Autonomic and Sense and Respond Logistics: the "foxhole to factory to foxhole" Continuum of Combat Service Support

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ABSTRACT

As the Australian Defence Force (ADF) embarks upon an ambitious re-equipment program involving strategic procurement of multi-billion dollar platforms, consideration should be given to the enhancement of the logistics supply chain required for the Introduction Into Service (IIS), sustainment and through-life support provided to this technology. A lead can be taken from the Joint Strike Fighter (JSF), to which Australia has so far committed as one of eight international partners.

Taking lessons from the civilian arena, principally mining and aviation, Lockheed Martin Corporation, the principle contractor, has augmented the flow of data from embedded key component sensors (Sense and Respond), to link directly to the supply chain, creating an autonomic, "foxhole to factory to foxhole", logistics continuum. This paper argues however, that caution needs to be exercised lest Local Operational Analysis Decisions (LOADs) tasking equipment become subserviant and overlooked, potentially jeopardising the application of battle-space effects and mission success.

Experience gained on operations in Iraq and Afghanistan by the United States Marine Corps will be used to illustrate potential benefits and pitfalls in the application of autonomic logistics concepts. Recognition of the advantages of autonomic logistics can then be used as inputs into the Military Integrated Logistics Information System (MILIS) and ultimately, to inform the Army Capability Development Continuum (ACDC).

1. Introduction

The Australian Defence Force (ADF) is in the midst of an evolutionary change. Whether it is called Network Centric Warfare (NCW), Network Centric Operations (NCO) or Network Enabled Operations (NEO), it is about the ability to share information seamlessly across the enterprise. The Defence Science and Technology Organisation (DSTO), in their discussion of the Australian NCW Concept and the specific aspects of the "network dimension", cite the Directorate of Future Warfare (DFW). "The network dimension, introduced in the third and fourth premises of Australian NCW, is described as having four aspects (DFW 2004):

- **Connect** units, platforms and facilities through networking,

appropriate doctrine, training and organisational processes and structure.

- **Collect** relevant information using networked assets and distribute it via the network.
- **Use** the information, and the intelligence derived from it, to effectively achieve military objectives.
- **Protect** the network established from external interference or technical failure."

For this discussion, we want to focus on the two "Cs", connect and collect. In order to provide guidance as to how the ADF will achieve these two states, the Department of Defence has compiled the NCW Roadmap, updated as of 2007.

Within this document, Logistics is included under "Collabrative Planning" and the Target State is entitled "Force Generation and Sustainment in 2020". This State is described as:

- Key logistic function networks within the National Support Area (NSA) are linked with those in theatre, and provide connectivity and a collaborative ability with industry and coalition partners.
- Commanders have an end-to-end visibility of the logistic system providing the ability to rapidly and effectively prioritise scarce resources required to generate and sustain deployed force elements.
- Automated ordering and replenishment takes place as supplies and ordnance are consumed by platforms and field units.
- The deployed force has minimised its vulnerabilites and greatly enhanced its mobility through more effective reach back, optimum force presence and the precision sustainment for the majority of logistics requirements.

1.1 Purpose

Based on a review of the NCW Roadmap, and the supported projects achieving their desired states, **the ADF will only partially achieve its' goal in logistics. Since the Operational Commander is dependant upon this element, their decision making ability will not be optimised. In addition, support costs will be higher than necessary.**

That is why a discussion of Autonomic Logistics (AL) Military Intergrated Logistics Information System (MILIS) and Sense and Respond Logistics (S&RL) is important. MILIS , by itself is not capable of generating the required data while AL was developed mainly to meet the supply pipeline needs and not optimised for the support of the Operational theater commander. S&RL brings all of the required components together to present the commander with a complete visibility of logistics.

1.2 Scope

This paper will define the concept of AL, provide an overview of two civilian applications, explain how AL works by making reference to a 'foxhole to factory to foxhole' continuum of Combat Service Support (CSS) and introduce the concept of Autonomic Sustainment (ASUS) being developed by the United States Marine Corps (USMC).

