NAVAL POSTGRADUATE SCHOOL

SYSTEM SUITABILITY ASSESSMENT

SE3302 SYSTEM SUITABILITY

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1. Introduction

1.1 Background

US, NATO, military, national police and even civilians in Afghanistan and Iraq continue to face the threat of injury and death from improvised explosive devices (IED) placed by insurgent and terrorist militia engaged in disruption of civil government and peacekeeping operations. The military has actively pursued IED detection for route clearance during the military operations conducted in the Afghan and Iraqi theaters of war over the past several years. As the military and peacekeeping operations diminish over the coming months, countering the IED threat as an area clearance objective becomes of greater concern given the threat to the general population that IEDs are likely to continue to pose.

The Micro Expeditionary Transforming Air Land-Vehicle (METAL-V) project has just completed a concept feasibility demonstration. The results of the demonstration have been analyzed to develop feasibility recommendations for the development and production of a concept design for the terrestrial locomotion and IED detection components of the METAL-V system.

The Advanced Counter IED Detection System (ACIDS) is a system operational concept for surveillance area IED detection. The ACIDS concept incorporates a programmable, all terrain, and miniature vehicle for IED detection that will also include support equipment and operations personnel. Figure 1 below illustrates the operational view for the ACIDS system as described above.

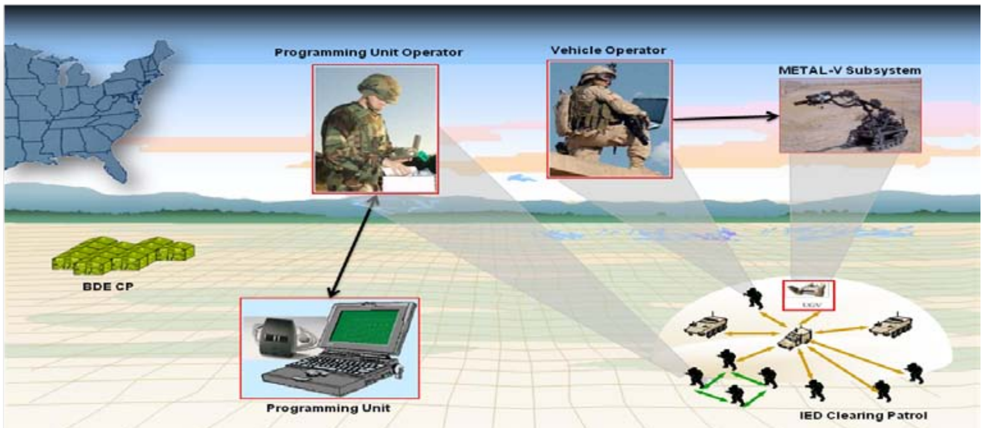

Figure 1: OV-1

The conceptual system integrates a contractor's prototype programmable vehicle, the Simulated METAL-V, which was built on available commercial off-the-shelf (COTS) technology. The SMETAL-V's demonstrated capability to perform autonomous IED searches in an assigned area has been endorsed by military service representatives. The customer will define the ACIDS subsystems that will include the autonomous search vehicle and should also include a maintenance diagnostics and a programming portable computer unit, operators for the systems functions and the storage container. Figure 1 and 2 below includes the functional hierarchy decomposition and the operational view of the ACIDS system Concept.

