



S O L I D I C A

**TARDEC Condition Based Maintenance
Workshop**

**Pantheon™ Advanced System Health,
Diagnostic and Telematic System**

29 November 2007

About Solidica

- Founded in 1999 by Michigan-based Venture Capital
- Award-winning engineering expertise in advanced wireless & wired sensor networks



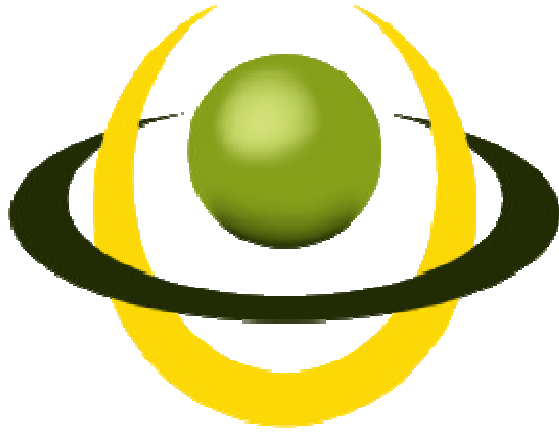
- Recipient of “50 Michigan Companies to Watch” Award



- Wide array of customers and partners – military & commercial



Wired and wireless sensing networks



PANTHEON™

Solidica's Pantheon™ product family is a fully integrated hardware/software sensor and secure telematics system that combines:

CHORUS™

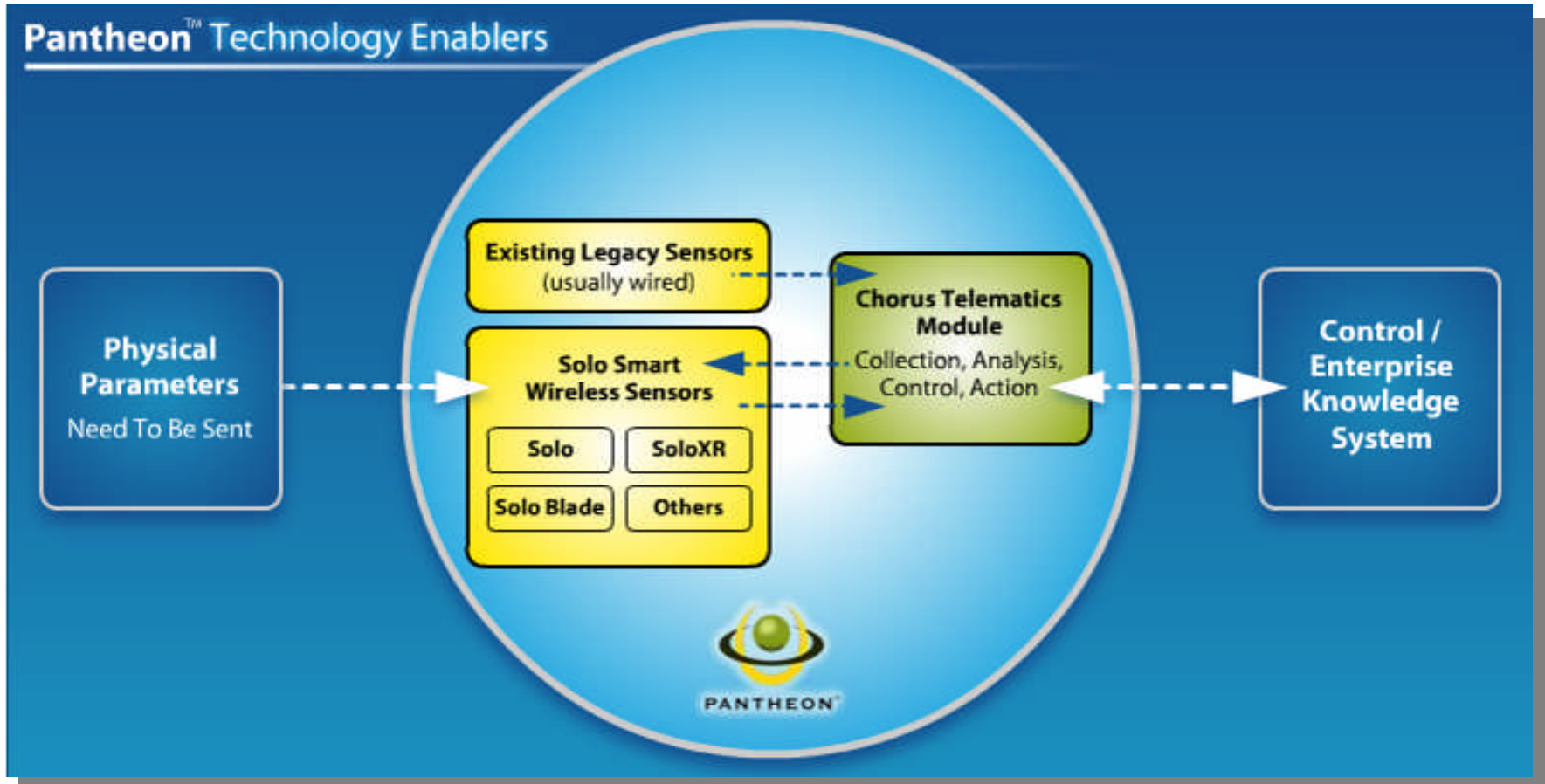
A State of the Art data collection and telematics hub with full GPS integration and embedded prognostics and diagnostics capabilities.

