# Protecting American Soldiers: The Development, Testing, and Fielding of the Enhanced Combat Helmet (ECH)

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## Current Situation, Summer 2013

**Monday Morning Project Management Office Staff Meeting:**

Chief Engineer, Project Office: "Sir, we have an Enhanced Combat Helmet (ECH) update. We just learned that Director, Operational Test & Evaluation sent Congress the ECH "Beyond Low Rate Initial Production Report," and recommended that the Army not buy or field the helmet. The report says the unit cost is too high and that soldiers wearing the ECH would have an unacceptably high risk of dying from excessive backface transient deformation from threat bullets."

Project Manager:[1] "Hmmm . . . that puts us right in the middle between the warfighters and the operational testers. Both Army senior leaders and Congress rely on the independent assessment of operational testers for good reasons. They have a lot of influence."

Chief Engineer: "Yes sir. Also, the testers received concurrence from the Army Surgeon General with their assessments and recommendations."

Project Manager: "So, after a four-year joint development and testing effort with the Marine Corps in which the ECH finally passed its requirements, now we have to get an Army decision on whether to buy and field the helmet against the recommendations of the testing and medical communities, who have legitimate safety concerns?"

Chief Engineer: "Yes sir. The warfighters and Army combat developers have been very involved in this effort, and they remain adamant that the ECH should be fielded to deploying soldiers. The requirement remains over 35,000 helmets. The Marine Corps is strongly in favor of buying and fielding the helmet as well."

[1]Within the U.S. Defense Acquisition, a project manager (usually a U.S. Army officer in the rank of colonel) reports to a politically appointed civilian called the Army Acquisition Executive—the ultimate program decision authority. The Director, Operational Test & Evaluation (DOT&E) is an independent, politically appointed, senior executive charged with overseeing operational live fire testing and reporting directly to the Secretary of Defense and Congress on program testing.

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Project Manager: "What's the funding situation?"

Chief Engineer: "We have over US$35 million in operations and maintenance funding reserved for the buy that must be obligated by the end of the September or the Army will lose the funding."

Project Manager: "Okay. Well, you know the drill. The operational testers probably already have the ear of the boss—the Army Acquisition Executive, who is the decision authority because the ECH was a wartime directed requirement with high visibility. Let's get together a solid briefing to review, and let's start scheduling the pre-briefs. Also, we need to be prepared to provide the congressional committees an update with the Army's decision. There are many stakeholders involved with the ECH, and some will not be happy. So, we need to think about how this will play out with the media and senior leaders from all the stakeholders with a solid strategic communications plan."

## Background

The protection of American soldiers in combat was a top priority for senior leaders in the U.S. Army, Defense Department, and Congress. The Defense Department committed considerable resources and funding over the years in research and development, resulting in advanced materials and manufacturing processes. These investments paid off. American soldiers went into battle with technologically advanced, rigorously tested combat equipment. Soldiers knew that their combat equipment worked as intended. In the end, that increased the combat effectiveness of the soldiers and their units. The force protection of soldiers was considered as a layered approach. The outer force protection layer for soldiers was situational awareness. The middle force protection layer was concealment. The inner force protection layer was personal protective equipment, like helmets, eyewear, and ballistic vests with ceramic plate inserts. Specifically, combat helmets provided soldiers skull and brain protection against both ballistic threats (e.g., bullets) and blunt impact forces, and prevented mild traumatic brain injury and concussions.

