
2. Weather Simulation

Maritime Discrete Event System Simulation

Traffic Rules
A Snapshot of the SF Bay Maritime Simulation

Simulation View

System Time: 8/12/2001 3:37 PM

Speed:
- Value: 365, 122.46
- Value: 1082, 37.77

Frequency:
- Constantly
- 5 Minutes
- Quarter
- Hour

Number of Vessels: 125

Estimated run time for simulation (hours): 0.73
Date: 8/12/2001 3:01 PM
Outline

- Building the Simulation (Modeling Traffic)
- Building the Simulation (Modeling Weather)
- Counting Interactions in a Maritime Simulation
- Results
  - Base Case
  - Alternatives 1, 2 and 3
Building a Base Case Simulation

• We Need:
  - Map of the study area
  - Ferry schedules and Ferry Routes
  - Traffic data from the VTS
  - Vessel track data from the VTS
  - Environmental data - wind, visibility.

• We need:
  - Small vessel data - Regatta Events
    (Particularly their locations in lat long coordinates)
Building the Simulation
(Modeling Traffic)
Map of the Study Area

- This map was created by converting NOAA electronic charts to bitmap format and by connecting them together.
Current and Future Ferry Schedules

- Base Case = Year 2000 Ferry Schedules (collected from Ferry Operators)
- Spreadsheets for Alternatives 1, 2 and 3 were supplied by URS Corporation

### Alternative 3 - Enhanced (Existing) Water Transit System

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<thead>
<tr>
<th>Corridor</th>
<th>Route</th>
<th>Vessel Type</th>
<th>Speed (Knots)</th>
<th>Headways</th>
<th>Sailing Time</th>
<th>Idle Time</th>
<th>Sailing Time</th>
<th>Idle Time</th>
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<th>Weekday Trips</th>
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DATE: 9-Apr-02
Ferry Schedules

- The spreadsheets were edited to match up with the routes in the simulation.

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<th>Route</th>
<th>From</th>
<th>To</th>
<th>Weekday Every</th>
<th>Weekend Every</th>
<th>From</th>
<th>To</th>
<th>Hours</th>
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<td>21:00</td>
<td>15</td>
<td>7</td>
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</tbody>
</table>

- VBA programs were written to create arrivals databases suitable for the simulation program.
Ferry Routes Developed by URS Corporation
Piecing URS MAP on top of NOAA Collage
Other Large Maritime Traffic

- Detailed Vessel Arrival and Departure Data for Multiple Years from VTS San Francisco:
  - Vessel Class
  - Arrival Time into Study Area (Time, Day and Month)
  - Origin and Destination
  - Vessel Route (or Way Points)

- VTS Waypoints data
  - 2001 data was used as the primary source
  - Augmented by 2000 data
  - 99.5% of traffic could be matched to a waypoint defined route
  - Remaining 0.5% had missing departure and destination point information
Example of Vessel Routes (LPG Carriers)

• Routes like the one shown were created using way points data supplied by SF VTS
Regatta Events

- The USCG supplied their Marine Event List

<table>
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<tr>
<th>EVENT NUMBER</th>
<th>EVENT</th>
<th>LOCATION</th>
<th>Sailing_Area</th>
<th>DATE</th>
<th>Start_Time</th>
<th>End_Time</th>
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</table>
Regatta Events

- The areas were matched up with maps supplied by Lieutenant Black and Stacey Shonk.
Comparison WSF Simulation to SF Bay Simulation

- Washington State
  - 13 Ferry Routes
  - 100 Routes for other VTS Traffic
  - No Special Events

- San Francisco Bay
  - 18 Ferry Routes (Base). 68 Ferry routes (Alternative 1)
  - 6000 Routes for other VTS Traffic
  - 1000 Special Events

COMPLEXITY DIFFERS BY ORDER OF MAGNITUDE!
Kudos To SF VTS!

