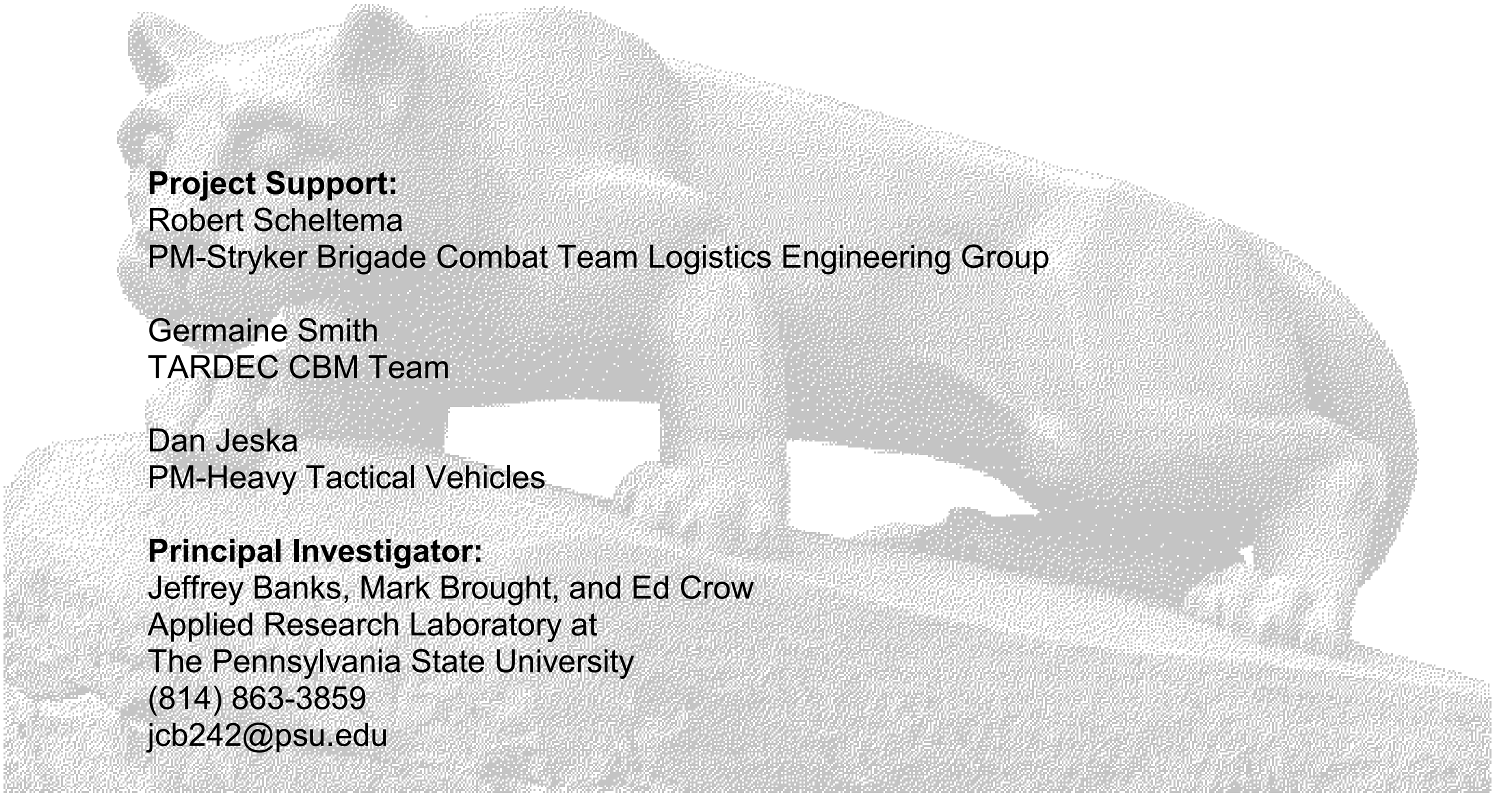
SBCT Embedded Data Collection and Analysis System (SEDCAS)

Project Final Report

12 September 2012



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14. ABSTRACT

The SBCT Embedded Data Collection and Analysis System (SEDCAS) program involved the collection and analysis of individual vehicle fault indication, usage and performance data to improve the vehicle fleet sustainment and condition based maintenance of Stryker Brigade Combat Team (SBCT) vehicles including the Stryker and HEMTT A4 platforms. The 56th SBCT of the 28th Infantry Division of the Pennsylvania Army National Guard (PAARNG) was selected as the test unit for this program. The focus of the program was to utilize existing GOTS (primary objective) and COTS (secondary objective) technologies to enable an automated health management and condition based maintenance capability for the Stryker platforms. The automated system is designed to operate with any ground vehicle that has a SAE standard digital data bus including the Stryker, HEMTT, FMTV, HET, M915 and MRAPS.

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Executive Summary:

The SBCT Embedded Data Collection and Analysis System (SEDCAS) program involved the collection and analysis of individual vehicle fault indication, usage and performance data to improve the vehicle fleet sustainment and condition based maintenance of Stryker Brigade Combat Team (SBCT) vehicles including the Stryker and HEMTT A4 platforms. The 56th SBCT of the 28th Infantry Division of the Pennsylvania Army National Guard (PAARNG) was selected as the test unit for this program.

The focus of the program was to utilize existing GOTS (primary objective) and COTS (secondary objective) technologies to enable an automated health management and condition based maintenance capability for the Stryker platforms. The automated system is designed to operate with any ground vehicle that has a SAE standard digital data bus including the Stryker, HEMTT, FMTV, HET, M915 and MRAPS.

The preliminary work for this program involved conducting a Stryker vehicle degrader analysis to determine where the application of diagnostic and predictive technologies could potentially have the greatest impact on the effective implementation of condition based maintenance. The degrader process for the Stryker platform used data from three sources including: multi-year part replacement data from DMIS and single year data from AMSAA, maintainer interviews, and an OEM questionnaire completed by GDLS-Canada. The results of the degrader analysis include a list of components and systems that could benefit from health management technologies because they contribute most to maintainability, reliability and vehicle operational availability issues.

The program functional requirements for the vehicle embedded digital source collection (DSC) system included the ability to interface with the vehicle digital data buses, collect vehicle digital bus data, conduct short term data storage (~ three weeks), enable conversion of the data into the standard Army Bulk CBM Data (ABCD) format, and wireless data transfer from vehicle to remote wireless access points using FIPS 140-2 data encryption. This functionality was implemented with a maintenance support device (MSD v3) with additional GOTS and COTS software. The DSC gathers vehicle data from the SAE J1708 digital data bus, the SAE J1939 controller area network (CAN) bus and several additional digital sensors that were designed for this program. The wireless local area network (WLAN) data transmission capability that moves data from each platform to the ARL Information Warehouse (ARL IW) located at ARL Penn State consists of a U.S. Army standard (GOTS) portable WLAN network communication system called Combat Service Support Automated Information Systems Interface (CAISI).

Once the vehicle data is received by the bridge module located at ARL Penn State, the data is ingested into the ARL Information Warehouse. This server system was designed to be similar to the Common CBM Data Warehouse that is part of the LOGSA Logistic Information Warehouse (LIW). This was done to develop ‘best practices’ for moving vehicle data to LOGSA and to implement technologies that are currently being developed and deployed by DoD. The general functionality of the ARL IW is to automatically analyze individual ABCD files as they arrive at the IW using data analytic techniques. The SBCT Unit Management Portal user interfaces were designed and implemented through a functioning web based application.

As of the conclusion of this project, the SEDCAS system remains automated and operational with five Strykers and one HEMTT equipped with data source collection systems, a functional wireless off-board data transfer system, off-board data storage, data handling system and the graphical user interface available for viewing.

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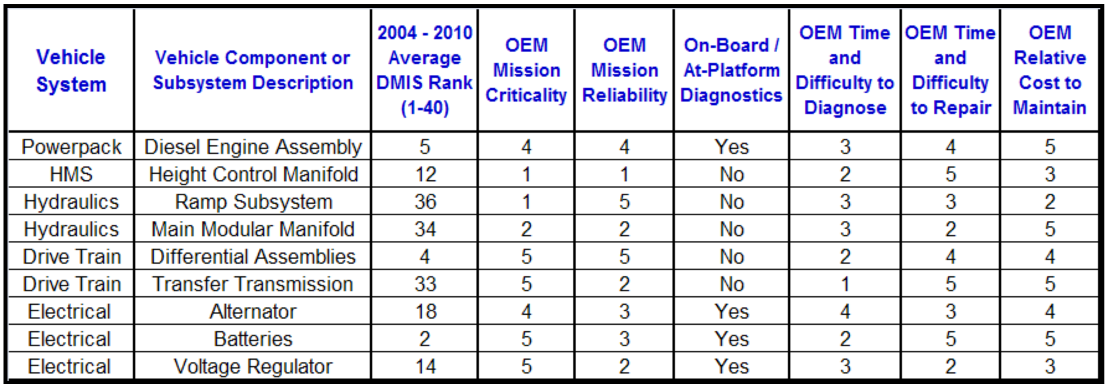
1.0 Degrader Analysis Summary: Stryker Platform

A Stryker vehicle degrader analysis was conducted to determine where the application of diagnostic and predictive technologies could potentially have the greatest impact on the effective implementation of condition based maintenance. The degrader process for the Stryker platform used data from three sources including: multi-year part replacement data from DMIS and single year data from AMSAA, maintainer interviews, and an OEM questionnaire completed by GDLS-Canada. The results of the degrader analysis include a list of components and systems that could benefit from health management technologies because they contribute most to maintainability, reliability and vehicle operational availability issues. The degrader list for the Stryker platform, shown in Figure 1, is based on the analysis results detailed in the *'SBCT Vehicle Degrader Analysis for the Stryker Platform'* report that was completed on 15 August 2011. The full report can be obtained from Mr. Robert Scheltema, at PM-SBCT.



Vehicle System	Vehicle Component or Subsystem Description	2004 - 2010 Average DMIS Rank (1-40)	OEM Mission Criticality	OEM Mission Reliability	On-Board / At-Platform Diagnostics	OEM Time and Difficulty to Diagnose	OEM Time and Difficulty to Repair	OEM Relative Cost to Maintain
Powerpack	Diesel Engine Assembly	5	4	4	Yes	3	4	5
HMS	Height Control Manifold	12	1	1	No	2	5	3
Hydraulics	Ramp Subsystem	36	1	5	No	3	3	2
Hydraulics	Main Modular Manifold	34	2	2	No	3	2	5
Drive Train	Differential Assemblies	4	5	5	No	2	4	4
Drive Train	Transfer Transmission	33	5	2	No	1	5	5
Electrical	Alternator	18	4	3	Yes	4	3	4
Electrical	Batteries	2	5	3	Yes	2	5	5
Electrical	Voltage Regulator	14	5	2	Yes	3	2	3

Figure 1: Stryker Platform Degrader List

The first two columns are the vehicle system and component/subsystem description. The next column provides the ranking results for the 2004 – 2010 DMIS average part replacement data. The fourth and fifth columns provide the mission criticality ratings (1 – failure has a negligible effect on functionality, 5 – failure results in complete loss of functionality) and mission reliability ratings (1 - most, 5 – least). The sixth column indicates whether there is an on-board or at-platform diagnostics capability for each component or sub-system. The final three columns indicate time and difficulty to diagnose (1 - effective diagnostics, 5 - less effective diagnostics), time and difficulty to repair (1 - short repair time, 5 - long repair time), and relative cost to maintain (1 - low repair/replacement cost, 5 - high repair/replacement cost). For a more detailed description of the rankings see pages 14-15.

The final step in the degrader process involved conducting an analysis known as failure modes, effects and criticality analysis (FMECA) for the degrader components. This analysis was conducted using the comments from the DMIS part replacement data to determine the failure modes that are occurring for each degrader component and subsystem. This vehicle degrader - potential health management solutions analysis provided a recommended list of sensors that either currently exist on the platform or would need to be added to enable a diagnostic or predictive capability for each system or component identified as a high probability degrader. In order to provide the degrader analysis conclusion results in a concise format, summary tables were created. The summaries include a table for the diesel engine assembly, the drive train system, the electrical power generation and storage system, and the height management system and hydraulic system, which are included in the degrader analysis final report. A summary of the conclusions and recommendations from the report are provided below.

The most significant and highest occurrence failure mode for the diesel engine is a low engine oil level from either engine oil leaks or non-replenishment of the fluid. A general low engine oil condition is detectable with the existing embedded diagnostics using the oil temperature switch and oil pressure switch that provide fault codes as well as the coolant temperature data. A more direct diagnostic capability as well as a predictive capability would require the addition of an oil level sensor.

The most significant and highest occurrence failure mode for both the differentials and the transfer case is low lubrication oil level from either leaks or non-replenishment of the fluid. A low lubrication oil condition for the differentials and the transfer case is not detectable with the existing embedded diagnostics and there are no existing sensors installed on the vehicle for monitoring the health of the differentials or transfer case. A diagnostic capability as well as a predictive capability would require the addition of a single vibration sensor (accelerometer) applied to each differential and transfer case.

The most significant and highest occurrence failure mode for the alternator, batteries and voltage regulator is charging issues that cannot be completely detected by the existing vehicle embedded capability. The alternator and voltage regulator would require the addition of a current sensor with a current and voltage trending algorithm for a diagnostic capability and a predictive capability for the alternator could be implemented with current signature analysis techniques. For the batteries, it is recommended that the existing U.S. Army at-platform battery diagnostic tools be fully utilized by the maintainers before an embedded solution is implemented on the platforms.