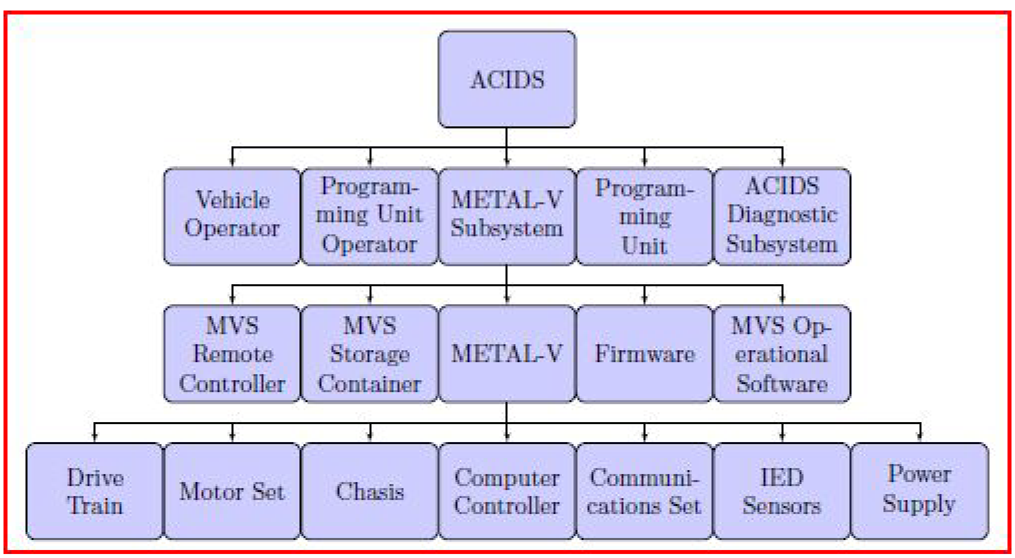

Figure 2: Functional Hierarchy Decomposition

Our team, ACIDS engineering and Suitability (ACES), has performed a Systems Suitability Assessment based on the Key Performance Parameters (KPP) defined for ACIDS (Table 1 Below). The system reliability, availability and software suitability have been thoroughly evaluated. Given the cost and schedule timetables required to develop software from the ground up, commercial off the shelf (COTS) technology offering cost effective and quick solutions was used extensively in the ACIDS concept. That said, the limitations in using COTS components pose constraints which are apparent in the suitability analysis.

The following KPPs have been established for ACIDS: KPPs	Threshold	Objective
Mission Reliability (DRM)	0.90	0.95
Operational Availability	0.80	0.90
DRM Elapsed Time	5 minutes	3 minutes
Deployed-to-Ready Time	10 minutes	5 minutes
Operational Team Size	2 people	1 person

Table 1: Key Performance Parameters (KPPs)

The ACIDS has four operational states and one inoperative state. The ACIDS states are the standby state, the deployed state, the ready state, the operating state, and the inoperative state. By way of additional background information, a short description of ACIDS operations[1], and the functional hierarchy in Figure 2, Figure 3 below (also in Appendix B) is an overall representation of the system data flow. Lastly, this report will discuss the results, recommendations, and the means of conducting the analysis, to determine the feasibility of the ACIDS system.

