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Neural Networks in Optimization of Safety Logic

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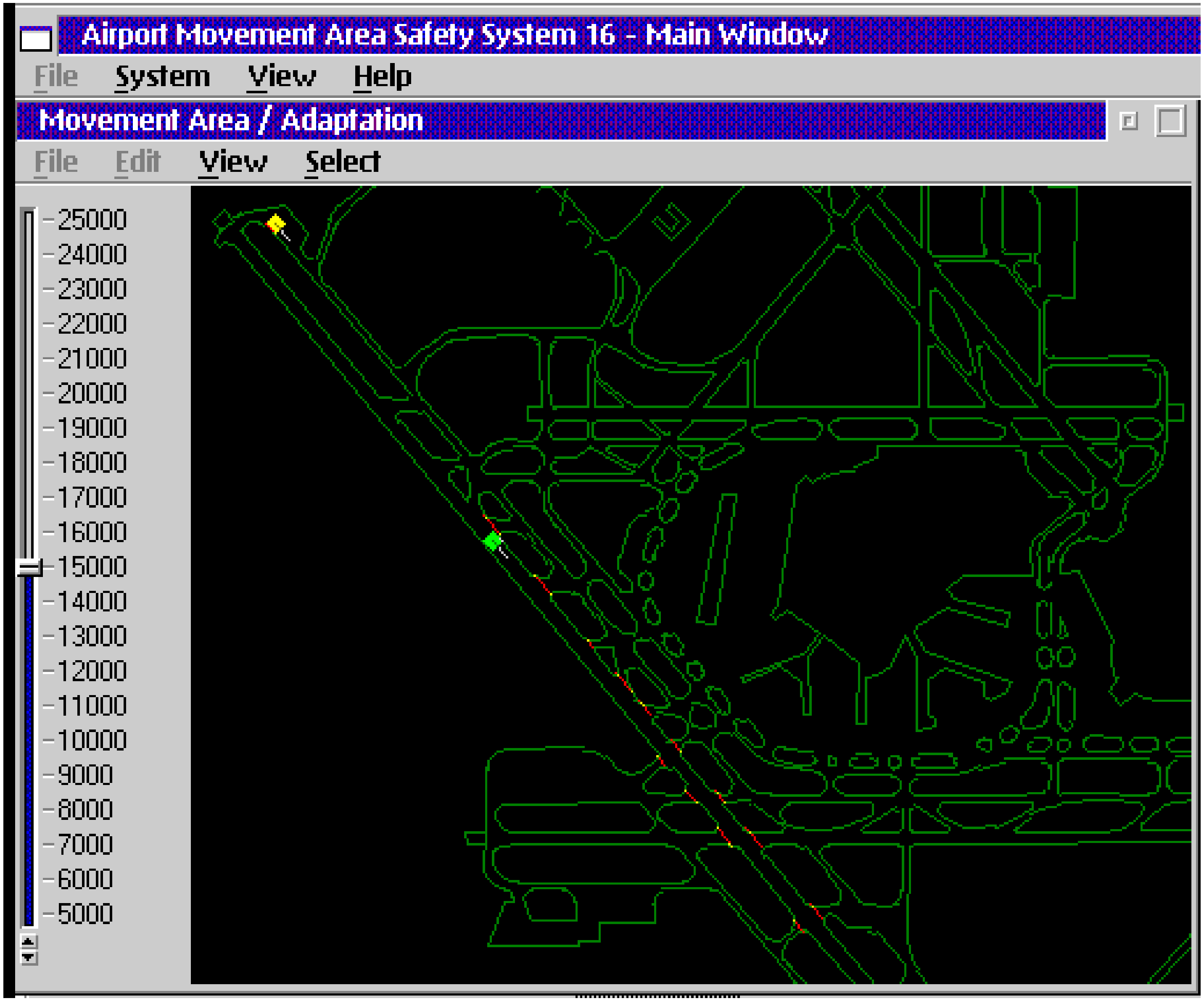
Runway Incursions

"On April 1, 1999, just after 2 o'clock in the morning, Korean Air flight 36 and Air China 9018, both Boeing 747s, nearly collided on runway 14 Right at the Chicago O'Hare International Airport. Air China had just landed and was rolling out on runway 14 right when the tower controller instructed Korean Air to taxi into position and hold. After Air China exited the runway at taxiway T10, the tower controller instructed the flight to turn left on taxiway Kilo and cross runway 27 left. The tower controller then cleared Korean Air for takeoff. As the airplane was rolling down the runway, Air China deviated from its assigned taxi route and taxied on to runway 14 Right. The Korean Air captain saw the 747 taxiing on to the runway but it was too late to stop. Instead, Korean Air 36 lifted off earlier than normal and banked left to avoid striking Air China. The two aircraft, carrying 382 people, missed colliding by about 80 feet."

NTSB

Click for Incursion

AMASS Simulation using Flight Data Recorders



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Introduction

- Airport Movement Area Safety System (AMASS)
  - Provides Air Traffic Controllers with early warnings of impending aircraft collisions
  - Utilizes 2 surveillance sensors
    - ASR-9 / ARTS (Approach Radar)
    - ASDE-3 (Surface Radar)
  - AMASS is an "add-on" to existing ASDE-3 equipment
  - Contractors:
    - Northrop Grumman Norden Systems
    - Dimensions International

