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A Systems Approach to Develop Requirements for the Kill Chain Process of the Next Generation Combat Vehicle

Joseph Allen, Nathanael Endo, Derik Kuykendall, Maxwell Regan, Adam Roe, and James Comstock

Department of Systems Engineering
United States Military Academy, West Point, NY

Corresponding author: maxwell.regan@westpoint.edu

Author Note: The authors completed this project as a part of their Systems Engineering Capstone Program. Major James Comstock is an Assistant Professor in the Department of Systems Engineering at the United States Military Academy who served as the faculty lead investigator.

Abstract: Robotics are becoming increasingly prevalent in modern life. These developments are paving the way for new military technologies and have re-defined how robotics are used on the battlefield. The Next Generation Combat Vehicle Cross Functional Team (NGCV-CFT) is leading the development of new major ground combat vehicles (GCV's), including a suite of Robotic Combat Vehicles (RCVs). The Cross Functional Team is responsible for developing the requirements for these vehicles and they have identified the processes for detection, identification, engagement and assessment, also known as the Kill Chain, as the greatest challenge to their research. This research used systems analysis tools, including functional analysis and simulation, to support the CFT's effort of developing requirements. The simulations results, combined with extensive stakeholder interviews, provided evidence that shaped numerous requirements for the Kill Chain process.

Keywords: Kill Chain, Requirements, Systems Approach, Next Generation Combat Vehicle

1. Introduction

The Kill Chain process refers to the functions and processes innate to neutralizing threats on the battlefield. Though it has drastically changed throughout history, it generally encompasses the detection, identification, and engagement of targets by an individual, machine, or weapon. Today, the US Army employs many different Kill Chains processes throughout their systems and operations to dominate the battlefield. According to the Chief of Staff of the Army, the improvement and incorporation of the Next Generation Combat Vehicles (NGCV's) into modern formations is the second top priority of the Army's modernization process (Milley, 2017). To meet these needs and reduce the burden of the Next Generation Combat Vehicle Cross Functional Team (NGCV CFT), the Capstone team conducted thorough analysis on the different functions of the Kill Chain process to develop requirements for the new system. These requirements will guide contractors' proposed systems to meet the needs of the Army.

2. Literature Review: Kill Chain

The current Kill Chain process of modern ground combat and robotic vehicles cannot fulfill the requirements of future operating environments. Since future combat is expected to shift to dense urban areas, future Ground Combat Vehicles (GCV's) and Robotic Combat Vehicles (RCV's) must be able to meet battlefield demands never before developed by the U.S. Army. Tying these demands together is the Kill Chain process. According to Ray Alderman, the Kill Chain process could be traced back to the Greeks and Romans. In those times, he categorized the Kill Chain as Find, Kill, and Pillage (FKP). Over time the Kill Chain developed into a more sophisticated process. During World War II, the United States Marines Kill Chain was Find Kill Repeat (FKR) which shortened the Kill Chain from months to weeks and eliminated the pillage portion of the process. At the end of World War II, the Army's Kill Chain developed into the Find, Fix, Fight, Finish (F4) model (Alderman, 2017). Eventually, it developed into a new Kill Chain: Detection, Identification, Decision, Engagement, and Assessment (DIDEA). However, this Kill Chain has many different structures and is employed differently across different branches and weapon systems (Peck, 2019). This is the model that the NGCV's Kill Chain revolves around in order to keep familiarity within the systems. This helps soldiers easily adapt to the new technology by utilizing the same process they are accustomed to.

3. Methodology

3.1 Overview

The research team's methodology for the development of a Kill Chain Process for the Robotic Combat Vehicle follows the System's Decision Process (SDP). A process developed by West Point's Department of Systems Engineering, "The SDP is a collaborative, iterative, and value-based process that can be applied in any system life cycle stage" (Driscoll 17). The SDP process is depicted in Figure 1 below.

Figure 1. Systems Decision Process

The team started with problem definition, which consists of research and stakeholder analysis, value modeling, and functional requirements analysis. The team met with the Next Generation Combat Vehicle Cross-Functional Team (NGCV-CFT), sensor experts at the Communications-Electronics Research Development and Engineering Center (CERDEC), and other individuals who are a part of the RCV development teams. Through research and analysis, the team created the redefined problem statement as follows: Develop requirements for the Kill Chain process that can identify targets and update the common operating picture as a component of Manned Unmanned Teams (MUM-T) and the Robotic Combat Vehicle. The research team then started the solution design phase of the systems design process.

