Evaluation of Loran Performance as a DGPS Backup System in the HEA Domain

Using a Target Level of Safety Criterion

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Overview

- In a series of USCG efforts from 1997 – 2002 the maritime performance of DGPS and specified backup systems was analyzed in terms of the Target Level of Safety (TLS).
- Of the backup systems considered, Loran was the only one that consistently satisfied the TLS criterion for a variety of harbor entrance and approach conditions.

Background

- USCG sponsored these studies with the goal of determining
  - The conditions under which DGPS satisfies the Target Level of Safety
    - placement and reliability of DGPS beacon stations
    - degree of visibility
    - vessel type
    - relative navigational risk of harbor channel
  - The type of DGPS backup systems needed for maritime navigation
    - onboard (marine radar, INS)
    - external
      - electronic, e.g., Loran-C
      - visual, e.g., short-range aids

The Target Level of Safety (TLS) Criterion

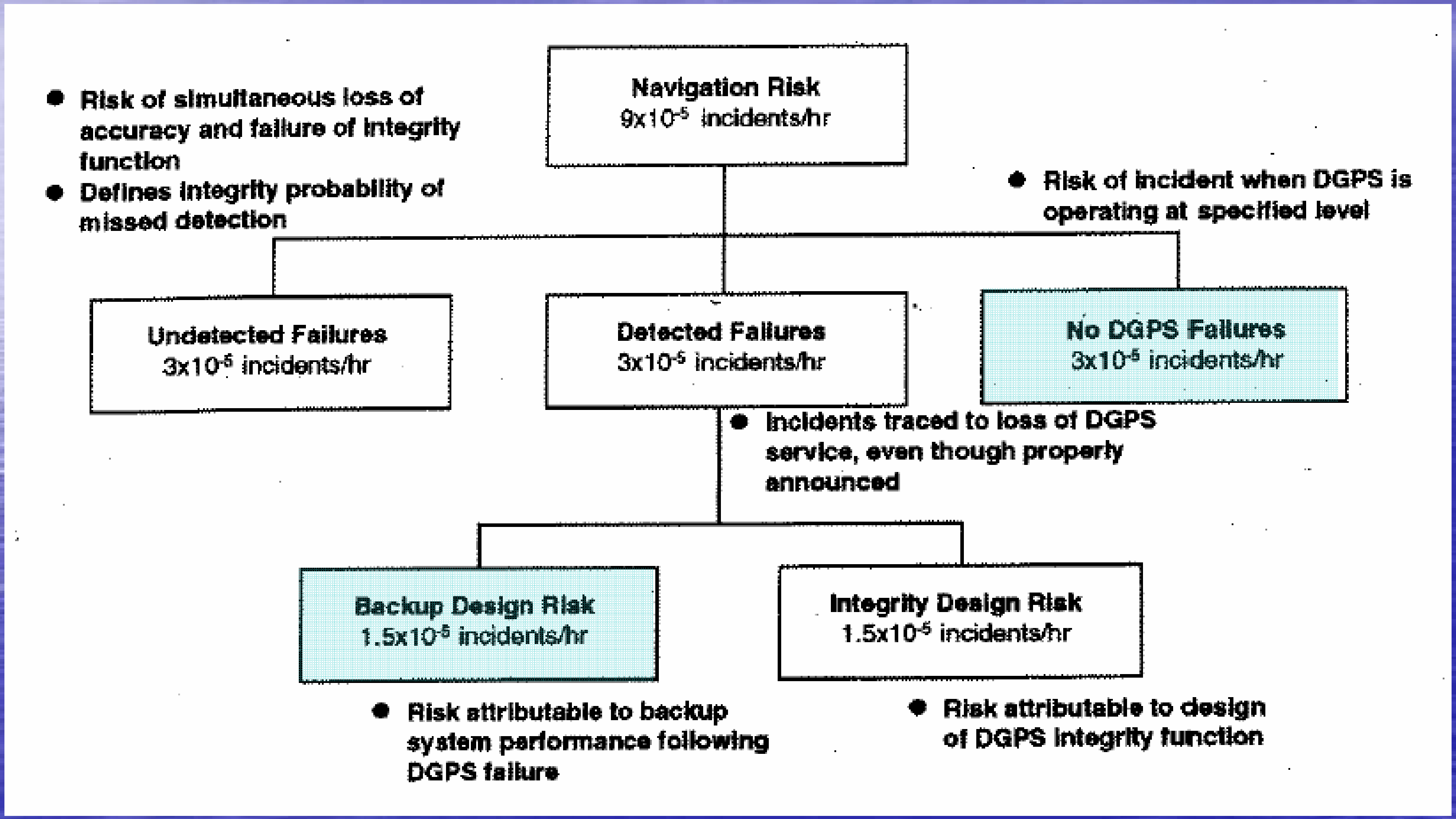
- The comprehensive *Port Needs Study* was consulted to determine the incident* rate/ship-hour in ports and harbors used by larger vessels in CONUS (>10,000 gross tons)
  - Total Incident Rate = 3×10^{-4} incidents/ship-hour
- Based on the categories used to classify incidents, those resulting from navigational errors were approximately 30% of the total
  - Incident Rate due to navigation errors
    = 9×10^{-5} incidents/ship-hour