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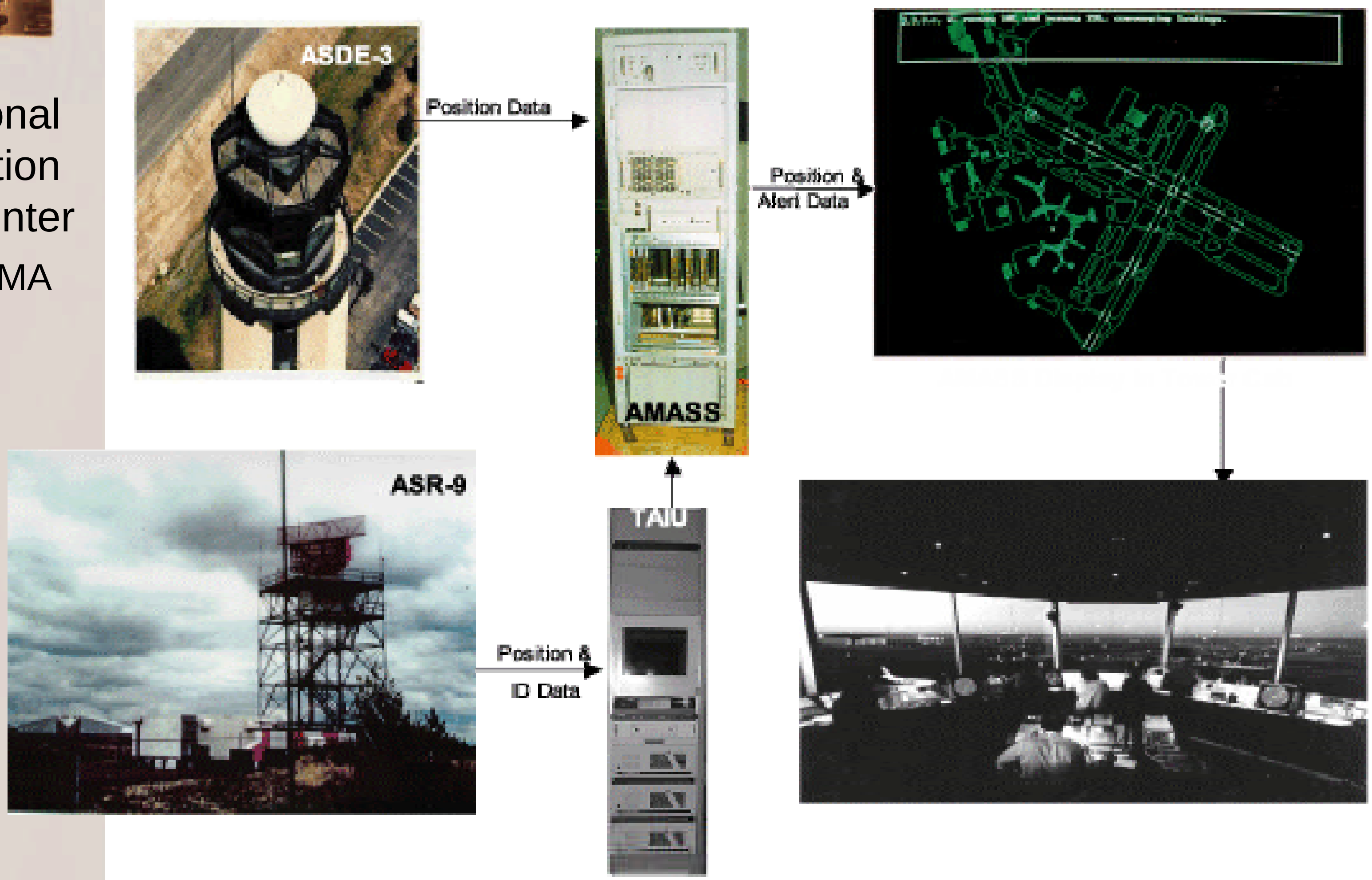
AMASS System



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Status

- AMASS has completed development and testing.
- AMASS has been commissioned at:
  - San Francisco International Airport (SFO)
  - Seattle-Tacoma International Airport (SEA)
  - Boston Logan International Airport (BOS)
  - Detroit Metro Wayne CO Airport (DTW)
- Six months are required to optimize and configure an individual AMASS for commissioning
- Thirty four (34) airports in the U.S. will have a commissioned AMASS

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Safety Logic

- Safety Logic
  - AMASS logic classifies aircraft behavior into logical situations. For example a "chase" situation is illustrated in the next slide. Each situation has an algorithm(s) that determines if the aircraft(s) will meet user defined safety parameters and generate an alert.
  - These safety parameters consist of a distance parameter, time parameter or combination of both.
  - Safety parameters were initially developed with a large set of options to provide the user with the flexibility necessary to configure each system to the site specific operating environment.
    - This was the first surface based safety warning system, it was essential to provide configuration flexibility.

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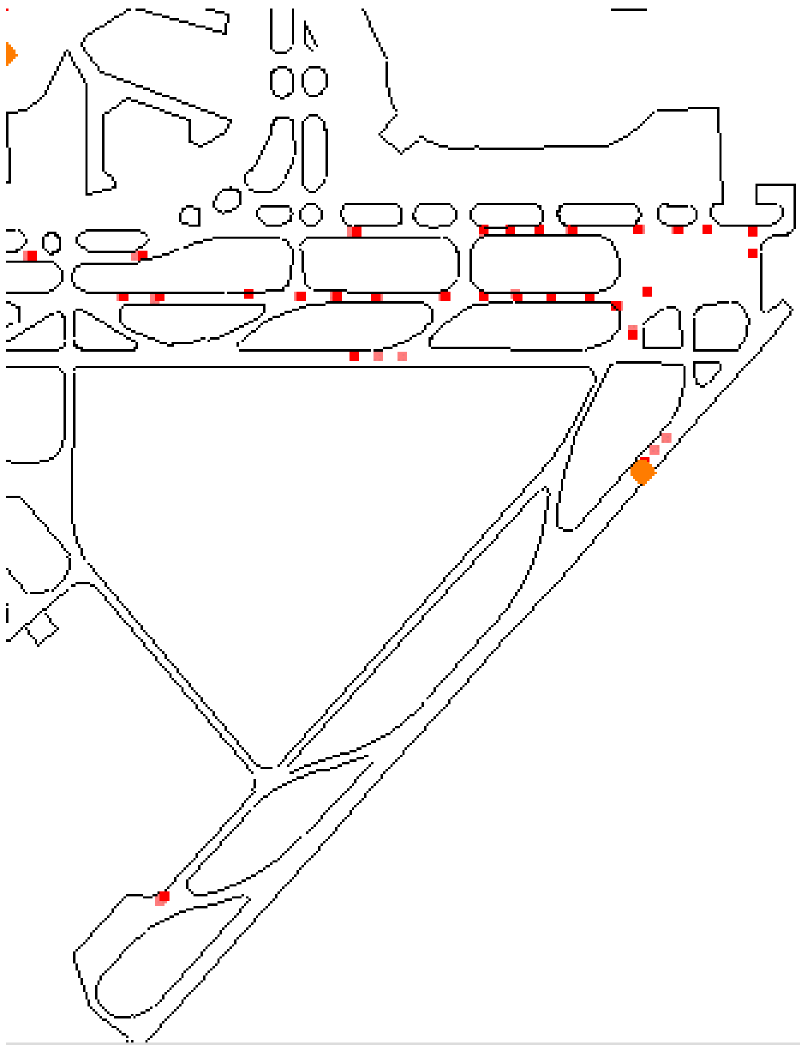
"Chase"



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Challenge

- The airports where AMASS is being installed vary by…
  - Size
  - Traffic flow
  - Runway configuration (parallel/intersecting)
  - Runway operations, construction, closings
  - Land and Hold Short Operations (LAHSO)

Each airport configuration is unique!

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Challenge (cont.)

- How do we efficiently configure AMASS to provide each individual airport with an “optimal” set of safety parameters?

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How to Utilize AMASS Flexibility?