3.2 Stakeholder Analysis

After interviewing the Director of NGCV CFT, the group determined that focusing on the Kill Chain process would provide the most utility to the NGCV CFT. This led the group to develop an FCR (Findings, Conclusions, and Recommendations) matrix, which helped to determine what solutions are needed to solve the problems of the NGCV. The NGCV-CFT needs an identifiable process that is easily broken down and understood. The process must be able to identify targets, update the common operating picture, determine courses of action, and notify the operator of the enemy situation. These baseline needs are achievable only through advanced sensory technology. Because of the capability gaps in modern sensor technology, the group must determine alternate courses of action and technology to use to meet these requirements.

After discussions with engineers at General Dynamics (GD), the group learned that the requirements developed should be broad and descriptive, non-prescriptive (Marcone, 2019). The requirements must also be viewed as a need for the Army. This provides engineers the creative freedom to develop ways to accomplish the requirements of the Kill Chain while not inhibiting their design capabilities. Broad requirements are also important for these systems because the United States currently does not have an adversary to base their technology requirements on. For example, the M1 Abrams tank was developed to combat Soviet Union armor on the plains of Eastern Europe. The Army was able to create requirements for the Abrams because they had a defined adversary with known capabilities. Today, the United States does not have a defined adversary whose capabilities shape technology requirements. Because of this, the capstone team must develop non-prescriptive requirements that will facilitate victory against a wide range of enemies. Since the NGCV could potentially be employed to combat terrorist organizations in the middle east, Chinese forces near the South China Sea, Russian armor on the

Polish border, or any other wide possibility of enemies, it must be able to meet a vast expanse of requirements. Given the unknown nature of future warfare, it is crucial that these design requirements for the Kill Chain process do not inhibit the capabilities of modern engineers.

3.3 Capability Gaps of Modern Ground Combat Vehicles

The NGCV CFT states that modern autonomous Kill Chains lack the functional capabilities to accurately identify targets and determine courses of action. Though modern sensors can scan fields of view, locate enemy units or vehicles, and reference a database, they cannot accurately identify targets as friendly, enemy, or civilian. This capability gap is perhaps the most important because target identification and classification directly influences the rest of the Kill Chain process. This is a very complex capability gap because humans struggle with consistently doing it all the time. The Army must develop a sensor that is more accurate than human agents at identifying and classifying targets (Wallace, 2019).

The second capability gap of modern GCVs relates to determining courses of action. While current technology can consistently locate friendly units, it has no way of developing probabilities of enemy killed by friendly units. Modern GCV's also lack the ability to develop courses of actions based on mission type. Fulfilling this capability gap is crucial to developing an autonomous Kill Chain process for future Robotic Combat Vehicles.

3.4 Functional Analysis and Value Modeling

Functional analysis serves as a critical tool to evaluate the needs of the kill chain process. The essential tasks for the Kill Chain are the top four functions in the qualitative value model, shown in Figure 2. The Kill Chain process must accurately identify targets, update the common operating picture, determine appropriate courses of action, and notify the Kill Chain Operator. Once this capability gap is fulfilled, RCV's must be able to update the Common Operating Picture. This will require an RCV to simply relay the target information gathered to friendly forces. Once the possible courses of action are determined, an RCV must inform the Kill Chain operator of their choices. This allows a human agent to make the final decision regarding how to engage enemies on the battlefield. After the operator selects the proper course of action, the RCV must be able to carry out the mission to completion.

The value hierarchy shown in Figure 2 explains a means of quantitatively measuring the main four functions for the Kill Chain process of the RCV. Identifying targets can be measured in three ways. These measures are the distance for detection range, the percent of positive identification and the detection time. The process for updating the common operating picture can be measured in the seconds it takes to relay information to the unit and the display effectiveness based on user feedback. The courses of action developed can be measured in the overkill on intended vs. unintended targets. The effectiveness of notifying the operator on recommended courses of action will be measured in the time that it takes from the initiation of the message to the receipt of the action by the operator. The importance of the value hierachy displayed in figure 2 lies in the framework it provides the client to evaluate future NGCV Kill Chain alternatives.