* An incident is defined as a grounding or allision

The Target Level of Safety (TLS) Criterion – Risk Allocation

- The risk of incidents resulting from navigational error were allocated using a standard risk tree approach
- The risk allocation for incidents arising from errors resulting from the following mutually exclusive events:
  - "no-fault" DGPS operations (3×10^{-5} inc./hr) **or**
  - backup system operation in the event of a detected DGPS failure (1.5×10^{-5} inc./hr)
- The resulting figure of 4.5×10^{-5} as the probability of an incident/ship-hour is generally referred to as the TLS in subsequent analysis

Risk Allocation



TLS as a Threshold

- Incidents comprising the navigational component of the TLS
  - resulted primarily from short-range aids
- With the advent of electronic aids in the maritime domain
  - more difficult operations (low visibility, ice) could be executed
- As a result, most pilots we interviewed recommended
  - the TLS threshold used to evaluate DGPS performance and backup systems should stay the same, i.e.,

riskier operations compensate for increased accuracy and situational awareness

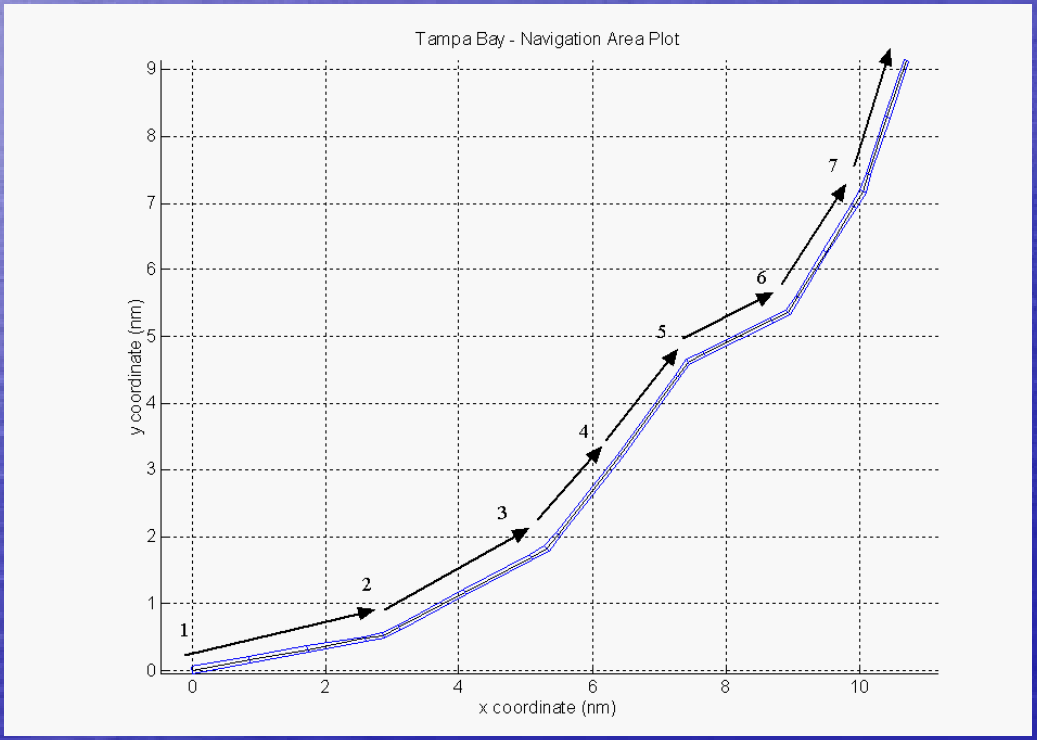
A Decision Aid Tool for System Performance Evaluation