- Proposed Approach: *Neural Networks*
- Volpe formed a collaborative with MIT to develop the Neural Network models
- Neural Networks have been demonstrated to solve complex and intricate problems with large sets of variables
- Construct a Neural Network that will…
  - Learn the actions of air traffic and pilots, specific to each airport
  - Predict separation distances early enough to provide ATC with “satisfactory” reaction time to prevent an accident

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Neural Networks

- Neural Networks are mathematical models that emulate some of the observed properties of biological nervous systems
- They draw on the analogies of adaptive biological learning
  - Learning usually takes place through training of a trusted data set where the algorithm adjusts connection weights
  - The connection weights store the knowledge to solve problems

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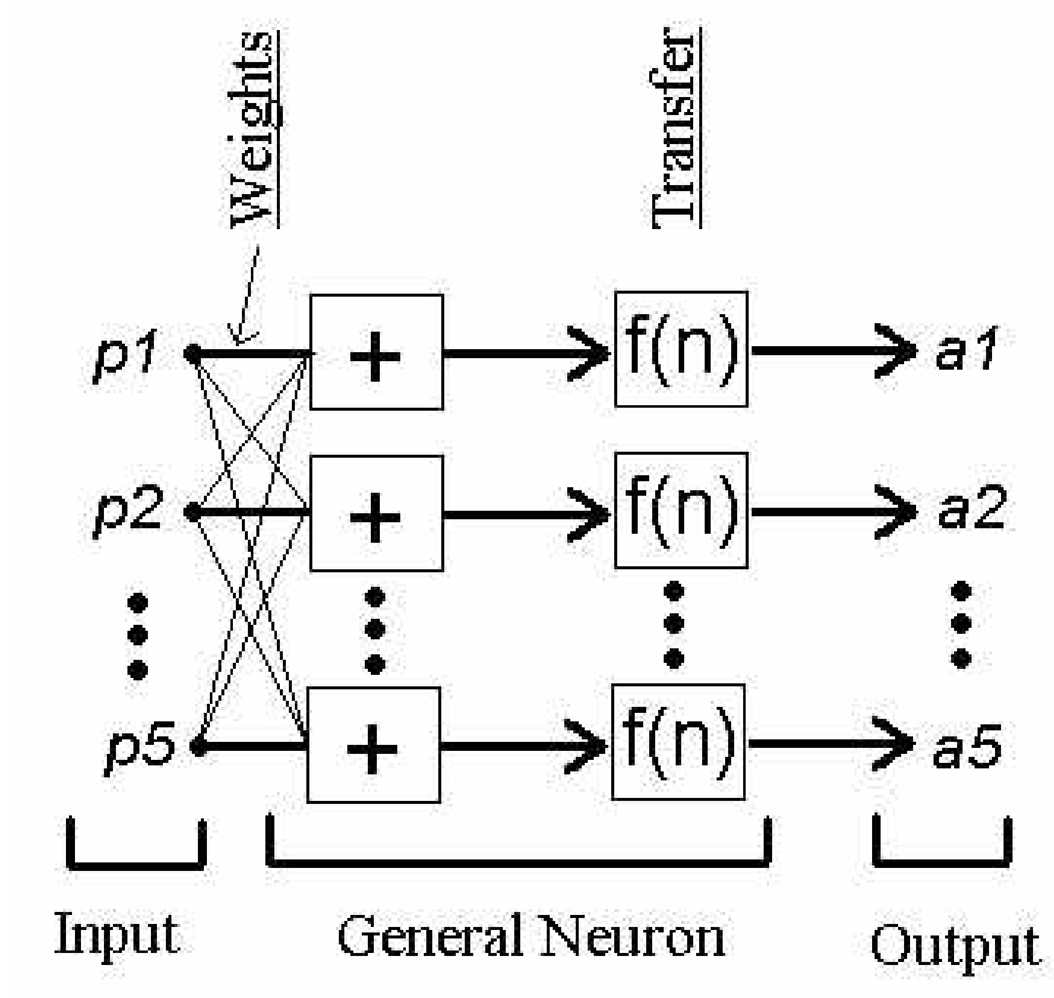
Neural Network Diagram



$$a = f(Wp+b)$$

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Approach Employed

- Train neural networks using AMASS data files
  - These files provide x,y position and time values for all aircraft tracked by AMASS.
  - Models have been tested on ~24 hours of data.
- Specific training cases include (these cases differ from AMASS situations):
  - Lander behind Lander (LL)
  - Lander behind Departure (LD)
  - Intersecting Runways
  - LAHSO
- Neural networks models are trained on data from each airport independently.
  - Models are further trained on specific landing/departing configurations.
- As an output the neural network provides projected separation distance

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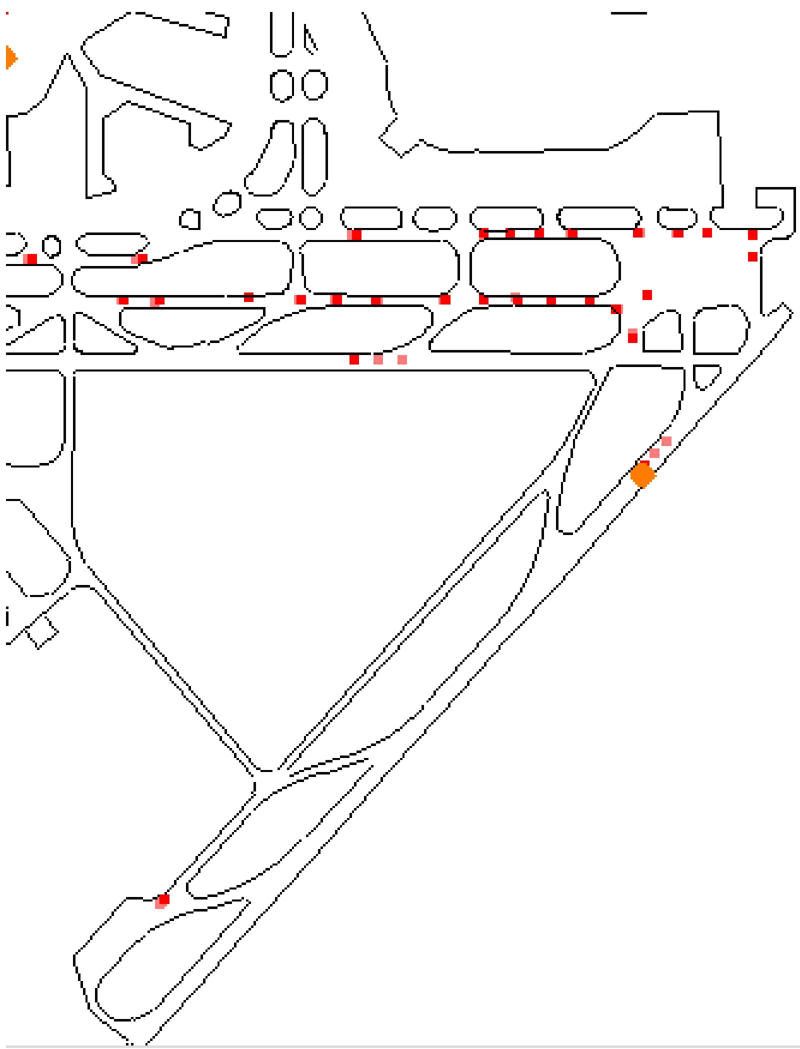
Lander behind departure



