Power Grid Monitoring and Alerting System

Adapting <u>The Morning Report</u> technology for monitoring the Electrical Power Grid

The Morning Report was originally developed as part of NASA's Aviation Safety Program. It has won several awards for its inventive and effective data analysis capability.

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Overview

Goals

- Adapt <u>The Morning Report</u> approach to the electric power grid and demonstrate its usefulness to identify atypical events.
- Create a Proof-of-Concept
- Involve the power grid community experts to build interest.

► Funding:

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- PNNL is funding this as an IR&D project.
- Very small seed funding
- Major Accomplishments
 - Access to a small set of archived data
 - Preliminary data processing
 - LiveMeeting with ~6 EIPP Power Grid Experts, April 11, 2006

Discussion

Presentation on approach

Data analysis preliminary results



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Why invest in this area?

Aviation Safety Program

- Aviation is one of the safest ways to travel in the world.
- Why does it warrant efforts to monitor and improve?
 - Number of flights is expected to double in the next few years, which means the number of accidents is likely to double (or worse).
 - Changes in the airspace can have subtle and unenvisioned but significant impact on safety.
- Monitoring 1000s of flights every day is almost impossible, but we can monitor
 - ~20 typical patterns (with ~99% of the flights)
 - ~20 atypical flights
- By studying all flights, we can find pre-cursor situations that increase the risk of incidents and accidents.

Electrical Power Grid

- Electrical Power Grid is one of the most reliable major systems in use today; largely as a result of significant efforts to make it reliable.
- Demand will continue to increase.
- Margin for recovering from incidents will continue to erode.

Hypothesis: Data analysis tools can identify typical patterns, atypical events, and pre-cursors.

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How to do it? The key elements of the approach

Aviation Safety Program uses:

- <u>On-board instrumentation</u> to record hundreds of variables that monitor the aircraft throughout every flight.
- <u>Sophisticated statistical analysis</u> programmed into a workstation that analyzes the data to find:
 - Typical patterns, that characterize ~99% of the flights
 - Atypical events, that are worthy of individual inspection
- <u>User-friendly software</u> enables the aviation user to rapidly and effectively drill into the gigabytes of data to find the insight needed to:
 - Understand safety issues and formulate corrective plans if appropriate
 - Monitor typical patterns for trends
- <u>Aviation Experts</u> inspired by new insight proactively identify and correct safety issues affecting aviation safety

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- Instrumented system operation exists
- Adapt statistical analysis: Proof-of-concept in work
- User-friendly software: On-hold
- Expert review of results: TBD

The Morning Report can be described in 12 Basic Steps

Step 1: Download Data



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- Download daily or weekly
- From tapes, disks, or solid state devices
- Use commercially available playback software
- Insert data into commercially vended database
 - PMU data continuously recorded
 - Multiple variables (2 to 10000)
 - Multiple 30 locations (1 to 100)
 - Data could be:
 - From archives
 - Live / real time

Step 2: Check the Data Quality



- Apply knowledge-based filters
- Identify "bad" data
- Remove the "bad" data
- Inform user of QA problems

Limited data checks to remove dramatically bad data.

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Step 3: Conduct Pre-defined Alerting Checks

- Airline experts define specific data comparisons to be made at specific routine events
 - Are the gear down while altitude is above 18,000 ft?
 - Are the flaps extended while airspeed is greater than 300 knots?
 - Etc.

	Time (secs)	Param 1	Param 2	 Param P	Routine Events	
	1	103.40	1	277.40	Start Takeoff	
	2	103.70	1	266.30		
	126	104.49	1	267.31		
	127	104.98	1	268.19		
	129	105.45	0	269.12	Gear Up	
	131	106.39	0	269.78		
	4021	106.82	0	270.71		
	4022	107.33	0	270.78		
	4023	107.89	0	270.85	10000 ft AFE	
	4024	108.40	0	271.14		
	4025	108.53	0	271.53		
	4026	109.38	0	272.03		
	N	110.68	0	273.70	Touchdown	

This requires that we <u>envision</u> the potential problems before they occur.

Power Grid Domain Experts could create Boolean expressions for automatic monitoring. This effort is not part of the Proof-of-Concept investigation.