SOLO™ & SOLO™-XR

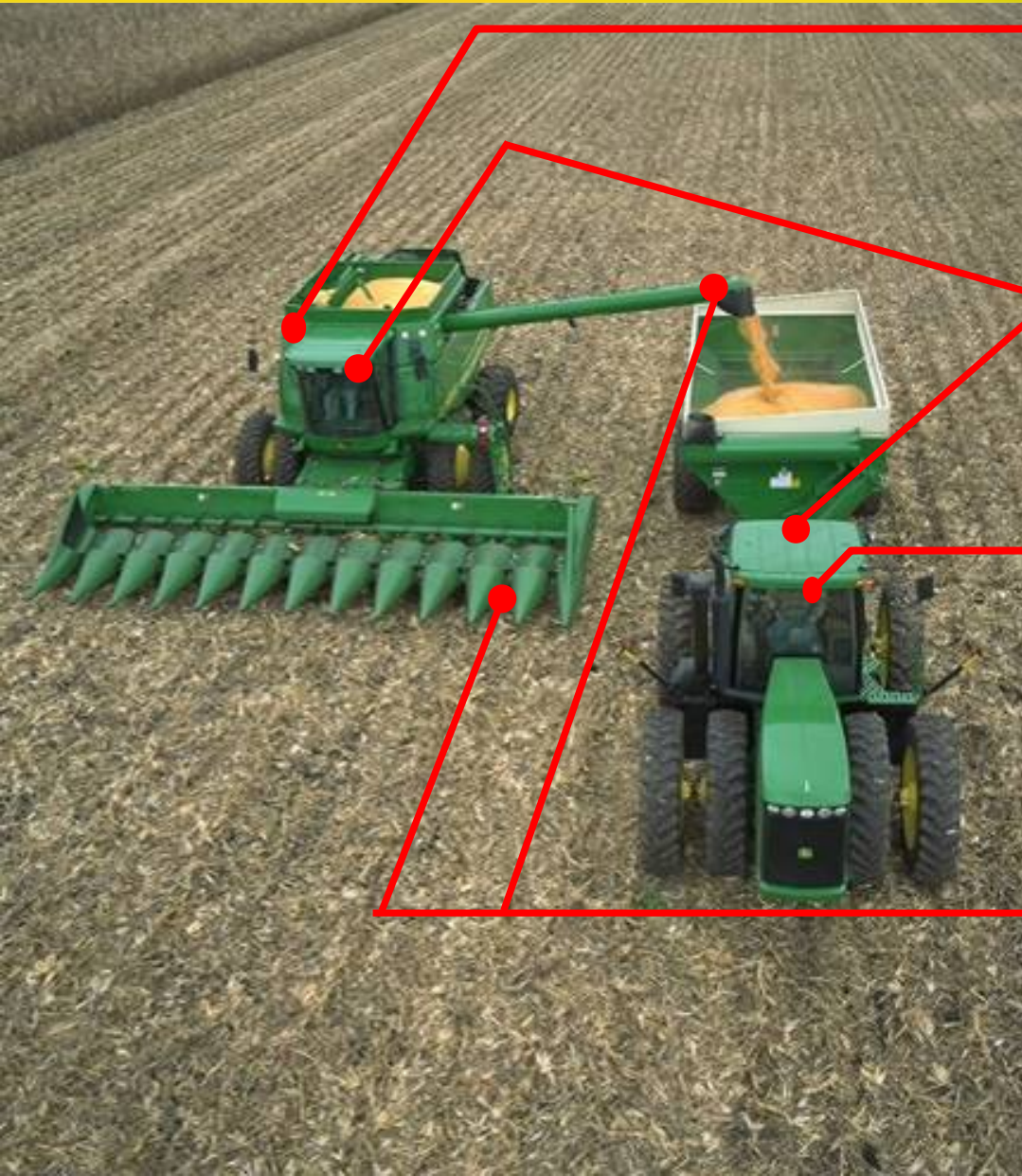
Combining award winning programmable sensor technology with industry leading secure mesh networking capability and rugged tamperproof packaging methods.



Pantheon™ – Functionality overview



Example Application: Agricultural Equipment



Solo Vertex™

Dynamic stability sensing, self-calibrating, driver and occupant proactive alerts – visual and audible, adaptable to nearly any platform.