During the wars in Iraq and Afghanistan, the Army collected battle-damaged helmets to better understand the threat and capabilities of the helmets. The battle-damaged helmets were often later returned to soldiers in ceremonies

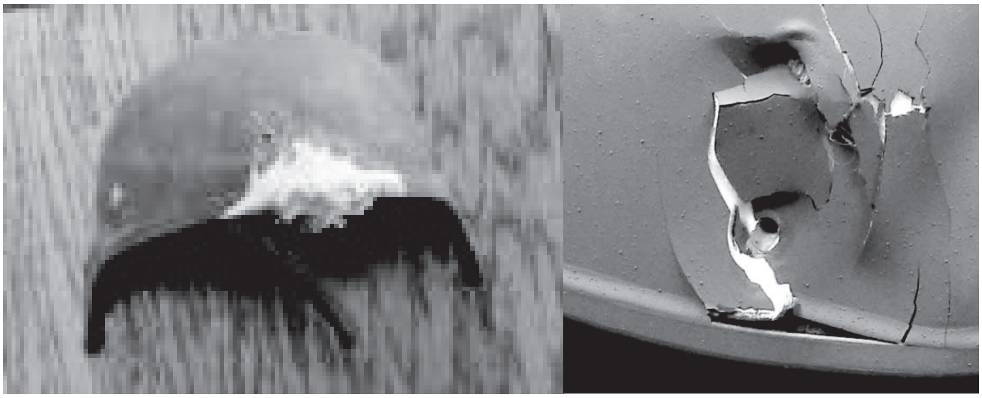


**Figure 1: Why were stakeholders so passionate about helmets?** The photo on the right was a photo taken by the Army of a battle-damaged helmet returned to a soldier in a ceremony at Fort Belvoir in 2016. In news coverage entitled **"U.S. Army soldier reunited with equipment that saved his life in Afghanistan,"** the reporter covered the soldier's description of how his helmet saved his life. The photo on the left was another photo taken of a recovered helmet damaged by enemy fire in Afghanistan.

as shown and described in Figure 1. In many situations, the helmets saved the soldier lives, and these ceremonies underscored the importance of soldier protective equipment for combat effectiveness and soldier force protection.

Despite an emphasis on improving force protection, efforts to modernize helmets faced the challenges that all programs within the Department of Defense faced: a complex, bureaucratic Defense Acquisition institution.[2] The accelerated pace of technology innovation, rapidly evolving threats, and declining defense budgets made program management within the DoD challenging but even more critical than ever. Defense Acquisition operated in an uncertain, complex, and ambiguous environment, but maintained a simple focus: develop, procure, and field advanced warfighting capability to soldiers to enable technological superiority on the modern battlefield.

### *Army Combat Helmet Evolution*

Army combat helmets evolved over time as the Army traded-off increased performance and cost (see Figure 2). The combat helmets that soldiers wore into battle showed a constant improvement in performance and increase in cost over time. Improvement in performance resulted from advances in material research and manufacturing techniques. Soldiers wore the M1 helmet, nicknamed the "steel pot," from the 1940s through the late 1970s. The M1 provided ballistic protection largely because steel is hard. The M1 helmet consisted of a pressed manganese steel shell with a webbing suspension that soldiers fitted to their heads. Despite being an improvement over previous helmets, the M1 helmet was heavy and uncomfortable, and it provided little blunt trauma protection.

Advances in material research provided the opportunity to increase ballistic protection at a reduced weight. The maturation of ballistic fabrics based on para-aramid polymer technology enabled the Army to replace the M1 with the Personnel Armor System for Ground Troops (PASGT) helmet in the mid-1980s. These helmets were in the three to four pound range (lighter than the M1) and provided increased ballistic protection. The shell of the helmet consisted of layers of ballistic aramid fabric, the most famous of which is DuPont's Kevlar®—resulting in the "Kevlar" or "K-pot" nicknames. The ballistic aramid technology allowed helmets to provide not only fragmentation protection from explosions but also small caliber hand gun protection at a reasonable weight. Eventually, the Modular Integrated Communication Helmet replaced the PASGT helmet on a limited basis. By the mid-2000s, the Advanced Combat Helmet was the Army's primary helmet. The basis for all combat helmets after the M1 "steel pot" and prior to 2008 was para-aramid polymer technology. These helmets provided soldiers important performance improvements like increased ballistic protection, reduced weight, and better blunt impact protection by replacing webbing suspension systems with padding systems between the helmet shell and the wearer's head.