- A system performance evaluation tool, known as the Navigation Aid Analysis Tool (NAAT), was developed as a decision aid for USCG NAVCEN to determine
  - The number and reliability of DGPS beacons required to satisfy the TLS under specified conditions
  - The performance (reliability, availability) of requisite backup navigation systems in the event that DGPS was unable to satisfy the TLS under certain conditions

Application of NAAT to the Comparison of Backup Navigation Systems

- A variety of vessel types was considered, but most emphasis was given to the larger vessels
  - Incidents involving these vessels had more serious financial and environmental consequences
- Oceanographic/Environmental conditions included in the model
  - Current
  - Fog (in terms of visibility)
  - Season/hour (for EM noise level in the LF band)

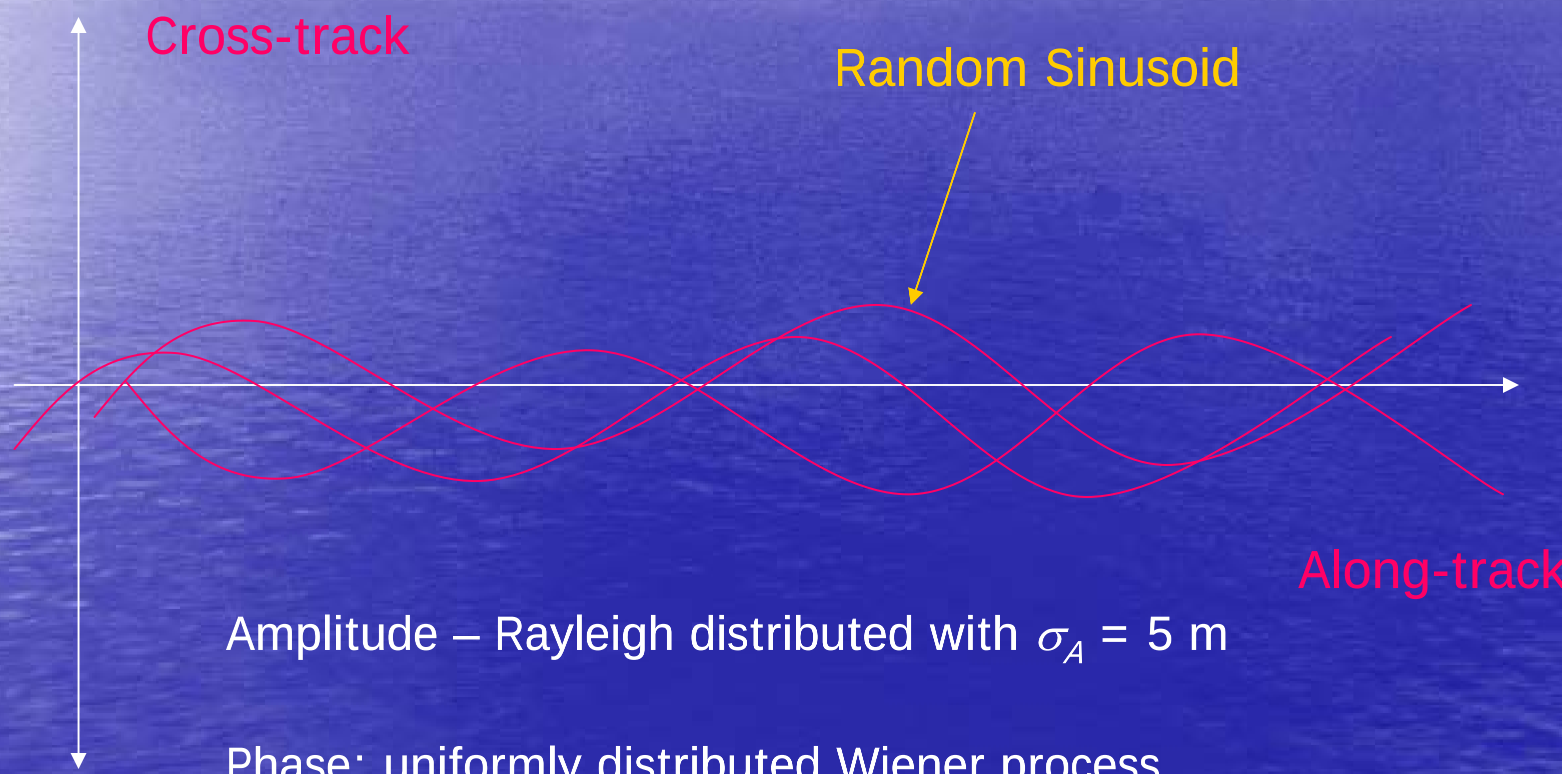
Tampa Bay Channel Plot



Piloting Error Model

- Track-keeping error was determined from data obtained by the Merchant Marine Academy at King's Point.
- Data was Fourier-decomposed and a peak period of 6 minutes was identified
- This random sinusoid of amplitude standard deviation of 4 – 6 meters was combined with the navigation sensor error to form the total error model

Piloting Error Model



Amplitude – Rayleigh distributed with σ_A = 5 m

Phase: uniformly distributed Wiener process

Application of NAAT to the Comparison of Backup Navigation Systems

- Backup navigation systems considered:
  - GPS (no augmentation)
  - Loran-C
  - INS/IMU
  - Marine radar
  - Visual aids
  - User-input navigation system
- Transition from primary to secondary (backup) system
  - Simulated using a Markov state space model
  - Assumes secondary is continuously calibrated by primary while both are available
  - After a certain period of time, secondary reverts to its native accuracy performance

DGPS/Loran Reliability Parameters

System	Reliability Parameters	
Service and Receivers	MTTR	MTBF
	(minutes)	(hours)
DGPS Service	10	1000
GPS Service*	5	900
Radar	30	4000
Loran-C Service - St. Mary's	14	587
Loran-C Service - Tampa Bay	14	587
Receivers**	?	20000

