

# Fleet Health Monitoring and Machine Learning Technology for CBM+

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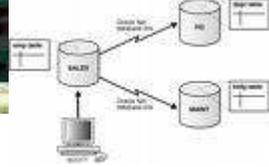
# BAE Systems Fleet Health Management Capabilities



## Depot / Office / Headquarters



Fleet Health Monitoring: Automated data processing, data base management, secure web servers, user



Model Based Reasoner provides advanced troubleshooting and fault isolation capabilities

## Maintainers



Maintenance Management Software



Wireless Data loggers automatically collect and offload vehicle data

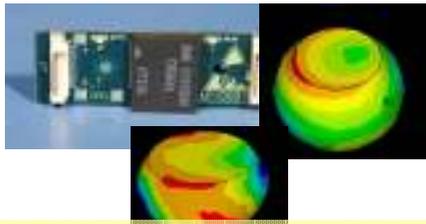


Advanced Machine Learning algorithms for anomaly detection and condition monitoring

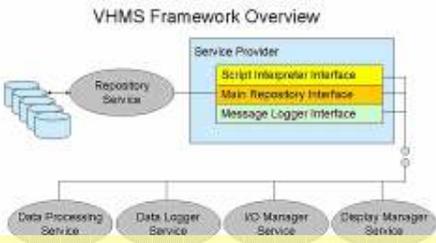


Wireless Sensor Modules to Collect Data on Vehicle with No Power or Data Bus Wiring

## Fielded Vehicles



Autonomous Environment Sensor and Algorithms for Electronics Prognostics



VHMS Framework hosts on-board algorithms and health displays



Algorithms and Approaches for Subsystem Health Monitoring

# Machine Learning Technology



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- 
- Efficient and effective methods to build models of complex systems are an enabling technology for successful prognostics
  
  - Machine Learning technology
    - Reduces development costs (more computer effort, less human effort)
    - Solves the problem: “We have a lot of data but don’t do anything with it”
    - Learns complex, non-linear, transient models from data
    - No detailed design information needed
  
  - State-of-the-art Recurrent Neural Network Algorithms
    - Ideally suited for modeling dynamic systems
    - Model based prognostics
  
  - Anomaly Detection using Statistical Based Neural Networks
    - Models normal systems characteristics to automatically detect any change in normal operation
    - Graphical tools highlight unusual conditions to guide human operators to appropriate maintenance decisions

# 2008 IEEE Prognostics Competition



International Conference on PHM - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address <http://www.phmconf.org/OC5/index.php/phm/>

**INTERNATIONAL CONFERENCE ON PROGNOSTICS AND HEALTH MANAGEMENT**

**User Home**  
You are logged in as...  
foh  
• My Profile

Home About Call For Papers Technical Program Submissions Challenge Problem Location Hotel Registration Contact

### ACTIVITIES

#### Challenge Problem

The PHM Data Analysis Challenge is a competition open to all conference attendees. The goal is to estimate the remaining life of an unspecified component using data-driven techniques. Current standings in the competition may be tracked [here](#). More details on the Challenge may be found [here](#).

#### Tutorials

PHM08 will include a full day of tutorials on diagnostics and prognostics taught by leading researchers. The tutorial sessions will be open to all registrants free of charge. More details may be found [here](#).

#### Exhibits

We are planning a comprehensive exhibit program for PHM08. The exhibit program will provide opportunities to companies, universities, and government organizations to demonstrate and promote their products, services, and technologies to PHM technologists and managers across the globe.

# PHM08

## International Conference on Prognostics and Health Management 2008

Marriott Tech Center  
4900 S. Syracuse Street  
Denver, CO 80237  
USA  
October 6, 2008 – October 9, 2008

**\$2,500 Prize**



#### Announcements

**Submission Deadline Extended!**  
Paper submission deadline is extended to May 19, 2008. [More...](#)

**PHM Data Challenge**  
The challenge data set is now available and the competition is open. [More...](#)

**Exhibits**  
We are planning a comprehensive exhibit program for PHM08. Exhibit registration is now open. [More...](#)

**Patrons**  
PHM08 welcomes financial contributions from corporate and...

Document number- 5

And the winner is....