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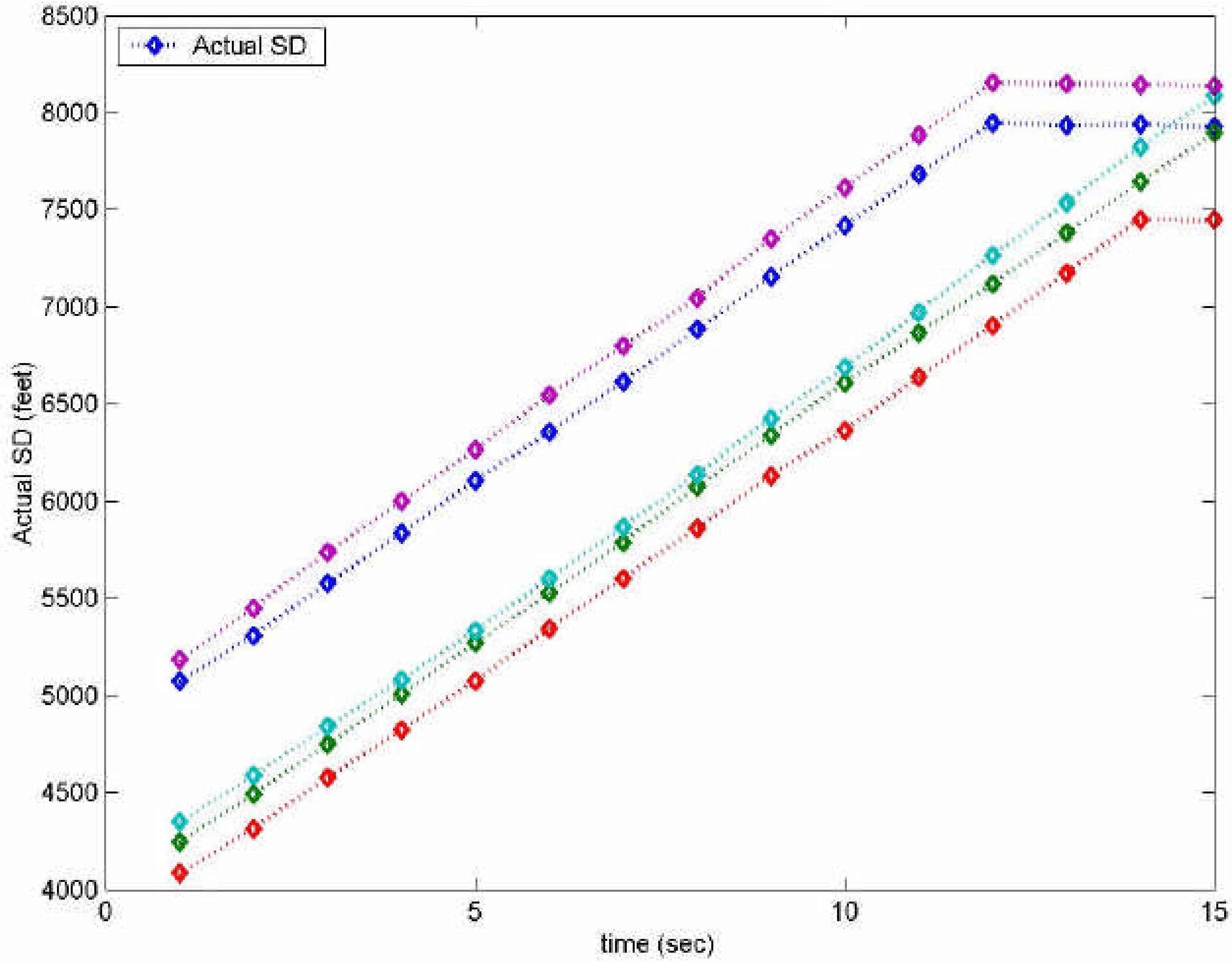
Actual Separation Distance for Five pairs of Aircraft (Lander behind Departure)



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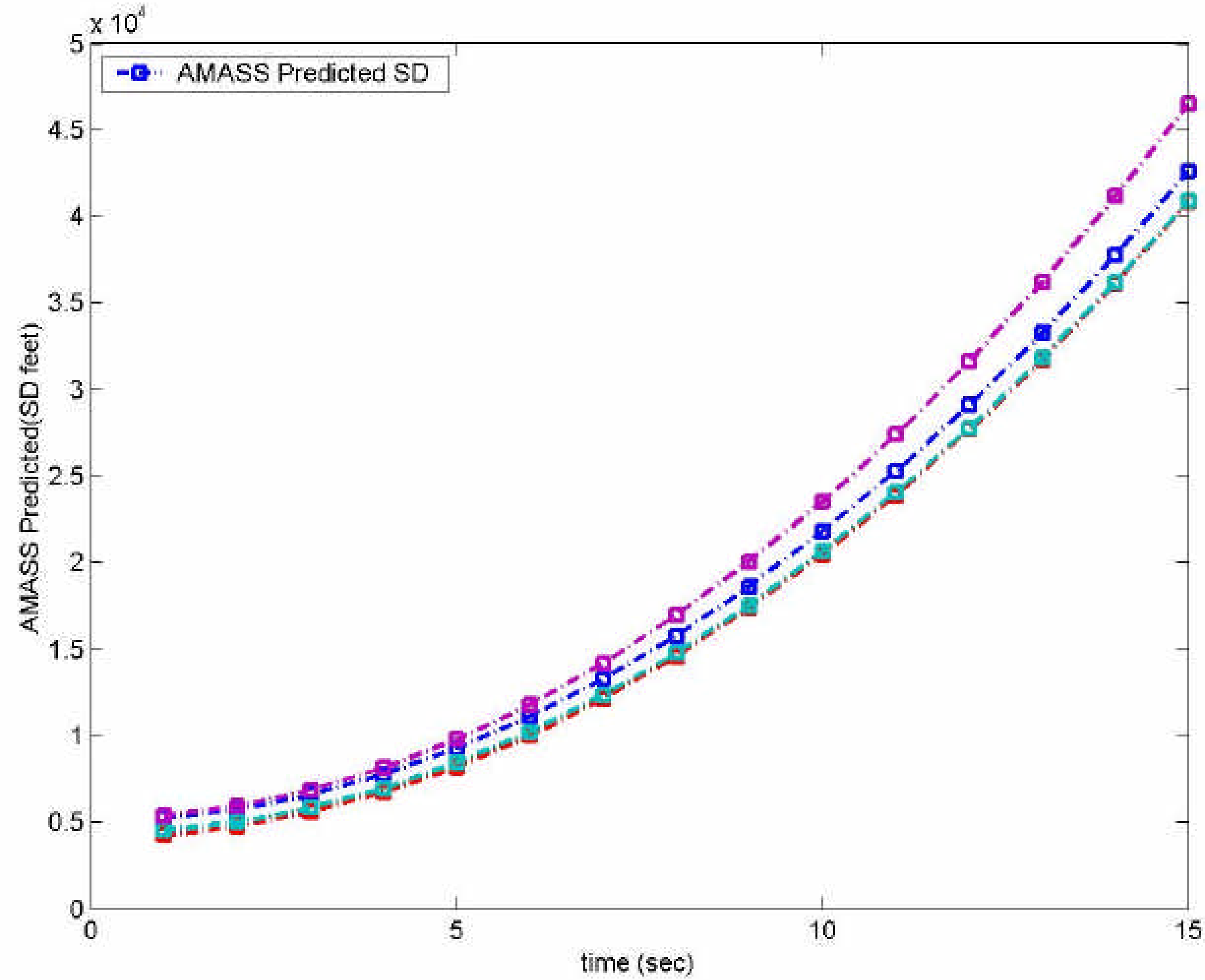
AMASS Projected Separation Distance for Five Pairs of Aircraft (Lander behind Departure)



