System Engineering approach to assessing Integrated Survivability

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List of Acronyms

AFV	Armoured Fighting Vehicles
CASTFORM	Combined Arms and Support Task Force Evaluation Model
CFD	Computational Fluid Dynamics
Combat XXI	Combined Arms Analysis Tool for the 21st Century
DLODs	Defence Lines of Development
ISAAC	Integrated Survivability Analysis and Assessment Code
JCATS	Joint Conflict and Tactical Simulation
JFAS	Joint Force Analysis Simulation
JANUS	Joint Army Navy Uniform Simulation
LS-DYNA	Livermore Software-Dynamics
MADYMO	Mathematical Dynamic MOdels
MUVES	Modular UNIX-based Vulnerability Estimation Suite
MOD	Ministry of Defence
MTO	Major Theater Operations
OneSAF	One Semi-Automated Forces
Pk(F)	Probability of Firepower kill
Pk(K)	Probability of Catastrophic kill
Pk(M)	Probability of Mobility kill
Pk(P)	Probability of Personnel kill
RDECs	Research, Development, and Engineering Center
SC	Survivability Concept
SM	Survivability Measure
SoS	System of Systems
SSTR	Stability, Security, Transition, and Reconstruction
TACOM	Tank-Automotive Armament COMmand
TLCM	Through-Life Capability Management
TOSOM	Threat Oriented Survivability Optimization Model
US	United States

Introduction

Land platforms are increasingly required to carry out a wide range of roles in support of very diverse operations ranging from high intensity conflict to Operations Other Than War (OOTW). The acceptance of casualties is low and reduction is a strategic political imperative. As a result, crew/platform survivability is important to mission effectiveness and success. Methods for achieving survivability need to be objectively assessed and prioritized to meet cost constraints. Integrated Survivability (IS) assessments and modelling are key capabilities to perform this task.

The United States Army defines survivability traditionally as the capability of the system and crew to avoid or withstand a man-made hostile environment without suffering an abortive impairment of their ability to accomplish their designated mission[i]. However, the US Army has moved towards a System of Systems (SoS) engagement and protection requirements with the traditional definition of survivability inadequate to describe the collaborative aspect of deployed systems. Survivability is more accurately defined by four levels: mission survivability; functional survivability; platform survivability; and personnel survivability. Personnel survivability defines the integration of the survivability of the individual soldier and the how the system affects the soldier's survivability. Platform survivability is the ability of a platform to avoid or withstand a man-made hostile environment without suffering an abortive impairment of its ability to contribute to the collaborative accomplishment of the SoS designated mission. Functional Survivability is the ability to maintain a capability through and after exposure to a man-made hostile environment. Mission survivability is the ability to accomplish the designated mission during and after exposure to a man-made hostile environment.

The Army uses a well defined and established process to assess SoS survivability with verified and validated analytical tools to optimize platform and system design for survivability. This paper will define the modelling tools and evaluation process for manned and unmanned ground vehicle systems to assess integrated design for survivability for ground vehicle platforms.

Design for Survivability

Design for survivability follows a traditional system's engineering approach based on technology development, system baseline, requirements, concepts and analysis to determine trade space and finally the integrated product (Figure 1). The primary focus within the systems engineering approach is to assess the individual system level survivability while maintaining cognizance of the systems of systems protection of the platform. This analysis allows an integrated assessment from both the threat and system point of view to account for single platforms or a brigade combat system structure to assess overall system level survivability.

System level survivability is dependent on the mission profile and protection of the baseline system. The mission profile is derived from the initial capability gap document and the concept of operations. The requirements are a compilation of the specific threat events projected for the identified platform missions and the user requirements identified. The intent of the system's engineering process is to provide traceability of the technology solutions to the requirements and the associated impact to the overall survivability and mobility of the system. This approach allows the balance of protection requirements, with payload and performance requirements.