- Without their help, efficient and timely response to our repeated questions and data requests we would have been pulling our hair out.
Building the Simulation
(Modeling Restricted Visibility)
Environmental Data

- Study Area has been divided into five separate zones to determine visibility pattern.
- Divisions made based on differences in visibility pattern noted in the Coast Pilot and data availability.
- Sea Visibility is generated using meteorological model utilizing Water Temp and Air Temp.
Environmental Data - Wind

• Hourly Wind direction and Speed Data
  - Golden Gate  1/1998 - 12/2001
  - Port Chicago  1/1998 - 12/2001
  - Redwood City  1/1998 - 12/2001
  - Richmond  1/1998 - 12/2001
  - Alameda  1/1998 - 12/2001
Environmental Data

- San Francisco International Airport
  - Hourly Air Temperature 1990-1995
  - Hourly Land Visibility 1990-1995
  - Hourly Dew Point 1990-1995
Sea Visibility Model

\[ W = \text{Water Surface Temperature (Celsius)} \]
\[ D = \text{Dewpoint Temperature (Celsius)} \]
\[ \Delta = W - D \]

\[
\begin{align*}
\text{Visibility} &= \begin{cases} 
\text{Good,} & \Delta \leq 0°C \\
\text{Bad,} & \Delta > 0°C 
\end{cases} 
\end{align*}
\]

Good = More than 0.6 miles
Bad = Less than 0.6 miles

Environmental Data - VISIBILITY

- Hourly Air and Water Temperature Data
  - Golden Gate  1/1998 - 12/2001
  - Port Chicago  1/1998 - 12/2001
  - Redwood City  1/1998 - 12/2001
  - Richmond  1/1998 - 12/2001
  - Alameda  1/1998 - 12/2001

Hourly Dew Point Data is not available for this time period and for these locations!
Calculation of Dew Point Temp.

• Used SFO Dew Point Data:

6 year averages of Dew points were calculated over the period from 1990-1995 per month and by an air temperature range of two degrees. These averages were used to convert 1998-2001 air temperature data to dew point data.

• For example: Average dew point for August was 13 in 1990-1995 when air temperature was between 14-16 degrees Celsius. An air temperature in August 1998 of 15 degrees would therefore be converted to a dew point of 13.
Visibility Model - Calibration

- To ensure the model more closely reflects restricted visibility conditions (mariners are required to use their fog signals) a calibration constant was be added for each month and location

\[
\text{Visibility} = \begin{cases} 
\text{Good, } & ? \leq k^\circ C \\
\text{Bad, } & ? > k^\circ C 
\end{cases}
\]
Calibrate to Sample Coast Pilot Data

Location Golden Gate:

- August: Fog signals operate 15-20% of the time in Golden Gate
- March and April, fog signals operate about 7-10% of the time.

WHAT ABOUT THE OTHER MONTHS?
WHAT ABOUT THE OTHER LOCATIONS?
Visibility Model Results

Visibility Pattern in: August        Location: Golden Gate
Average Bad Visibility: 19.89% of the time
Visibility Model

• To calibrate the percentage of times restricted visibility conditions occur within each location, information from the Coast Pilot 2000 was combined with expert judgment elicited using the Analytical Hierarchy Process technique.

Please compare the two locations in terms of the percentage of time that vessels operate in restricted visibility (i.e. vessels are required to use their fog signal) in the specified quarter.

THIRD QUARTER: July - August - September

<table>
<thead>
<tr>
<th>Location</th>
<th>Golden Gate</th>
<th>Location</th>
<th>San Pablo Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Hand Side More</td>
<td>Right Hand Side More</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 9 Same amount of time
- 8 Three times more
- 7 Five times more
- 6 Seven times more
- 5 Nine times or more
Visibility Model

• There was remarkable agreement between the VTS Operators and the SF Bar Pilots regarding visibility conditions at Golden Gate.

Relative Comparison by Quarter : GOLDEN GATE

% OF TIME WITH RESTRICTED VISIBILITY

QUARTER

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There was some level of disagreement regarding visibility conditions in the first quarter of the year.