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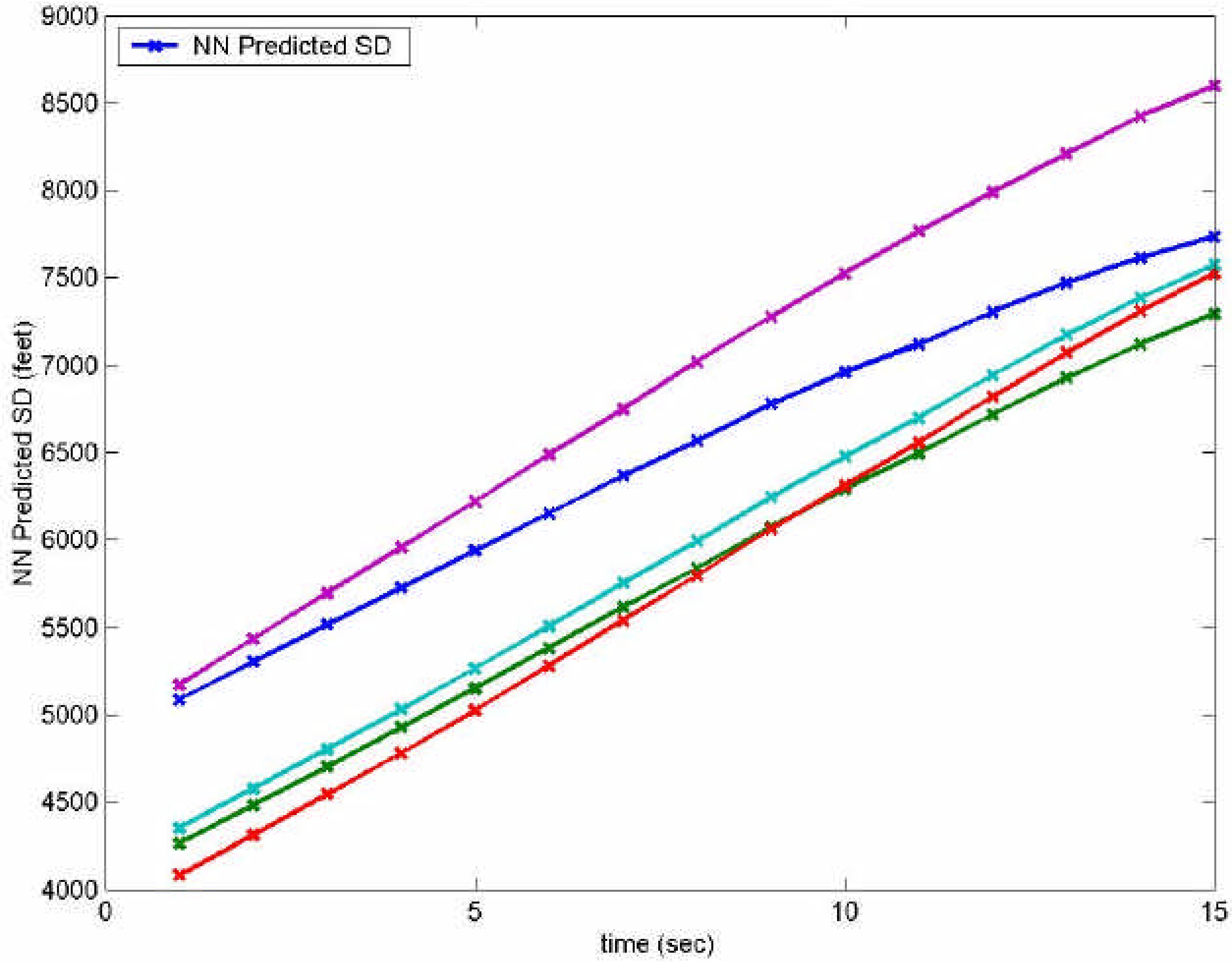
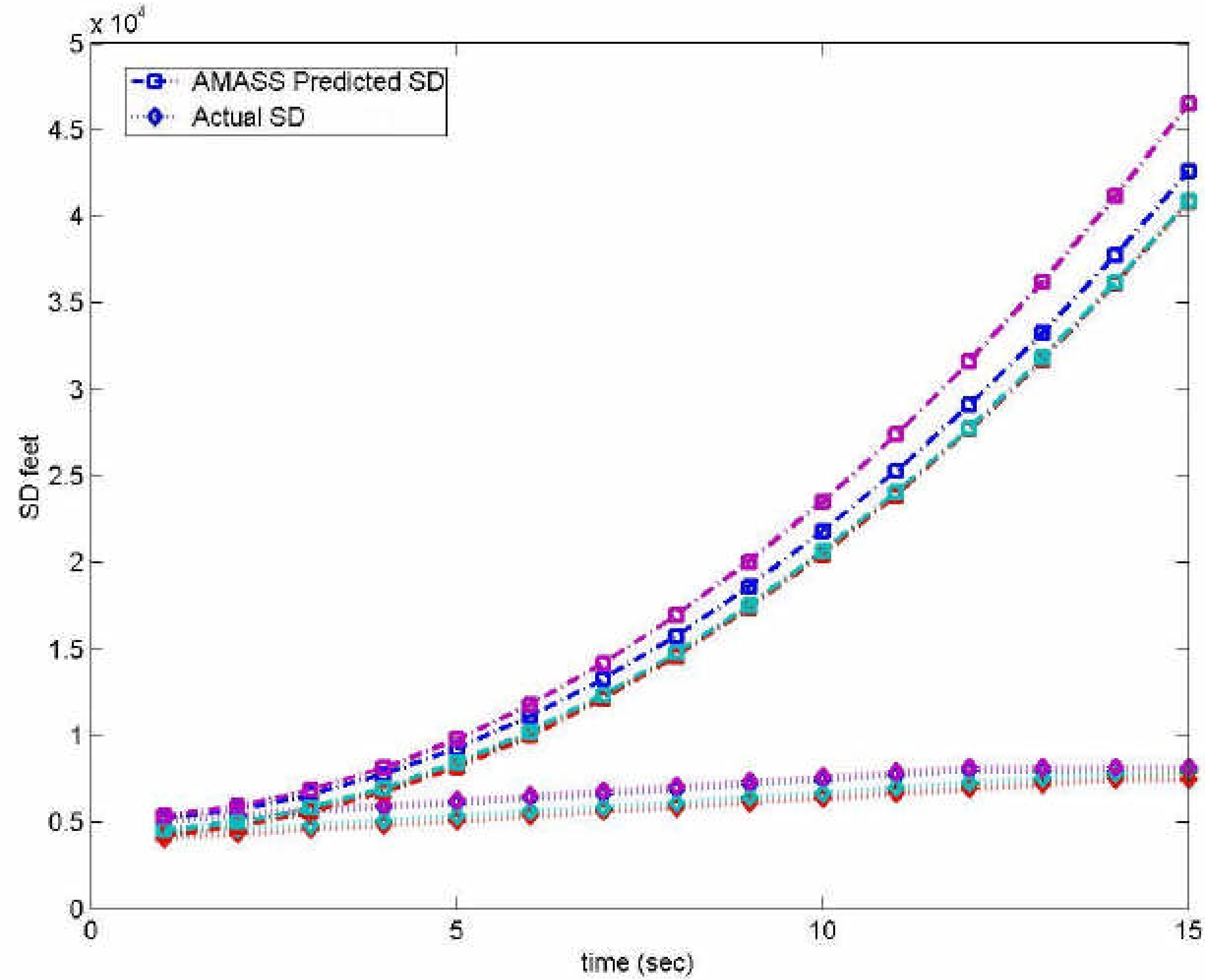
Neural Network Projected Separation Distance for Five Pairs of Aircraft (Lander behind Departure)