The US Army expresses similar sentiments regarding the importance of S&RL.

The first goal of S&RL is to maximise the readiness and logistics effectiveness of the force. S&RL requires a network-centric enterprise and mandates collaboration within and across communities of interest.

The second goal of S&RL is enabling the logisticians to accurately observe, orient, decide and act faster than the supported customer. Improving the logistician's decision cycle enables more accurate and timely support to the warfighter. With the integration of tracking, platform autonomics, information technologies and flexible business rules, logisticians will be able to proactively sustain the dynamic battlefield of the 21st Century.

2. What are Autonomic Logistics and Sense and Respond Logistics?

2.1 Definitions and Civilian Applications

Autonomic is taken from human physiology and refers to the autonomic nervous system which controls functions such as breatheing or heart beats, which occur without having to think about them. Therefore, an autonomic logistics system is designed to function without having to be "told" to act. The AL system we are discussing here supports the F-35 Joint Strike Fighter (JSF). The main elements of this system are the sensors embedded in the system (JSF) the information system (ALIS) that links the aircraft to the Lockheed Martin facility in the U.S.A. as well as the supporting elements in between and the concept of Prognostics & Health Monitoring (P&HM).

> *Prognostics is the actual material condition assessment which includes predicting & determining the useful life & performance life remaining of components by modeling fault progression. Health Management is the capability to make intelligent, informed, appropriate decisions about maintenance & logistics actions based on diagnostics/prognostics information, available resources & operational demand.*

This system optimises the efficiency of supplying resources. However, the analogy with the human autonomic system shouldn't be forgotten. The system functions automatically, it does not think / reason. Deviations required due to operational needs are not automatically input.

Autonomic Logistics is employed in the mining industry in Australia by heavy equipment vendors such as Caterpillar as a component of 'condition based maintenance'. Data collected from sensors embedded in major components of the equipment and downloaded into an information system every time the vehicle comes within range of a receiving device.

QANTAS has invested in the Airbus AIRTRAC system via their acquisition of the A380. This system provides a link between the airframe and a dedicated support facility staffed with specialist engineers available 365 days a year. (Thomas, 2007).

"The A380's onboard software monitors every system and instantly sends an email to AIRTRAC if any anomaly is spotted. The instant the email is received, the required part is ordered so it's ready for the arrival of the A380."

QANTAS's application of AL through the AIRTRAC system focuses on the temporal concentration of the various elements required for the performance of a maintenance event (ME), (the required component, technicians, specialist equipment and tools, hanger space, airframe and necessary consumables). "**Condition Based Maintenance (CBM+)…** [provides] the ability to predict future health status of a system or component, as well as providing the ability to anticipate faults, problems, potential failures, and required maintenance actions." The aim of condition based maintenance is to detect wear within components, compare this to

established safe operating parameters and replace them prior to failure.

Additional considerations intervene in the scheduling of a ME in the military context. S&RL defined by the Office of Force Transformation as: "… a transformational network-centric concept that enables Joint effects-based operations and provides agile support", includes the same system elements as AL but it also incorporates the capability to vary actions based on Local Operational Analysis Decisions (LOADs). An example would be whether a parts package and repairer were needed to be sent in or if it could be completed by the operators. Another could be if the operational situation didn't allow for that asset to be "down" and it was deemed acceptable for it to operate at a reduced capability.