Relative Comparison by Location: FIRST QUARTER

- Golden Gate
- San Pablo Bay
- South Bay
- Grizzly Bay

% of Time with Restricted Visibility

- VTS
- Pilots
- Used
Visibility Model

- Estimated Percentages of Time that Restricted Visibility Occurs by Quarter and by Location

<table>
<thead>
<tr>
<th>Location</th>
<th>First Quarter J - F - M</th>
<th>Second Quarter A - M - J</th>
<th>Third Quarter J - A - S</th>
<th>Fourth Quarter O - N - D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Golden Gate</td>
<td>5.17%</td>
<td>11.66%</td>
<td><strong>20.00%</strong></td>
<td>6.69%</td>
</tr>
<tr>
<td>San Pablo Bay</td>
<td>12.38%</td>
<td>6.17%</td>
<td>6.30%</td>
<td>9.62%</td>
</tr>
<tr>
<td>Alameda</td>
<td>7.49%</td>
<td>7.61%</td>
<td>10.61%</td>
<td>7.02%</td>
</tr>
<tr>
<td>South Bay</td>
<td>4.92%</td>
<td>5.00%</td>
<td>5.53%</td>
<td>4.74%</td>
</tr>
<tr>
<td>Grizzly Bay</td>
<td>14.40%</td>
<td>5.17%</td>
<td>5.34%</td>
<td>11.06%</td>
</tr>
</tbody>
</table>
Visibility Model Results - GOLDEN GATE 2000

Visibility Pattern in: January  Location: Golden Gate
Average Bad Visibility: 5.34% of the time

Visibility Pattern in: February  Location: Golden Gate
Average Bad Visibility: 11.22% of the time

Visibility Pattern in: March  Location: Golden Gate
Average Bad Visibility: 12.83% of the time

Visibility Pattern in: April  Location: Golden Gate
Average Bad Visibility: 19.89% of the time

Visibility Pattern in: May  Location: Golden Gate
Average Bad Visibility: 6.79% of the time

Visibility Pattern in: June  Location: Golden Gate
Average Bad Visibility: 19.97% of the time

Visibility Pattern in: July  Location: Golden Gate
Average Bad Visibility: 5.53% of the time

Visibility Pattern in: August  Location: Golden Gate
Average Bad Visibility: 12.04% of the time

Visibility Pattern in: September  Location: Golden Gate
Average Bad Visibility: 5.90% of the time

Visibility Pattern in: October  Location: Golden Gate
Average Bad Visibility: 6.82% of the time

Visibility Pattern in: November  Location: Golden Gate
Average Bad Visibility: 5.34% of the time

Visibility Pattern in: December  Location: Golden Gate
Average Bad Visibility: 5.65% of the time

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Locations in Visibility Model
Building the Simulation
(Counting Interactions)
Risk During Interactions

- PWS = 5 minutes
- WSF = 2.5 minutes
- SF Bay = 1 minute
Simulation Counting - Crossing

Vessel 1/2 hour 1 mile
Ferry 1/2 mile
Simulation Counting - < 1/2 Mile

CROSSING

θ\_FRONT

θ\_BACK

θ\_BACK

Vessel

Ferry

© GWU - VCU 2003
Format of Output Results

% of Max Exposure

X%  
Y%  
Z%  
Etc.
Simulation Analysis Results (Base Case, Alternative 1,2,3)
## Overall Comparisons

<table>
<thead>
<tr>
<th></th>
<th># Ferry Transits</th>
<th># Grid Cells Covered</th>
<th># Interactions</th>
<th>% Base Case Interactions in 20% of Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>97%</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>1228%</td>
<td>233%</td>
<td>4620%</td>
<td>4500%</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>365%</td>
<td>116%</td>
<td>624%</td>
<td>600%</td>
</tr>
<tr>
<td>Alternative 1</td>
<td>1559%</td>
<td>240%</td>
<td>8359%</td>
<td>8200%</td>
</tr>
</tbody>
</table>

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# Transits vs. # Interactions

SF Bay Maritime Simulation

% of Base Case Ferry Transits

% of Base Case Interactions

© GWU - VCU 2003
Base Case
Base Case

52.59% of Total Base Case Interactions
Alternative 3

372 48% of Total Base Case Interactions
Alternative 2

Scenario: Alternative 2  Period: 2000

Date: 7-9-02

% of Max Exposure in
Factor X Average Exposure in:

Base Case

500% 400% 300% 200% 100% 50% 0% 0-11.146 % 11.146 - 22.292 % 22.292 - 33.438 % 33.438 - 44.584 % 44.584 - 55.730 % 55.730 - 66.876 % 66.876 - 78.022 % 78.022 - 89.168 % 89.168 - 100.000 %

% of Base Case Grid Cells

- Base Case
- Alternative 2

1,705,32% of Total
Base Case

Background map is a composite of officialNautical NOAA electronic charts.