In the late 1990s and early 2000s, the U.S. Army Research Lab, the U.S. Army Research Development and Engineering Command, and commercial industry teamed to mature the next generation of ballistics materials, resulting in the development of high-molecular-weight polyethylene ballistics fibers that could be weaved into fabrics with application to combat helmets. Polyethylene polymer materials had different performance characteristics than para-aramid polymer materials. Above certain temperatures, para-aramids (classified as thermosets) polymers broke down, lost their properties, and could

[2]Refer to Figure 4 and Appendix 1 for a description of the U.S. Defense Department Acquisition institution.

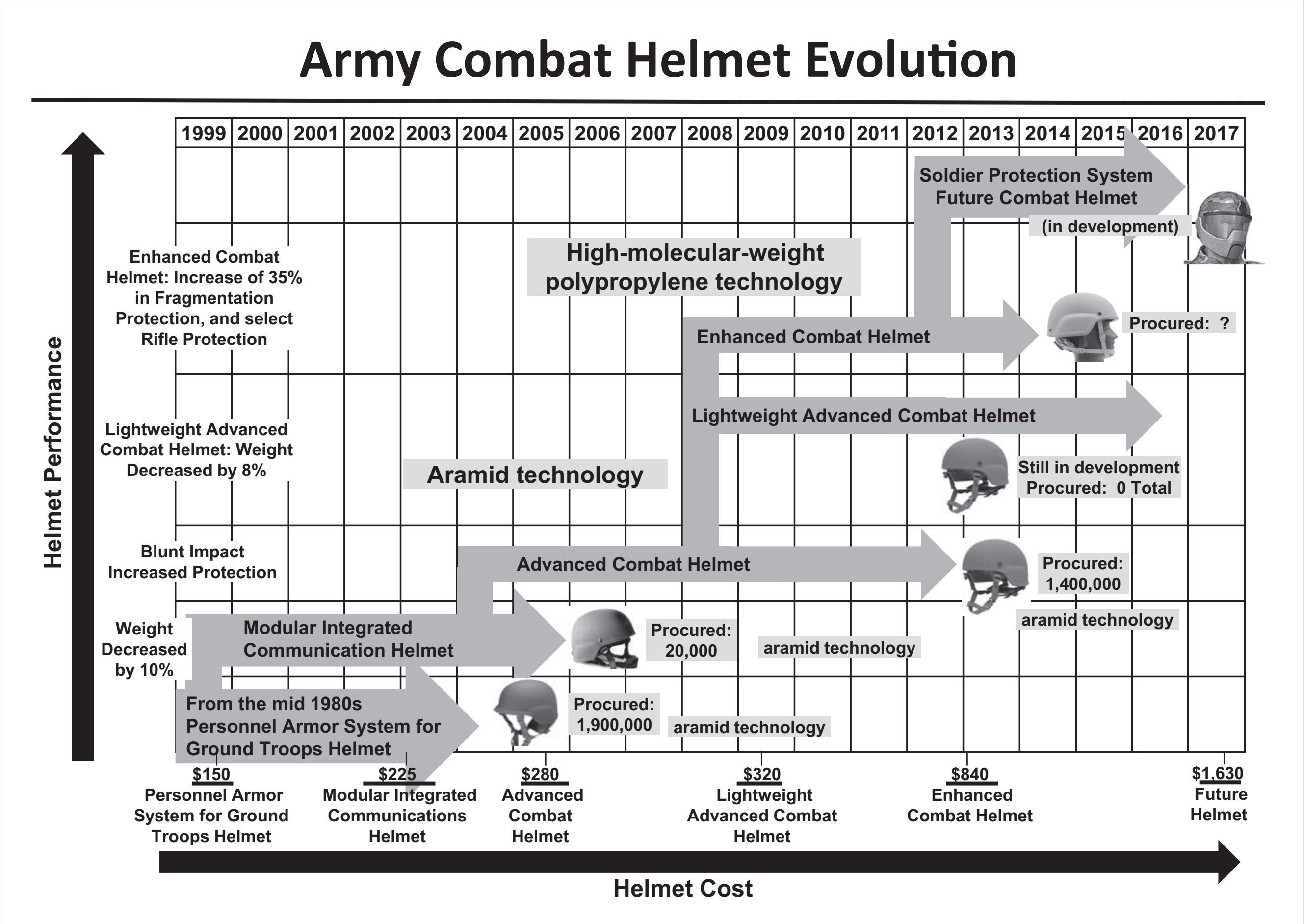



**Figure 2:** The evolution of combat helmets.

not be remolded back into their original states when cooled. On the other hand, above certain temperatures, polyethylene polymers (classified as thermoplastics) broke down but could be remolded into their original state when cooled. The application of high-molecular-weight polyethylene fiber material in helmets created the misperception that helmets might easily lose their form under ballistic events and potentially jeopardize soldiers' safety. Ultimately, the advantages of polyethylene helmets for reduced weight and greater ballistic capability outweighed this concern. The basis of future Army helmets—both the ECH and its eventual replacement, the Soldier Protection System future combat helmet—remained high-molecular-weight polyethylene technology.

### *Helmet Testing Basics*[3]

The Army rigorously tested combat helmets worn by soldiers against protocols to ensure they conform to stringent requirements to protect soldiers against both blunt trauma and ballistic threats. Three ballistic properties remained particularly important for describing impacts to helmets: complete penetration (the bullets goes completely through the helmet), partial penetration (the bullet does not go completely through the helmet), and backface deformation (a measure for the amount the round's impact indents the helmet material).