The old concept of **Factory to Foxhole** is now **Foxhole to Factory to Foxhole.**

2.2 The Elements

2.2.1 Equipment Health Monitoring Systems

Equipment Health Monitoring Systems have been around for decades. One such system was developed for jet engines used in the F-15 and F-16. The Engine Monitoring System (EMS) recorded the operating conditions and any anomalies. Once the aircraft was on the ground, the Ground Monitoring System (GMS) was plugged into the EMS and the data was downloaded so that it could be analysed. The commercial arm of the company applied this not only to other (commercial) aircraft engines but also to automobiles. When you take your car into the shop to have it worked on and they hook it up to the diagnostic analyser, the predecessor was the EMS/GMS system. You will note that this system only details what has actually occurred and the system has to be hooked-up and downloaded to be analysed. In both the AL and S&R systems, prognostics has been added. That is, the electronic suite located in the aircraft/vehicle compares values obtained from sensors throughout the asset to preset values using algorithms in order to **predict** the status/longevity of the part/unit. In other words, the ASLAV tells the operator and the Operations Centre, the main wheel bearing on the right front shaft will seize in 20 more hours of use. This prediction aspect is a new feature while another is that instead of the system being brought in for the information to be downloaded, it communicates while in operation.

2.2.2 The Information System (Connectivity)

To continue the anatomical analogy, the IS would be the nervous system. In the Autonomic system it would connect the brain to the heart, lungs, etc. It carries a repetitive signal that may vary in repetition rate and magnitude but not content. In the S&R system it connects the brain to the fingers, arms,legs and so on. The signals are received from and sent to different parts and vary in content. The body senses it is cold and a message is sent to the arms to put on a jacket. The eyes see a threat and the fists are told to fight or the legs to flee. The IS systems within the Autonomic and Sense & Respond systems are both important and serve their purpose.

A major element of both systems is that they have a complete path from one end to the other and that the information is capable of being understood by all recipients.

3. Logistics Costs

When acquiring a new system a common rule of thumb that is used to estimate the life cycle costs is that the system itself accounts for one third. Logistics and Operational costs make up the other two

thirds. An example is the Australian Joint Strike Fighter (JSF) program.

A 100 aircraft buy is prefered. Using a per aircraft cost of US$ 50 million, this would amount to a US$ 5 billion purchase. Using the general rule above, support / operating costs would equate to US$ 10 billion for a program cost of US$ 15 billion. The supplier of the JSF (Lockheed Martin Corp.) estimates a 20 % reduction in the operations / logistics costs over the life cycle due to the application of Autonomic Logistics. This equates to a US$ 2 Billion savings for the Australian JSF program.

Figure 1: ASLAV

If the same concept was applied to the ASLAV, the following would apply. (Note: Based on original cost w/o enhancements such as stabilised gun and remote turret)

Acq. Cost (US$2 million/unit 257 units) – US$ 514 million

Log. / Ops. Cost - US$1.028 Billion

20% Savings – US$ 205.6 million

Obviously this comparison does not take into account that the original unit cost would have been greater due to the addition of sensors, communications equipment and upgraded logistics resources. However, it does show that an increase in unit cost that causes a similar percentage decrease in operations / logistics, will result in a 2 for 1 savings in real dollars. The comparison also does not take into account that the ADF keeps asset types in inventory for longer periods (F-111, M-113AS). This would increase the Log / Ops. To Acq cost ratio.

As progress is made along the Army Capability Development Contiuum (ACDC), the number of new equipment acquisitions invites serious consideration of embedding Prognostics and Health Monitoring (P&HM) devices as enablers for AL and S&RL in order to access the potential savings available over the full life cycle of the platforms.

4. End to End Visibility

4.1 What are the ends?

When discussing the operational end of either AL or S&RL one end is the individual aircraft, vehicle or other unit, the "foxhole". The other end differs based on who "owns" the system. In the case of the JSF, Lockheed Martin (LM) controls the entire process and the ultimate end is it's facility in Denver, CO in the USA. This is a basis for belonging to the consortium.

The S&RL concepts discussed here are based upon the US Marine Corp. (USMC) application. As such, the entire system is called the Enterprise and the ultimate end point is the USMC HQ in Washington D.C.

4.2 Data Usage

In the JSF AL system, the data generated is specifcally support the logistics and supply chain operations by Lockheed. This does not mean that the individual countries won't be able to "bleed" the information off in some manner for Operational input. It does mean that it will have to be adapted for this purpose.