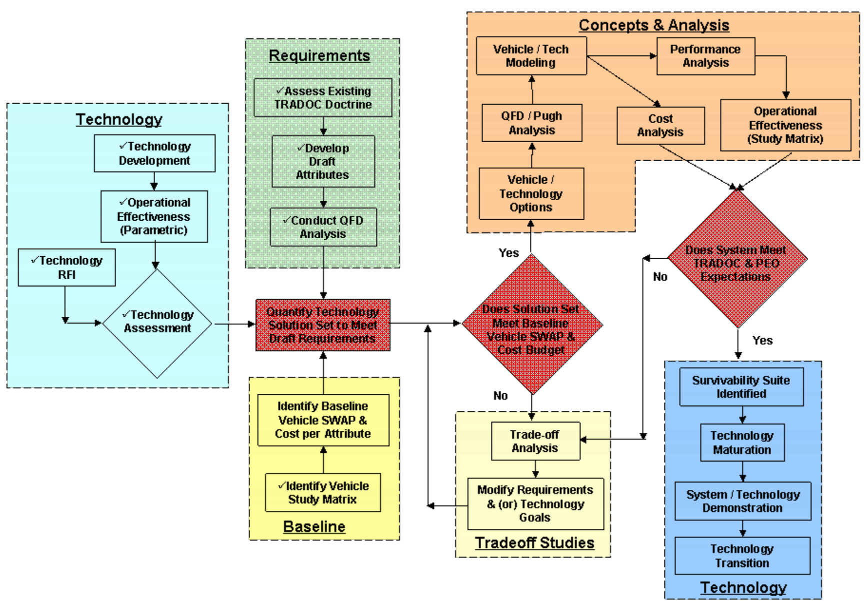

Figure 1: System Engineering Assessment Process

The design for survivability or integrated survivability approach assesses each layer of the identified threat lethality based on the event chain for engagement of a vehicle system. The threat lethality accounts for the acquisition of the system, the threat accuracy of impacting the system based on static or dynamic system considerations and the penetration capability of the threat. This is summarized by the following equation:

$$\textit{Threat Lethality} = P_{Acquisition} * P_{Hit} * P_{Kill} \quad [1]$$

The integrated survivability approach further defines the survivability protection layers by encompassing soft attributes to the survivability protection (i.e. the "don't be seen" and the "don't be killed" layers). These attributes, given that they normally have a human in the loop and require cognitive behavioural processing of data points, are much harder to quantify in the "don't be seen" protection layer. Technologies that are listed within the "don't be seen" layer are typically situational awareness technologies (Global Information Grid, visual situational awareness of hostiles, etc.) and signature management technologies.

The "don't be killed" layer of survivability protection accounts for many of the mitigation technologies (i.e. blast mitigating seats/structures, safety harnesses, fire suppression technologies, and spall liners). These technologies are event specific and given that each engagement may cause a different vehicle response it is challenging to quantify the contribution without using high fidelity models to characterize the interplay between the threat, system, and environmental conditions. The US Army has modelling and simulations tools to quantify the physics based response for the above engagements using LS-Dyna for blast modelling, MADYMO for safety and human response, CFD software (Fluent) is used to model the fire suppression capabilities and MUVES is used to identify the impact of spall liners based on the placement for crew survivability.

Furthermore, the mitigation technologies rely significantly on the crew interface and their interaction with the technologies. For example, optimizing seat restraint systems may identify that five point restraints provide greater protection during crash events than three point restraint systems, but the crew may be less likely to use the five point restraint given the time considerations, negating the benefit. The human factor element of mitigation technologies is the challenging area to quantify for trade-space and overall system survivability.

