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THE UNWRITTEN TRUTHS OF MILITARY GROUND VEHICLE ARCHITECTURE

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ABSTRACT

From the hard-earned lessons learned over years of architecting, designing, and integrating systems on military ground combat vehicles, we have repeatedly encountered and identified challenges that are not captured by the system level vehicles requirements.

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1. INTRODUCTION

From the hard-earned lessons learned over years of architecting, designing, and integrating systems on military ground combat vehicles, we have repeatedly encountered and identified challenges that are not captured by the system level vehicles requirements. Many of the architecturally significant requirements for a military ground combat vehicle exist between the system level requirements as 2nd, 3rd, or 4th level derived requirements for the system level. The derived nature of the architecturally significant requirements makes them difficult to identify and difficult to trace. Architecture literature talks about these challenges as heuristics, "guidelines, abstractions, and pragmatics generated by lessons learned from experience" [1]. Systems Engineering has identified these types of challenges as the Laws of Systems Engineering [2]. We have chosen to call these challenges the unwritten truths of military ground vehicle architecture. These truths are not a law, regulation, policy, or requirement; they are the recurring bloody knuckle lessons taught by experience. These are truths that impact electrical, electronic, and software systems and components, but some can be applied more broadly.

The term "architecture" is applied differently in different domains and by different practitioners. In this case, we are using the IEEE 1471:2000 definition, "The fundamental organization of a system embodied in its components, their relationships to each other, and to the environment, and the principles guiding its design and evolution [3]." The impacts of the unwritten truths of military ground vehicle architectures can be seen in the relationships among components, the relationships between components and military ground vehicle environments, and the principles guiding the design and evolution of military ground vehicles.

2. TRUTHS

2.1. Volume - The space isn't going to get bigger

Under-armor volume is a military ground vehicles most precious resource. The volume of a military ground vehicle is limited by the need to transport our vehicles; MIL-STD-1366 defines vehicle maximum dimensions based the highway, rail, fixed-wing aircraft, and ship transport envelopes[4]. Under-armor volume drives the cost and weight of a ground vehicle. As the size of the vehicle increases, so does the weight and the corresponding cost of many systems required to support the increased weight.

Colloquially, this paper will refer to individual vehicle hardware elements or components as boxes. If you are developing a box for a ground vehicle, the vehicle size has already been determined, so the available volume is a constraint and not part of your trade space.

Successfully putting a component onto a ground vehicle can often be defined by whether your box is bigger or smaller than a bread box. Most existing ground combat vehicle will only have space for one or two bread box size boxes. Most of those bread boxes spaces are already used. If you want to add another one, you either have to remove an existing box or replace it, and all of its functionality, in a smaller package.

The additional packaging space you want around your box for airflow, connectors, and cable bend radius are all part of your box size. Target quarter or half bread box size boxes. Smaller is better. The soldier's prioritized list of packing concerns for a vehicle architect go in this order:

1. Everything that makes the vehicle move
2. The weapons and ammunition
3. The crew
4. Fuel, food, and water
5. The squad
6. Electronics boxes

If your solution is bread box size or bigger, then what are we going to remove from the vehicle to make it fit?

2.2. Cost - We're not cheap we're frugal.

Cost is king in the development of military ground vehicles. Ground vehicles are not aircraft. They won't fall out of the sky. If the Army can't afford a ground vehicle, then soldiers can always walk, so the decision space is not the same as it is for the Air Force or the Navy. If your box, device, or solution is too expensive, the Army just won't buy it.

The Army is frugal not because it wants to be. The Army is frugal because the volume of vehicles it can afford to produce is not great enough to get to commercial automotive cost and scales, but it is significantly greater in scale than the production quantities for aircraft.

The cost range for military ground vehicle has four different levels. From highest to lowest cost point, they are:

- Heavy Combat Vehicles
  - 7-10x less than midrange aircraft systems
- Medium Combat Vehicles
  - 1/3 to 2/3 the cost of a Heavy Combat Vehicle
- Tactical Truck
  - Similar cost to Commercial Trucking
- Command Vehicles
  - Cost range of a Tactical Truck, but might take similar equipment to Medium Combat Vehicle

For example, on one platform the equipment and functionality had grown over time, but the performance requirements had not changed. In this case we saw an opportunity to replace two boxes with one. After explaining to a vendor what we were trying to accomplish and how we were attempting to accomplish it, the vendor said, "You're so cheap that you're want to remove" a box from your system? The answer was, "Yes" we wanted the cost and volume savings. We will make trades to reduce cost and volume as long as we can still maintain the reliability of the system.

2.3. Environment Hot and Cold – Is it hot enough for ya?

Thermal is the greatest ground vehicle technical challenge which is compounded by our limited volume. The environment that military ground combat vehicles must be able to survive in is defined in MIL-STD-810. MIL-STD-810 defines the environment at the system level but does not define the induced environment within the vehicle that the soldiers and boxes must survive. The thermal environment for a component within a ground vehicle can best be modeled as being wrapped in a blanket. Does your box work while wrapped in a blanket, without airflow or significant ambient cooling on a hot day in Death Valley, California? If it does, then it is perfect for ground combat vehicles.