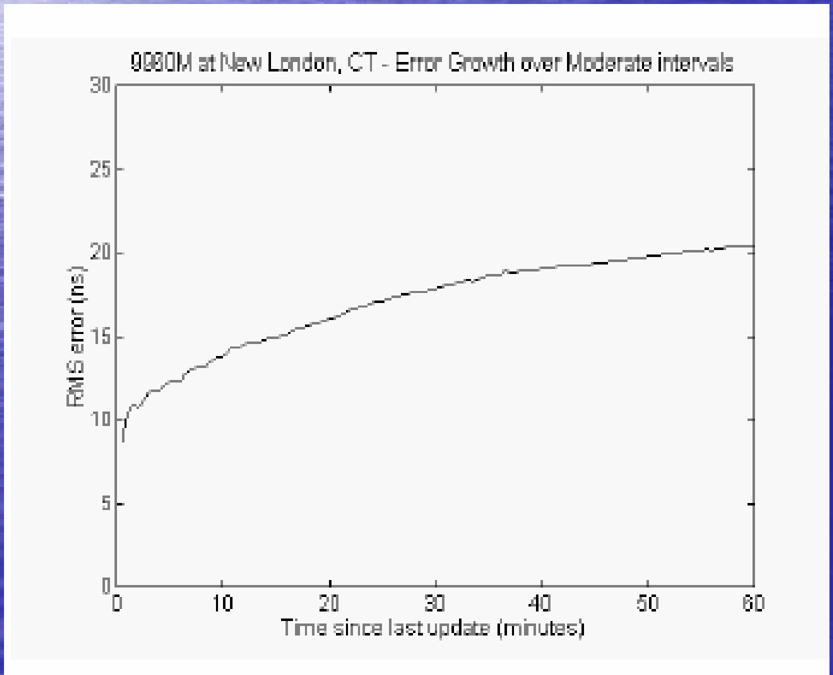
* For GPS interference emulation, MTTR = transit time for waterway

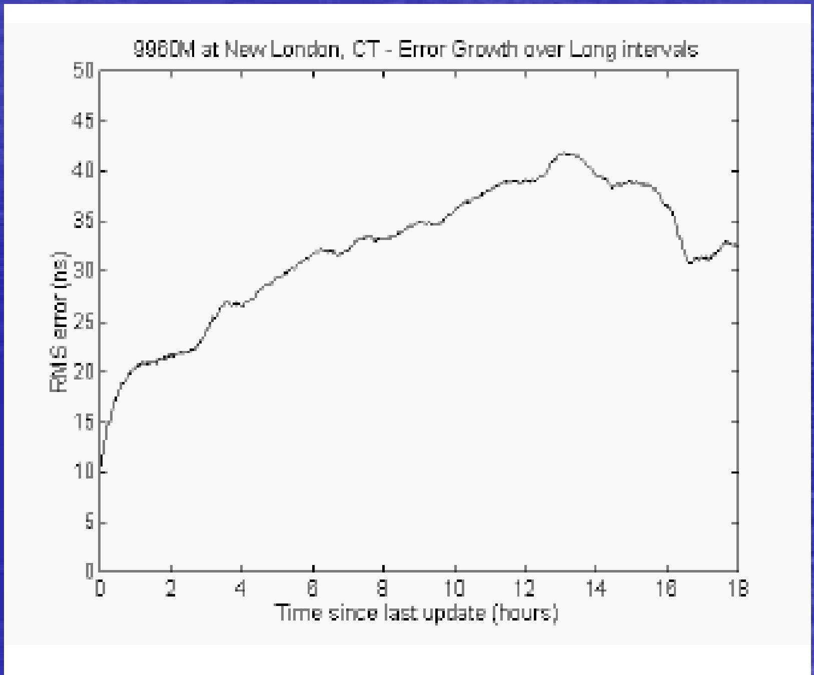
Accuracy/Availability Models

- GPS: 5 – 8 m pseudorange error
  - Availability criterion: HDOP<4 ; 5° mask angle
- DGPS: 10 m $CEP_{95\%}$; 5.8m $CTE_{95\%}$
  - Availability criterion: when GPS is available and the beacon service is available
- Loran-C: Accuracy is a function of location (typically 20 – 50 m $CTE_{95\%}$)
  - Availability criterion: when all Loran stations in the coverage area are available