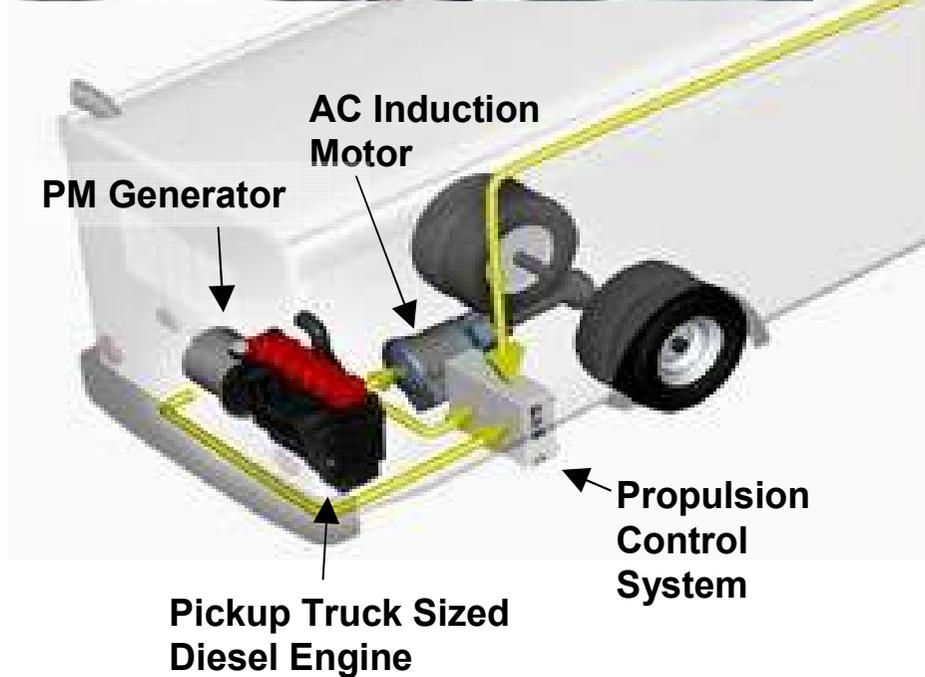
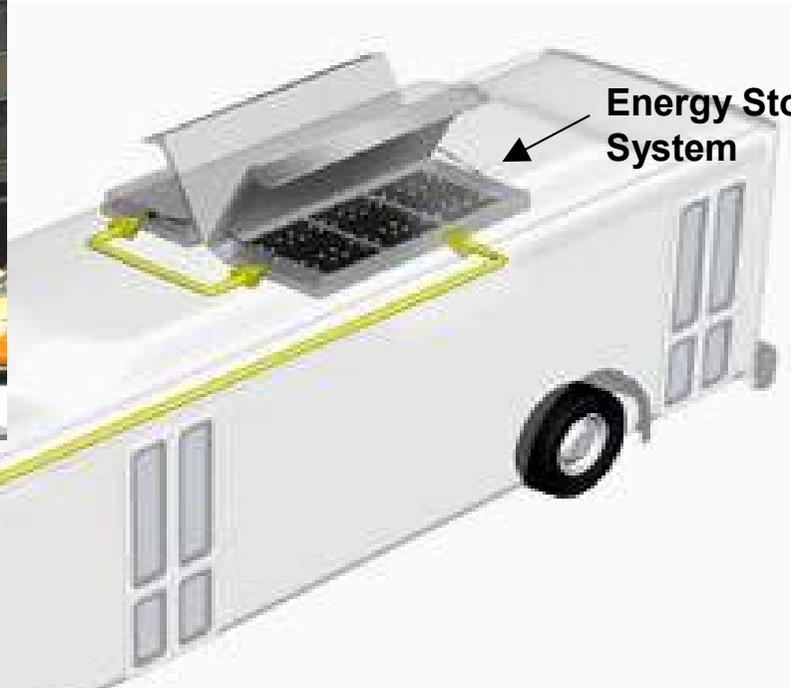
- 60 Participants