The most significant and highest occurrence failure mode for the height control manifold in the height management system is nitrogen gas leaks. The existing embedded diagnostics has a partial capability to detect this failure mode using fault codes. In order to provide a comprehensive leak detection capability as well as a predictive indication it is recommended that a pressure sensor be installed on both the low and high pressure sides of the system in addition to or as a replacement for the existing pressure switches.

The most significant and highest occurrence failure mode for the hydraulic system is the loss of hydraulic fluid. The loss of fluid is a direct consequence of hydraulic fluid leaks that can be generally detected with the existing reservoir level switch but the specific source of the leaking fluid failure mode cannot be determined (i.e. isolated) with the existing vehicle sensors. The implementation of an embedded fault isolation or predictive capability for hydraulic fluid leaks is not recommended for this application due to low effectiveness of the current technology.

Additional diagnostic capabilities using parametric data from the existing vehicle sensors could be developed. These capabilities include an oil life condition algorithm that provides an actionable and definitive indication of when the oil should be changed using engine speed and coolant temperature sensors. In addition, an engine performance and general health indication using a data fusion technique with parametric data from multiple existing sensors including engine speed, boost pressure, engine coolant temperature, fuel rate, and manifold temperature sensors could be developed. Finally, an electrical power generation system general health indication could be developed using parametric data from the engine speed and voltage sensors. The approach would provide a course health assessment of the electrical power generation system including the alternator, voltage regulator and batteries.

The results of the degrader analysis provide a list of existing platform sensors as well as a list of potential additional sensors that could be added to the vehicle. Some of these sensors were developed and added to the test vehicle for this program but not all of the potential additional sensors were implemented. This report will describe the sensors that were developed and added to the platform for this program.

2.0 Overview of the SEDCAS Program:

The SBCT Embedded Data Collection and Analysis System (SEDCAS) program involves the collection and analysis of individual vehicle usage and performance data to improve the vehicle fleet sustainment and condition based maintenance of Stryker Brigade Combat Team vehicles including the Stryker and HEMTT A4 platforms. The 56th Stryker Brigade Combat Team of the 28th Infantry Division of the Pennsylvania Army National Guard (PAARNG) was selected as the test unit for this program. A high level operational view of the SEDCAS program is shown in Figure 2.

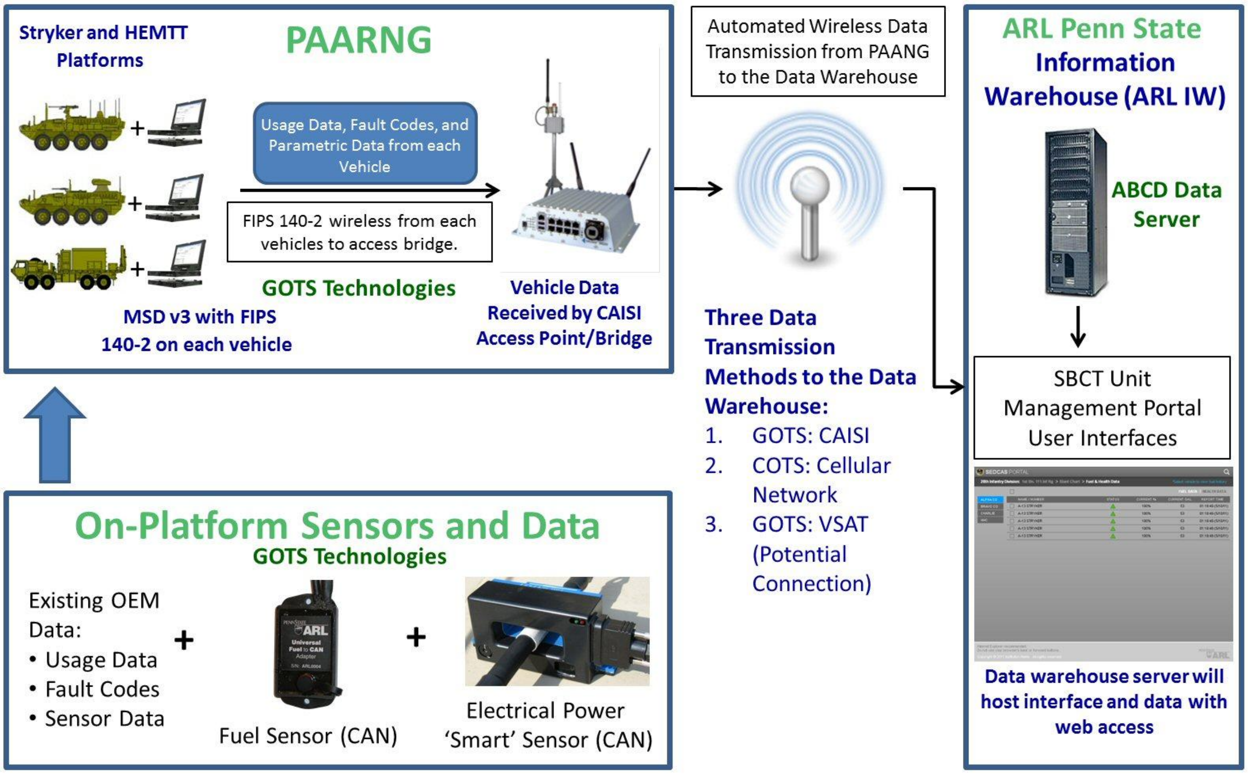


Figure 2: SEDCAS Operational View

The focus of the program was to utilize existing GOTS (primary objective) and COTS (secondary objective) technologies to enable an automated health management and condition based maintenance capability for the Stryker platforms. The automated system is designed to operate with any ground vehicle that has a SAE standard digital data bus including the Stryker, HEMTT, FMTV, HET, M915 and MRAPS. As shown in Figure 2, the on-platform sensors and data for assessing platform health includes the existing vehicle sensors and fault codes as well as the addition of a fuel sensor and an electrical power sensor. A maintenance support device (MSD v3) laptop computer was installed on five Stryker platforms and one HEMTT A4 platform to provide the capability to collect and store vehicle digital bus data in the Army Bulk CBM Data (ABCD) format. The data from each platform is automatically transferred from each vehicle to wireless access points located at the PAARNG maintenance facility in State College, PA using the encrypted FIPS 140-2 protocol. The access points store the data from all of the vehicles and transfers the data to servers located at ARL Penn State facility in State College, PA using either a U.S. Army standard CAISI network or a commercial cellular network to demonstrate the feasibility of either approach. The vehicle data is collected and stored at ARL Penn State data warehouse that is designed to emulate the LOGSA CBM data warehouse. The data processing architecture is employed to conduct automated data analytics including: fleet usage; vehicle performance and fuel usage; and using fault/failure codes to conduct condition based maintenance. The vehicle data and the results of the data analysis are presented in a vehicle fleet information interface that is designed to support vehicle fleet health management and condition based maintenance. This information will be used to optimize operations and conduct focused and tailored maintenance on Stryker platforms. This effort will support the transition from contractor logistic support to organic maintenance performed by the U.S. Army.

3.0 Platform Data and Sensor Development:

The embedded data collection system gathers vehicle data from the SAE J1708 (old standard) digital data bus. In order to facilitate the integration of additional sensors to the platforms, ARL Penn State installed a SAE J1939 (new standard) controller area network (CAN) digital data bus specifically to support the additional sensors described below.

3.1 Existing Vehicle Sensors on the Digital Data Bus:

The platform has data from many sensors, alerts and fault codes that exist on the J1708 data bus. Data was gathered from the list shown in Table 1.

Table 1: Platform Sensors, Alerts and Fault Codes

Engine

- Engine Speed
- Engine Load
- Boost Pressure
- Accelerator Pedal Position
- Coolant Temp
- Fuel Consumption Rate
- Fuel Econ
- Power Take-Off Information
- Rated Engine Power
- Total Times (Engine Hours, Driving Time, Fuel Used, Idle Hours, Idle Fuel Used, Idle Time Percentage)

Transmission

- Oil Temperature
- Output Shaft Speed
- Transmission Range Attained
- Transmission Range Selected

Brakes

- ABS Brake Control Status
- ABS Retarder Control Status
- ABS Warning Lamp Status
- ATC Spin-Out Signal Detection
- ATC Status Lamp
- Battery Potential
- Hard Braking Event
- Rapid Accel Event
- Trip Drive Time
- Vehicle Speed
- Wheel Speeds

Alerts and Faults

- Alert Name
- Alert Reason
- Alert Severity Code and Color
- Alert Time
- Fault Amber Warning Lamp
- Fault Description
- Fault FMI
- Fault Malfunction Indicator Lamp
- Fault Status
- Fault Time
- Fault Count

3.2 Universal Fuel to CAN Adaptor:

Since the Stryker platforms do not have the capability to provide the fuel level sensor data to the J1939 bus, ARL Penn State developed and built a Universal Fuel to CAN (UFC) adaptor that converts the analog fuel level sensor data into a J1939 message that enables the ability to record the fuel level data during vehicle operations as shown in Figure 3.

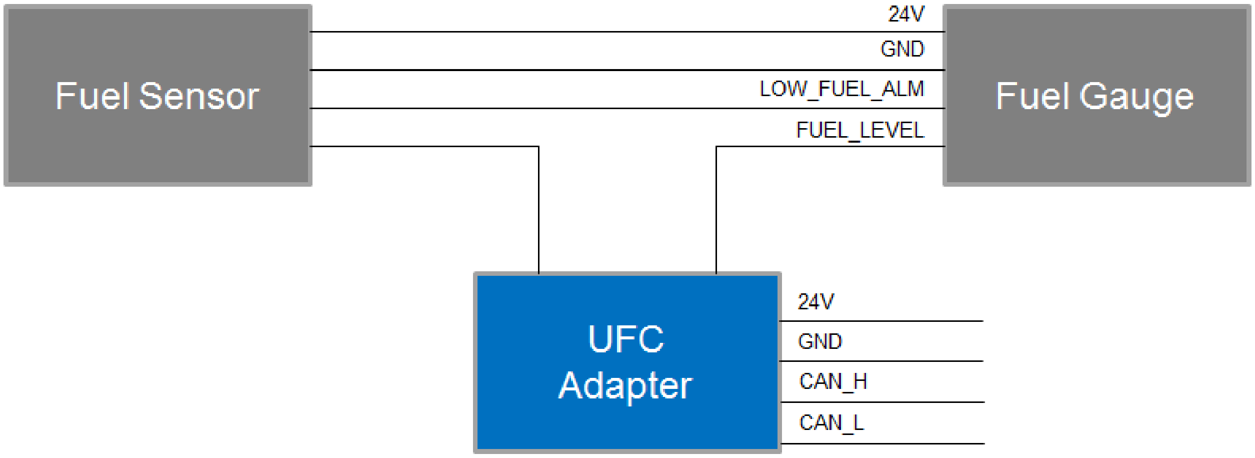


Figure 3: Universal Fuel to CAN (UFC) Adaptor

The Stryker fuel sensor is a current sink. The fuel gauge intermittently sources current, once every 12 seconds. The sensor sinks current proportional to the fuel level on the sensing element. The UFC is shunted between the gauge and sensor. The UFC adaptor design accommodates other fuel sender / gauge styles widely used across other military platforms such as current loop, Pulse Width Modulated signal (PWM) and potential (voltage) type. The adaptor outputs message on SAE J1939, (PGN65276 and SPN 96) at a one second update rate with field upgradeable firmware. The adaptor has a form factor of 2.00” x 3.25” x 0.5” and the enclosure is epoxy filled and environmentally sealed with a LED status that indicates functioning or disconnected or invalid sensor data. Each platform in the SEDCAS program has an embedded UFC adaptor.

3.3 Advanced Electrical Power Sensor:

In order to monitor the vehicle electrical power system performance data and provide an embedded health management capability an advanced electrical power (AEP) sensor was develop and built as shown in Figure 4.

Figure 4: Advanced Electrical Power Sensor

The sensor is designed so that the same sensor design can be used to monitor the vehicle alternator and each battery string with individual sensors. The sensor is designed to measure and record voltage, current and temperature and output messages on the J1939 CAN bus (PGN65300 – PGN65317) at a one second update rate. The measurements include minimum, maximum, mean, and rms of the current and voltage as well as mean temperature. The power cycle measurements include minimum voltage, maximum current, and elapsed time. The lifetime measurements include total current and elapsed time. The sensor can store 30 minutes of collected data before publishing to the CAN bus and it has field upgradeable firmware.

The AEP sensor implementation configuration for the alternator is shown in Figure 5.

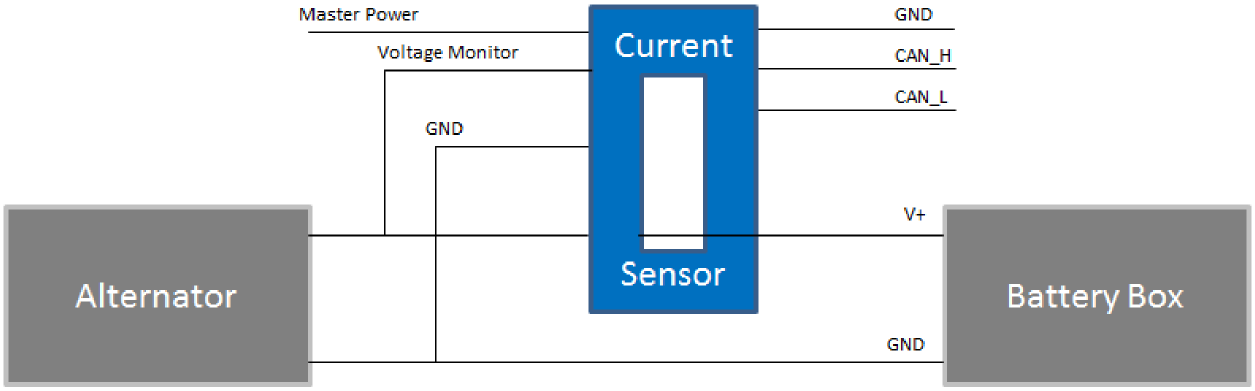


Figure 5: AEP Sensor Implementation for the Alternator

The alternator power lead(s) pass through sensor and the sensor is powered by a master power switch. The voltage monitor measures alternator output voltage.