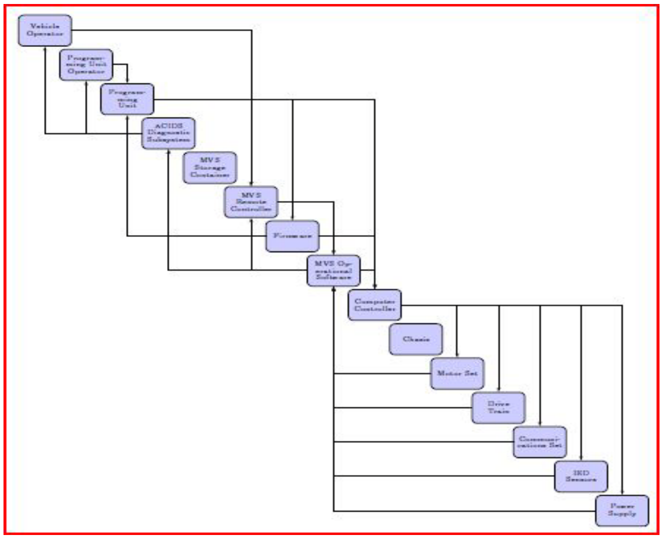

Figure 3: Data Flow Diagram

1.2 System Lifecycle

ACIDS reliability and availability requirements have been established based on the operational requirements and maintenance concept developed during the system conceptual design. Quantitative requirements for the mean time between failures and maintenance, the component failure rates and scheduled maintenance periods that support the conceptual design will necessarily be reallocated during the system design and development through such means as reliability and maintainability analysis and system design trade-offs. Failure modes effects cause and analysis, fault tree analysis, maintenance task analysis, and level of repair analysis are techniques that will be used to derive the reliability and maintainability design factors for ACIDS. Reliability tests and evaluations conducted during the design and production against the test performance measures and metrics will be used to establish that the availability of the system and

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[1] Reference SE3302 System Suitability, Systems Engineering Project, Advanced Counter IED Detection System (ACIDS) Robotic Detection of IED Description

its logistical footprint meets the user's operational needs. Continued evaluation of the system's reliability and maintainability factors during the utilization will be used to ascertain the need for modifications to improve the service life of the ACIDS.

The total cost of ownership (TOC) to the user includes the reliability, availability and the logistical footprint necessary to operate and dispose of the ACIDS during the utilization and end of life system phases. Establishing the TOC early on, will enable better program planning and facilitate design of the ACIDS to accommodate the suitability requirements desired for the system.

2. Results

2.1 Reliability

ACIDS has five high level functions; Initialize ACIDS, Position METAL-V within search space, search for IEDS, determine if time is up, and return ACIDS to ready state. All five of those functions are in series with each other. Since the functions are in series the individual functions need a very high level reliability each to achieve the 90% Key Performance Parameter (KPP) for total system reliability. In order to evaluate the system reliability we focused on the 94% reliability operation for IED functionality or R_{F3}, as identified in the Reliability Network Diagram below.

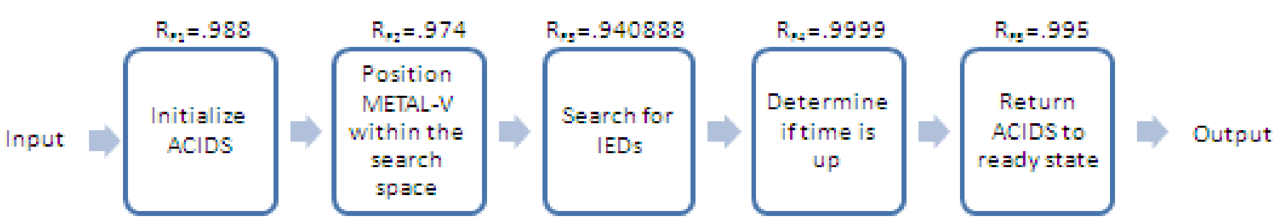


Figure 4: ACIDS Network Reliability Diagram

During our design analysis for reliability we determined that we could benefit from redundant IED sensors. This would increases the reliability of the sensors from 0.993 for one to 0.999951 which eases the requirement somewhat for non-IED-sensor components of METAL-V. Specifically it allows us to reduce the mean time between failure for non-IED-sensor components from 263 hours to approximately 203 hours while still maintaining the same overall reliability of 0.9708 for the METAL-V subsystem. Given the derived allocations for the search function (RF3), the overall Mission Reliability KPP can be achieved if these allocations are met by each component within the system.

2.2 Operational Availability

For the operational availability requirement we considered system uptime consisting of Mean Time Between Maintenance (MTBM) and system downtime which includes MTBM and Maintenance Downtime (MDT). One of the key things to consider in operational availability is to ensure that the ratio of uptime over downtime is sufficient to meet the requirement. Hence, the goal is to ensure that the system is "up" long enough before a maintenance action occurs to take the system "down" which causes the system to be unavailable.