## Wireless Fleet Health Monitoring System



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# HybriDrive Electric Bus

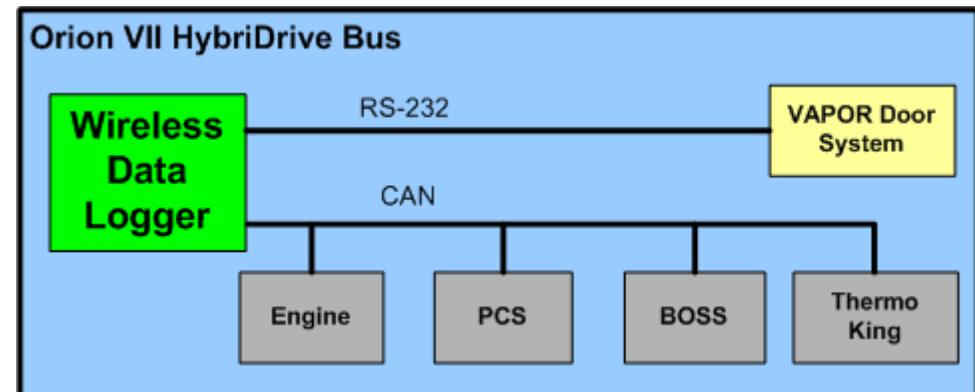


- 44,000 lb, 40-foot heavy duty transit bus
- Powered by 200kW liquid cooled inverter and 120kW boost rectifier
- Air Cooled 120kW PM Generator
- Single 250hp AC traction motor
- 120kW Lead-Acid energy storage & management system

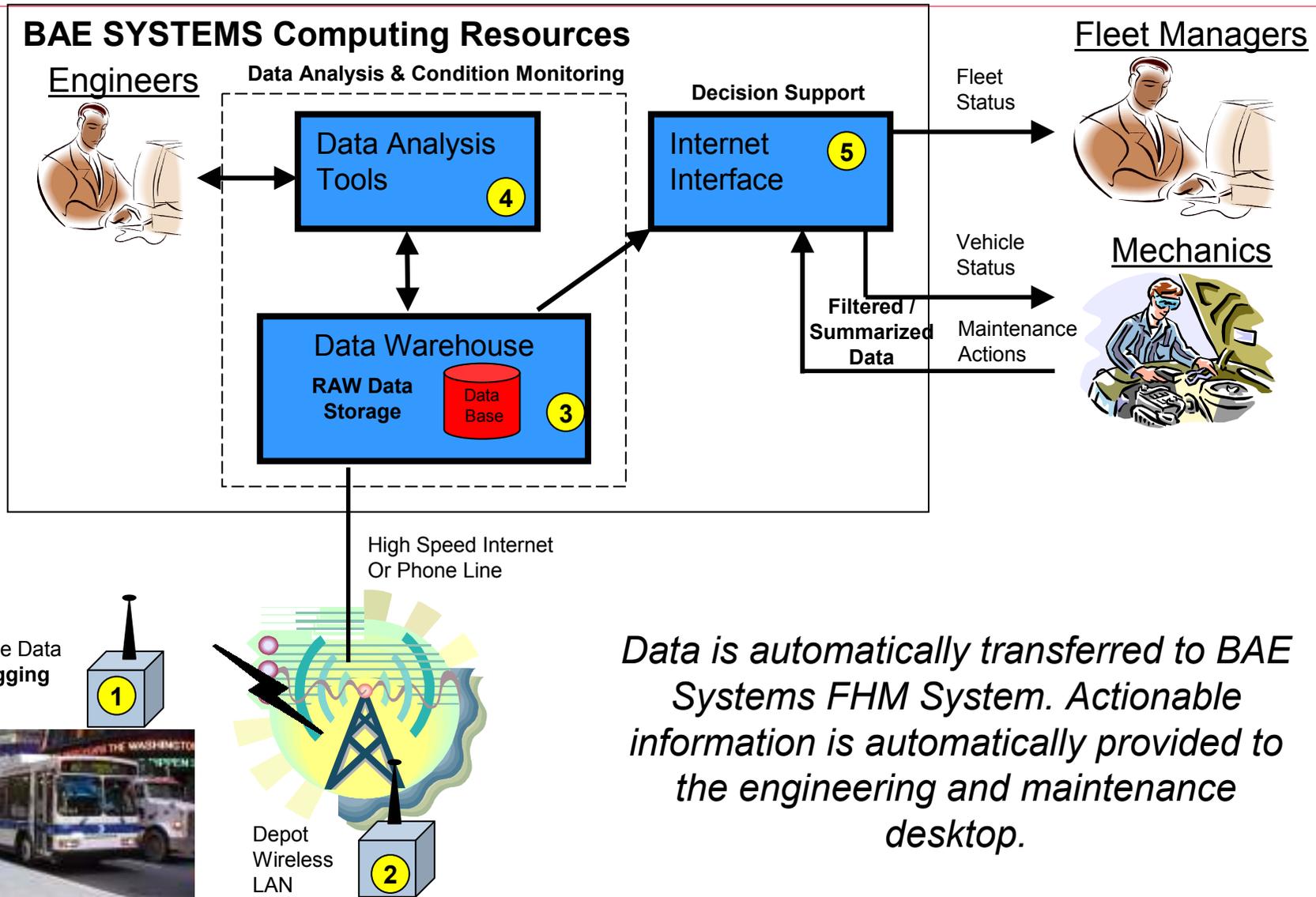
# Data Logger Capabilities and Specifications