The AEP sensor implementation configuration for each 24 volt battery string is shown in Figure 6.

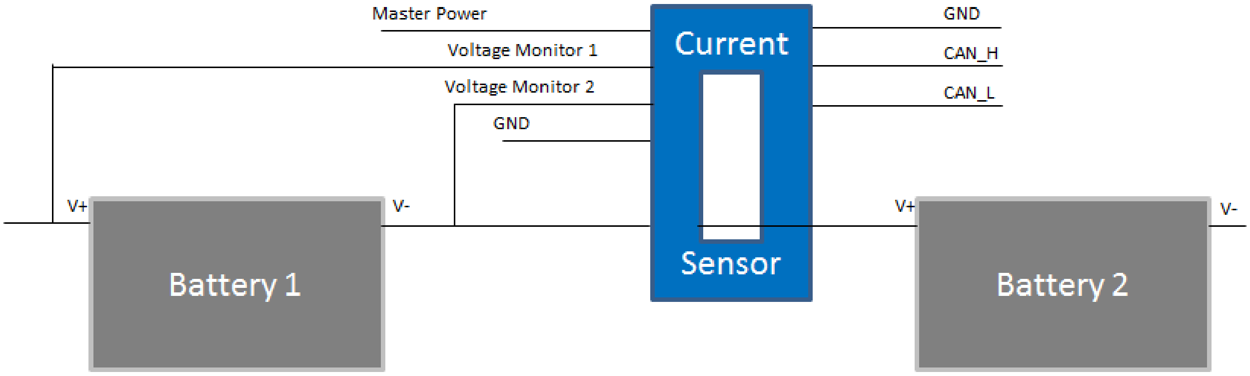


Figure 6: AEP Sensor Implementation for the Battery String

The voltage monitors measures both battery voltages and the voltage monitors 'disconnect' when powered down.

Each platform in the SEDCAS program has embedded advanced electrical power sensors.

3.4 Differential Lubrication Level Sensor:

In order to address the differential lubrication loss failure mode, we explored various sensor solutions for this critical failure mode. There are many technology choices for conducting lubrication loss diagnostics on differentials. A simple first assessment for determining the best method for detecting a loss of lubrication is to measure the level directly using a level transmitter. Due to space constraints within the differential and reading inaccuracies because of fluid movement this choice is considered to have a low effective feasibility.

Another method is to look for effects of lubrication loss, like a temperature increase of the differential case. Temperature monitoring can be an effective health monitoring technique but it is limited in that it has a slow reaction time relative to the fault degradation time of mechanical system components. Damage to the gears and bearings can occur between when the lubrication loss occurs and the differential sensor shows a significant increase in temperature. Temperature does not provide an early indication of lubrication loss and it is not effective for detecting and diagnosing gear and bearing faults in the differential. Temperature monitoring by itself may not be a good diagnostic indicator but it could provide non-commensurate data for sensor fusion and prognostic techniques.

One of the most effective techniques for diagnosing mechanical system faults is vibration analysis. Many vibration based techniques have proven to be sensitive and early indicators of bearing and gear faults in mechanical systems. Since vibration sensors have been used to detect bearing and gear faults in differentials, their use in the detection of low lubrication level would provide for a much simpler and efficient multi-purpose sensor implementation. The focus of this work is to determine if vibration analysis can be an effective indictor of low lubrication level.

We gathered data from both a Stryker differential and a HEMTT differential, processed the data and conducted data analysis to evaluate the correlation between the vibration measured by the transducer and the differential lubrication level. Based on the analysis, we were able to create an algorithm that uses vibration data from the differential to determine the lubrication level as shown in Figure 7.

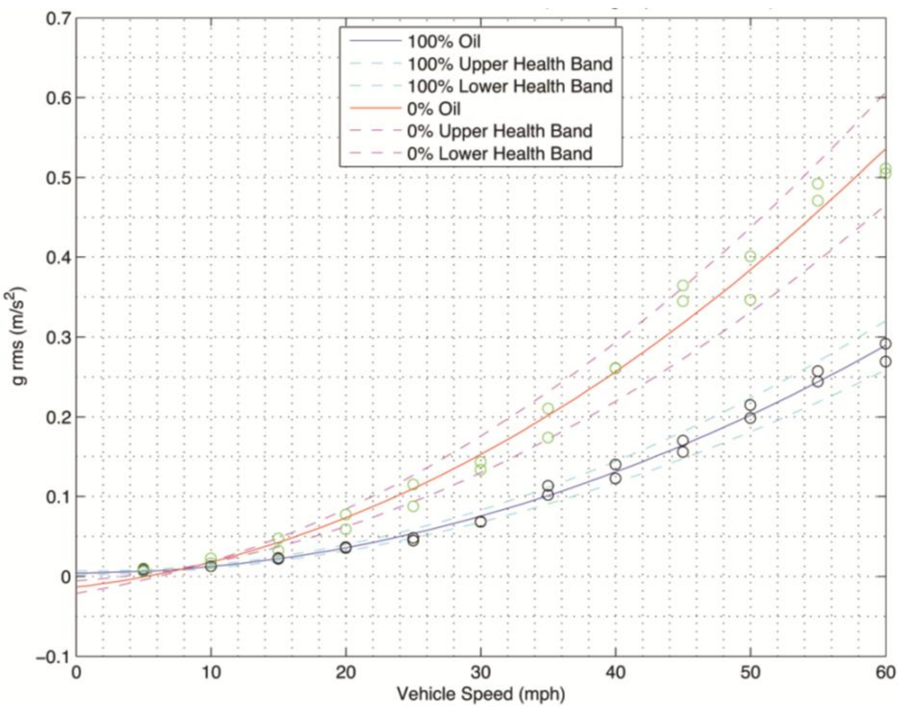


Figure 7: Curve Fit of Differential Vibration data as a Function of Vehicle Speed

The data in Figure 7 shows the results of 2nd order polynomial curve fits for both the 100% full lubrication level vibration data represented by the blue circles and the 0% empty lubrication level vibration data represented by the green circles. The vibration data in g's is the RMS (root mean squared) value over a narrow frequency range that was selected for optimum sensitivity to lubrication level and it is plotted against the vehicle speed in miles per hour (mph). The dashed lines for each curve fit represents two standard deviations (i.e. 95% confidence bounds) for the curve fit.

What the data shows is that above a vehicle speed of 25 mph, there is an indication of the lubrication level for differential that changes as a function of vehicle speed. As the vehicle speed increases the ability to distinguish between the levels is greater which provides increased confidence in the level indication. Based on the results of the algorithm development, we are proposing to develop a digital sensor that can implement this algorithm and be attached to the differential to provide a lubrication level capability. This work would be conducted through a future effort.

4.0 On-Platform Digital Source Collection System:

The program functional requirements for the vehicle embedded digital source collection (DSC) system includes the ability to interface with the vehicle digital data buses, collect vehicle digital bus data, conduct short term data storage (~ three weeks), enable conversion of the data into the standard Army Bulk CBM Data (ABCD) format, and CAISI wireless data transfer from vehicle to remote wireless access points using FIPS 140-2 data encryption.

4.1 Digital Source Collector:

The DSC data collection and storage device that was used for this program is the Miltope Maintenance Support Device (MSD V3) that is Government Off-The-Shelf (GOTS) equipment. The reason that the MSD v3 was selected as the DSC device for this program is because the U.S. Army has plans to integrate an MSD standard laptop computer to each Stryker platform to host the IETM and potentially serve as a ground digital logbook. This SEDCAS program utilized the MSD and configured it to serve the additional purpose of a digital source collection device that could enable a condition based maintenance capability for the platforms.

The components of the digital source collection system include the MSD v3, Noregon JPRO Military Diagnostics software and a Noregon DLA+ bus adaptor as shown by the brown components in Figure 8. The components shown in blue are the additional sensors that were described in the previous section.

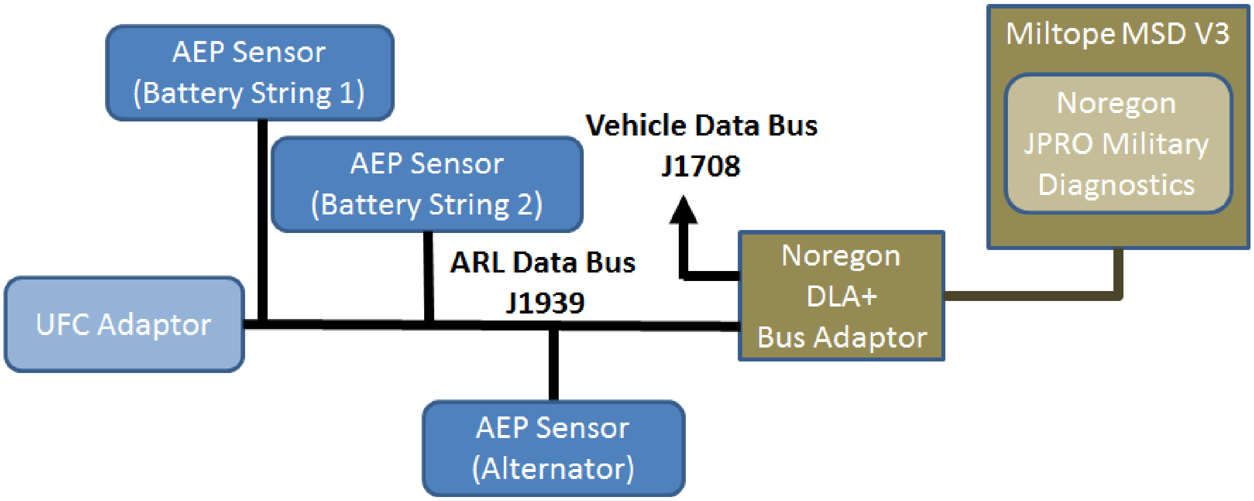


Figure 8: Digital Source Collection System and Sensors

The MSD v3 laptop computer that uses the Windows 7 operating system, was configured as a digital source collection device with the implementation of the Noregon JPRO Military software that enables the ability to collect data from the J1939 and J1708 data buses. This software is based on a commercial fleet vehicle software product that was adapted for military use with requirements and funding for the adaptation being provided by U.S. Army AMSAA. We selected this software for this program because it has been functionally validated by AMSAA through their sample data collection program and it is considered GOTS technology. This program provided the technical direction and the funding to incorporate an ABCD data format conversion capability into the JPRO software.

The MSD gathered data from the J1708 and J1939 digital data buses with the utilization of a data bus protocol adaptor. There are several commercially available protocol adaptors but the Noregon DLA+ bus adaptor was selected for this effort because we were using the Noregon JPRO Military software and their adaptor allowed direct compatibility with their software. The integration of the protocol adaptor into the DSC system is shown in both Figure 8 and 9.

In order to enable the MSD to boot-up when main vehicle power was applied to the device, the software BIOS was updated by the MSD manufacturer (Miltope) to enable this capability. ARL Penn State created an MSD power-off application that enabled a ‘graceful’ shut down capability when all of the required functions (i.e. data collection and transmission tasks) were completed by the MSD at the end of each mission.

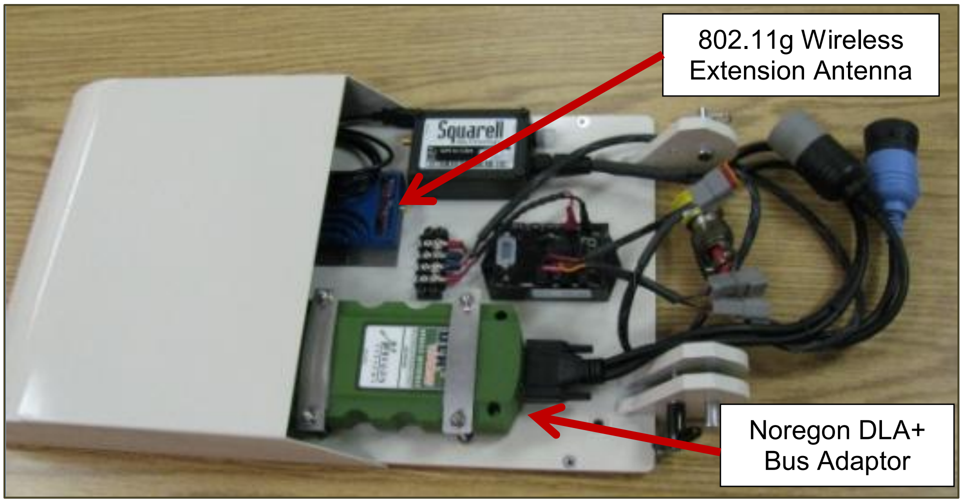


Figure 9: DSC System Support Components

MSD Lessons Learned:
There are two factors that need to be addressed to effectively utilize an MSD as an embedded DSC.

1. Implement the update BIOS for all of the MSD's being integrated to the platform to enable the MSD to boot-up when main vehicle power is applied to the device.
2. It is recommended that the current standard USB connectors on the MSDv3 be upgraded to accept hardened stud mounted USB connectors as shown in Figure 10.