For the analysis we began by calculating both the MTBM and MDT. In regards to MTBM we concluded that the system would go approximately 49hrs before maintenance action was required. For the MDT we evaluated the Administrative Downtime (ADT) and Logistics Downtime (LDT) and concluded that the overall MDT was approximately 13hrs. To calculate Ao we used the equation of MTBM/(MTBM+MDT) to which gave the system an operational availability of 17.6%; drastically lower than the 80% threshold requirement key performance parameter (KPP).

In order to mitigate this issue and to work towards meeting the KPP the following actions are recommended: 1. Decrease the amount of time for a maintenance action to be completed. This can be done by reviewing the doctrine, organization, training, material, leadership, personnel, and facilities (DOTMLPF) to determine if any of these agents are contributing to the LDT or ADT. Next review the fault isolation procedures and built in test diagnostics to ensure they are adequate for use by the skill level being trained to conduct the maintenance operations. 2. While conducting the DOTMLPF review and reviewing the troubleshooting procedures you would consider methods to increase the MTBM. This could be done by increasing the reliability of the system or creating more redundancies within the system such that maintenance actions do not have to occur as often as with a single point failure.

2.3 Software Suitability

Given the critical nature of the mission and the hostile environment for which the ACIDS system is targeted, an emphasis on usability, reliability, and correctness is suggested for software suitability evaluation. Although it is fundamentally important in almost every system that the developed software implement and support the system requirements correctly, the importance is elevated in a system such as ACIDS that supports mission critical activities like IED clearing. Failure to correctly and adequately cover the system requirements could unduly place warfighters in harm's way. Having established correctness, the software must also be reliable. That is to say, it must perform the correct actions consistently, predictably, and without fail. If the software is correct and defect-free then it will also be reliable. Rechtin & Maier suggest that the number of defects remaining in a piece of software is proportional to the number of defects found. Where lives are at stake the goal should always be to produce the highest quality error-free software.

Usability in the field is of great concern. Software that is difficult to use increases the potential for catastrophic human errors. The first step to enforcing these criteria is to state each as a requirement or set of requirements. Examples of this are as follows:

- Correctness- "Each system requirement shall be supported directly by one or more calls, methods, procedures, components, classes, or libraries of the METAL-V operational software which shall map directly to and support system requirements."
- Reliability-"The METAL-V operational software shall perform consistently as written under normal operating conditions with a reliability greater than 0.98."
- Usability- 1. "The METAL-V operational software shall present an interface that closely resembles the physical operation of the system." 2. "The METAL-V operational software shall prevent over rotation of the number six servo5."

For verification we recommend conducting a functional qualification test (FQT) program that tests every the correctness of every command and function of the system in the various environments the system spec has indicated operation in. To test reliability we recommend conducting a Reliability Software Qualification Test (RSQT) test for an extended period of time to ensure the system can consistently perform under normal operating conditions with a 98% reliability. Lastly for usability we would conduct soldier interface tests, i.e. Limited User Tests, or some sort of interactive training with the end user to ensure that it meets usability requirements.

2.4 Other Suitability Areas

Other Suitability areas for consideration on the ACIDS system include usability or Human Systems Integration (HSI), supportability, and survivability. When considering HSI, it is imperative to ensure that the vehicle operator and the programming unit operator are included when designing for operational feasibility (Blanchard and Fabricky, 2010). ACIDS system will need to consider the manpower, training, personnel needed, and the safety of the design to ensure that the warfighter can be integrated into the system with optimized performance, comfort and safety. While the ACIDS concept is being developed it is important to develop the supportability or logistics strategy with it to ensure that we design a system that can be sustained in the field. The system will need to be designed to include detection, isolation, repair, diagnostics, prognostics, and all factors that are included in the logistical footprint to ensure that the overall cost and time to support are minimized (Young, 2011). Lastly survivability is a major consideration give the purpose of the ACIDS system is to detect IEDs. The ACIDS system survivability will need to be evaluated against all possible sources of threats and in specified levels of conflict (Young, 2011). In the event the system detects the IED but is unable to avoid detonation, the system design should survive a catastrophic event while protecting the operators.