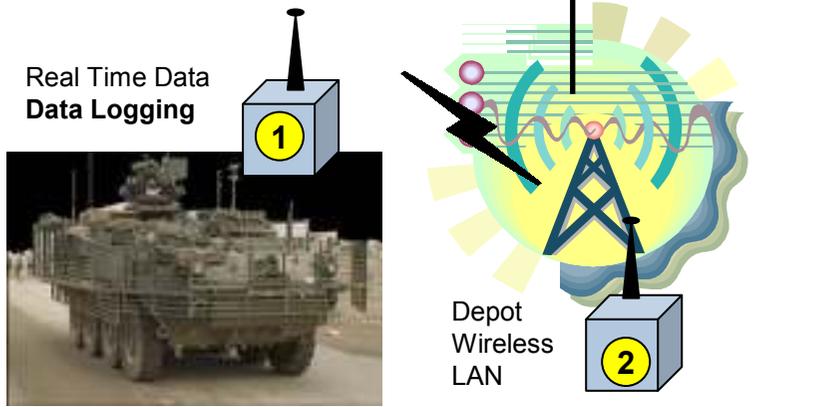
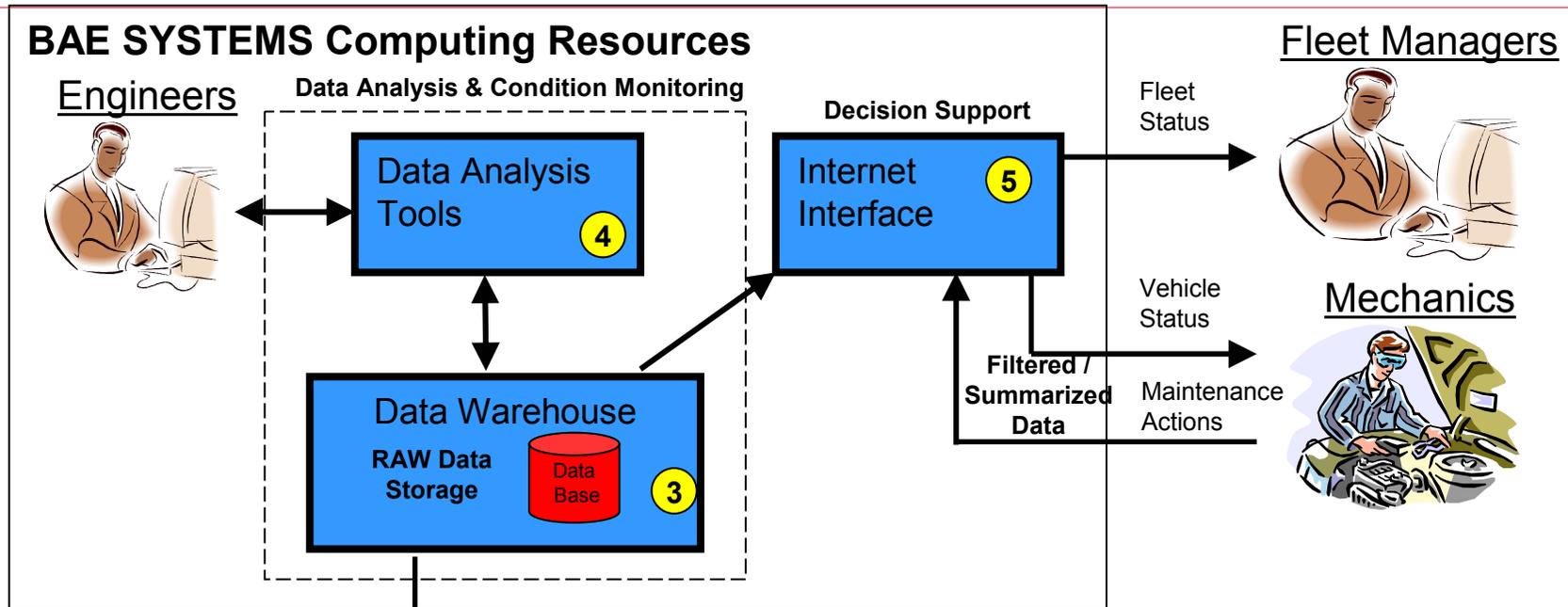
- J1939 CAN Bus logs data from:
  - Diesel Engine
  - Hybrid Propulsion Control System
  - Battery Optimization SubSystem (BOSS)
  - Air Conditioning Unit (ThermoKing)
- 2 RS-232 ports logs data from:
  - Door Control System (VAPOR)
  - GPS (optional)
- Data logger stores real-time data while bus is in-service
- Wireless Ethernet (IEEE 802.11g) utilized for automated data off-load when vehicle returns to Depot.
- Data automatically feeds into Fleet Health Monitoring System.
- Data logging signal definition and data rate are easily modifiable