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Step 4: Structure the Data

- Data are parsed into flight segments
- Flight Segments based on Event Markers, e.g.
 - Gear-up
 - Cross outer-marker
 - Descent through 1000 ft AFE
- Customizable to each air carrier phase definitions

Time (sees)	Param 1	Daram 2		Param P	Evont Markor	ACP Phase
151	Faram I	Faran 2		Faram	Event Marker	ACK Fliase
157	102.40	1		277.40	Potato	Takooff
152	103.40	1		103 70	Rotate	Takeon
155	103.70	1		103.70		
335	105 13	1	•••	105 13		
335	105.15	1		105.15	Coorlin	
330	105.45	0		105.45	Gear Op	
337	105.73	0		105.73		
						climb
1225	106.82	0		106.82		
1226	107.89	0		107.89	10000 ft AFE	
1227	108.10	0		108.07		
3236	108.51	0		109.04		
3237	109.33	0		109.12	Max Altitude	Cruise
3238	110.25	0		109.74		
6259	109.04	0		108.60		
6260	109.85	0		109.57	10000 ft AFE	
6261	109.87	0		110.39		
						Approach
6673	110.70	0		110.53		
6674	111.19	0		110.68	Gear Down	
6675	111.90	1		111.29		
7786	112.13	1		112.10		Landing
7787	112.91	1		112.43	Touchdown	
7788	113.63	1		112.90		



Data maybe partitioned into "60 second" observations. Observations may be grouped for comparison as function of Time-of-Day and Day-of-Week.

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Step 8: Select the Data

- Select a subset of data:
 - Aircraft type
 - Airports
 - Flight Phase
 - Time Frames
 - Other Parameters

Time (ac co)	Dorom 1	Baram 2		Baram B	
	103.40			277 40	Start Takooff
2	103.40	1		266.30	Start Takeon
2	105.70			200.30	
126	104 49			267.31	
127	104.98	1		268.19	
		-			
129	105.45	0		269.12	Gear Up
130	105.73	0		269.73	
131	106.39	0		269.78	
4021	106.82	0		270.71	
4022	107.33	0		270.78	
4023	107.89	0		270.85	10000 ft AFE
4025	108.53	0		271.53	
4026	109.38	0		272.03	
N	110.68	0		273.70	Touchdown
Time (secs)	Param 1	Param 2		Param P	Event Marker
Time (secs) 129	Param 1 105.45	Param 2 0		Param P 269.12	Event Marker Gear Up
Time (secs) 129 130	Param 1 105.45 105.73	Param 2 0 0		Param P 269.12 269.73	Event Marker Gear Up
Time (secs) 129 130 131	Param 1 105.45 105.73 106.39	Param 2 0 0 0	•••	Param P 269.12 269.73 269.78	Event Marker Gear Up
Time (secs) 129 130 131	Param 1 105.45 105.73 106.39	Param 2 0 0 0	· · · ·	Param P 269.12 269.73 269.78	Event Marker Gear Up
Time (secs) 129 130 131 4021	Param 1 105.45 105.73 106.39	Param 2 0 0 0	· · · ·	Param P 269.12 269.73 269.78 270.71	Event Marker Gear Up
Time (secs) 129 130 131 4021 4022	Param 1 105.45 105.73 106.39	Param 2 0 0 0 0 0	· · · ·	Param P 269.12 269.73 269.78 270.71 270.78	Event Marker Gear Up
Time (secs) 129 130 131 4021 4022	Param 1 105.45 105.73 106.39 107.35	Param 2 0 0 0 0 0	· · · ·	Param P 269.12 269.73 269.78 270.71 270.78	Event Marker Gear Up
Time (secs) 129 130 131 4021 4022 4023	Param 1 105.45 105.73 106.39 107.5- 107.5-	Param 2 0 0 0		Param P 269.12 269.73 269.78 270.71 270.78	Event Marker Gear Up
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Time (secs) 129 130 131 4021 4022 4023	Param 1 105.45 105.73 106.39 107.55 107.55 107.55 107.55 107.55 107.55 107.55 107.55 107.55 107.55 107.55 107.55 107.55 107.55 107.55 105.75 105.	ay look Subset	at d of the	Param P 269.12 269.73 269.78 270.71 270.78	Event Marker Gear Up
Time (secs) 129 130 131 4021 4022 4023	Param 1 105.45 105.73 106.39 107.55 107.55 107.55 107 • F	ay look Subset	at d of the	Param P 269.12 269.73 269.73 269.78 270.71 270.78	Event Marker Gear Up