3. Summary

3.1 Evaluation

Improvised explosive devices (IED) have been and continue to be a serious threat to military forces and to civilian populations. Currently, dismounting scouts to conduct reconnaissance with the vehicles in traveling over watch is the best method for identifying IEDs before entering the kill zone. Advanced Counter IED Detection System (ACIDS) aim is to successfully conduct area clearance missions without risking the lives of scouts. Although both land and aerial can be utilized for area clearance at this time the focus is on using the Micro Expeditionary Transforming Air Land-Vehicle (METAL-V) subsystem for land reconnaissance.

ACIDS has established five Key Performance Parameters (KPP) for system assessment. Mission Reliability (DRM) has been set at a threshold of 90% probability of the system completing the mission in a satisfactory manner with an objective of 95%. A high level physical architecture for ACIDS has been laid out with reliability values set at the component level to achieve meet desired threshold. A second KPP is DRM elapsed time. The threshold set is five minutes with an objective of three minutes. An ACIDS Limited Objective Exercise (LOE) has been completed testing for meeting the threshold of DRM elapsed time. Another established KPP is Operational Availability. The overall threshold for Operational Availability has been set at the system being available 80% of the time with an objective of achieving 90% operational availability. Current design calculations show the actual availability of only 17.6% of the time. This is not an acceptable level of operational availability. Although is there is no one simple solution to boost operation availability using one ACIDS, various methods to achieve the threshold have been discussed. A forth KPP is the Operational Team Size, with a threshold of two people and an objective of one person. Currently ACIDS requires two people to operate; the programming unit operator will initialize ACIDS then the vehicle operator will position the METAL-V subsystem within the designated search area as demonstrated by the LOE. The final established KPP is Deployed-to-Ready Time. The threshold for this KPP is ten minutes with an objective of five minutes. Once again, the LOE was conducted to test that the Deployed-to-Ready Time meets the required threshold.

Currently, the acquisition of ACIDS is in the concept definition phase. An Architecture Definition is being established as well as a Prototype System for Development and Testing. As consistent with many modern systems, ACIDS will largely be software driven. The suitability of the software utilized by ACIDS is vital to successful completion of its mission. The overall state of the ACIDS prototype software is not suitable for acceptance and lifecycle use. Too much relies on the specific implementation which uses the Lego Mindstorm NXT brick. Sufficient software engineering by way of abstraction and encapsulation may result in the ability to re-use (or at least leverage) some of the prototype operational software, but the fielded implementation may well be similarly tailored to the specifics of the production hardware. This is due to the hardware specific nature of programmable microcontrollers and the lack of portable and generalized routines and libraries for sensor and actuator access. Nonetheless, the prototype system is valuable in that it provides early feedback on system viability, user adoption, and important lessons learned.

At its current state ACIDS is not suitable to successfully complete its mission but does have a solid foundation moving forward. Future analysis needs to be conducted before the concept design phase is complete. Moving forward, the next phase for ACIDS acquisition is system development.