Figure 10: Hardened Stud Mounted USB Connectors

4.2 Wireless Data Transfer:

The data that is collected on the MSD was stored until the vehicle came into range of a wireless access points that are located at the State College PAARNG Maintenance Facility. The wireless data transfer capability was implemented with the existing 802.11b/g wireless that is resident on the MSD with the addition of a USB wireless extension antenna (shown in Figure 9) that was placed outside the vehicle hull. The FIPS 140-2 encryption of the data was implemented through a standard embedded function in the Windows 7 operating system.

The organization and synchronization of the data downloads from each vehicle to the access points was facilitated with GoodSync software that was installed on each platform DSC and the access points. This COTS product was utilized for this program due to its relatively low cost and high reliability. The ARMY's future plans are to handle the synchronization function and data downloads using a GOTS product under development by LOGSA named Common

Information Management Services CIMS). This will replace GoodSync in the SEDCAS system when it is available in the future.

5.0 Off-Platform Data Transmission System:

The wireless local area network (WLAN) data transmission capability that moves data from each platform to the ARL Information Warehouse (ARL IW) located at ARL Penn State consists of a U.S. Army standard (GOTS) portable, weatherproof WLAN network communication system called Combat Service Support Automated Information Systems Interface (CAISI). The CAISI system consists of a 802.11b/g wireless access point that receive data from each platform, a switch, security gateway and a bridge module that transfers the data from the access point to the ARL IW. The CAISI system has a maximum range of 32 miles point to point. For this program we used a directional antenna at each end point with an omnidirectional intermediate antenna at the midpoint to overcome an elevation peak in the middle of our 5.5 mile data hop. In addition to the CAISI wireless network system, we integrated a data buffer with synchronization capability with the access point. We also implemented an additional functional bridge module using commercial cellular wireless solution and developed a potential future SATCOM data transmission capability as shown in Figure 11.

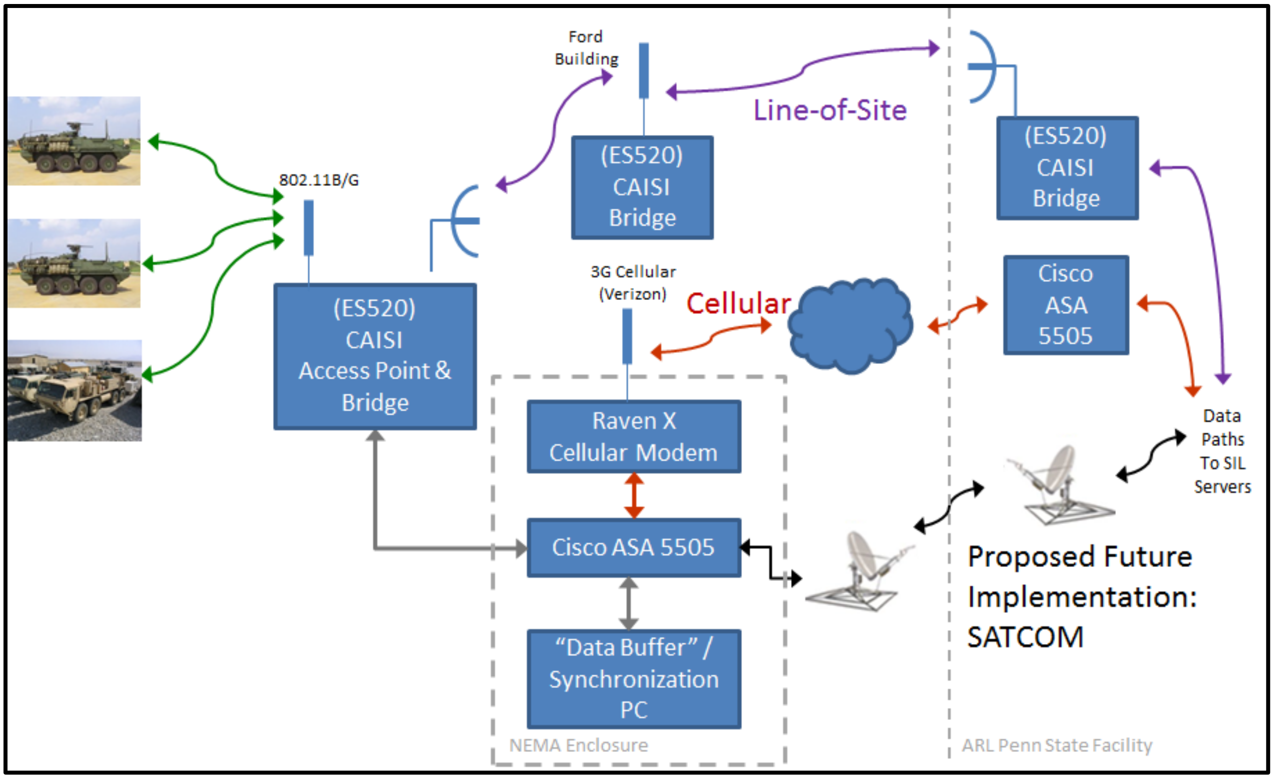


Figure 11: Access Point to Data Servers Operational View

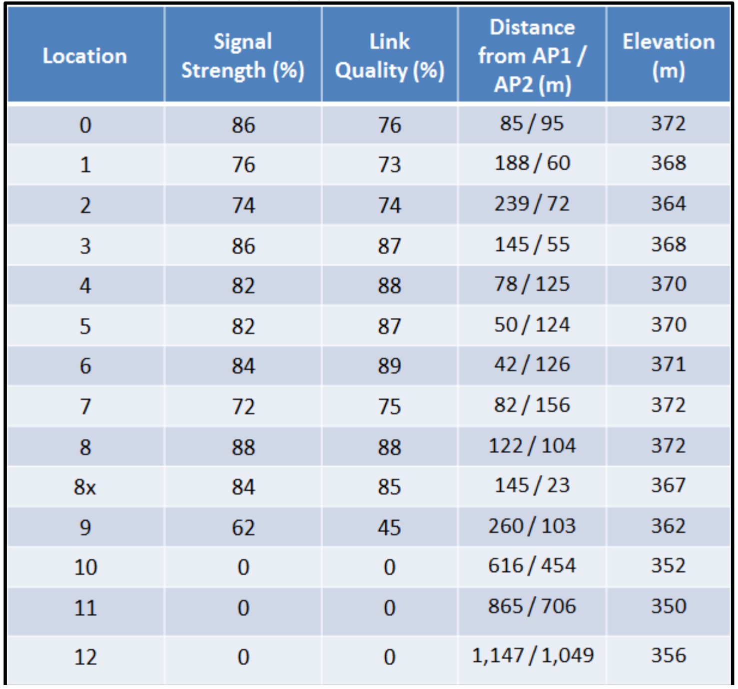
When a platform is in transmission range of an access point/bridge module located at the PAARNG Maintenance Facility in State College, PA, the on-platform MSD digital source collection system with GoodSync software automatically downloads stored data to the CAISI access point. The access point has an embedded computer that supports the GoodSync software and serves as a data buffer to provide short term data storage for all of the platforms that it serves until the data can be transferred to the ARL IW located at ARL Penn State.

A survey was conducted to validate the configuration of the access points at the PAARNG Maintenance Facility. Initial testing showed that there were ‘dead spots’ when only one access point was used, so two access points were implemented for this compound. The location of the two CAISI access point/bridge modules and the wireless data transmission test points are shown in Figure 12. Test points 10, 11, and 12 are not shown on the map because they are located at extreme distances from the access points, near the limit of their range.

Figure 12: Wireless Data Transmission Test Map

The survey consisted of wirelessly transferring data from a test vehicle equipped with a DSC system to the access points from each of the locations indicated in Figure 12. The results of the data analysis that included signal strength, link quality, distance from each access point and elevation from sea level for each of the test points are shown in Table 2.

Table 2: Wireless Survey Results with Two Access Points



Location	Signal Strength (%)	Link Quality (%)	Distance from AP1 / AP2 (m)	Elevation (m)
0	86	76	85 / 95	372
1	76	73	188 / 60	368
2	74	74	239 / 72	364
3	86	87	145 / 55	368
4	82	88	78 / 125	370
5	82	87	50 / 124	370
6	84	89	42 / 126	371
7	72	75	82 / 156	372
8	88	88	122 / 104	372
8x	84	85	145 / 23	367
9	62	45	260 / 103	362
10	0	0	616 / 454	352
11	0	0	865 / 706	350
12	0	0	1,147 / 1,049	356

The survey data shown in Table 2 indicates that all of the test locations within the compound provide relatively high signal strength and link quality with the exception of the extreme distance test points 10, 11 and 12 that had zero signal strength and link quality.

Once the vehicle data is transferred to the access point data buffer, then the bridge portion of the device can send the data to the ARL Penn State data repository using the CAISI bridge module capability as shown in Figure 11. Since it was not pre-determined that U.S. Army CAISI technology would be available for this program, a commercial cellular technology was implemented as the developmental approach for data transmission to the ARL IW. The implementation of this commercial technology allowed us to build an end to end capability while waiting for the CAISI bridge modules, which was a risk reduction activity. For this approach, a Verizon Raven X 3G cellular modem device (COTS) with a Cisco ASA 5500 Series Adaptive Security Appliance (COTS) that provides firewall functionality was integrated with the CAISI access point system. A third potential bridge capability was also partially developed to allow for the future integration of a VSAT data transfer capability. Since a VSAT system was not available for this effort it was not implemented.

6.0 ARL Penn State Data Server:

Once the vehicle data is received by the bridge module located at ARL Penn State, the data is ingested into the ARL Information Warehouse. This server system was designed to be similar to the Common CBM Data Warehouse that is part of the LOGSA Logistic Information Warehouse (LIW). This was done to develop 'best practices' for moving vehicle data to LOGSA and to implement technologies are currently being developed and deployed by DoD. The general functionality of the ARL IW is to automatically analyze individual ABCD files as they arrive at the IW, calculate derived metadata parameters and usage/fault detection algorithms associated with each file and save the derived metadata parameters and the usage/fault detection algorithms to the IW and the user interface Data Mart via the Metadata Injection web service as shown in Figure 13.

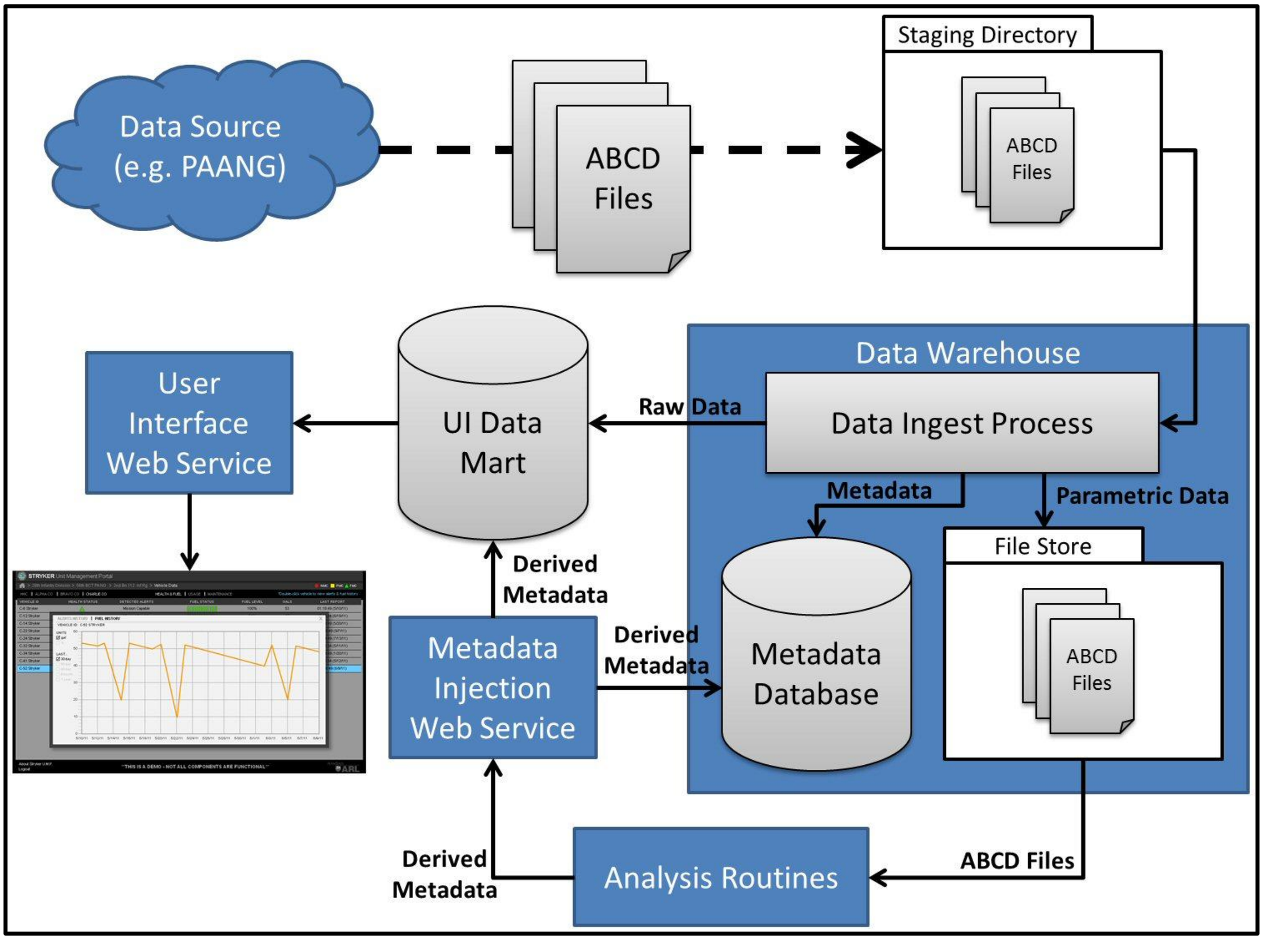


Figure 13: System View for the ARL Information Warehouse

The specifics of the ARL IW process starts with the vehicle ABCD files being placed in a staging area before being loaded into the data ingest process in the data warehouse. The ABCD files are split into their two components consisting of the metadata, which is the textual description of the data file such as the vehicle and sensor identification and the parametric data, which is the actual sensor data. The metadata portions of the ABCD file are stored in a database that enables the ability to conduct search queries on the data. Each metadata input is linked to the corresponding parametric file that is stored in a flat file storage format. This provides an optimum data search and storage capability as defined by the ABCD format best practices.