The final performance of the helmet in testing and in combat depended both on the inherent properties of the materials used to develop the helmet and the processing techniques used to manufacture the helmet. Helmet requirements used performance-based requirements. Each helmet manufacturer optimized its design over time using a combination of materials (layers of polymer fibers woven into sheets with chemical binders) and different processes based on temperature, pressure, and time. The use of statistics was important in testing because testing simulates live combat, and the warfighter required a high confidence that the

[3]Appendix 2 presents a tutorial on helmet testing.

helmets performed as advertised. The testing balanced the need for statistical confidence with the costly and destructive nature of the testing.

#### *Operational Field Data*

As was presented previously, the Army collected battle-damaged helmets from soldiers. Before returning them, the Army conducted forensic studies to better understand enemy threats and analyzed the performance of the helmets to improve future designs. From combat operations in Iraq and Afghanistan, the Army collected 77 helmets hit by small arms bullets. When the bullet completely penetrated the helmet, the soldiers died nearly 75% of the time. When the bullets did not completely penetrate the helmet (partial penetration), the average permanent helmet deformation was about 9 mm and the soldiers all survived with relatively minor head/neck injuries and eventually returned to duty.

## Part One: Project Initiation Decision, Early 2009 Timeframe

Colonel Bob Smith[4] was recently assigned as the Project Manager, Soldier Protection and Individual Equipment—the office responsible for developing, testing, procuring, and fielding helmets to soldiers. Colonel Smith was a seasoned defense acquisition veteran with over 15 years of project management experience. During his preparation for this position, the guidance from the warfighting community and senior leaders was clear: the top priorities were maximum protection and weight reduction.

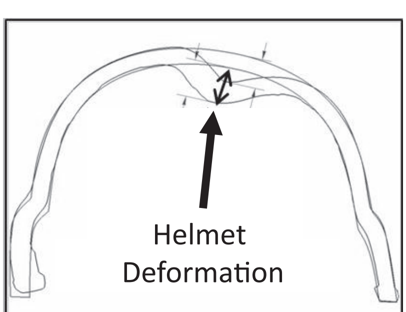
Colonel Smith was preparing for a key decision in the Pentagon regarding the start of a new helmet program, named the Enhanced Combat Helmet (ECH). Luckily, Colonel Smith's chief engineer for the program office was an armor expert, Dr. James Suchez. Dr. Suchez led the efforts to mature high-molecular-weight polyethylene technologies across the DoD