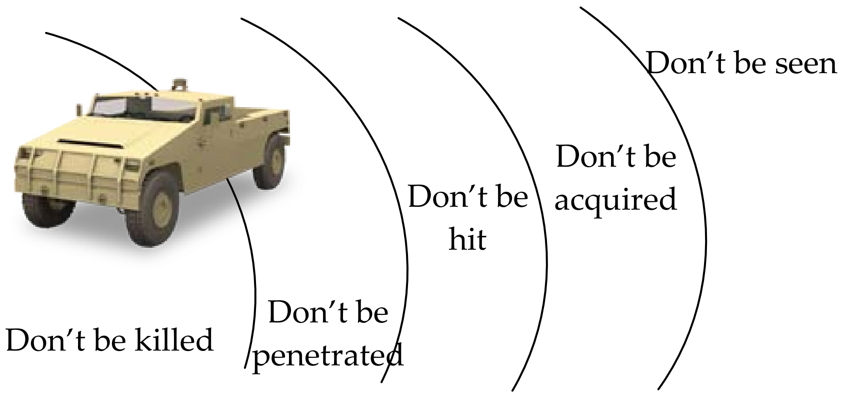

Figure 2: US survivability protection layers

The “don’t be penetrated” layer of protection accounts for the vehicle level protection to include passive and active armor solutions and active protection systems. The main distinction between the “don’t be hit” technologies and the “don’t be penetrated” technologies are the “don’t be hit” technologies defeat the threat at the vehicle level or very near vehicle level within a small radius. This is critical because defeating the threat near the vehicle system requires characterization of the residuals of the threat event.

The “don’t be hit” layer of protection accounts for neutralization technologies that may disable or pre-detonate the threat at a standoff distance required to have a safety bubble of protection for the vehicle system. This could include some active protection systems, soft-kill systems such as electronic countermeasures and sensors. The challenging component of assessing technologies within this survivability protection layer is the understanding of compatibility issues between electronic technologies and soft kill measures.

The “don’t be acquired” layer of protection accounts for technologies that disrupt the sensor of the threat comprising eyes, binos or thermal sensors. The intent is to distract the sensor by using tactics, techniques, and procedures such as suppressive fire; disable thermal, acoustic, or radar sensors with signature management applications; or provide obscuration of the vehicles using various types of obscurants.

The survivability protection layers correspond to the threat lethality with the probability of acquisition coupling the "don't be seen" and "don't be acquired" technology solutions; the probability of hit is a direct correlation to the "don't be hit" technology solutions; and the probability of kill couples the "don't be penetrated" and "don't be killed" technology solutions.

The integrated/design for survivability approach first assesses the technologies at each layer of the survivability protection and completes trades within the layer, across the layers of protection and then it is an iteration between the technology solutions provided and the system constraints.

The following sections will discuss the system's engineering assessment process and critical deliverables associated with the tasks to provide the appropriate level of information to the decision makers.

1.1. Technology Development Phase

The technology development phase identifies all survivability technologies across the many layers of protection. The layers of protection provide protection by employing technologies that attack the sensor capabilities of the threat event and thus provide protection by not being acquired nor seen. If the system is acquired and a threat is launched, then the next layer of protection is activated through avoidance technologies or technologies that attack the specific threat event. If the threat event is able to defeat the techniques and technologies, then the next layer of protection is initiated as the system is not penetrated by the threat event via active protection systems or passive or reactive armor solutions. If the threat event penetrates the system, the final layer of protection is initiated for the crew during the mitigation layer of protection (figure 2). The mitigation technologies provide protection to the crew of the system to contain the damage of the threat event penetrating all previous layers of protection. Technologies through an integrated survivability approach are assessed across these layers and trades are conducted within the layers to identify the technologies that provide the significant capability based on the operational context.

1.2. Requirements Phase

The requirements phase of the system's engineering process reviews the mission requirements for the system of interests within the platform and brigade combat structure to identify the critical requirements and relationship among the requirements. This is primarily completed through a house of quality assessment with the critical stakeholders. The results of the requirements phase will provide the platform manager with the assessment of the critical attributes of the system and the interrelationships among the requirements and potential solutions. This will allow the identification of technology gaps for the requirements.