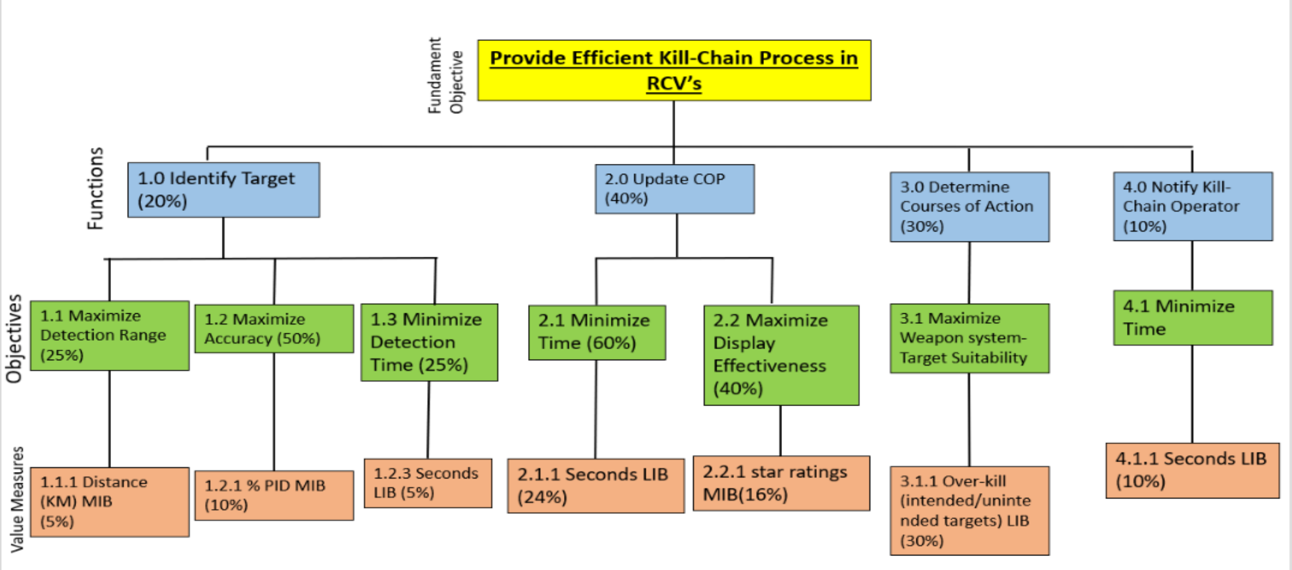

Figure 2. Value Hierarchy

3.5 Solution Design

In a problem as complex as developing requirements for the kill chain process, innovative thinking is critical to solution design. This effort began with the group members exercising individual brainwriting to develop an initial list of possible requirements for the kill chain process. Beginning with brainwriting sessions limited the possibility of group think and stimulated individual idea generation. This list was then used in group brainstorming sessions where the capstone team used information gathered from both individual research and stakeholder analysis to create a further refined list of possible requirements. The list of possible requirements then informed discussions both internally and with the stakeholder, which led to a refined list that accounted for time, scope, and budget. This final list of requirements was screened against simulation, constraints, and feasibility. The end goal of this process was turning the list of possible requirements into candidate solution requirements (Driscoll 353-358).

To screen the sensor portion included in the requirement list, the group generated alternatives that consisted of various combinations of sensors.

The sensors are the Long-Range Advanced Scout Surveillance System (LRAS3), Cross Platform Pointing Laser Receiver (CPPLR), Hostile Fire Detection and Location (HFDL), and the Beam 220. These sensor combinations are just a few systems the capstone received data on and were able to simulate. They are not required to be on these systems but are possible alternatives.

4. Modeling and Analysis

4.1 Methodology

To model the different alternatives, the team used the Infantry Warrior Simulation (IWARS) program, which is a computer program for combat modeling situations. IWARS allows for analysis on the effectiveness of the different combinations of sensors identified through the systems engineering process (see Figure 1); however, IWARS only allows one sensor to be attached to a vehicle for each simulation. Although IWARS has limitations, alternative packages were not suitable either. After collecting data on the different sensors, the data was compiled to create a single sensor that represents the different combinations of sensors. IWARS considers several variables for each sensor which include: Scan Time Per Field of View, Angular Width and Height for the Field of Regard, Horizontal and Vertical Field of View, and Magnification. Since the LRAS3 has two modes, wide and narrow field of view, a magnification of 10 is used across all sensors because 10x is half way between the magnification for wide and narrow field of view. A constant magnification is used because the LRAS3 is included in each combination of sensors and therefore provides a constant. Scan time per field of view and the dimensions of the field of view were altered to represent the different sets of sensors being modeled.