Automated data analysis routines can then pull ABCD files and apply usage and fault detection algorithms to convert the data into information. Examples of the information include trip distance, time spent idling, total fuel consumed, fuel consumed at idle, average speed when moving, maximum vehicle speed, total engine revolutions and engine oil life parameter. The information (i.e. derived metadata) generated by the analysis routines is sent to the metadata injection web service that sends the derived metadata to be stored in the metadata database and also sends the derived metadata to the user interface (UI) data mart. The final step in the process involves the user interface web service taking the latest data from the UI data mart and inserting it into the user interface. All of these steps are conducted automatically by the ARL IW.

7.0 SEDCAS Information Interface:

The Stryker Brigade Combat Team Unit Management Portal information interface was designed to provide individual platform status, health, fuel, usage, and maintenance information to the appropriate information users to enable fleet management and condition based maintenance capabilities. The unit that was selected for this technology insertion is 56th Stryker Brigade Combat Team of the 28th Infantry Division of the Pennsylvania Army National Guard (PAARNG).

7.1 Use Cases:

The first step in the design of the user interface involved identifying the information users and the development of use cases. For this program, the information users include the battalion maintenance officer (BMO) and the unit maintainers.

The first use case involves readiness reporting. There are two scenarios that were developed for this use case.

1. The BMO wants to be periodically advised as to the status, health and condition of the vehicles and equipment to enable the ability to report readiness status to higher command.
2. The BMO wants to be periodically advised as to the status, health and condition of the vehicles and equipment to enable proactive management of the flow of consumables, parts supply, and labor supporting the units and vehicles in a streamlined and efficient manner to maximize equipment availability, and minimize operational cost.

In order to enable this capability the following information categories should be incorporated into the information interface:
Vehicle Status - current state of vehicles indicating fuel levels and other indicators of system state
Vehicle Health - current state of vehicles indicating existence of fault/faults, error codes alarms or alerts localized to the subsystem or component, tailored to the top degraders and expressed in plain text, not just numerical codes
Vehicle Condition - current state of units and vehicles indicating mission readiness levels expressed with both doctrinal symbols and plain text

The second use case involves fleet management reporting. There is one scenario that was developed for this use case.

1. The BMO and unit maintainer want to be notified as to the vehicle usage and consumption information to enable planning, scheduling and to conduct preventive maintenance.

In order to enable this capability the following information categories should be incorporated into the information interface:
Usage Indicators - indicators of time and mileage based usage and other indicators that inform of wear and tear on the vehicle and advise future need for scheduled maintenance actions.

The third use case involves maintenance repair actions. There is one scenario that was developed for this use case.

1. The BMO and unit maintainer want to be notified, at the individual vehicle level, as to the existence of fault/failure indicators, alarms/alerts that are localized to the subsystem or component in order for me to align skills, parts and tools to quickly and effectively execute maintenance actions returning the vehicle to operational readiness.

In order to enable this capability the following information categories should be incorporated into the information interface:
Diagnostics - on-board diagnostics codes and plain text descriptions of the type and location of such occurrence as soon as possible after vehicle shut down. Each incident should bear a time stamp that indicates the date/time when the occurrence was caught by the system.

7.2 User Interface Displays:

Based on the use cases the following SBCT (Stryker Brigade Combat Team) Unit Management Portal user interfaces were designed and implemented. The functioning web based application is located: http://army-cbmplus.sil.arl.psu.edu/StrykerPortal/. A user's guide to the web portal can be provided on request.

User Display 1: The first display is a conceptual global readiness display that shows the high level readiness for units in various locations around the world shown in Figure 14.

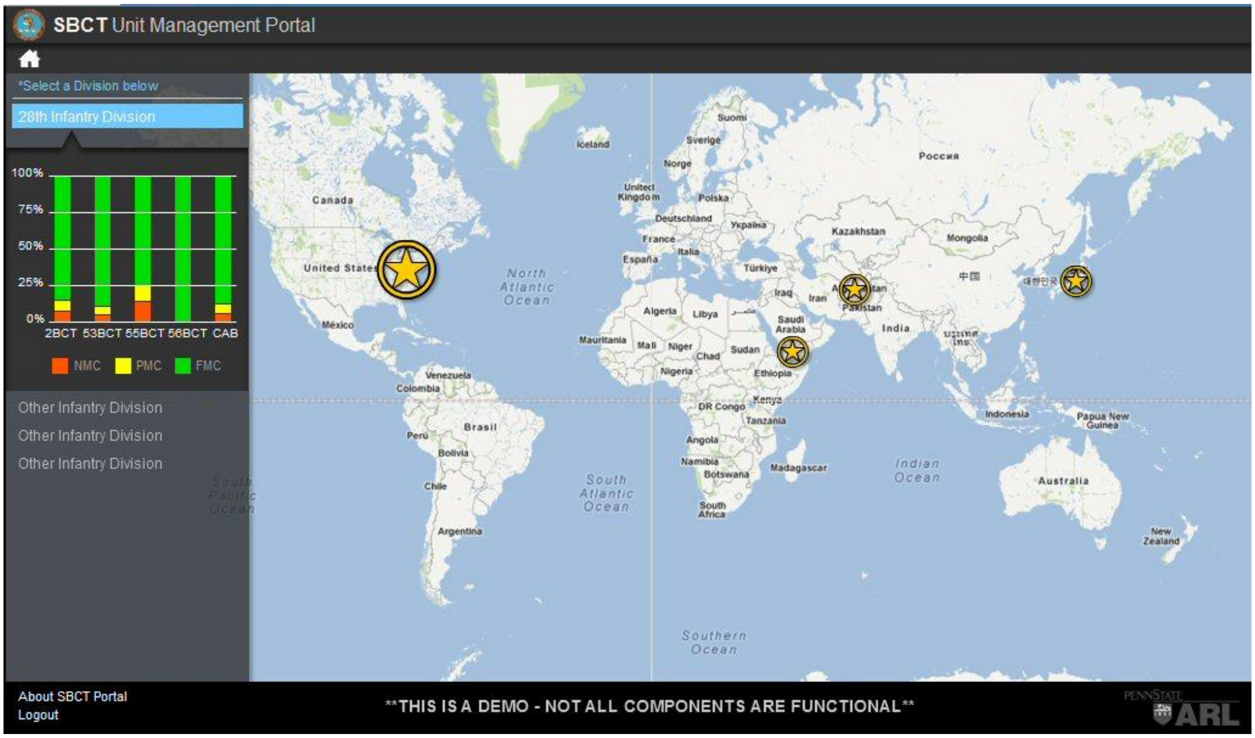


Figure 14: Global Readiness View

Though this is a prototype display with simulated data because we only have a few platforms in one SBCT instrumented, it is designed to show the aggregated non-mission capable (NMC), partial mission capable (PMC) and full mission capable levels for various brigade combat teams (BCT). This information is useful to higher level command and control information customers to help inform fleet vehicle readiness levels.

User Display 2: When the CONUS Army logo (star inside circle) icon is selected in Figure 14, the map will zoom into the United States region. The CONUS unit location and a high level color coded readiness symbol are displayed as shown in Figure 15.

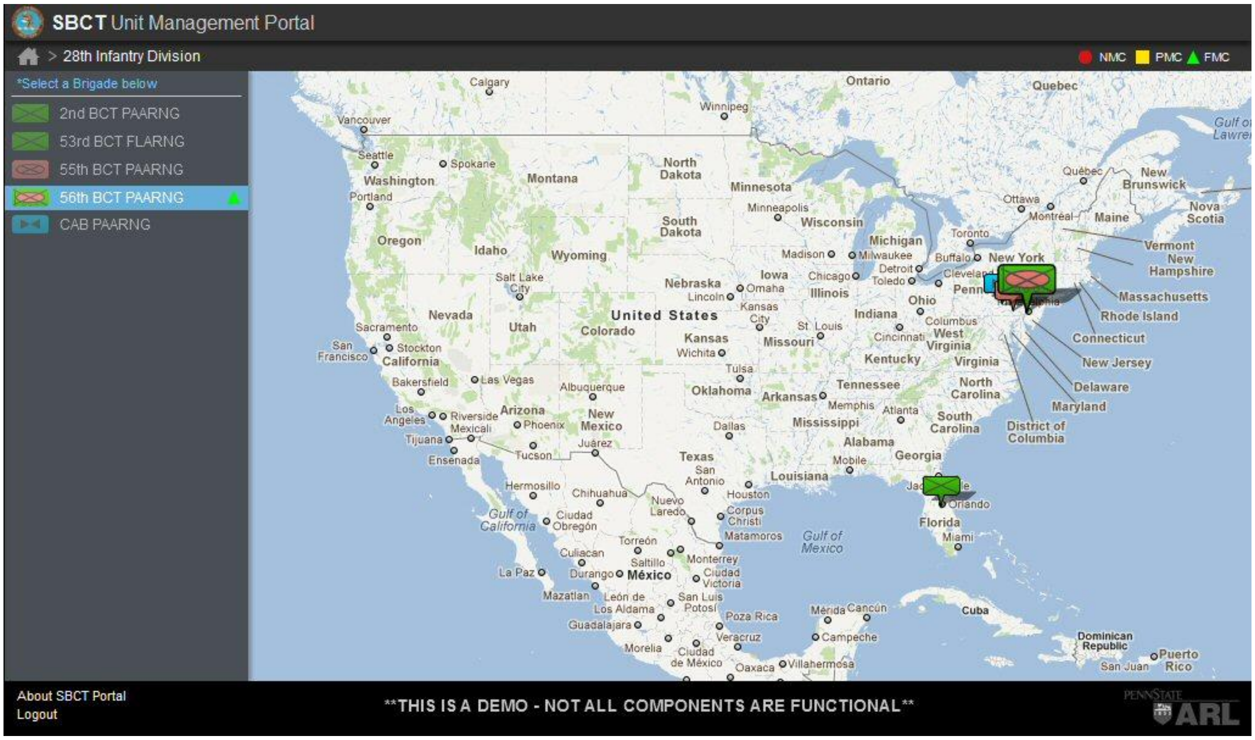


Figure 15: CONUS BCT Location and High Level Readiness View

The display currently shows information for only the 56th SBCT of the PAARNG, which is the unit that was instrumented with DSC systems for this program. When the user selects a BCT from the list located in the left portion of Figure 15, the display will zoom into the representative icons on the map for the selected unit.

User Display 3: The third display shown in Figure 16 is similar to the display in Figure 15 but it represents the unit location and high level readiness display for only the 56th PAARNG unit.