# BAE SYSTEMS Fleet Health Management Infrastructure



# BAE SYSTEMS Fleet Health Management Infrastructure



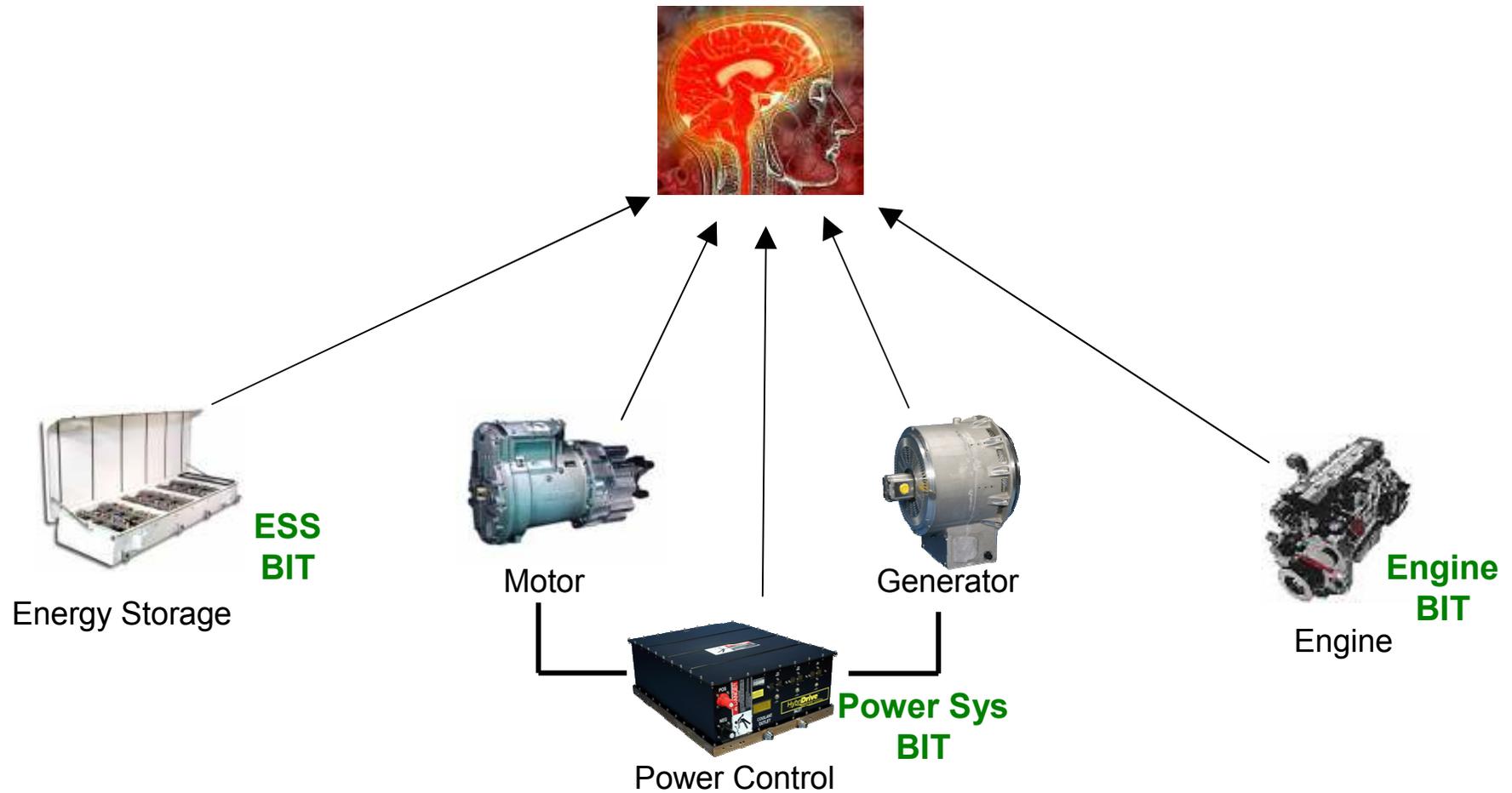
*Data is automatically transferred to BAE Systems FHM System. Actionable information is automatically provided to the engineering and maintenance desktop.*