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Alternative 1

Scenario: Alternative 1  Period: 2000

Date: 7 - 10 - 02

% of Max Exposure in Base Case

<table>
<thead>
<tr>
<th>% of Max Exposure in Base Case</th>
<th>Factor X Average Exposure in Base Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 - 24572 %</td>
<td>5.63</td>
</tr>
<tr>
<td>9.48 %</td>
<td>5.63</td>
</tr>
<tr>
<td>7.37 %</td>
<td>4.38</td>
</tr>
<tr>
<td>6.11 %</td>
<td>3.63</td>
</tr>
<tr>
<td>5.21 %</td>
<td>3.09</td>
</tr>
<tr>
<td>4.51 %</td>
<td>2.67</td>
</tr>
<tr>
<td>3.93 %</td>
<td>2.33</td>
</tr>
<tr>
<td>3.43 %</td>
<td>2.04</td>
</tr>
<tr>
<td>3.00 %</td>
<td>1.78</td>
</tr>
<tr>
<td>2.62 %</td>
<td>1.56</td>
</tr>
<tr>
<td>2.28 %</td>
<td>1.35</td>
</tr>
<tr>
<td>1.97 %</td>
<td>1.17</td>
</tr>
<tr>
<td>1.68 %</td>
<td>1.00</td>
</tr>
<tr>
<td>1.42 %</td>
<td>0.84</td>
</tr>
<tr>
<td>1.18 %</td>
<td>0.70</td>
</tr>
<tr>
<td>0.95 %</td>
<td>0.57</td>
</tr>
<tr>
<td>0.74 %</td>
<td>0.44</td>
</tr>
<tr>
<td>0.54 %</td>
<td>0.32</td>
</tr>
<tr>
<td>0.35 %</td>
<td>0.21</td>
</tr>
<tr>
<td>0.17 %</td>
<td>0.10</td>
</tr>
<tr>
<td>0.00 %</td>
<td>0.00</td>
</tr>
</tbody>
</table>

2,745.90% at least three times interactions

% of Base Case Grid Cells

- Base Case
- Alternative 1

Background map is a composite of official Nautical NOM electronic charts.
Alternative 1

2.745.90% of Total Base Case Interactions
Base Case in Bad Visibility
Base Case in Bad Visibility

6.57% of Total Base Case Interactions
Alternative 3 in Bad Visibility
Alternative 3 in Bad Visibility

57.92% of Total Base Case Interactions
## Comparisons: Restricted Visibility

<table>
<thead>
<tr>
<th></th>
<th># Ferry Transits</th>
<th># Grid Cells Covered</th>
<th># Interactions</th>
<th>% Base Case Interactions in Red Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>53%</td>
</tr>
<tr>
<td>Base Case - BVI</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>73%</td>
<td>16%</td>
<td></td>
<td>6.6%</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>365%</td>
<td>116%</td>
<td>624%</td>
<td>372%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6.2 X</td>
<td>7.0 X</td>
</tr>
<tr>
<td>Alternative 3 - BVI</td>
<td>91%</td>
<td>110%</td>
<td></td>
<td>58%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6.9 X</td>
<td>8.8</td>
</tr>
</tbody>
</table>
Conclusion

The results seem to indicate that the safety levels currently enjoyed by the SF Bay ferry service cannot be maintained under the planned expansion scenarios without equally aggressive investment in risk intervention.
Recommendations

• Conduct **Probabilistic Risk Assessment** of SF Bay Ferry Service (i.e. analyze accident risk, not just interactions)

• Consider the Ferry Service as an **Maritime Transportation System**, not an individual collection of Ferry Routes
  a. Design a Ferry Route System (using traffic separation)
  b. Design a Ferry Schedules that distribute the arrivals and departures at major terminals

• Develop **additional risk intervention measures** that reduce the accident probability on a per interaction basis

• Test the **effectiveness** of these measures using the **Maritime Extended Simulation Risk Model**
Maritime Risk Assessment Links

- Maritime Risk Assessment Links
  - http://www.seas.gwu.edu/~dorpjr
  - http://www.people.vcu.edu/~jrmerrick

- Available for downloading
  - Journal Papers, Proceedings, Reports
  - SF Bay Simulation Movies
QUESTIONS?