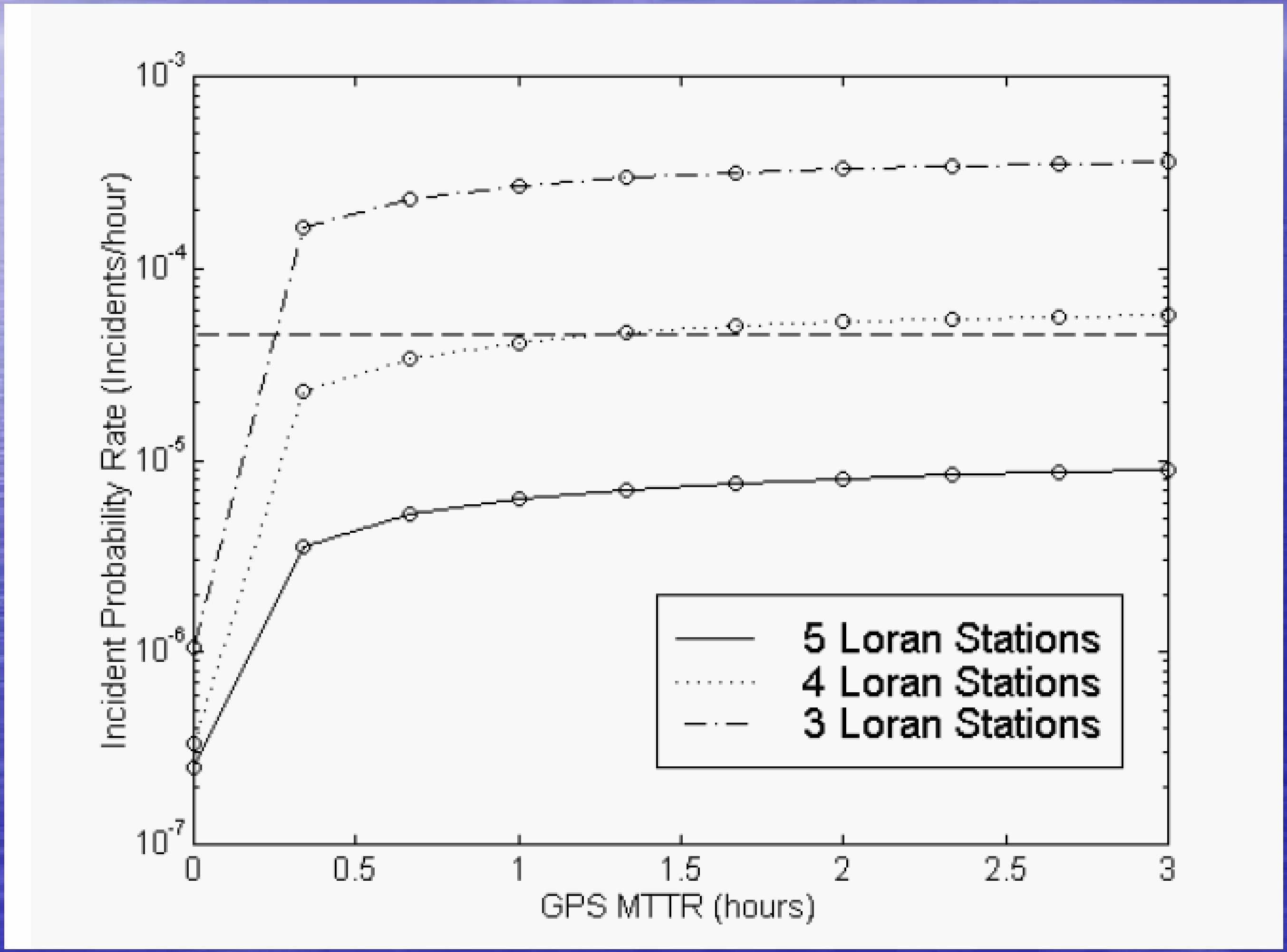
Accuracy-Preserving Characteristics of Loran-C