# Bus Fleet Health Monitoring Network

**BAE SYSTEMS**



Machine Learning Algorithms Simultaneously Consider State Information of All Systems and Provide System Level Performance Modeling and Health Estimation



## Main page

– High level information for each bus (miles, hours, location)

– Red, yellow, green icons indicate health state (click on ID number to see details)

– Fault code column indicates if there are any active faults

The screenshot shows the iSupport web application interface. The browser title is "iSupport - - Microsoft Internet Explorer". The address bar shows the URL: [http://virtual-oracle.cs.na.baesystems.com:8011/OA\\_HTML/CONTEXT213B.jsp?tfm0=\\_0\\_3\\_0\\_-1\\_f\\_nv\\_custom=y&jfn=ZGAAB72BB5274DB3096](http://virtual-oracle.cs.na.baesystems.com:8011/OA_HTML/CONTEXT213B.jsp?tfm0=_0_3_0_-1_f_nv_custom=y&jfn=ZGAAB72BB5274DB3096). The page header includes the BAE SYSTEMS logo and the text "Electronics & Integrated Solutions". The navigation menu includes "Home", "Service Requests", "Support Documents", and "Fleet Health". The "Fleet Status" tab is selected.

Customer: NEW YORK CITY TRANSIT AUTHORITY  
Depot Filter: All  
Status Filter: All

Vehicle Number	Depot	Last Operation Date	Operating Time (Hrs)	Distance (miles)	Status	Fault Code
<a href="#">6401</a>	MANHATTANVILLE BUS DEPOT	06/02/2008	11	97		Prior
<a href="#">6762</a>	MANHATTANVILLE BUS DEPOT	05/27/2008	13.3	78.7		New
<a href="#">6533</a>	FRESH POND DEPOT	06/02/2008	9.9	63.8		New
<a href="#">6783</a>	MANHATTANVILLE BUS DEPOT	05/28/2008	6.6	36.7		No Fault Codes
<a href="#">6753</a>	MANHATTANVILLE BUS DEPOT	06/02/2008	18.3	127.9		Prior
<a href="#">6654</a>	MANHATTANVILLE BUS DEPOT	06/02/2008	15.5	117.7		No Fault Codes
<a href="#">6516</a>	FRESH POND DEPOT	06/02/2008	13.7	101.2		No Fault Codes
<a href="#">6761</a>	MANHATTANVILLE BUS DEPOT	06/01/2008	12.2	79.1		Prior
<a href="#">6778</a>	MANHATTANVILLE BUS DEPOT	06/02/2008	9.8	45.3		New
<a href="#">6402</a>	MANHATTANVILLE BUS DEPOT	05/28/2008	1.8	20.8		New
<a href="#">6785</a>	MANHATTANVILLE BUS DEPOT	06/02/2008	12	58.2		Prior
<a href="#">6468</a>	MANHATTANVILLE BUS DEPOT	05/30/2008	7.9	94.5		New
<a href="#">6767</a>	MANHATTANVILLE BUS DEPOT	06/02/2008	18.1	135.2		No Fault Codes
.....	MANHATTANVILLE BUS	.....	-	-		No Fault