Chorus™ Telematics Module

Sensor control, data stream management, telematics, prognostics, maintenance & logistics coordination

Solidica Antenna

2.45GHz DES FIPS-compatible digital radio signals. Real-time load, grain quality/moisture content, vehicle-to-vehicle communication & data stream

Solo™ Sensor/UID

Ground proximity, relative & absolute position, sonar-based sensing (height, soil quality, type, crop moisture), vision systems, predictive failure sensing, bearing temp. & lubrication monitoring

Sense & Respond Program History



- **Collaborative program between:**
 - Private industry
 - National Center for Manufacturing Sciences (NCMS)
 - PMLAV
- **Program sponsored by NCMS through their Commercial Technologies for Maintenance Activities Program (CTMA)**
- **1/3 funding from the DOD, 2/3 by industry**
- **Sense and Respond I was winner of 2004 Defense Manufacturing Excellence Award**



Sense & Respond I



- **Sense and Respond I – 2003-2005** – explore the utility of automotive COTS technology deployed onto an LAV and establish a LAV vehicle network (CAN).
 - COTS and legacy sensors
 - J1939 CAN network
 - Commercial diagnostic tool demonstration
 - Live field access to remote maintenance expert
- **Key Lessons Learned**
 - COTS very useful but does not fully satisfy military requirements
 - Commercial OEM's do not own the customer
 - Planetary gear sensors
 - Trend data storage and analysis
 - Lack of data interoperability with DOD enterprise software
 - Affordably converting legacy analog sensors to CAN is difficult
 - Data analysis must be robust and well thought out



Sense & Respond II



- **Sense and Respond II – 2005-2006** – Establish more robust on-board hardware with greater PC based processing connected to COTS and Customized LAV sensors (ie. Planetary Gear, shots counter)
- **Key Lessons Learned**
 - PC in the critical path is highly problematic
 - High power draw
 - Misses key pre and post ignition stage vehicle data
 - Prone to crash, shutting down the entire system
 - First level processing of sensor data must happen fast to avoid data bottlenecks
 - Must perform holistic vehicle electro-mechanical analysis first
 - Better to achieve a 90% CBM solution and get it deployed
 - Need to consolidate hardware into affordable single Hub
 - Conduct all first level data processing on hub so that users are only retrieving useful data.
 - make the PC a peripheral
 - make it easy to get data off of the Hub
 - Hub must have COTS and legacy sensor connectability
 - Hub should provide “black box” key data recording and configuration management
 - Must be low power and always on
 - Ensure Hub can be updated easily with future CBM algorithms
 - Provide data in fully interoperable formats – XML, engineering units, CAN, etc.



Planetary Gear Example



S&RIII Program

Potential Outcomes and Objectives

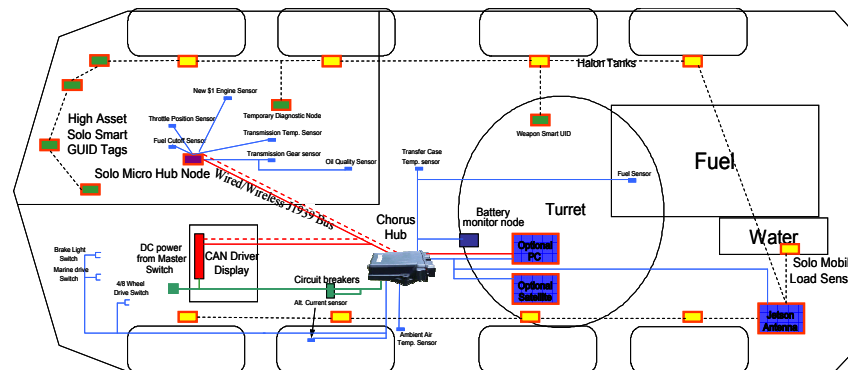
Sense and Respond III – Combination of robust vehicle analysis with a COTS on-board hardware Hub that embodies the lessons learned within the previous phases into a final state of the art Sense and Respond demonstration. The key objectives of this program will be:

1. **Vehicle Analysis**: Conduct holistic vehicle operation and electro-mechanical performance analysis to determine the 90% “must know” characteristics/temperament of the LAV.
2. **SRH Hardware Upgrade**: Deploy **Pantheon™** hardware onto 1 LAV to serve as backbone of S&RIII program. This hardware will provide a synergistic enhancement to future EPLS hardware and will enable new functionality necessary for robust CBM and S&R flexibility.
3. **Sensor Network Scalability**: Demonstrate ease of adding new/existing high value wired and wireless sensor technology to include PGS v.2, Shots Counter v.2, and a new LAV Ride Harshness Sensor (RHS).
4. **Demonstrate Mini Maintenance Aid interface**. Low cost handheld device to provide quick wireless viewing of live vehicle sensor data and related IETM’s. The device would be usable for quick diagnostics, IETM views, and configuration management queries.
5. **Demonstrate “Smart” Data storage/retrieval and select CBM algorithm(s)**. This task will demonstrate how to capture, store, and analyze the “right” data on the LAV. Further, it will showcase how a small hardware footprint, combined with well thought out CBM algorithms, can deliver a robust solution that both supports and enhances future EPLS hardware.
6. **UID integration to LAV for mobile load Configuration Management**: Demonstrate ability of the SRH to sense UID mobile load presence and automatically add it to the “transient configuration” of the LAV.
7. **VCM Demonstration**: Demonstrate LAV control and performance optimization capability using the Vehicle Control Module (VCM) within the SRH for high value maintenance/operation application (based upon vehicle analysis guidance).



Vehicle Analysis

- Conduct holistic vehicle operation and electro-mechanical performance analysis combined with RCM analysis to determine the 90% “must know” characteristics/temperament of the LAV.
 - Condition Sensing – Identification and prioritization of vehicle system level conditions that most affect vehicle operation and health.
 - Algorithm development for condition based maintenance - Development and implementation of initial algorithms for a limited number of identified vehicle conditions.
- The vehicle analysis will drive subsequent sensor and control algorithm selection necessary for S&R and CBM.

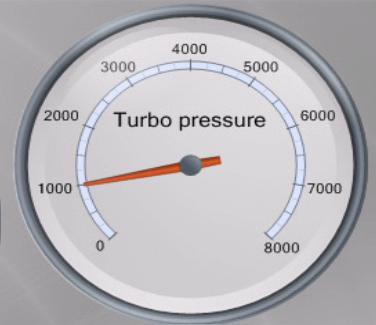


Pantheon™ Hardware Upgrade

- Installation of Pantheon™ hardware onto LAV testbed
 - Sensor interface and digitization (wired and wireless)
 - Wireless bridge
 - ECM or VCM capability
 - GPS
 - “Black Box”
 - Macro Configuration Mgmt.
 - SAE J1939 and J1708
 - Up to 92 channel A-D conversion
 - USB 2.0, 802.11 g/b, RS232, RS485, Bluetooth™, 802.15.4
 - 20 GB onboard data storage
 - 9-40V (with 60+V power spike and reverse load dump protection)
 - -55 to +85°C
- Always On operation
 - Ultra low current draw
 - Critical ignition cycle vehicle data will be collected
 - Asset health during storage or power-off will be possible (ie. know if the vehicle will start before even trying.)
 - OBC – OS independent operation avoids crashes
- Pantheon™ will provide tactical enhancement and critical data redundancy to future EPLS hardware.
- Rapid retrofit to LAV possible

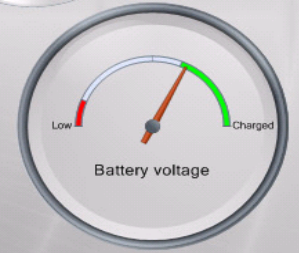
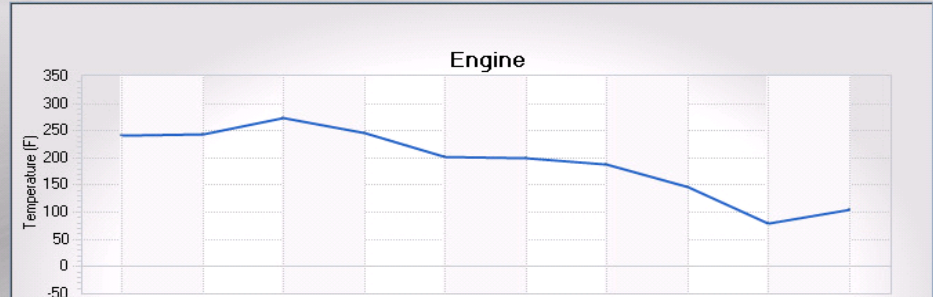
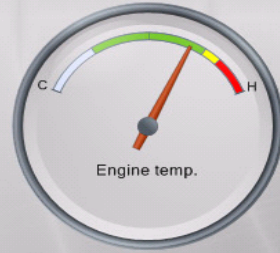
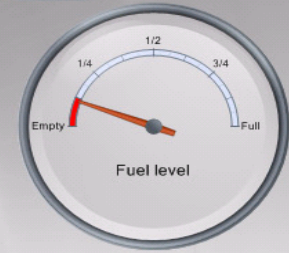
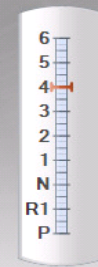