The USMC's S&RL system is being developed to support both the Logistics / Supply Chain as well as Operations. Data is gathered for level usage as well as transmitted to the next level for accumulation. That accummulated data

provides input for the decision making process. Shown in figure 2 are the levels as envisioned by the USMC as well as the activities the data will support.

The ADF NCW implementation plans for connectivity (logistics) is based on the Military Integrated Logistics Information System (MILIS, JP 2077). The "end " points for this system are the Forward Logistics Centers and the main depot re-supply points in Australia. As can be seen this is a truncated version of the AL and S&RL systems. It does not accumulate platform level information nor does it appear to be used for real time operational input.

While MILIS will improve efficiency and reduce costs due to inventory identification, traceability, the use of RFIDs and interconnectivity / reduction of legacy systems, it is still limited to being an automated ordering and shipping system that is not meant to provide real time information into the operations situational analysis.It also does not, at this time, provide the prognostics or current health of the assets that are critical for the real time Theater picture. The Theater Commander, under S&RL will have advice based not only on what has occurred and is currently happening , but also the projected health of the assets under their control. Since all resources are identified at the part level and location, immediate re-direction to meet requirements is possible.

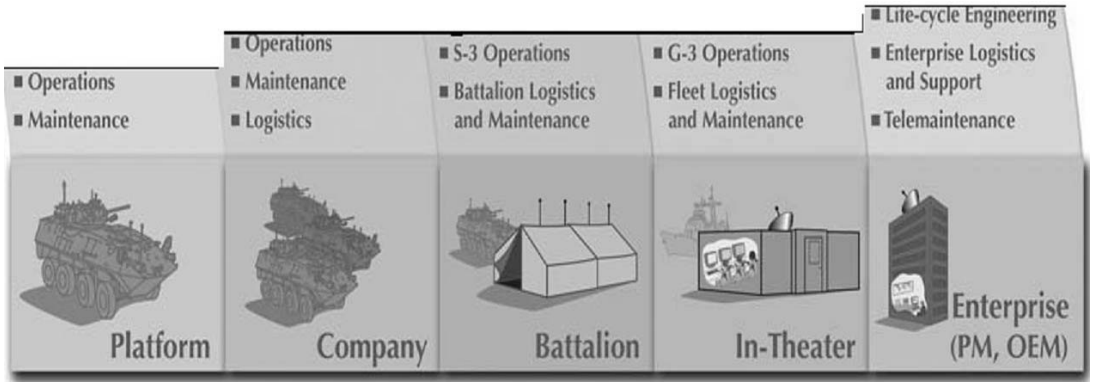

Figure 2: Overview of S&RL

4.3 Force Generation in 2020

The listed projects in the NCW Roadmap for the desired state of logistics do not appear to achieve the optimal goals. While MILIS is an automated supply and replenishment system and is significantly advanced over current practices, it does not have access to consumption of resources and ordance on a **real time basis** since it is not connected to the individual platforms. The data input into the system must be taken from usage at the forward supply points. The same type of data must be collected by the Operations Commander manually so that they know how much **fight** is left in their assets. Under S&RL this is done automatically for both uses.

5. Towards Automatic Sustainment

Using the LAV-25 as an example of the current USMC program to fit sensor systems to their assets, we can see the type of information available in the early stages (first delivery July 2008, retrofit fleet 2009).