# Red or Yellow Status Page



Address [http://virtual-oracle.cs.na.baesystems.com:8011/OA\\_HTML/CONTEXT213C.jsp?jtst0=30488\\_52020%2C52020%2C-1%2C0%2C&ibudnr=15&jtfi](http://virtual-oracle.cs.na.baesystems.com:8011/OA_HTML/CONTEXT213C.jsp?jtst0=30488_52020%2C52020%2C-1%2C0%2C&ibudnr=15&jtfi) Go Links

Home Profile Sign Out

**BAE SYSTEMS** Electronics & Integrated Solutions

Home Service Requests Support Documents Fleet Health

Fleet Status Vehicle Summary Vehicle Data Fault Codes Health Action Messages

### Vehicle Summary for Customer: NEW YORK CITY TRANSIT AUTHORITY

Vehicle Number	Depot	Last Operation Date	Operating Time (Hrs)	Distance (miles)	Status
6402	MANHATTANVILLE BUS DEPOT	08/03/2008	6.2	65.5	Alarm

**Current Fault Codes** [History](#)

Fault Code	Subsystem	Fault Description
149	PCS	Exhaust Filter Maintenance Required

**Current Out of Range Vehicle Data:**

Type	Name	Value	
SIGNAL	Ave Exhaust Pressure > 2000 RPM	48.4166	<a href="#">History</a>

**Current Health Action Messages** [History](#)

Message #	Status	Action	Reason	First Occurred	Type	Name	Clear
1061	Alarm	Trap should be inspected and cleaned soon	Engine exhaust pressure at trap inlet is high	06/29/2008	SIGNAL	Ave Exhaust Pressure > 2000 RPM	<input type="checkbox"/>

# Active Faults Page



– Clicking on an entry in the fault column of the main page bring you here

The screenshot shows the iSupport web application interface. The browser title is "iSupport - Microsoft Internet Explorer". The address bar shows the URL: [http://virtual-oracle.cs.na.baesystems.com:8011/OA\\_HTML/CONTEXT213E.jsp?jtst0=30488\\_52020%2C52020%2C-1%2C0%2C&ibudnr=15&jtfr](http://virtual-oracle.cs.na.baesystems.com:8011/OA_HTML/CONTEXT213E.jsp?jtst0=30488_52020%2C52020%2C-1%2C0%2C&ibudnr=15&jtfr). The page header includes the BAE SYSTEMS logo and the text "Electronics & Integrated Solutions". The navigation menu has tabs for "Home", "Service Requests", "Support Documents", and "Fleet Health". The "Fleet Health" tab is active, and the "Vehicle Fault Codes" page is displayed. The page shows the customer "NEW YORK CITY TRANSIT AUTHORITY" and filters for "Vehicle: 6401" and "Fault Code: All". The date range is "Start Date: 03-MAY-2008" to "End Date: 02-JUN-2008". The table below lists the fault records.

Vehicle Number	Subsystem	Fault Code	Fault Description	Fault Date
6401	PCS	133	PCS System Controller Loss of Communication From Battery System TBE #1	05/29/2008
6401	PCS	033	ACTM Oil Tank Coolant Level Low	05/28/2008
6401	PCS	033	ACTM Oil Tank Coolant Level Low	05/27/2008
6401	PCS	033	ACTM Oil Tank Coolant Level Low	05/26/2008
6401	PCS	033	ACTM Oil Tank Coolant Level Low	05/25/2008
6401	PCS	033	ACTM Oil Tank Coolant Level Low	05/24/2008
6401	PCS	033	ACTM Oil Tank Coolant Level Low	05/23/2008

# Data Viewing Page



- Users can get a history of any parameter in table format
- Plots may be added at a later time
- Toronto would be able to download MPG data from standard Diesels and Hybrids at any time