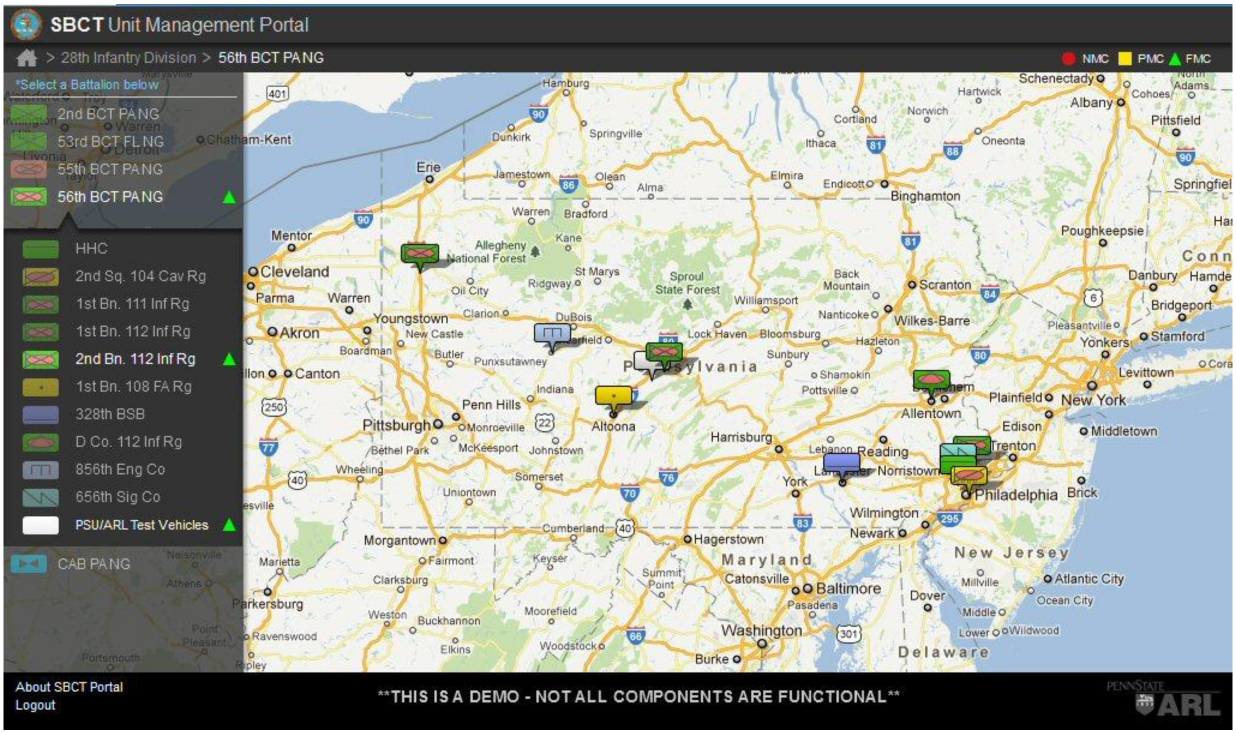
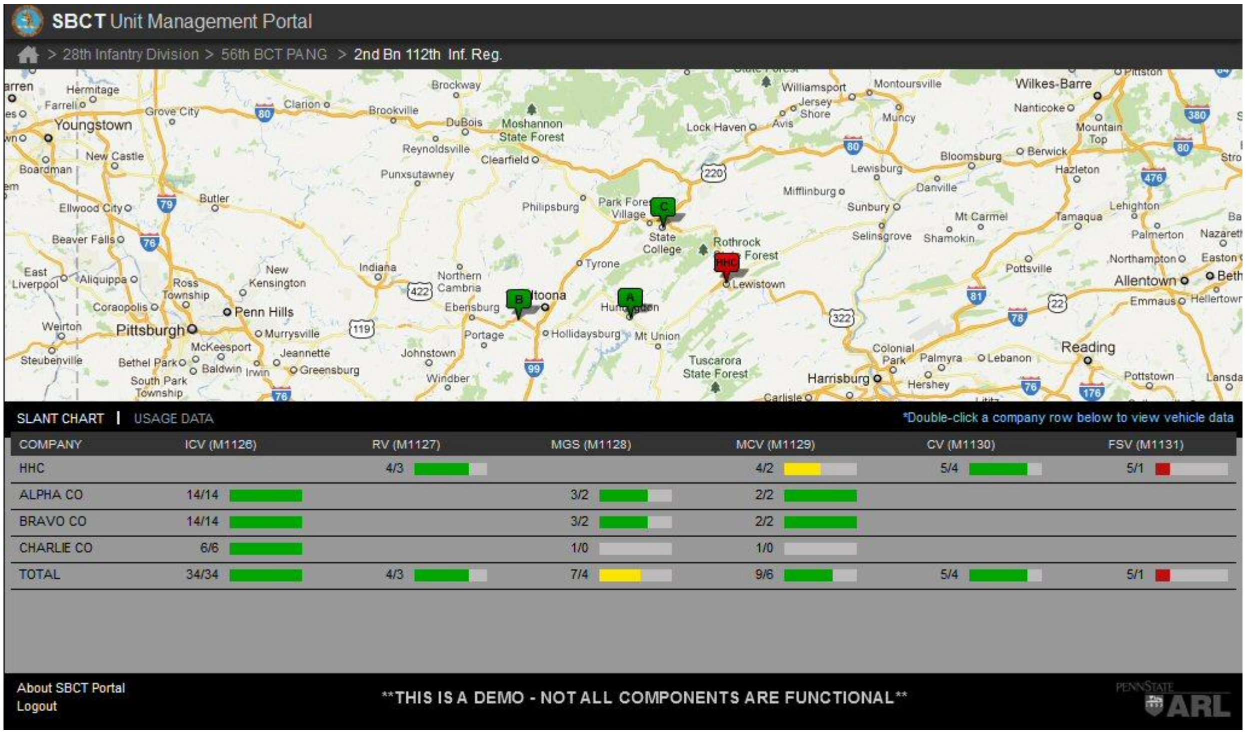


Figure 16: PAARNG BCT Location and High Level Readiness View

This display indicates the location and readiness of the regiment and company level units within the 56th SBCT.

User Display 4: The fourth display shown in Figure 17 shows the company level readiness.



COMPANY	ICV (M1126)	RV (M1127)	MGS (M1128)	MCV (M1129)	CV (M1130)	FSV (M1131)
HHC		4/3 🟩		4/2 🟨	5/4 🟩	5/1 🟥
ALPHA CO	14/14 🟩		3/2 🟩	2/2 🟩		
BRAVO CO	14/14 🟩		3/2 🟩	2/2 🟩		
CHARLIE CO	6/6 🟩		1/0	1/0		
TOTAL	34/34 🟩	4/3 🟩	7/4 🟨	9/6 🟩	5/4 🟩	5/1 🟥

Figure 17: PAARNG BCT Location and High Level Readiness View

The information is presented in a ‘slant chart’ format where the first number indicates the total number of each type of vehicle (i.e. ICV M1126, RV M1127, etc.) in each company (i.e. HHC, Alpha Company, etc.) and the second number indicates how many of the vehicles are full mission capable. The color coded strip (i.e. red, yellow, and green) after the number provides a quickly recognizable general indication of unit readiness.

User Display 5: When the company icon is selected on the map portion of the interface in Figure 17, the general health and fuel level status for individual vehicles is displayed as shown in Figure 18. This display is designed to be used by the operators and maintainers to quickly assess fault codes alerts and fuel level.

COMPANY: CHARLIE CO

*Historical data can be accessed via the table below

VEHICLE ID	HEALTH STATUS	TOTAL ACTIVE ALERTS	FUEL STATUS	FUEL LEVEL	GALS	LAST REPORT TIME (UTC)
C-6 Stryker ICV	▲	0	▮▮▮▮▮▮▮▮▯▯	82%	43.5	2012-06-12 18:12:33
C-12 Stryker ICV	▲	0	▮▮▮▮▮▮▮▮▮▯	87%	46.0	2012-08-11 10:59:00
C-22 Stryker ICV	▲	0	▮▮▮▮▮▮▮▮▮▮	97%	51.3	2012-08-10 21:48:33
C-24 Stryker ICV	●	3	▮▮▮▮▮▮▮▮▮▮	100%	53.0	2012-08-10 18:43:08
C-32 Stryker ICV	▲	0	▮▮▮▮▮▮▮▮▮▮	100%	53.0	2012-08-10 18:02:06
C-34 Stryker ICV	▲	0	▮▮▮▮▮▮▮▮▮▮	100%	53.0	2012-08-10 18:00:46

● NMC ■ PMC ▲ FMC

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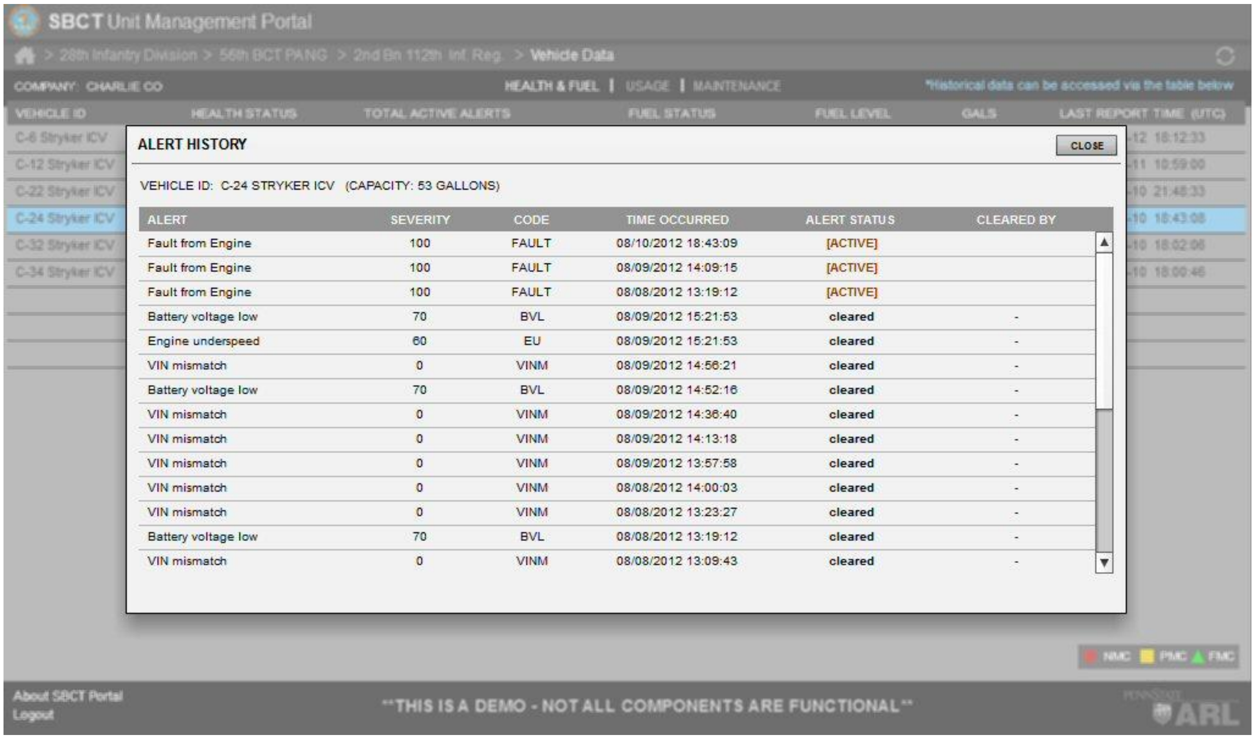
Figure 18: Vehicle Health and Fuel Information

The display includes health status represented by a green, yellow or red symbol that is based on the total active alerts. The display also shows a fuel level indication through a gauge, as a percent level and by number of gallons with the last report time and date stamp in universal time code (UTC) format for each individual vehicle. The alert and fuel data of this information display is populated by the vehicle sensor data that is collected by the DSC system from each vehicle.

User Display 6: When a health status icon for an individual vehicle is selected from the display in Figure 18, the alert history information for that vehicle is displayed. The table in Figure 19 shows the alert history for each platform. This display is designed to enable the maintainers to assess the condition of individual platforms based on the faults codes so that they can better manage their maintenance activities including allocating the appropriate maintainer and tool resources for each platform that requires maintenance.



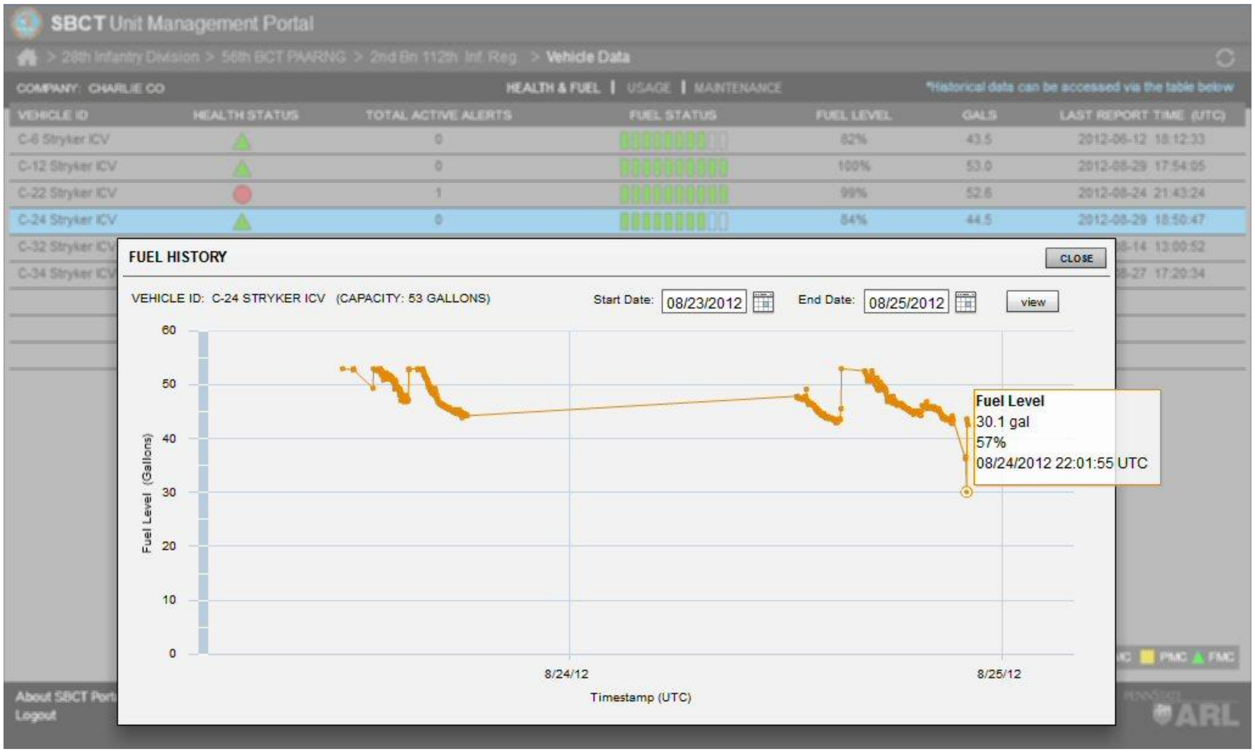
VEHICLE ID: C-24 STRYKER ICV (CAPACITY: 53 GALLONS)

ALERT	SEVERITY	CODE	TIME OCCURRED	ALERT STATUS	CLEARED BY
Fault from Engine	100	FAULT	08/10/2012 18:43:09	[ACTIVE]	
Fault from Engine	100	FAULT	08/09/2012 14:09:15	[ACTIVE]	
Fault from Engine	100	FAULT	08/08/2012 13:19:12	[ACTIVE]	
Battery voltage low	70	BVL	08/09/2012 15:21:53	cleared	-
Engine underspeed	60	EU	08/09/2012 15:21:53	cleared	-
VIN mismatch	0	VINM	08/09/2012 14:56:21	cleared	-
Battery voltage low	70	BVL	08/09/2012 14:52:16	cleared	-
VIN mismatch	0	VINM	08/09/2012 14:36:40	cleared	-
VIN mismatch	0	VINM	08/09/2012 14:13:18	cleared	-
VIN mismatch	0	VINM	08/09/2012 13:57:58	cleared	-
VIN mismatch	0	VINM	08/08/2012 14:00:03	cleared	-
VIN mismatch	0	VINM	08/08/2012 13:23:27	cleared	-
Battery voltage low	70	BVL	08/08/2012 13:19:12	cleared	-
VIN mismatch	0	VINM	08/08/2012 13:09:43	cleared	-

Figure 19: Individual Vehicle Alert History

The alerts are generated from built-in-tests (BIT) that are integrated into the vehicle and published to the J1708 bus by the respective faulted components. The display table provides the vehicle ID, an alert description, severity of the alert, alert code, the time stamp and the alert status (i.e. active, inactive and cleared). Each active alert can be selected and cleared by a maintainer who is logged into the interface, once the fault code has been appropriately addressed.