4.2 Assumptions/Limitations

To produce an accurate model representative of the Kill Chain process, it was necessary to make assumptions regarding the test scenario. The IWARS program was originally designed to simulate dismounted combat scenarios. Using vehicles and simulating their effectiveness is not the primary purpose of the program. There are many limitations and capability gaps in IWARS that drastically affected the results. The simulation tests the time it takes to engage a target and the percentage of successful engagements, a process including the detection, identification, and engagement criteria of the system Kill Chain. A total of four scenarios were built in IWARS to simulate the different potential combat roles in which the NGCV could encounter. The "stationary" scenario depicts two combat vehicles facing each other. "Red moving" features a stationary friendly vehicle firing at an enemy vehicle. "Blue moving" is the opposite: a moving friendly vehicle fires at a stationary enemy vehicle. Finally, "Both moving" depicts two vehicles facing and moving towards each other. In every scenario, the friendly vehicle fires upon the enemy vehicle. Since IWARS cannot accurately simulate vehicle engagements, the simulation was restricted so the enemy vehicle would not fire upon the friendly vehicle. The combat effectiveness of friendly munitions or accuracy was not measured as well. Doing so would only add variability to the findings. Instead, the simulation measured the time it took the friendly vehicle to detect, identify, and fire at the enemy vehicle. The sensor combinations used by the friendly vehicle were varied to test the effectiveness of different sensor combinations. The combination "All 4" refers to using the LRAS3, CCPRL, Beam220, and HFDL. "LBH" is the sensor combination of LRAS3, Beam220, and HFDL. "LCB" refers to using the LRAS 3, CCPLR, and Beam220 sensors, while "LCH" refers to using the LRAS3, CCPLR, and HFDL sensors. The last sensor package was the "Gen 2 FLIR". This served as the base case and represents the US Army's current sensor configuration. Each scenario ran 30 times for 300 seconds each. The results were analyzed based on average time to first shot, and percentage of successful engagements. A successful engagement refers to a run where the friendly vehicle successfully detects, identifies, and engages the enemy vehicle.

4.3 Results

Based on the simulation results, the best sensor combination is using the LRAS3, CCPLR, Beam220, and HFDL altogether. This sensor combination had far better results than the other sensor combinations. However, it is key to note that the next best option is the LCH alternative, which is the combination of the LRAS3, CCPLR and HFDL. This is the only combination other than all 4 sensors that can detect and engage an enemy in IWARs when the friendly vehicle is in motion. Though the results cannot be applied to real world combat, they do speak to the potential overwhelming effectiveness of using all sensors rather than using a different combination of other sensors or the US Army's current sensor configuration. Reference Figures 3 and 4 below for a detailed visual of the findings. This analysis, in combination with stakeholder interviews, helped the team determine appropriate requirements for the NGCV. The development of these requirements early in the acquisition cycle suggests that the SDP allows for faster analysis and is a more efficient process than the current method.

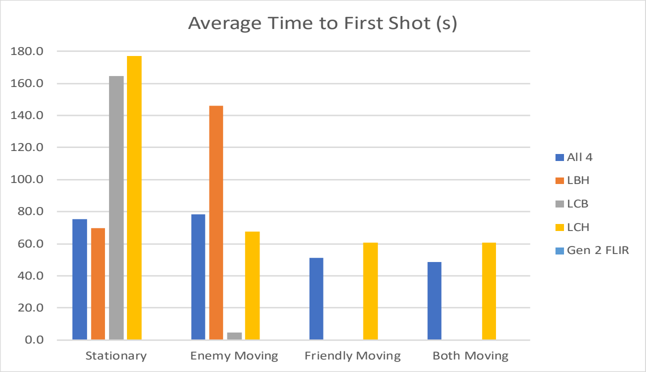

Figure 3. Average Time to First Shot

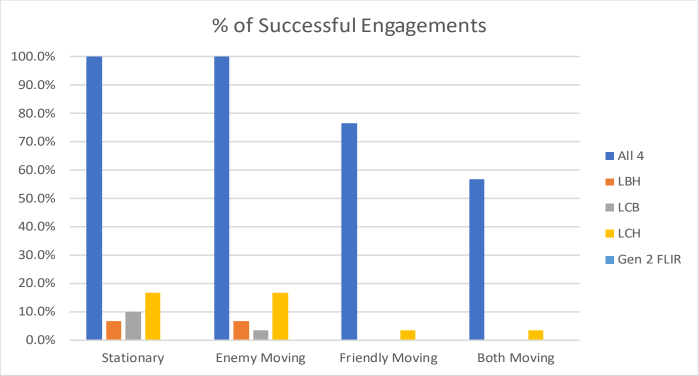

Figure 4. % of Successful Engagements

Based on the simulation results, the best sensor combination is using the LRAS3, CCPLR, Beam220, and HFDL altogether. This sensor combination had far better results than the other sensor combinations. However, it is key to note that the next best option is the LCH alternative which is the combination of the LRAS3, CCPLR and HFDL. This is the only

combination other than all 4 sensors that can detect and engage an enemy in IWARs when the friendly vehicle is in motion. Though the results cannot be applied to real world combat, they do speak to the potential overwhelming effectiveness of using all sensors rather than using a different combination of other sensors or the US Army's current sensor configuration. Based on a linear regression of the data, the varying of sensors is only statistically significant at increasing the percentage of successful engagements. The model has a p-value of 2.42e-8 while the adjusted R squared for the model is .91. These findings show that, when using IWARS, improving sensory technology only has a significant effect on the percentage of successful engagements. A successful engagement captures the detection, identification, and engagement criteria of the Kill Chain process. Reference Figures 3 and 4 above for a detailed visual of the findings.