The screenshot shows a web browser window titled "iSupport - Microsoft Internet Explorer". The address bar contains the URL: [http://virtual-oracle.cs.na.baesystems.com:8011/OA\\_HTML/CONTEXT213D.jsp?jtst0=30488\\_52020%2C52020%2C-1%2C0%2C&budnr=15&jtfr](http://virtual-oracle.cs.na.baesystems.com:8011/OA_HTML/CONTEXT213D.jsp?jtst0=30488_52020%2C52020%2C-1%2C0%2C&budnr=15&jtfr). The page header includes the BAE SYSTEMS logo and the text "Electronics & Integrated Solutions". Below the header is a navigation menu with tabs for "Home", "Service Requests", "Support Documents", and "Fleet Health". The main content area is titled "Vehicle Data for Customer: NEW YORK CITY TRANSIT AUTHORITY". It features a form with the following fields: "Vehicle:" (dropdown menu with "6761" selected), "Attrib:" (dropdown menu with "Fuel Efficiency (MPG)" selected), "Start Date:" (text input with "02-MAY-2008"), "End Date:" (text input with "01-JUN-2008"), and a "Filter Dates" button. Below the form is a table with the following data:

Vehicle Number	Subsystem	Type	Name	Value	Date
6761		SIGNAL	Fuel Efficiency (MPG)	2.65546	06/01/2008
6761		SIGNAL	Fuel Efficiency (MPG)	2.51282	05/31/2008
6761		SIGNAL	Fuel Efficiency (MPG)	3.32743	05/30/2008
6761		SIGNAL	Fuel Efficiency (MPG)	4	05/29/2008
6761		SIGNAL	Fuel Efficiency (MPG)	3.34545	05/28/2008
6761		SIGNAL	Fuel Efficiency (MPG)	3.22148	05/27/2008
6761		SIGNAL	Fuel Efficiency (MPG)	2.89796	05/26/2008
6761		SIGNAL	Fuel Efficiency (MPG)	2.65403	05/25/2008
6761		SIGNAL	Fuel Efficiency (MPG)	3.05344	05/23/2008
6761		SIGNAL	Fuel Efficiency (MPG)	3.57282	05/22/2008
6761		SIGNAL	Fuel Efficiency (MPG)	3.8593	05/20/2008
6761		SIGNAL	Fuel Efficiency (MPG)	4.33028	05/18/2008
6761		SIGNAL	Fuel Efficiency (MPG)	2.60241	05/17/2008

At the bottom of the page, there is a footer with the text: "Send comments regarding this Web site to [cs-customer\\_service@baesystems.com](mailto:cs-customer_service@baesystems.com) Copyright © 2005, BAE SYSTEMS Platform Solutions".

# London Hybrid Bus Fleet Health Monitoring



– Initial Fleet of Hybrid Buses in London is Being Closely Scrutinized with BAE Systems Fleet Health Monitoring System

## Alexander Dennis Enviro200H



## Alexander Dennis Enviro400H



**ADL BusMonitor(64 bit)**

Battery Stats | Sorted Voltages | 1D Profiles | Bool Profiles | Anomaly | Gen

Refresh  Second to Last Day  Suppress Warnings on OI

Vehicle	Date	TimeON	DashMiles	Miles	AveMPH	MPG
GAGEH1	09/24/09	14.28	96.00	97.29	6.82	
GAGEH2	09/24/09	8.35	56.00	56.78	6.80	
GAGEH3	09/24/09	6.28	39.00	40.41	6.44	
GAGEH4	09/24/09	9.82	64.00	66.51	6.79	
GAGEH5	09/24/09	14.45	96.00	97.06	6.72	
HDE1	09/24/09	12.02	137.93	137.93	11.48	
HDE2	09/24/09	6.56	64.53	64.53	9.85	
HDE3	09/24/09	14.49	143.23	143.23	9.89	
HDE4	09/23/09	11.10	101.79	101.79	9.18	
HDE5	09/24/09	10.15	100.98	100.98	9.95	
TDGDH2	09/24/09	16.88	199.00	201.00	11.92	
TDGGH1	09/24/09	6.48	89.00	90.01	13.90	
TEH915	09/19/09	3.58	25.00	25.79	7.20	
TEH916	09/24/09	8.37	58.00	60.04	7.18	
TEH917	09/24/09	6.71	48.00	49.91	7.44	
TEH918	09/24/09	9.01	62.00	62.37	6.93	
TEH919	09/24/09	14.04	98.00	99.52	7.10	

## The Bad Part is Repaired

- Field Support technicians are dispatched to repair the problem
- Field Support knows to check the intake manifold and turbo output
- “Cobra Head” is found to be damaged and is quickly repaired
- On-vehicle diagnostics did not detect the problem and it would have developed into a more serious problem without the use of Neural Network technology



Note: UK date format, May 6, 2009