1.3. System Baseline

Concurrent with the requirements phase is an assessment of the baseline capabilities of the system. The baseline requirements characterize the current protection levels and technologies integrated onto the platform. The current power and weight burdens are assessed at the current configurations identifying the available power and weight limitations for additional protection. Traditionally, an assessment will also be conducted to determine the vehicle dynamics of the system such as roll over angle, top speed, acceleration, braking distance, lane change maneuvers, and other relevant vehicle performance specification as required by the platform and mission. This characterization will define the baseline capabilities not only for survivability, but the powertrain performance attributes of the system.

The first three stages (Technology, Requirements, and baseline) provide a full characterization of what technologies are available across the layers of protection; the baseline performance of the system of interest; and the identified requirements for modernization or modification of the system. The next three stages provide decisions makers the critical information to assess the impact of adding additional capabilities to the system and the additional constraints within the vehicle.

1.4. Concepts and Analysis

The concepts and analysis phase is the analytical assessment of the theoretical performance of the system simulated through various mission relevant tasks. The technologies are mapped to the requirements using tools like a pugh analysis or house of quality (Quality Functional Deployment). The mapped technologies define an enhanced capability of the system. The technologies are assessed by subject matter experts prioritizing the technologies within the layer of protection based on the critical attributes of the protection. For example, technologies that could be identified for "the don't be hit" layer of protection are identified as signature management, obscurants, mounted weapons, electronic countermeasures, and tactics. Often multiple technologies exist within each of the general areas and must be assessed to provide a manageable solution set for the requirement.

The project manager will conduct multiple analyses for technologies using operational effectiveness applications at a brigade or unit level to determine how soldiers might use the technology in various war gaming scenarios. This assessment identifies the measure of effectiveness of that technology in a relevant environment and standardizes characterization of the technology within modelling environments. The Army has standardized the modelling of obscurants, active protection systems, passive armor, reactive armor, signature management, and electronic countermeasures. The information comprising the effectiveness of technologies and their capabilities are validated through an independent organization before applied in any modelling scenario.

The technologies that provide the significant protection to the system are then integrated onto the platform using a synthetic environment (Computer Aided Design) to assess the internal and external volume requirements. If technologies are unable to be integrated onto the exterior or interior of the system, then they are moved into trade space to assess if the benefit warrants a development effort to reduce the size of the system or if a system that fits the space claim and offers similar capability is available.

The integrated solution will be assessed at the terminal ballistic protection level against the identified threat sets and at the powertrain, vehicle dynamic performance attributes. This characterizes the survivability of the system and the mobility performance attributes to be presented to the stakeholders mapping the requirements to the technology solutions provided. Additionally, gaps are identified where technology solutions are not available to assess if additional tactics, techniques, and procedures should be used to fulfil the requirement.

Once the mobility and survivability attributes are characterized, the final assessment within this stage is a life cycle cost assessment on the technologies and additional operational effectiveness (wargaming) assessment at a brigade or unit level exercise. The combination of the integration criteria (internal/external volume requirements, power, and cooling requirements), coupled with the life cycle cost, vehicle dynamic, powertrain performance, and operational effectiveness provide the decision makers the specific information to enter the next phase of the process-tradeoffs.

1.5. Tradeoffs

Tradeoffs are ever present when assessing the desired capability and the system constraints. Often, the technology solutions available to meet a certain requirement exceed the weight or power allocation available. The assessment tools will be used to tailor any armor solutions to reduce the weight, but decision makers must make the final determination as to the technologies integrated onto the platforms. This is also the opportunity to development technology development programs to reduce the weight or power requirements of the technologies or requirements. This is an iterative process between the stakeholders and technology developers/integrators to determine the acceptable weight, power constraints and the optimal survivability protection. The time spent in the concepts and analysis phase allow "what-if" drills and assessment for the stakeholders to understand the impact on the ground vehicle power and mobility and survivability of integrating technologies onto the platform. Once the technologies and protection are viable for the platform, the final phase of the system's engineering process is initiated which is the technology transition.