3.2 Recommendation and Future Analysis

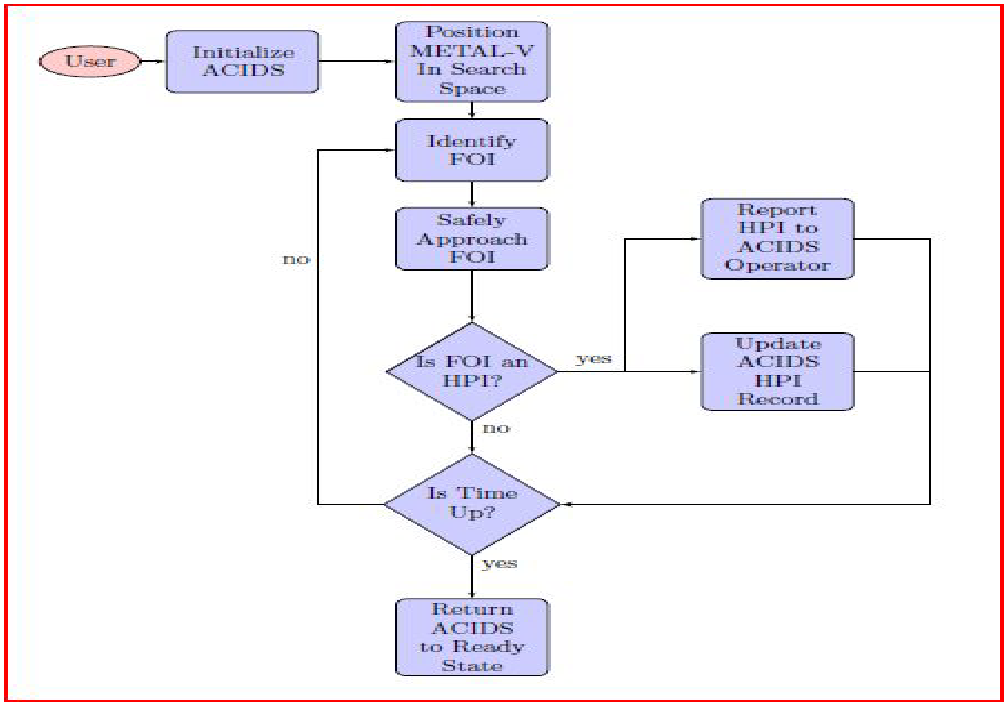
Although analysis can never be fully exhaustive for a system, the current analysis level of ACIDS is restrictive in determining its overall suitability for terrestrial locomotion and IED detection. Further analysis of ACIDS functionality, software traceability, and flexibility can allow ACIDS to proceed from the concept design phase to system development phase.

One major suitability characteristic that has not yet been demonstrated is functionality. IED detection is not a trivial task and ACIDS has yet to demonstrate it is able to successfully detect an IED. Metrics need to be assigned for success rate of correctly identifying an IED, probability of identifying something as an IED that is not, and probability of failing to identify something that is an IED. KPPs need to be established for those metrics to ensure ACIDS is suitable to complete a mission of successfully identifying IEDs within a given area. Failure to identify an IED could pose grave safety risks for the Warfighter if the limitations of ACIDS are not well established. Conversely, having a high false alarm rate could drastically slow down a mission, jeopardizing its successful completion.