Pantheon™ Example User Interface

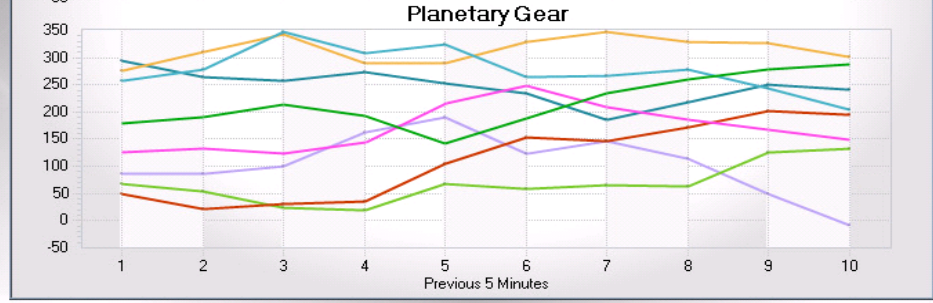


Mission trip 162

Mission time 1:36

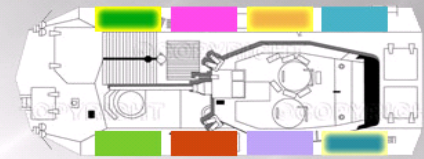


09:13:15 <WARNING> Planetary gear #4 exceeding acceptable temperature range
 09:13:41 Planetary gear #4 stabilized
 09:14:28 Mission time has exceeded 01:30
 09:17:54 <WARNING> Fuel low, estimated 00:21 minutes or 13 miles of operating time at current fuel consumption



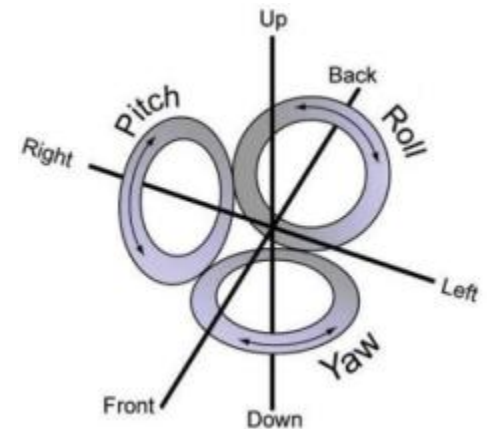
Fuel Range 221

Rounds Fired 32



Sensor Network Scalability

- Demonstrate ease of adding new/existing high value wired and wireless sensor technology per vehicle analysis.
- Demonstrate Planetary Gear Sensor and Shots Counter version 2.0
- Additionally, the system will include a new **Ride Harshness and Vehicle Stability Sensor (RHS)** that will store and aggregate operational harshness to provide system level CBM correlation:
 - Sophisticated dynamic motion/vibration sensor
 - Currently being tested on other military ground platforms
 - Once calibrated for LAV will store and aggregate a ride harshness factor on an hourly basis.
 - Algorithm includes real time assessment of the rate of change and the maximum and minimum values for, among others:
 - Roll, pitch, yaw
 - 3 Axis G-forces
 - Vibration intensity
 - Speed



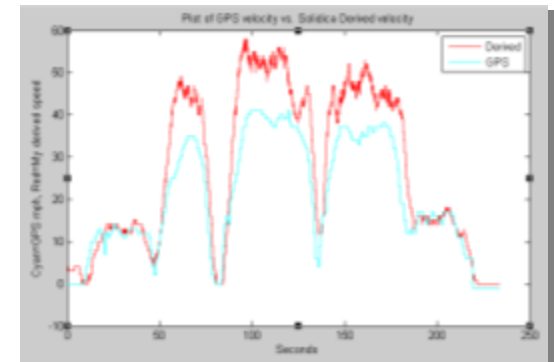
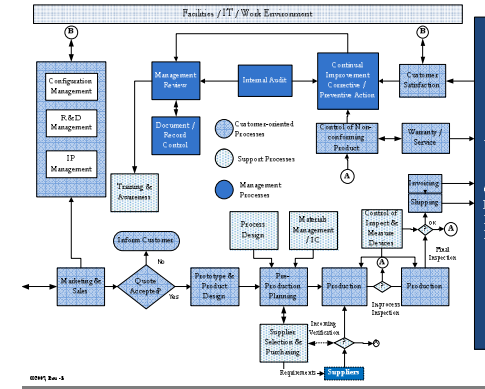
Mini Maintenance Aid

- Cargo-pocket sized
- Showcase highly interoperable Sensor Control Panel software that can run on a variety of handheld devices and provide quick wireless and/or wired viewing of:
 - live and trended vehicle sensor data
 - related IETM's
 - configuration management
- Usable while vehicle is running or turned off due to “always on” Pantheon II™ capability
- Can be used a means of offloading stored vehicle data from vehicle



“Smart” Data Storage/Retrieval and CBM

1. Demonstrate “Smart” Data storage/retrieval and select CBM algorithm(s).
2. This task will demonstrate how to capture, store, and analyze the “right” data on the LAV.
3. Further, it will showcase how a small hardware footprint, combined with well thought out CBM algorithms, can deliver a robust solution that both supports and enhances future EPLS hardware.