Loran Coherence Profiles
Seneca, NY to New London, CT





St. Mary's River with Loran as DGPS Backup under GPS Interference Conditions

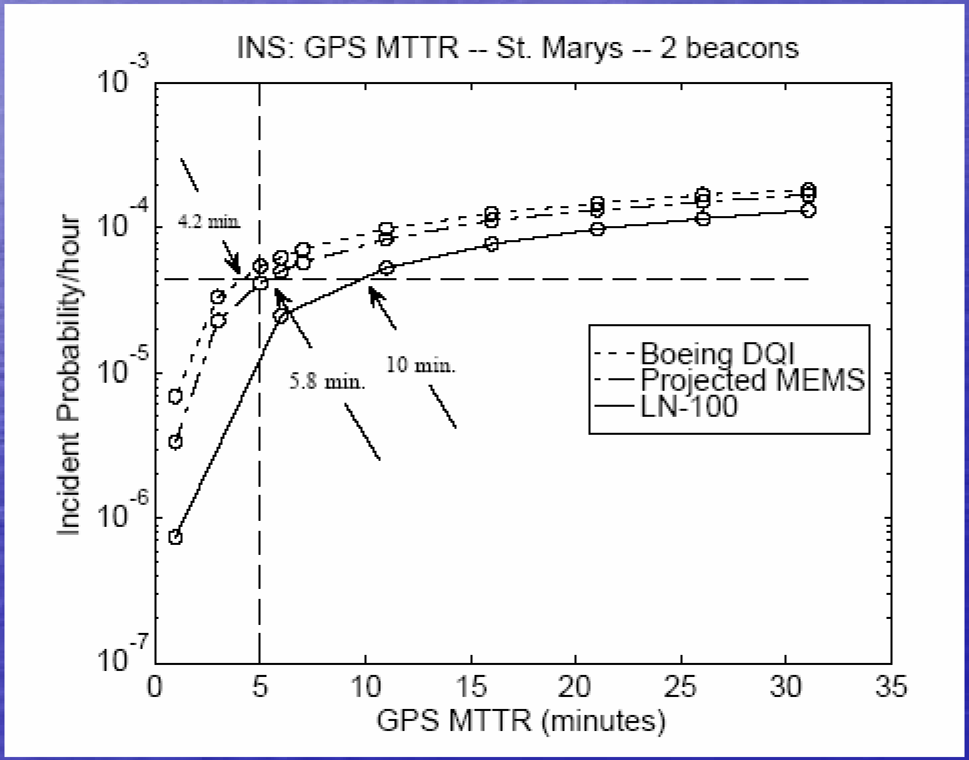


Changing Propagation Conditions

- DGPS is assumed to continuously calibrate Loran while the two systems are available
- What if propagation conditions change following loss of GPS?
- We assume that a future ASF model (embedded in each receiver) continuously monitors the propagation path to each station
  - When the predicted ASFs change by more than a designated threshold, the ASF model will add the change in ASFs to the prior DGPS-calibrated ASF value

Changing Propagation Conditions

St. Mary's River with INS/IMU as DGPS Backup under GPS Interference Conditions



Comparison of FRP Requirements and the TLS

- FRP requirement for availability is 0.999 for the inland waterway domain
- Equivalence of the two is not direct since availability is related to MTTR/MTBF, whereas TLS = TLS(MTTR,MTBF)
- Looking over a range of reasonableness parameters, we found that the TLS is roughly equivalent to an availability of 0.9999

Conclusions

- In work done for the USCG, Loran was the only DGPS backup system that consistently satisfied the TLS criterion for large vessels transiting the most challenging harbors under low visibility conditions.
- For several of the HEA conditions we considered, DGPS, either stand-alone or with non-Loran backups, was unable to satisfy the TLS
- If we require the TLS criterion to be satisfied under all HEA conditions, Loran backup to DGPS is absolutely required.

Backup Slides

Tampa Bay Channel Description

Segment ID	Latitude (degrees)	Longitude (degrees)	Width 1 (feet)	Width 2 (feet)	Description
1	27.6047	82.7244	600	N/A	start point
2	27.6133	82.6705	500	500	turn point
3	27.635	82.6244	500	500	turn point
4	27.6581	82.6038	550	N/A	straight segment/diff. width
5	27.6817	82.5846	500	500	turn point
6	27.694	82.564	500	500	turn point
7	27.7242	82.5353	500	500	turn/start of last segment
	27.7569	82.5231	500	N/A	end of last segment

Time-to-Alarm for Maneuvering