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Step 9: Transform the Signatures

- Multivariate mathematical statistical techniques used enable:
 - Time series analysis
 - Characterization independent of phase duration
 - Flight mode transitions
 - Quantification captures values, trends, & noise

Time (secs)	Param 1	Param 2		Param P	Event Marker	ACR Phase
151						
152	103.40	1		277.40	Rotate	Takeoff
153	103.70	1		103.70		
335	105.13	1		105.13		
336	105.45	0		105.45	Gear Up	
337	105.73	0		105.73		
						climb
1225	106.82	0		106.82		
1226	107.89	0		197.89	10000 ft AFE	
1227	108.10	0		108.07		
3236	108.51	0		109.04		
3237	109.33	0		109.12	Max Altitude	Cruise
3238	110.25	0		109.74		
6259	109.04	0		108.60		
6260	109.85	0		9.57	10000 ft AFE	
6261	109.87	0		110.39		
						Approach
6673	110.70	0		110.53		
6674	111.19	0		110.68	Gear Down	
6675	111.90	1		111.29		
7786	112.13	1		112.10		Landing
7787	112,91	1		112.43	Touchdown	
7788		1		112.90		
			_			

May combine adjacent time periods (e.g.; 8-9am and 9-10am maybe combined)

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Step 10: Cluster the Transformed Signatures

- Use several alternative clustering methods
 - Then, generate a consensus
- Typical patterns
 - Clusters of similar flights
 - Summarized in plain English
- Atypical flights
 - Singletons, clusters of one or two
 - Summarized in plain English
- Performed for each user-defined and selected flight phase
- Each dot represents a observation (maybe1 minute of grid operation; 1440 obs./day
- Dots are mapped to patterns with similar characteristics.
- Some observations may be mapped to very small clusters or even singletons.



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Step 11: Find the Atypical Flights

- Atypical flights are defined to be
 - Singletons

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- Very small clusters (atypical clusters)
- Differs from classic exceedance analysis
 - Which look for triggers of Boolean expressions
- Can be the impetus for further investigation
 - By operationally knowledgeable persons

Finds the unenvisioned.

End-users don't have to know what they are looking for !!

The analysis finds atypical events never dreamt of !!

• Atypical behavior of the Power Grid will be identified by the methodology.

- Domain Experts will assess the significance of the atypical behavior.
- If it represents insightful finding: EUREKA !!!!

Step 12: Present the Findings

- Data processing occurs over night
- Morning report is ready by 7am every morning.
- Identifies most atypical flights
 - Excludes flights previously reviewed and dispositioned
 - Enables drill down to flight details
 - Allows capture images in Microsoft PowerPoint files for communication ease.
 - Nature of the displays are TBD.
 - Frequency of the displays are TBD.
 - Display focuses on atypical events.

This may evolve to <u>The Minute Report.</u>

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	del : B737-700
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	Level 3 Phases: 178 Go To Flight List
	Lovel 2 Flights : 194
	Level 2 Phases : 610
	Lovel 1 Flights : 727
	(Level 1 Phases : 1726
	Level 3 Phases : 179 Go To Flight List Lovel 2 Flights : 194 Level 2 Phases : 610 Lovel 1 Flights : 727 Level 1 Phases : 1726