IUID/UID to LAV Configuration Mgmt.

- Demonstrate ability of Pantheon™ to sense UID mobile load presence and automatically add it to the “transient configuration” of the LAV.
- Utilize new 802.15.4 body armor sensors to automatically identify and associate a Marine with an LAV they enter.
- Could also demonstrate similar association with other high asset mobile loads.
- Leverage vehicle communications to transmit injury report

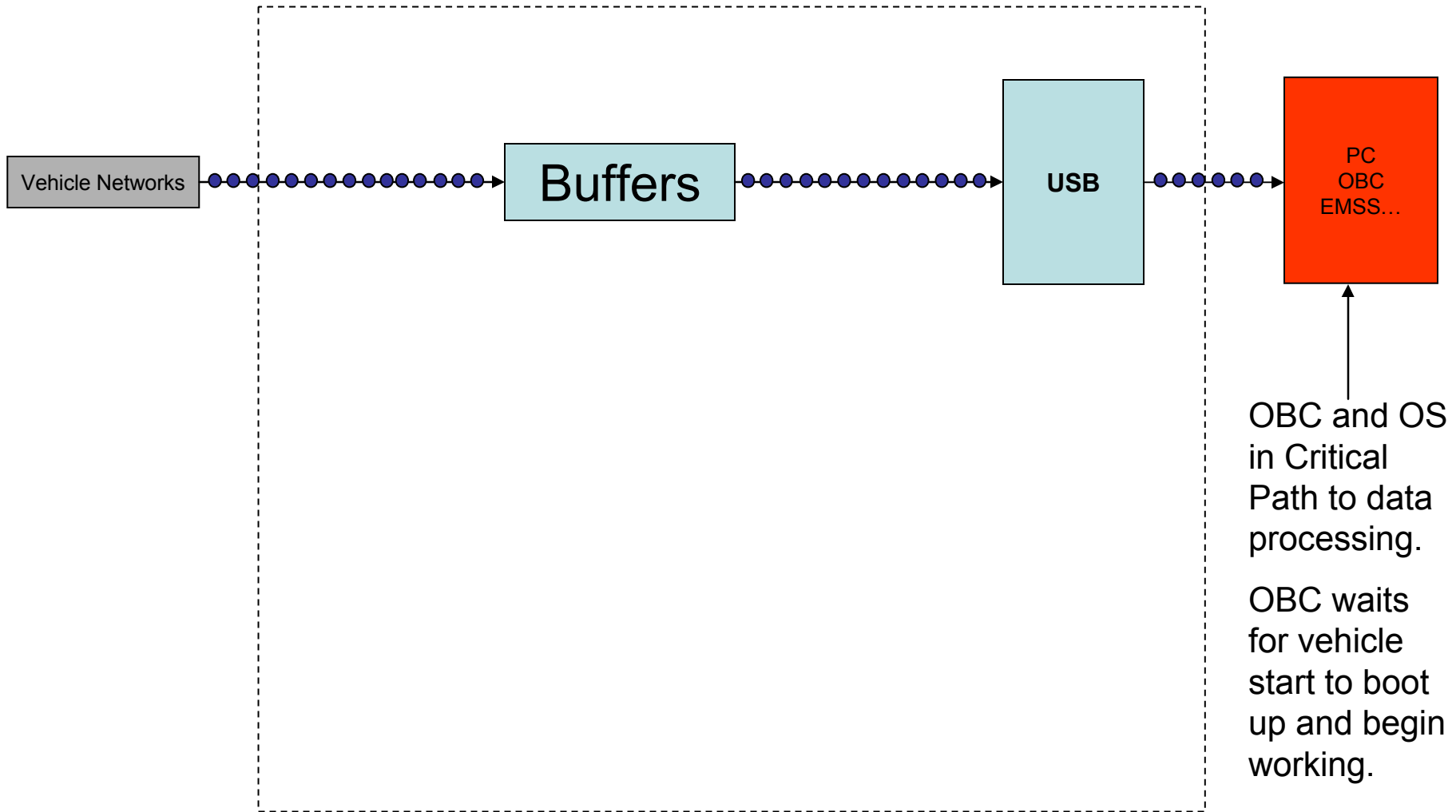


VCM Demonstration

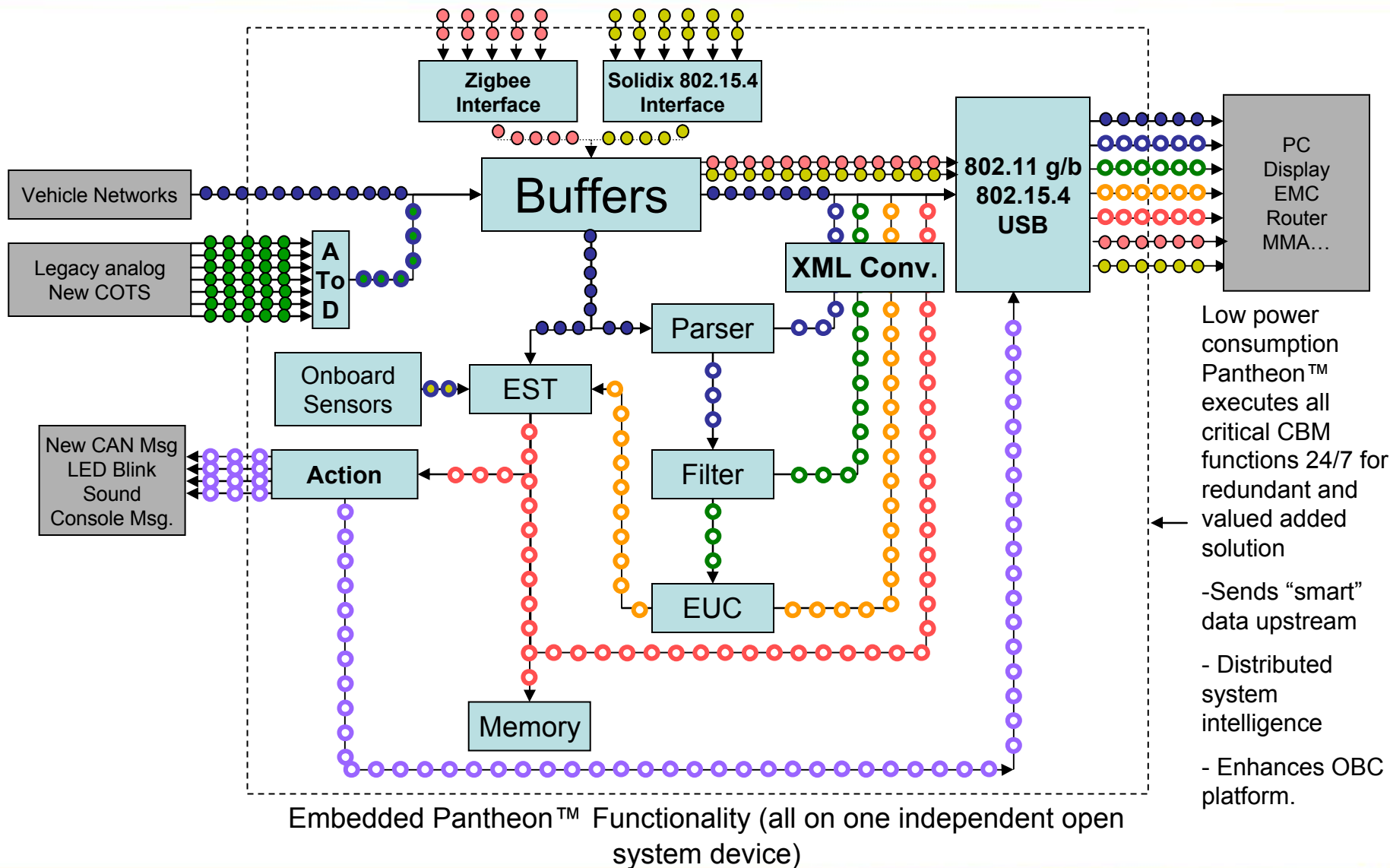
- The LAV has limited computer control, all sensors read to analog gauges and rely on the operator to monitor and adjust control. Potential control uses for the Pantheon™ System that may be demonstrated in S&R III are:
 - Optimized Torque Output – The limiting factor in the torque output of a Diesel engine is the exhaust gas temperature. In an open loop system the injection pump timing and turbo boost must be set in a very conservative fashion to prevent the EGT from exceeding its limits under the harshest conditions. The problem with this is that under normal operating conditions, the engine cannot operate to its full capacity. Implementing turbo waste gate control, electronic throttle control, and a simple exhaust gas temperature sensor would allow for maximum engine output for a given set of conditions.
 - Cooling System Control - Traditional cooling pumps are completely mechanical and are designed to provide adequate coolant flow under worst case scenarios. Under normal conditions, the cooling flow from the pump is excessive and wasting energy. If an electric pump that provided desired flow replaced the mechanical pump, energy savings could be realized. Additionally, replacing the wax-bulb thermostat with a stepper motor could further enhance the design.
 - Transmission Control – Having engine parameters available as digital output from the SRH would provide the inputs necessary to use a modern electronically controlled transmission behind the LAV engine. The additional gear ratios and torque converter lock-up would provide significant energy savings (20%) as well as better shift control for loads and off-road situations.
 - Glow System Control – Diesel engines are notorious for being hard to start in cold weather. Most often poor starting is the direct result of inadequate operation of the glow system. If a temperature sensor could be located inside of the engine, precise glow time could be controlled by the SRH to insure reliable starting in the coldest of conditions.
 - Engine Life: Military Diesel engines are often subjected to the harshest conditions and changing engine oil at specified intervals may not be enough. Diesel engine oil life is direct function of the amount of soot contamination in the oil. Sensors have been employed to try to measure oil quality but relatively simple algorithms can also be put in place that will estimate oil life by keeping track of engine load, temperature and number of cycles.