A military ground vehicle is a large metal box with no extra space. That large metal box will be heated or cooled by the outside temperature and solar heat load. Just like the being wrapped in a blanket, there isn't much air flow in our metal box. People, structures, components, cable harnesses, ammunition, water, and food will fill the nooks and crannies in the vehicle restricting air flow.

Every solution to address the thermal needs of a box comes at the cost of volume. For example: fans need space for air flow and need maintenance for cleaning; air conditioning needs space for condensers, evaporators, and compressors along with ducting to move the air; liquid cooling requires radiators, a liquid reservoir, pumps, and hoses. If packaging your box and its thermal solution displaces a soldier, weapons, ammunition, food, water, or fuel we'll leave your box on the curb.

2.4. Dirty and Wet Environment – Time to get your hands dirty.

Army ground vehicles are dirty and work in dirty environments. Dirt will get everywhere and very quickly. If your box isn't sealed, then it will get dirt inside the unsealed areas.

When military ground vehicles get dirty, they don't get detailed; they get cleaned out with a hose. If your box isn't sealed tightly, then it will get water in it.

Dirt becomes a reliability and a maintainability issue in a ground vehicle. The dirt and immersion, along with the thermal environment, are significant discriminators between boxes created for ground vehicles and those created for labs, command centers, ships, or aircraft.

2.5. Physical Abuse – That's not a handhold or a step

From TM 9-8000 Principles of Automotive Vehicles, "Electrical connectors must be capable of withstanding the effects of the military environment. Protection against damage due to temperature extremes, water, oil, and physical abuse is mandatory."[5] Soldiers are not gentle with their vehicles and the vehicles tend to not be designed to be gentle on the soldiers. The space is tight. Hatches, controls, and equipment can be awkwardly placed. As a result, everything becomes a handhold or a step. Cable harnesses, connectors, computers, displays, etcetera are all handholds and steps in this environment. Ground vehicle equipment needs to be designed with this in mind.

2.6. Monuments - Can't change, you just need to work around it.

Once a vehicle is fielded, there isn't going to be a clean sheet design for any upgrades. There are monuments in all existing vehicles, and they tend to be things like the structure of the vehicle (including openings, mounting provisions, and pass through holes), space claims for the placement of people, gear, supplies, and other equipment, and existing equipment, connectors, cable harness and interfaces. The number of monuments increases once a vehicle has reached the field.

When architecting an upgrade to an existing vehicle, you need to identify the monuments to understand the real trade-space for the system. A key factor associated with any upgrade is the identification of the space claims not identified in the structural Computer Aided Design (CAD) models. The key take away from all of this is, if you ever find a large, seemingly open space in a vehicle, that means you haven't found out what is already allocated to that space.

Monuments also exist in the limited spaces to pass cables through the structure from inside the hull to the outside. Monuments exist in the interfaces and the physical structure of the existing cable and connectors because the cost the remove and replace them is significant enough to warrant their reuse. Monuments exist within the vehicles ability to provide power to upgraded components.

In most cases an upgrade will require consolidation of functionality to maximize reuse of box space and existing cable routings and pass throughs.

2.7. Previous Monuments – A corollary

When a vehicle is being originally designed, there isn't a clean sheet design either. Monuments will still exist in terms of limits on the size or envelope of the vehicle, the historical placement of people, gear, supplies, and other equipment. Monuments will exist for the equipment that will be provided from other programs, the limits of commercially available equipment, and what portions of the system the program is willing to develop.

Even when architecting a new vehicle, you need to identify the monuments to understand the real trade-space for the system.

2.8. Commonality - Stick together

Commonality through Modular Open Systems Approach (MOSA) is one mechanism within the ground vehicle community to achieve the goal of cost savings. Commonality is the holy grail of military ground vehicles. Commonality can be achieved at many different levels:

1. Requirement
2. Function
3. Architecture and Interface
4. Component (Part Level)

The Ground Combat Vehicle (GCS) Common Infrastructure Architecture (GCIA) is the military ground combat vehicles architecture and interface MOSA approach to address commonality.

Component (Part Level) commonality is the goal of creating a box and software that can provide the same functionality and capabilities across multiple vehicle platforms. Component commonality has the goal of achieving cost saving through reduced spare parts, cost saving through large volume purchases, reduced Non-Recurring Engineering (NRE) and testing for development. Along with these saving comes the goal of reducing high the cost of high performance solutions per vehicle equipped by increasing the purchase volume.

The component commonality objective is challenging to achieve because it requires commonality at the higher levels (Requirement, Function, and Architecture and Interface) which can be provided by efforts like GCIA. Component commonality faces the specific challenges of differences in space claim volume, box cost profiles, specific vehicle architectural monuments, specific vehicle space claim monuments, and interface monuments across vehicle platforms.

Another type of commonality targets the uses a group of smaller common parts that provide different functions aggregated into a single box. The purpose of this approach is to achieve the same goals as part number commonality while also achieving volume savings. The challenge to achieve this goal is aligning the requirements, functions, architectures, and interfaces across a fleet ground vehicles. The desire to incorporate specific high performance requirements or functions needed by a small number of specialized vehicles into the aggregate common solutions introduces additional cost and integration burdens for the less specialized vehicle platforms.