User Display 7: When a fuel status is selected for an individual vehicle from the display in Figure 18, the fuel level history information for that vehicle is displayed as shown in the plot in Figure 20.



VEHICLE ID	HEALTH STATUS	TOTAL ACTIVE ALERTS	FUEL STATUS	FUEL LEVEL	GALS	LAST REPORT TIME (UTC)
C-6 Stryker ICV	▲	0	🟩🟩🟩🟩🟩🟩🟩🟩🟩☐☐	82%	43.5	2012-06-12 18:12:33
C-12 Stryker ICV	▲	0	🟩🟩🟩🟩🟩🟩🟩🟩🟩🟩🟩	100%	53.0	2012-08-29 17:54:05
C-22 Stryker ICV	●	1	🟩🟩🟩🟩🟩🟩🟩🟩🟩🟩🟩	99%	52.6	2012-08-24 21:43:24
C-24 Stryker ICV	▲	0	🟩🟩🟩🟩🟩🟩🟩🟩🟩☐☐	84%	44.5	2012-08-29 18:50:47
C-32 Stryker IC						8-14 13:00:52
C-34 Stryker IC						8-27 17:20:34

FUEL HISTORY

VEHICLE ID: C-24 STRYKER ICV (CAPACITY: 53 GALLONS)

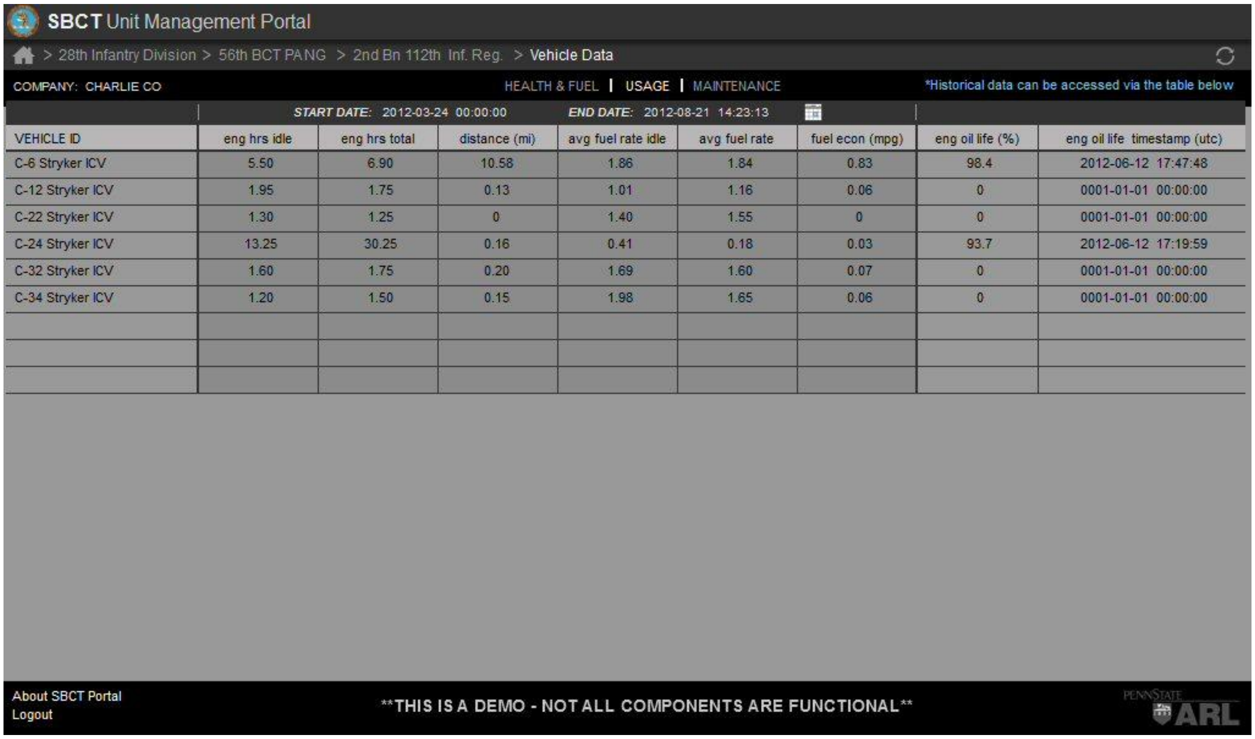
Start Date: 08/23/2012

End Date: 08/25/2012

Figure 20: Individual Vehicle Fuel Level History

The fuel level history display provides a data trend plot of the fuel level that is provided by each vehicle over a user selected date range. Individual fuel level data points can be selected to provide the level in gallons, percentage and the time and date stamp. This data can be used to better understand vehicle fuel consumption profiles to manage the resupply of fuel to individual vehicles.

User Display 8: The eighth display provides individual vehicle usage information as shown in Figure 21.



COMPANY: CHARLIE CO

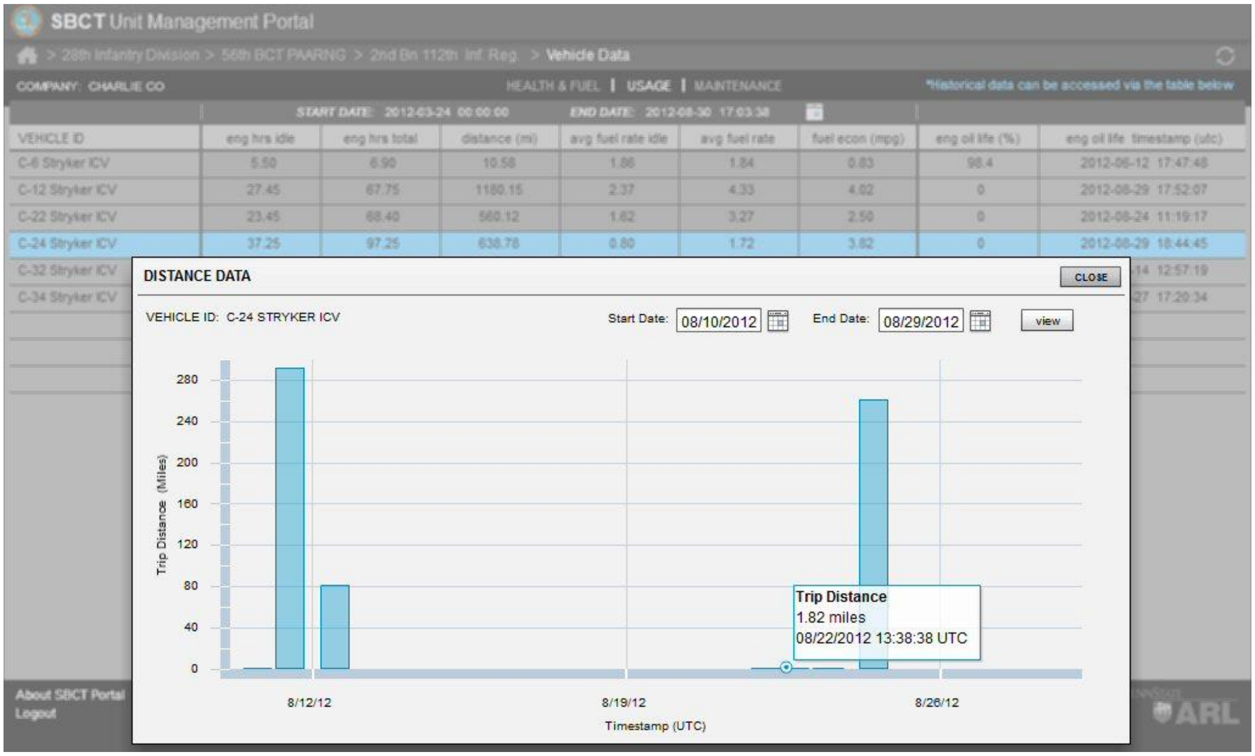
START DATE: 2012-03-24 00:00:00 END DATE: 2012-08-21 14:23:13

VEHICLE ID	eng hrs idle	eng hrs total	distance (mi)	avg fuel rate idle	avg fuel rate	fuel econ (mpg)	eng oil life (%)	eng oil life timestamp (utc)
C-6 Stryker ICV	5.50	6.90	10.58	1.86	1.84	0.83	98.4	2012-06-12 17:47:48
C-12 Stryker ICV	1.95	1.75	0.13	1.01	1.16	0.06	0	0001-01-01 00:00:00
C-22 Stryker ICV	1.30	1.25	0	1.40	1.55	0	0	0001-01-01 00:00:00
C-24 Stryker ICV	13.25	30.25	0.16	0.41	0.18	0.03	93.7	2012-06-12 17:19:59
C-32 Stryker ICV	1.60	1.75	0.20	1.69	1.60	0.07	0	0001-01-01 00:00:00
C-34 Stryker ICV	1.20	1.50	0.15	1.98	1.65	0.06	0	0001-01-01 00:00:00

Figure 21: Individual Vehicle Usage Information

The usage display provides the engine hours at idle, the total engine hours, the vehicle distance in miles, the average fuel rate at idle in gallons per hour (GPH), the total average fuel rate in GPH, and the fuel economy in miles per gallon (MPG). All these parameters can be provided over a user selected date range. In addition, the engine oil remaining life as a percentage and the engine oil life timestamp is provided. This display is designed to provide the battalion maintenance officer with multiple pieces of information. The first piece of information is how each individual vehicle is being utilized, spending most of its time idling or being driven. The second piece of information is the fuel rate and fuel economy levels for each vehicle can be compared against each other to indicate a platform that is not performing well and may be in need of maintenance. The third piece of information is that the maintainers can proactively plan oil changes based on remaining oil life information for each platform.

User Display 9: When the distance for an individual vehicle is selected from the display in Figure 21, the distance traveled history information for that vehicle is displayed as shown in the plot in Figure 22.



COMPANY: CHARLIE CO

*Historical data can be accessed via the table below

START DATE: 2012-03-24 00:00:00 END DATE: 2012-08-30 17:03:38

VEHICLE ID	eng hrs idle	eng hrs total	distance (mi)	avg fuel rate idle	avg fuel rate	fuel econ (mpg)	eng oil life (%)	eng oil life timestamp (utc)
C-6 Stryker ICV	5.50	6.90	10.58	1.86	1.84	0.83	98.4	2012-06-12 17:47:48
C-12 Stryker ICV	27.45	67.75	1180.15	2.37	4.33	4.02	0	2012-08-29 17:52:07
C-22 Stryker ICV	23.45	68.40	560.12	1.62	3.27	2.50	0	2012-08-24 11:19:17
C-24 Stryker ICV	37.25	97.25	638.78	0.80	1.72	3.82	0	2012-08-29 18:44:45
C-32 Stryker ICV								14 12:57:19
C-34 Stryker ICV								27 17:20:34

DISTANCE DATA

VEHICLE ID: C-24 STRYKER ICV

Start Date: 08/10/2012 End Date: 08/29/2012

Figure 22: Individual Vehicle Distance Traveled History Data

The distance traveled history display provides a plot of the individual vehicle miles traveled for individual days over a user selected date range. This information is useful to the maintainers to better understand which vehicles are accumulating the most miles and which vehicles are being underutilized.

User Display 10: The maintenance data display provides individual vehicle actionable information as shown in Figure 23. The maintenance display was designed to provide actionable information to the maintainer for vehicle components that are considered vehicle degraders. The intent is to provide 'visibility' for component level data that provides a condition indication to the maintainer so that they can proactively manage the health of the vehicles. Not all of the data fields are populated with data because the sensors do not currently exist on these platforms but we want to emphasis the future integration of sensors for these degrader components to provide this valuable actionable information to the maintainers.