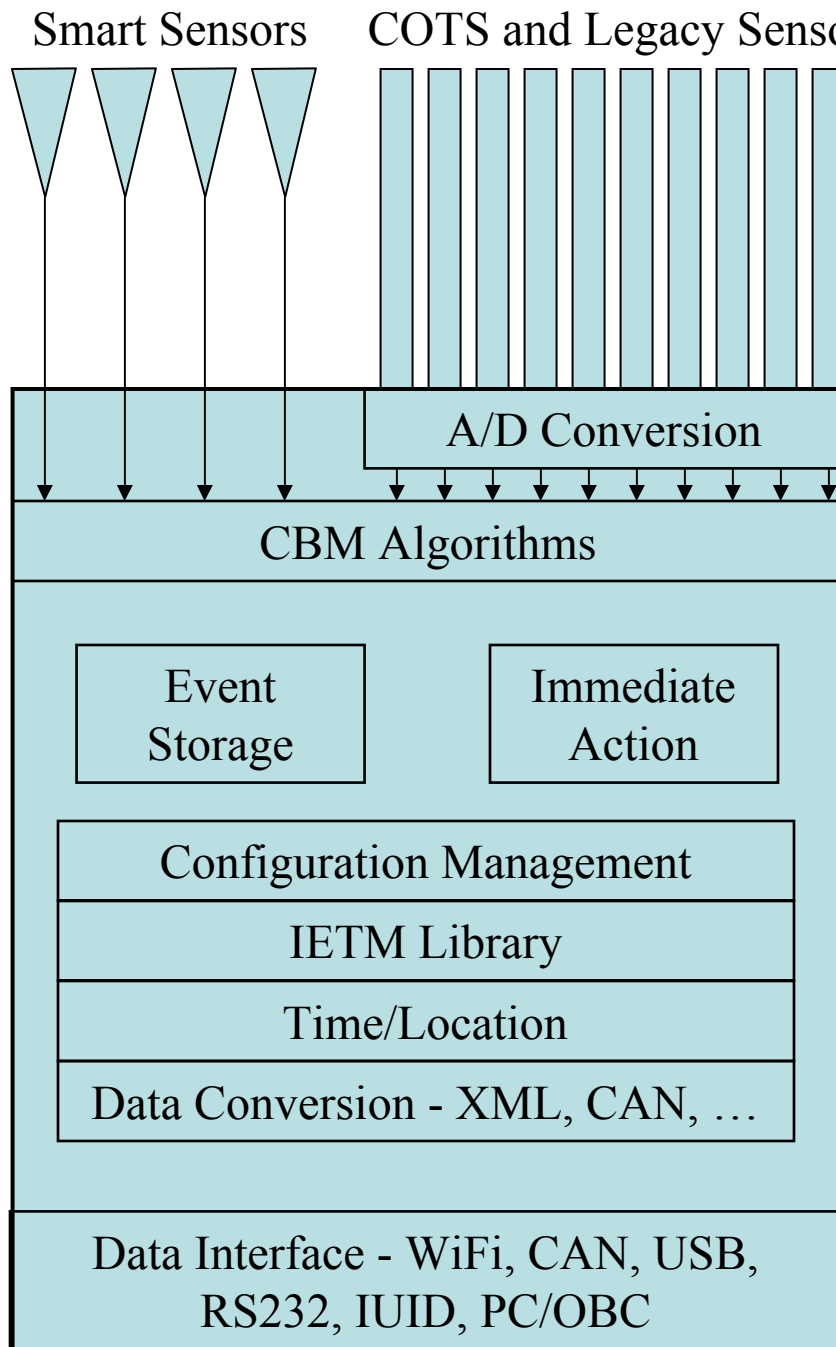
Old Data Processing Architecture



Solidica's Pantheon™ Embedded Data Flow



Potential Sense and Respond III Architecture



Detailed vehicle electro-mechanical analysis combined with RCM to identify the right sensor points necessary for **useful** CBM - 90/10 rule.

Always On - All key vehicle sensing and CBM algorithms active 24/7

Smart Storage – Self Powered “Black Box”, Trends, Config. Mgmt., Trouble Codes, IETM’s, ...

Action - high value vehicle control

Data Interface - PC, SatCom, Diagnostic Handhelds, flash memory

Data Conversion - enterprise interoperability, MIMOSA, etc.



S O L I D I C A

WWW.SOLIDICA.COM