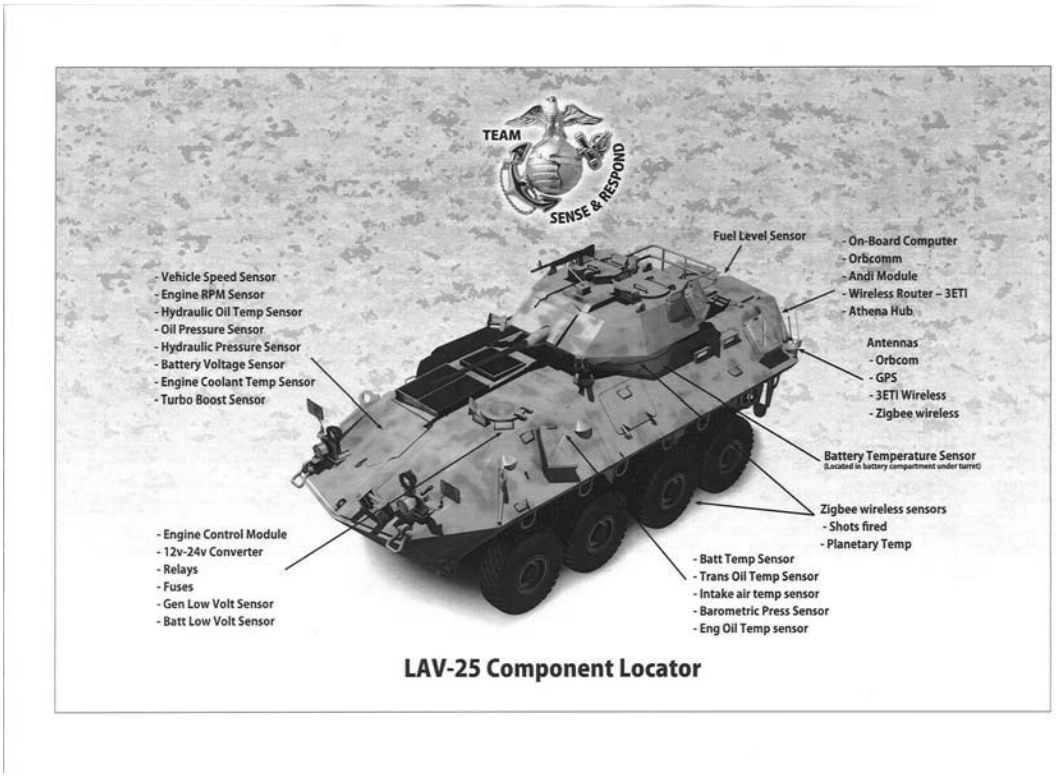

Figure 3: LAV 25 platform sensors

As can be seen, the information generated is useful at the asset operator level (especially in the context that LAVs in Iraq experience overheating in the hub reduction gear case and a crewman must dismount and touch the unit to see if it is running hot). The addition of real time logistics data plus the operational situation awareness being transmitted up the line, substantiates the connectivity created by S&RL.

Autonomic sustainment has the potential to provide end-to-end visability of maintenance events and the status of the supply chain through an extension of the MILIS system to interface with ALIS.

6. Conclusion

Autonomic Logistics in the JSF case was developed to measure and respond to support maintenance requirements accurately and efficiently.

In fact, with the in-built P&HM, it is supposed to predict future needs and pre-position resources just-in-time. It was not developed to provide to support a theater commander (although the information generated as to status would be useful at that level).

S&RL, in this case the USMC version as applied to the LAV-25, incorporates AL concepts but enhances that to not only meet the Logistics requirements but to create the interconnectivity required to support theater operations at all levels.

The ADF's MILIS project was not designed to meet the requirements of the optimal end – to - end system. With it's related projects such as RFIDs, it should provide the designed capabilities of inventory and resource identification, shipping and tracking. Since it does not extend to the platform level, it cannot provide real time data and therefore cannot optimally support

the logistics function or C2 decision making.

A possible step that could be taken would be a review to determine to what extent the LAV-25 modifications and related software could be transferred to a few ASLAVs. This would be a low cost (development has already been paid for) method for the ADF to experiment with the systems and determine hardware/software integration requirements.

The ultimate embodiment of the 'foxhole-to-factory-to-foxhole' logistics contiuum for the ADF will be realised when current developments in information systems like MILIS connect with envisaged developments which diagnose and communicate status data generated at platform level from sense and respond devices. Combined with the deductive capacity of S&RL and the predictive capability of AL, MILIS would have the capability of fully realising the logistics goal identified in the NCW Roadmap.

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