COMPANY: CHARLIE CO

VEHICLE ID	ENGINE			ELECTRICAL			TRANSMISSION	DIFF/T-CASE	LAST REPORT TIME
	oil level	change oil (hrs)	coolant temp	battery (v)	alternator (v)	VR	oil temp	lube level	UTC
C-6 Stryker ICV	-	-	185	28.1	-	-	123	-	2012-06-12 18:15:19
C-12 Stryker ICV	-	-	120	28.3	-	-	100	-	2012-08-11 11:01:18
C-22 Stryker ICV	-	-	106	28.3	-	-	82	-	2012-08-10 21:48:51
C-24 Stryker ICV	-	-	118	28.3	-	-	85	-	2012-08-10 18:43:07
C-32 Stryker ICV	-	-	136	28.1	-	-	117	-	2012-08-10 18:15:44
C-34 Stryker ICV	-	-	151	1.6	-	-	98	-	2012-08-10 18:07:55

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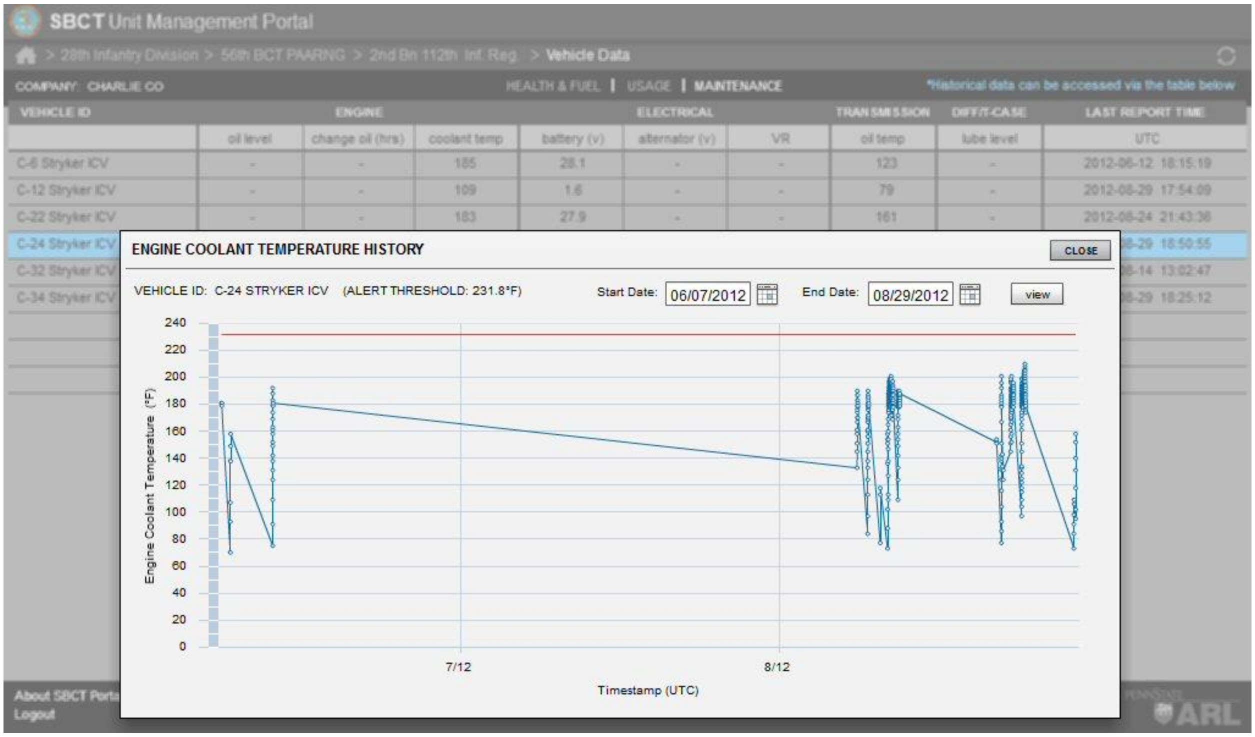
Figure 23: Individual Vehicle Maintenance Information

The maintenance display provides vehicle data for engine coolant temperature, battery voltage, and transmission oil temperature with the last report time and date stamp in universal time code (UTC) format.

User Display 11: When the engine coolant temperature status is selected for an individual vehicle from the display in Figure 23, the engine coolant temperature history for that vehicle is displayed as shown in the plot in Figure 24.



COMPANY: CHARLIE CO

*Historical data can be accessed via the table below

VEHICLE ID	ENGINE			ELECTRICAL			TRANSMISSION	DIFF/T-CASE	LAST REPORT TIME
	oil level	change oil (hrs)	coolant temp	battery (v)	alternator (v)	VR	oil temp	lube level	UTC
C-6 Stryker ICV	-	-	185	28.1	-	-	123	-	2012-06-12 18:15:19
C-12 Stryker ICV	-	-	109	1.6	-	-	79	-	2012-08-29 17:54:09
C-22 Stryker ICV	-	-	183	27.9	-	-	161	-	2012-08-24 21:43:36
C-24 Stryker ICV									08-29 18:50:55
C-32 Stryker ICV									08-14 13:02:47
C-34 Stryker ICV									08-29 18:25:12

ENGINE COOLANT TEMPERATURE HISTORY

VEHICLE ID: C-24 STRYKER ICV (ALERT THRESHOLD: 231.8°F)

Start Date: 06/07/2012

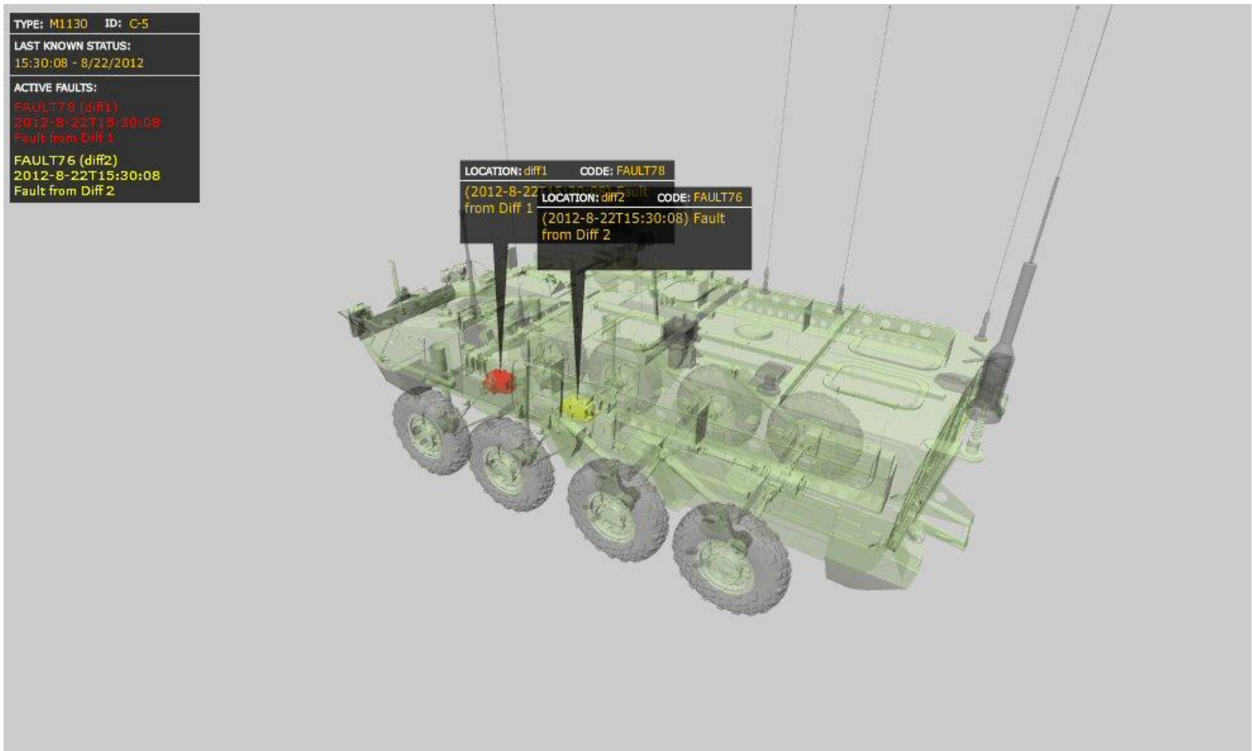
End Date: 08/29/2012

Figure 24: Individual Vehicle Engine Coolant Temperature History

Each parameter on the maintenance display can be selected to provide a trend plot with the parameter history. The data in Figure 24 shows the engine coolant temperature history display that provides a plot of the coolant temperature for individual days over a user selected date range with an indication of the maximum temperature level as shown by the red line. The vehicle has a coolant temperature fault message but this data trend provides additional information to the maintainers to help them assess the duration of the temperature exceedence which provides insight into the severity of the condition and potential damage to the engine. The trend data also provides an indication of the rate of change of the temperature that can help them to better understand the root cause of the coolant exceedence fault.

7.3 Prototype Concept Displays:

In addition to the SBCT Unit Management Portal, we developed a prototype graphical fault isolation indicator model for the Stryker Platform as shown in Figure 25.



TYPE: M1130 **ID:** C-5

LAST KNOWN STATUS:
15:30:08 - 8/22/2012

ACTIVE FAULTS:
FAULT78 (diff1)
2012-8-22T15:30:08
Fault from Diff 1

FAULT76 (diff2)
2012-8-22T15:30:08
Fault from Diff 2

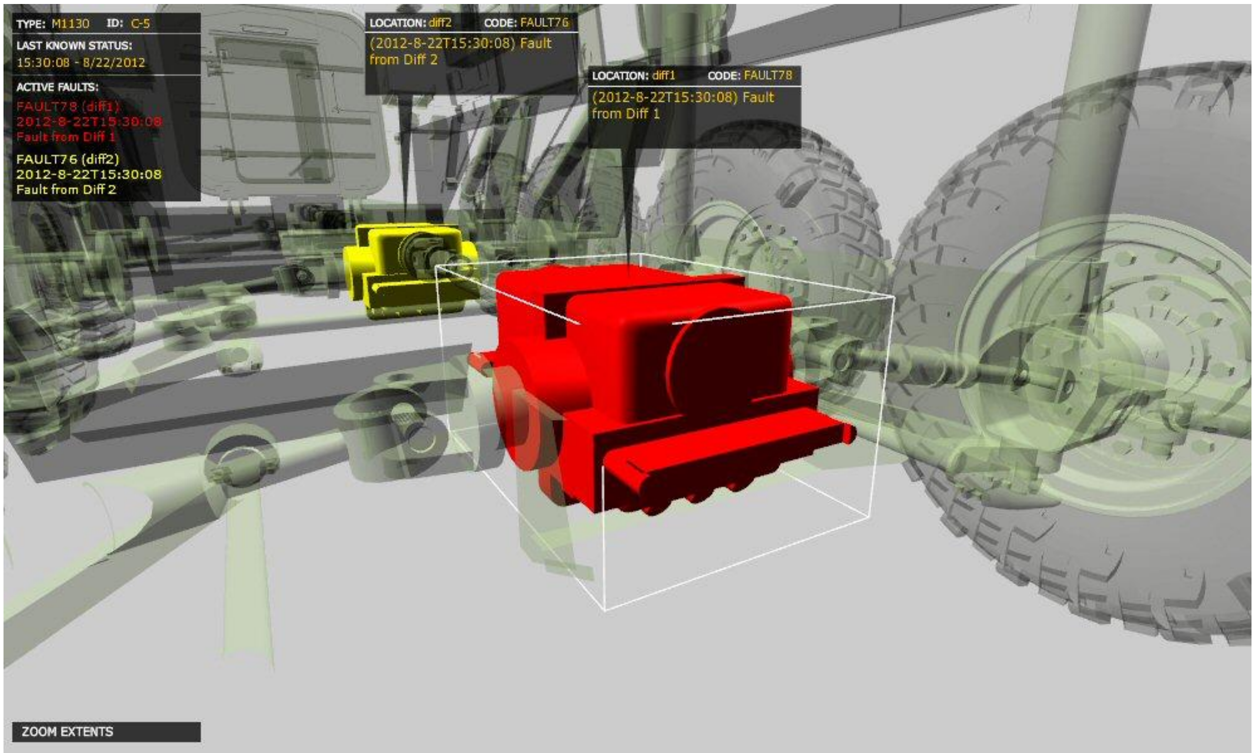
LOCATION: diff1 **CODE:** FAULT78
(2012-8-22
from Diff 1

LOCATION: diff2 **CODE:** FAULT76
(2012-8-22T15:30:08) Fault
from Diff 2

Figure 25: Stryker Fault Indication and Isolation Model – Vehicle View

The intent of using the model is to provide a straight forward and direct method for providing fault identification and isolation information to the maintainer through the use of 3-D models that are linked to the fault codes and condition indication algorithms. One of the short comings of using text based fault codes is it is difficult to precisely indicate which component the fault is associated with especially for common multiple components such as differentials, suspension components, tires and batteries. When the fault is indicated through a 3-D model then the ability to correctly identify and repair the correct component increases.

The maintainer would select the color coded fault code in the upper left corner of Figure 25 and the model will zoom to the component view as shown in Figure 26.



TYPE: M1130 ID: C-5

LAST KNOWN STATUS:
15:30:08 - 8/22/2012

ACTIVE FAULTS:
FAULT78 (diff1)
2012-8-22T15:30:08
Fault from Diff 1

FAULT76 (diff2)
2012-8-22T15:30:08
Fault from Diff 2

LOCATION: diff2 CODE: FAULT76
(2012-8-22T15:30:08) Fault from Diff 2

LOCATION: diff1 CODE: FAULT78
(2012-8-22T15:30:08) Fault from Diff 1

Figure 26: Stryker Fault Indication and Isolation Model – Component View

The zoom capability enables the ability to assess the maintenance action that will need to be implemented to replace or repair the component.

The prototype model will be potential integrated into the next version of the SBCT Unit Management Portal and linked to the fault codes and condition indication algorithms through the follow on effort to this program.