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-	3701_20040329_037	5701	5/24/2004 2:15:24 444	3-Landing	LINT	410	Pending	(1) shige_or_actack_t, (2) cong_rm	
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5	3762 20040302 003	3762	5/24/2004 2-10-57 AM	3 - Landro	500	90	Pending	(1)Ab CAE Corr (2)Marks Above	
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3	3705 20040229 014	3705	5/24/2004 12:59:29 AM	3 - Takeoff	8.0	805	Pending	(1)Height Above TD. (2)AR ONE	
3	3751 20040331 020	3751	5/24/2004 2:15:24 AM	3-Landing	SEA	ATL	Pending	(1)Angle of attack L (2)Long Pro	
3	3761 20040330 004	3761	5/24/2004 1:21:50 AM	3 - Low Seeed Climb	ATL	CDL.	Pending	(1)Eda Gr Sel Dwp. (2)Apple of	
3	3761 20040330 013	3761	5/24/2004 2:15:24 AM	3-Landing	MYB.	ATL	Pending	(1)Apple of attack L (2)Long Pro	
3	3745 20040309 010	3745	5/24/2004 1:17:20 AM	3 - Low Speed Climb	80	SC	Pending	(1)Elevator Pos L (2)Pitch Angle	
3	3712 20040322 054	3712	5/24/2004 2:15:24 AM	2 - Landing	C05	ATL	Pending	(1)Angle of sttack L (2)Long Pri	
3	3758 20040325 049	3758	5/24/2004 1:34:14 AM	3 - Low Speed Descent	EWR	S.C.	Pending	(1)Dwn Adv, (2)Fuel Burn Hr Av	
3	3724 20040329 019	3724	5/24/2004 1:21:50 AM	3 - Low Speed Clinib	ATL	IAD	Pending	(1)Edg Gr Sel Dwn, (2)Angle of	

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In Summary

- The Morning Report uses:
 - Multivariate statistical analysis and
 - User-friendly software
- It enables the user to understand:
 - Typical patterns observed in the operation of 1000s of flights
 - Atypical events
 - Identify flights and their flight characteristics associated with safety issues
 - Share the information with a community of aviation experts, thus enabling them to formulate improved aviation policies and action plans.
- A very important characteristic about the Morning Report is the basic approach is extendable to numerous other domains, including:
 - Air traffic control (in work)
 - Cyber Security (in work)

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• Electrical Power Grid (in work)

- PNNL is "betting" its internal R&D funding that this will work for the Electrical Power Grid.
- We are betting that we will be able to:
 - Monitor hundreds of hours of operation and identify typical patterns
 - Identify atypical events very quickly with helpful insight as to the nature of the source of the atypicality
 - Identify pre-cursors
 - Share the information in a timely and useful manner.

Next Steps

- The Morning Report so excited the aviation community (Air carriers, FAA, Pilots association, NASA, etc.) that they have formed an Information Sharing Initiative
 - The air carriers will not share their data
 - We have devised a way to aggregate characteristics of the National Airspace without ever possessing the data.
- In FY06/07, System Level Morning Report will monitor aggregate performance of air carriers

► In FY06/07, maintenance interests will be investigated.

A very early look at Proof-of-Concept Analysis intermediate results

This illustrates the approach with real power grid data.

The purpose is not to look at data or assess the behavior of the power grid, today.

Proof-of-Concept Analysis intermediate results

Data

- Data from historic archives
- Data has been de-identified: no location, no date, no units
- Data consisted of
 - Voltage Magnitude
 - Phase Angle
 - Frequency
- Data came from multiple locations
- Analysis

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- Processed data to generate atypicality index
- Identified components contributing significantly to the atypicality
- Much to be done
 - Incorporate more data and more derived variables
 - Refine methodology further
 - Refine atypicality rationale what made this observation atypical?
 - Compare operation logs with data analysis results!!

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Atypicality Index for 1 day



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Atypicality Index for 4 hours



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Long Term Vision Once the proof-of-concept demonstration is achieved, when could this capability go???

Identification of

- Typical patterns
- Atypical events
- Trends over time (long term and cyclic)
- Precursor identification
- Associations
- Application approach
 - Stage 1. Off-line study of archives
 - Stage ... Testing, refinements, improvements, testing
 - Stage n. On-line real-time decision support??
- Support for

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- National Power Grid
- Individual organizations/utilities
- Individual power generation system or distribution system maintenance and prognostics

Plans

Data analysis extensions

- Refine atypical event identification
- Explore pre-cursor event identification
- Process additional data
- Build interest in Power Grid Community
 - Scheduled meeting May 10-11 to EIPP
 - Establish contacts and stimulate follow-on interactions
 - Disturbance Monitoring Working Group (West Coast)
 - EIPP On-Line Analysis Task Team
 - ???

Are you interested in participating? What do you think about this concept? tom.ferryman @pnl.gov