This analysis, in combination with stakeholder interviews, helped the team determine appropriate requirements for the NGCV. One such requirement related to this simulation is that the new sensor package shall exceed the current senor's range. In all of the simulation scenarios, the current sensor never had a successful engagement which shows that all of the simulated alternatives exceed the current sensor's range. Furthermore, the simulation also offered a proof of concept relating to the requirement of gunnery time standards. It is crucial that the addition of sensor packages meets or exceeds the time standards of modern Army gunnery standards. Though these requirements are simple, they are crucial to define and establish the foundation for further Kill Chain improvement by the NGCV CFT. The development of these requirements early in the acquisition cycle suggests that the SDP allows for faster analysis and is a more efficient process than the current method (Reference requirements 1 and 4 in Table 1).

5. Requirement Recommendations

The end state of the research project is the development of requirement recommendations for the NGCV's Kill Chain process and its integration with the MUM-T. Although some of the details of the study are sensitive in nature, Table 1, below, shows a sample of the generalized requirement recommendations.

Table 1. Kill Chain Requirement Recommendations

1. The RCV shall have a sensor package that allows for human or AI-aided detection and identification of enemy units that exceeds the current sensor's range.
2. The Kill Chain process shall have an AI-aided (AITR) system that will be able to identify units and vehicles within a pre-determined margin of error.
3. The Kill Chain process shall have an AI system that determines threat level for an enemy unit or vehicle and recommends courses of action to the ground force commander.
4. The Kill Chain process shall be able to detect, identify, and provide AI-aided recommendations for courses of action to the ground commander that meet or exceed the current gunnery time standards.
5. The RCV and Controller Vehicle shall have a communications range that allows the Kill Chain process to employ effective fire and maneuver, reconnaissance, and support capabilities to the MUM-T and adjacent units.

6. Conclusion

To create new weapons systems and combat vehicles that can face a wide range of threats across multiple domains and in numerous environments, the Kill Chain must be modernized. Accomplishing this is one of the Army's top priorities. Because the Army does not face a singular threat in which to base capability requirements, the NGCV CFT must develop descriptive requirements that will guide contractors' proposed systems to meet the needs of the Army. Doing so will give developers the engineering freedom to meet the needs of the Army while not prescribing them to developmental requirements that have plagued Army systems projects of the past. Application of the systems decision process resulted in multiple requirements that will help the NGCV CFT accomplish this goal. In-depth stakeholder interviews, literature reviews on the historical development of past Kill Chains, advanced simulation of modern Army platforms, and hands-on exposure with current sensory technology over the past nine months have informed these requirement recommendations. Developing the Kill Chain of Next Generation Combat Vehicles to meet these requirements will fulfill the modernization needs of the Army.

7. References

Alderman, Ray. (2017). Shrinking the Kill Chain. Retrieved from: mil-embedded.com/guest-blogs/shrinking-the-kill-chain/

CODAN. Why HF Radio?. Retrieved from: https://www.codanradio.com/about-codan-radio/why-hf-radio//white-papers/ground-combat-systems--common-vehicle-electronics-architecture-and-application.html

Marcone, Rock. (2019, March 29). Personal Interview. Executive of General Dynamics. Detroit, MI.

Milley, Mark GEN. (2017, October 3). *Modernization Principles for the United States Army*. 1-2.

NGCV Cross Functional Team. (2018). The U.S. Army Robotic and Autonomous Systems Strategy (USARASS).

Parnell, Gregory S., Driscoll, Patrick J., & Henderson, Dale L., (2011). *Decision Making in Systems Engineering and Management*: 2nd Edition. Wiley & Sons Inc. Hoboken, New Jersey.

Peck, Jamie 1SG. (2019, March 25). Personal Subject Matter Expert Interview (Master Gunner). West Point, NY.

Wallace, Cory MAJ. (2018). Information Paper: *Robotic Combat Vehicle Genealogy*. 1-2.

Wallace, Cory MAJ. (2019). Personal Interview. Client Meeting. Detroit, MI.