AMASS Predicted Separation Distance vs. Actual Separation Distance

(Lander behind Departure)



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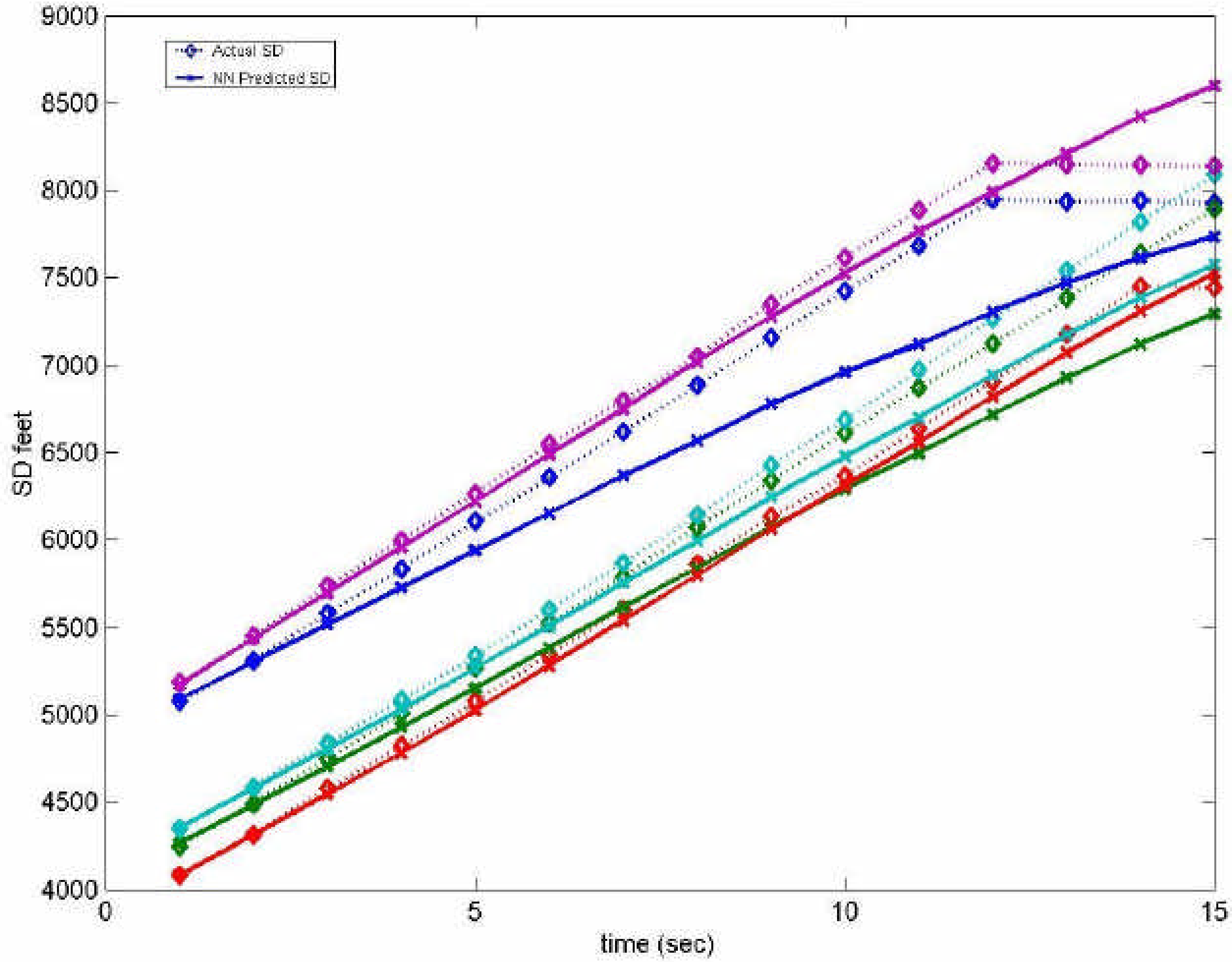
NN Predicted Separation Distance vs. Actual Separation Distance

(Lander behind Departure)



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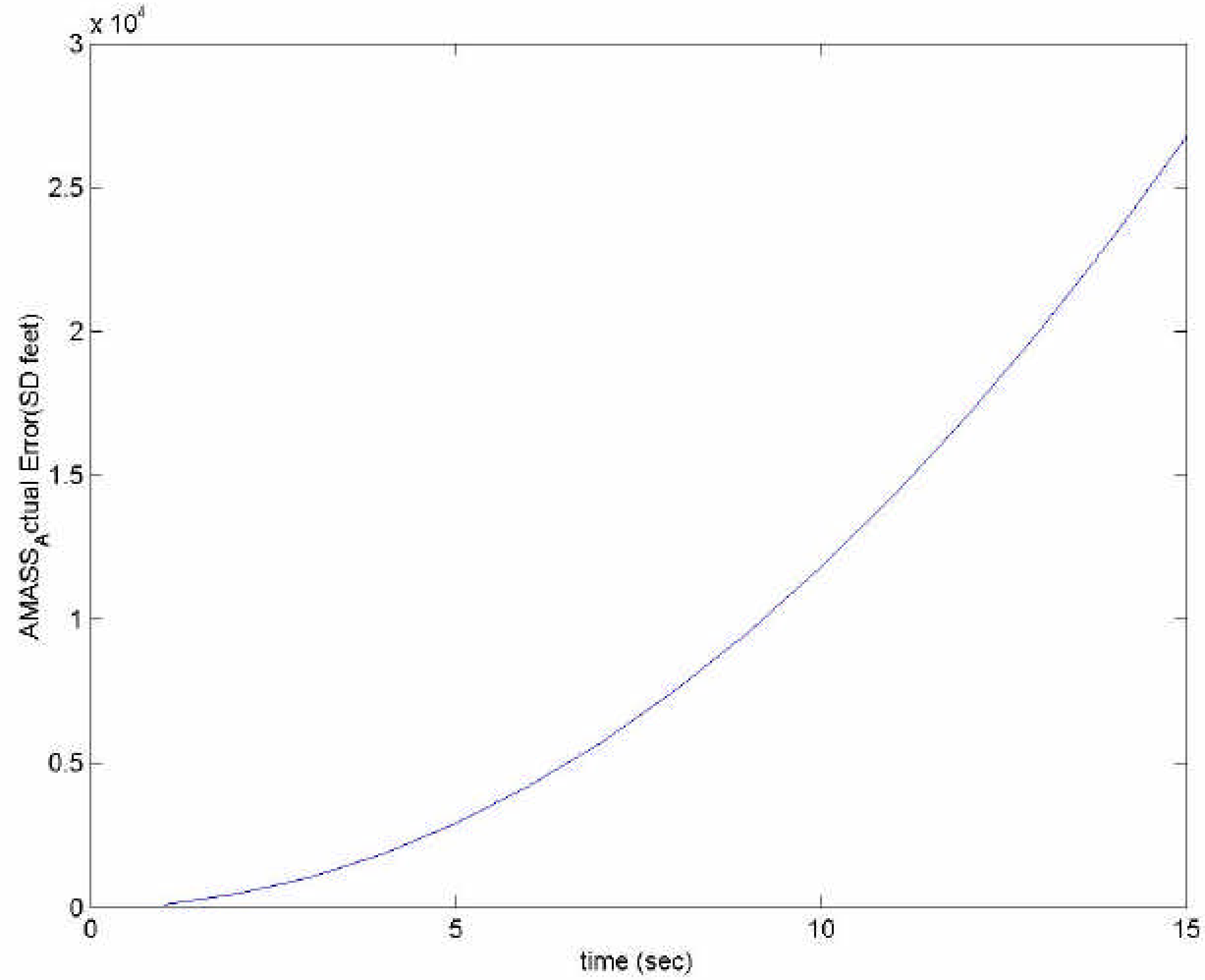
Error on One Runway for 24hrs of Data (AMASS vs. Actual)