1.6. Technology Transition

The technology transition phase will complete the necessary testing required to integrate the technology and capability onto the system. This state normally conducts life-fire testing; reliability, availability, and maintainability testing; and durability testing to verify that the system as design and integrated meet the final specification identified by the user community. This phase will identify potential technology development initiatives to increase specific performance attributes and assess the technology at an increase technology readiness level.

Integrated Survivability Scenarios

When assessing survivability at the platform and brigade level, it is critical to understand the threat event or operational profile for the system(s). When designing holistic survivability for new platform development, it is necessary to have multiple threat engagements or scenarios such as Stability, Security, Transition, and Reconstruction (SSTR); Major Theater Operations (MTO); and current operational examples based on recent deployments. This is necessary to understand the core technologies that are required and provide protection across a broad spectrum of threats versus niche technologies that are essential in specific engagement scenarios, but may constraint the system during standard operations. It will also help to avoid designing future systems to fight today's wars.

The US accomplishes much of these missions through the various wargaming scenarios and operational models such as COMBAT XXI, CASTFOREM, JANUS, OneSAF, JFAS, JCATs, TOSOM etc. Each model has strengths and limitations of capabilities and depending on the risk, multiple scenarios and models may be used to reduce requirement development risk to understand the various contexts of operations.

Summary

Integrated survivability is assessed across all layers of protection with numerous analytical and simulation tools that attempt to equalize the technologies capabilities across the layers. The process of integrated survivability allows stakeholders to understand the impact of redundant technologies attacking a threat at various levels of protection. Additionally, it provides a quantifiable assessment of the burdens of the technologies across the multiple layers. It is a known fact that technologies in the outer layers of protection normally are lighter weight than the solutions in the inner layer of protection. It is normally identified as a trade between power versus weight between the outer layers of protection and the inner. Integrated survivability provides decision makers standardized quantifiable assessment of technologies across the layers of protection to understand the constraints and impacts of the solutions on the platform.

The Research, Development, Engineering Command has invested significant resources across the Research, Development, and Engineering Centers (RDECs) to improve the modelling and simulation characterization capability of technology solutions. Across the RDECs we are able to model fire suppression initiation and neutralization with various technologies; blast mitigation technologies are modelled via testing and analysis to determine structural and seat/restraint benefits. Leveraging our TACOM life cycle management commands allows the various wargaming scenarios to be accomplished with validated and verified scenarios and tactics. The strengths of our modelling community allow a solid understanding of the penetration of the threats; mitigation technology representation at the physics based level; and thermal modelling. The limitation within our modelling capability is to understand human cognitive response with specific technologies such as situational awareness, non-lethal technologies, and the “don’t be seen” layer of the onion when attempting to couple that with robotic follower type applications.

The critical technologies that the RDECs model effectively across the board with physics based models to support as well as test data is thermal modelling, radar modelling, obscuration, passive/active armor, soft-kill countermeasures, electronic countermeasures, active protection systems or defensive aid suites, and IED defeat technologies. The technologies that have significant assumptions with the model and are not coupled to physics based models are situational awareness (visual and auditory), system level blast modelling (working to define standardized process of understanding charge placement coupled with environmental impacts), system level fire suppression based on threat impact location (current modelling assumes initiation of fire given threat event). Additionally, it is critical to not only understand how each of the technologies impact the survivability, but coupling those technologies to the performance and payload attributes required to the system and brigade is a main focal area for improvement within our models.

The end result for any survivability assessment or design for survivability approach is to provide the right technology solution to our Warfighter providing improved current force capabilities and superior future force capabilities. The integrated survivability approach and process at a subscale is used to assess current capabilities and identify gaps for technology portfolio management; supports requirements generation for new technology platforms; and provide trade space support for current platform modernization efforts. The information presented to the user is in terms of probability of survivability, loss exchange ratios, and killer victim metrics to understand the full capabilities of the system and theoretical survivability.

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[i] Army Regulation 70-75, Research, Development, and Acquisition Survivability of Army Personnel and Materiel, dtd 02 May 2005.