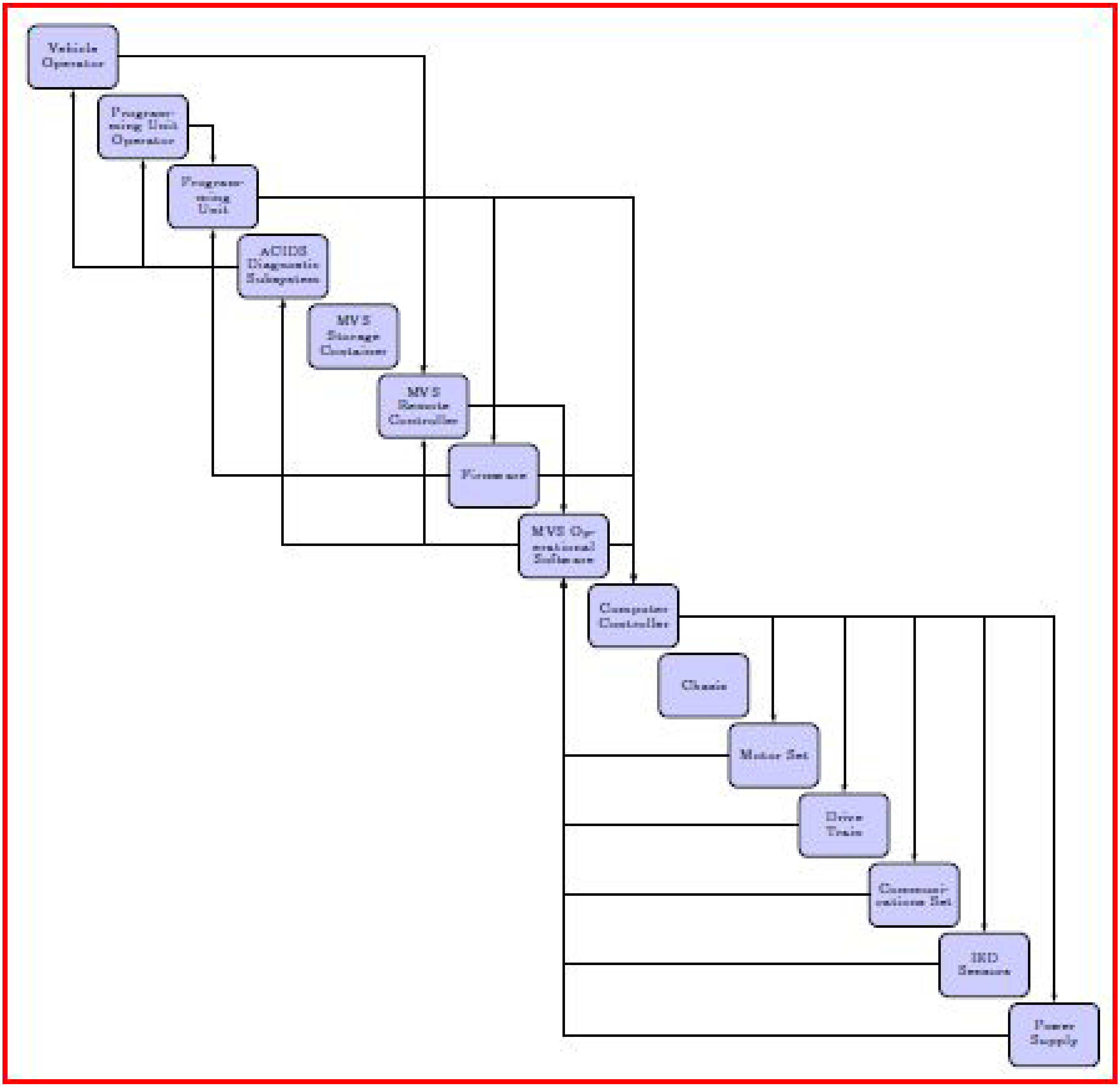
As noted previously, analysis of software suitability for ACIDS is not complete. Although the selected GOTS and COTS software packages appear to fit into the over architecture of ACIDS, their ability to integrate into a complete system to that detect IEDs has not been established. The ability to tailor the proposed software into a system that meets functionality requirements is not currently known. By providing traceability back to the requirements of the software components we can assure that coverage is complete.

The enemy has shown an ability to be flexible and adapt to the Warfighters' counter attacks against IEDs. The enemy will likely adapt by creating IEDs that are most difficult for the METAL-V detect and as a result ACIDS will need to adapt or suffer a degradation of usefulness. The METAL-V will need to function in a wide variety of environments. A mission cannot be altered simply because ACIDS is not able to function in a certain condition. The METAL-V is a programmable unit, theoretically allowing the software algorithms to be updated with ease. Concepts such as the IED searches being conducted purely off hard coded algorithms vs. the advantages/ disadvantages of learning algorithms needs to be considered. Many advanced learning algorithms rely on extensive memory availability, hardware limitations on such algorithms need to be considered. Successful analysis of the aforementioned areas of design would aid in determining the overall suitability of ACIDS.