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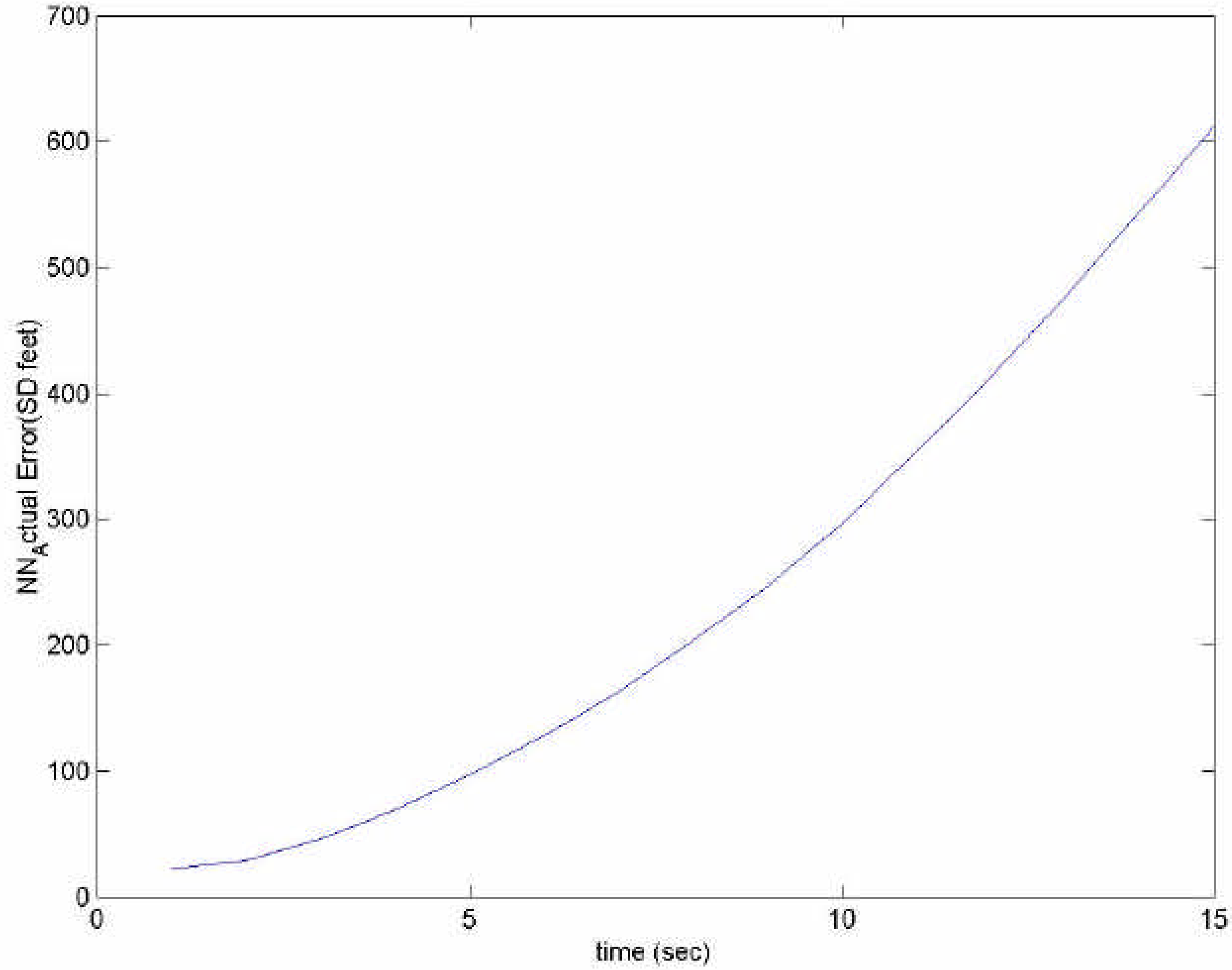
Error on One Runway for 24hrs of Data (Neural Network vs. Actual)



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Projected Separation Distance Comparison

- Neural Networks, on average, provide 37x higher accuracy for projected separation distance compared to existing projections.

	Projected Separation Distance (seconds)		
	5	***10***	***15***
Neural Network vs. Actual *Average Error*	96.3(ft)	296.6(ft)	612.1(ft)
AMASS vs. Actual *Average Error*	2924(ft)	11,841(ft)	26,807(ft)

* *24 hours of data, ~4000 data points, one runway.*

* *Neural Network training time ~8 hours.*

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Conclusions

- Neural Network models can be developed for each type of situation (LL, LD, etc.) or for individual safety parameters.
- The Neural Network outputs can be used to provide AMASS with projected separation distances and times in an autonomous fashion.
- Neural Networks will be trained “offline”.
- Neural Networks provide possible insight into future safety system logic.

Future

- Near Term:
  - Integrate the outputs of the Neural Network into AMASS.
  - Increase learning rates of Neural Networks.
  - Train Neural Networks on a more diverse set of data (Airports, runways, un-common runway configurations, etc.).
  - Continue development of Neural Network models on intersecting runway and LAHSO operations.
  - Determine false alert rates with existing prediction algorithms vs. Neural Network algorithms.

- Long Term:
  - Integrate Neural Network prediction algorithms into existing and future safety systems.

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Backup

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Data Points

- The neural network trains on pairs of aircraft.
- A “pair” is classified as a lander behind a lander, lander behind departure, etc. before it is input to the neural network.
- Each second that both pairs of aircraft remain in the same classification is counted as one data point.

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Projections

- A history of aircraft position reports are necessary before a prediction can be made.
- The neural networks require 5 data points before a projection is made.
- AMASS requires the same 5 second history in its velocity calculations.