Creating commonality at the Architecture and Interface level through GCIA provides a path to MOSA. GCIA provides a structure to support part level commonality.

2.9. Boundaries – Why is it that all battles are fought in the middle of the night, in downpouring rain, and at the corners of four different maps? – George S. Patton

Military ground combat vehicles have many boundaries that an architect needs to work around. These challenges and pain points include physical boundaries such as transitioning between the hull and the turret and transitioning between the inside of the vehicle and the outside of the vehicle. These challenges and pain points also include the functional and logical transitions between security domains and transitioning between safety-critical and non-safety-critical domains.

The physical boundaries create architectural interface limitations and space claim limitations especially within existing systems. These physical boundaries are also impacted by the limitations of varies electrical interface due to cable run lengths, limitations of the existing electrical medium, and electrical noise.

Security and safety identify another type of boundary within the architecture of a military ground vehicles. The boundary of safety and security is created by another type of monument within the system: policy. Security and safety are represented within the vehicle by different levels based upon the criticality levels of these domains. Department of Defense policies for security are many and varied adding to the challenges.

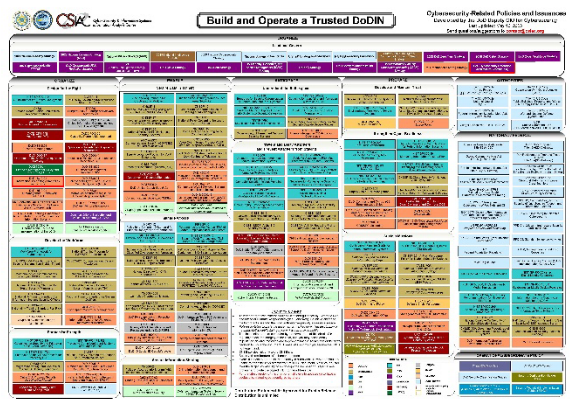

Figure 1: DoD Cybersecurity-Related Policies and Issuances [6]

In the domains of safety and security transitioning between different levels of criticality or mixing levels of criticality will drastically increase the cost and complexity of the boxes.

Boxes that operate at the boundaries of safety and security domains or that operate at a mixed levels of safety and security criticality will become monuments within a military ground vehicle system. These boxes should be carefully identified and isolated to allow the system to change and adapt in the future.

There ain't no such thing as a free lunch when faced with addressing security and safety boundaries. Early identification of these boundaries and mindful decision making during box development can simplify vehicle integration and reduce cost over the life of the system.

2.10. Coupling – Spreading like the tentacles of an Octopus

Military ground vehicles need to support a wide number of system interfaces based upon their form, fit, and function. At the box these interfaces are represented by physical connectors and at the system level these interfaces are represented by the physical cables connecting the boxes together. Cables and connectors for a military environment are expensive and they take up space. The number of connectors and the size of the connectors can often drive the physical size of the box. The size impact and the cost of connectors tend to drive toward the use of high density connectors supporting multiple diverse interfaces. These large connectors supporting multiple interfaces tend to drive the creating of "Octopus" cabling harness that interconnects multiple boxes over a single cable harness. These cable harnesses are referred to as "Octopus" cables because they spread through the vehicle like the tentacles of an Octopus.

These approaches suffer from high coupling. "Two components are coupled if a change made to one component requires a change to the other component in order for the overall product to work correctly[7]." Interface coupling includes physical connections, electrical signals, or software interfaces. The greater the degree of interdependence a box has within a vehicle, the greater the coupling. The greater the coupling increases the cost and complexity to change or upgrade ta box. Higher degrees of coupling increase the likelihood that a box becomes a monument inhibiting change or the addition of new capabilities to the vehicle platform.

2.11. Cohesion – It slices, it dices, and makes Julienne Fries

Everyone wants one thing that can do everything and solve all of your problems. The military ground vehicles are no different. Military ground vehicles often build boxes that combine widely varying functions and capabilities with the goal of reducing cost and volume. Military ground vehicle often build a catchall boxes that house all the functions that didn't find a home in other boxes. These solutions suffer from having low cohesion. Cohesion, in software terms, is the "degree to which the elements inside a module belong together".[8] This definition can be applied to systems and architectures, with the same impact to a Modular Open System Architecture as to software. A low cohesion box mixes functions from a wide variety of functional areas which means a change to that box will impact multiple function areas driving the cost and complexity of the change. Low cohesion boxes will quickly become monuments in your architecture. Low cohesion boxes will be the element within your architecture that will prevent your system from being upgraded.

Lower cohesion boxes are unavoidable, but they should be limited to implementing functionality to two major functional areas to try to avoid becoming monuments.

3. Conclusion

The unwritten truths of military ground vehicle architectures are driven by the environment of military ground vehicles. The unwritten truths define the design trade-space for components, the relationships between components, and the principles guiding the design and evolution of military ground vehicles.

These truths define what is good enough for the equipment used in military vehicles and good enough to be put in the hands of our soldiers.

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