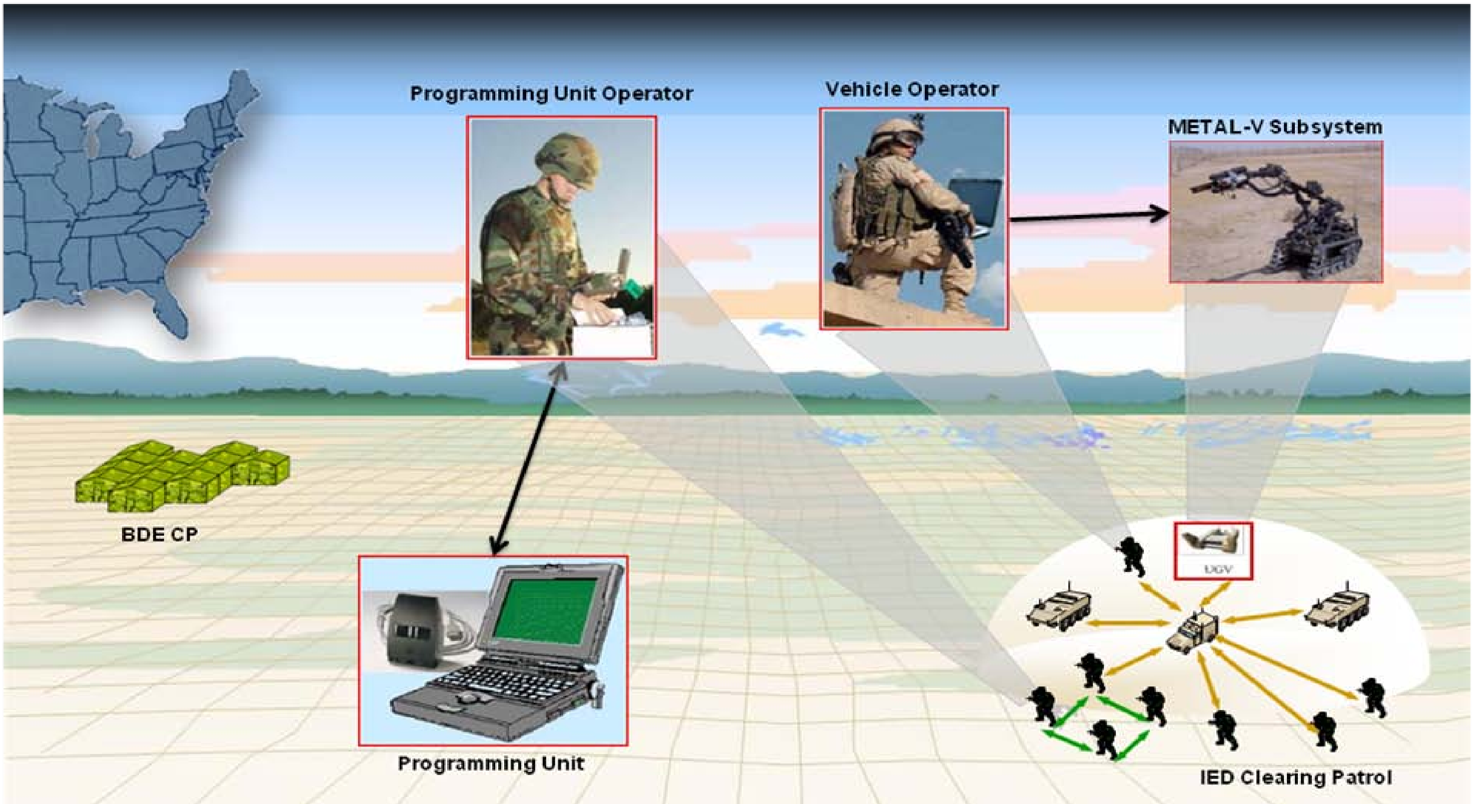
APPENDIX A: Functional Flow Diagram



APPENDIX B: Data Flow Diagram



APPENDIX C: .OV-1



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