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Integration of Neural Networks with AMASS

- Option 1:
  - – Insert the distance and time parameters that are output from the neural network and physically insert these values into the existing safety cells of AMASS.
    - No modifications to the AMASS code
    - Limited to existing safety logic algorithms
    - Again, safety cells “act” as trigger points for the alerts
- Option 2:
  - – Modify the safety logic software module, where projection distances are calculated, with the neural network projection algorithms.
    - Provides AMASS with the beneficial projection capabilities of neural networks
    - Neural networks remain static when part of AMASS, all training is still performed off-site

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Data Quality

- Log system and radar system not in synchronism
  - Radar information is stored an log files every second (exactly)
  - The radar system takes data every 1008 +/- 30 ms
  - Since both systems are not in synchronism, there is a problem of missing data or duplicate information every 5 minutes (approximate).
- Data incorrectly stored in log files
  - For some reason, when sampling time and log time do not match, the systems mixes data:
    - One group of airplanes is stored at one timestamp.
    - Another group of airplanes is stored at the following timestamp.
  - Sometimes data collection is interrupted for periods larger than one minute.

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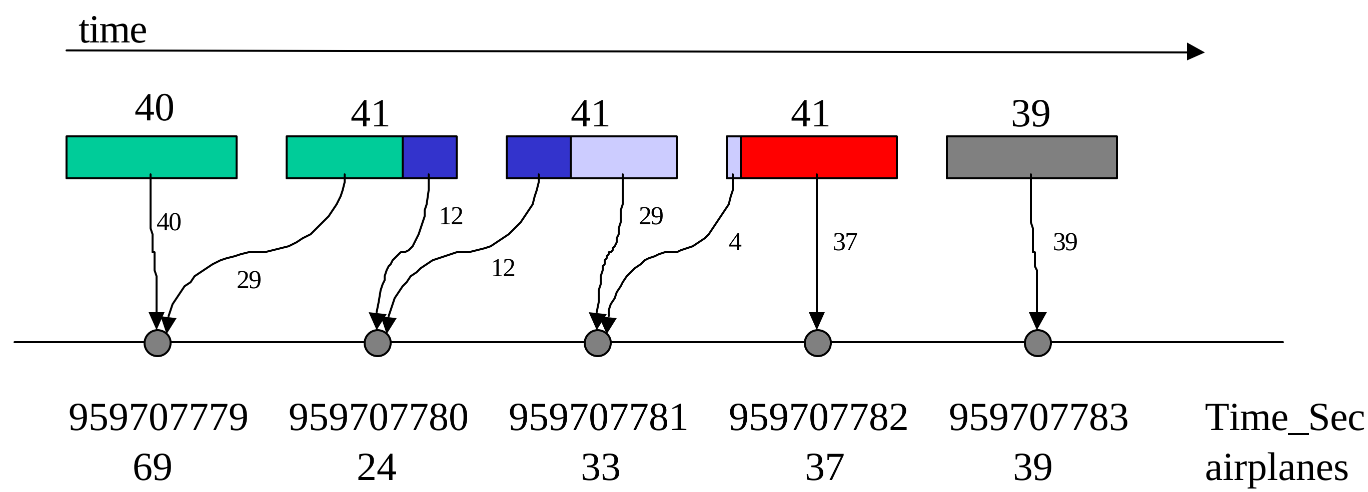
Example of Mixed Data

- Data from file “ORD_530_TRK” (This file contains data about ORD airport from 2000/05/30 15:42:08 UTC to 2000/05/31 03:59:55 UTC).



Consequences

- The number of simultaneous airplanes may change suddenly
- There are inconsistencies: the same airplane, at the same time has different coordinates. 959707779
- Airplanes *magically* disappear. 959707780, 959707781, 959707782

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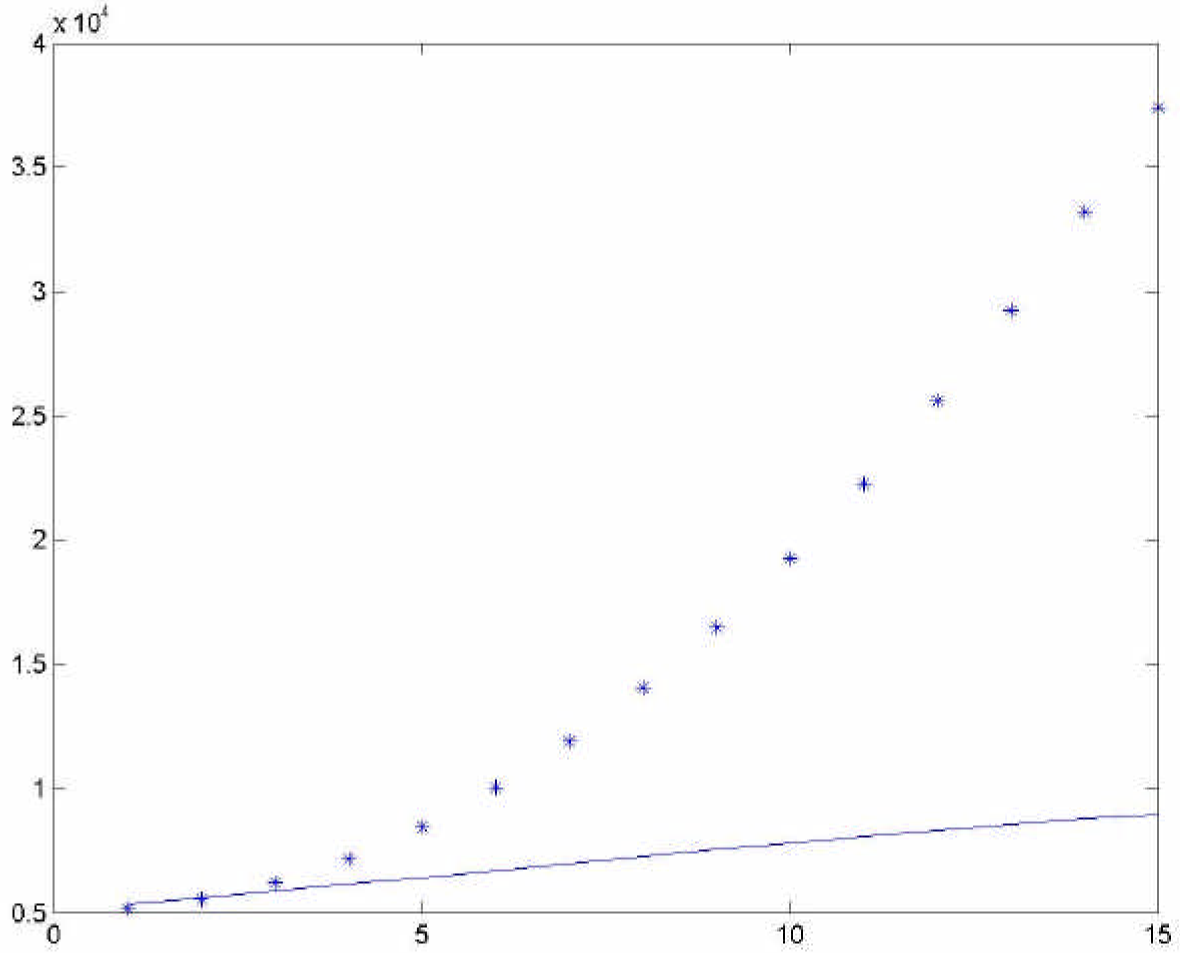
Alerts



-------SD as Predicted by NN

****** SD as Predicted by AMASS**