# Recovered Battle Damaged Helmet Data

- **77 Helmets collected:**
  - All resulting from Small Arms Fire
  - 31 engagements resulted in wounded-in-action soldiers
  - 45 engagements resulted in killed-in-action soldiers

| Ballistic Results | Total # | Wounded-in-Action | Killed-in-Action | Fatality % |
|---|---|---|---|---|
| Partial Penetration | 16 | 16 | 0 | 0% |
| Complete Penetration | 61 | 15 | 45 | 73.7% |

- Analysis:
  - **If a helmet stopped the bullets, the soldier had a very high probability for survival**
  - 0% fatality rate for partial penetrations
  - For partial penetrations, no serious behind helmet blunt trauma reported and no serious neck injuries reported
  - 73.7% fatality rate for complete penetrations




| Helmet Deformation (mm) | Ballistic Result | Injury Summary |
|---|---|---|
| 4.29 | Partial Penetration | Ranged from no injuries to minor injuries and eventual returned-to-duty |
| 1.52 | Partial Penetration | |
| 15.61 | Partial Penetration | |
| 15.25 | Complete Penetration | |
| 2.07 | Partial Penetration | |
| 0.48 | Partial Penetration | |
| 10.34 | Complete Penetration | |
| 1.42 | Partial Penetration | |
| 23.98 | Complete Penetration | |
| 5.32 | Partial Penetration | |
| 14.99 | Complete Penetration | |
| 13.68 | Complete Penetration | |
| 7.41 | Complete Penetration | |
| 9.66 | Complete Penetration | |
| 3.02 | Partial Penetration | |
| 15.99 | Complete Penetration | |
| 2.41 | Partial Penetration | |
| 3.53 | Partial Penetration | |
| 9.53 | Partial Penetration | |
| 15.78 | Complete Penetration | |
| 6.49 | Partial Penetration | |
| 11.04 | Complete Penetration | |
| 9.22 | Partial Penetration | |
| 10.12 | Partial Penetration | |
| 6.64 | Partial Penetration | |
| 17.22 | Complete Penetration | |
| 9.79 | Complete Penetration | |
| 13.93 | Complete Penetration | |
| 0.88 | Partial Penetration | |

Average helmet deformation depth = 9.02 mm

**Figure 3:** Recovered battle damaged helmet data.

[4]The names in this case are fictitious.

and with commercial industry for the last decade. Dr. Suchez explained that the application of these new novel polymers to helmets allowed the Army to consider the following basic options for the new helmet requirements: (1) maintain the protection levels of the current helmets with a reduced weight of up to 20%, or (2) increase the protection levels but maintain (or increase) the weight of the helmet.

Colonel Smith knew that the Army's senior leaders would rely on the advice and recommendations of the project manager during the meeting. The final decision would be made by the Army Acquisition Executive, the Honorable (Hon) Ron Cho. The Hon Cho would likely turn to key stakeholders before making the final decision.

The first stakeholder was the project manager, and Colonel Smith thought that he was well prepared to discuss key considerations from a cost, schedule, performance, and technology perspective. The second stakeholder was the warfighter representative, also called the "user" representative. The warfighter representative was a crusty old officer named Colonel Billy Johnson from Fort Benning, home of the U.S. Army Maneuver Center of Excellence. Colonel Johnson spent most of his time in the Army leading soldiers in combat. Colonel Johnson took his job seriously as the ultimate approver of the requirements. He was passionate about the possibility for a new helmet because he believed that the current helmets were too heavy and uncomfortable. He also represented the warfighters currently downrange in combat, and was under extreme pressure to approve requirements for a new helmet to protect soldiers not only against fragmentation and handgun rounds, but also against enemy rifle threats. Another key stakeholder was Colonel Harry Crisp, the representative from the testing community—specifically from the Director, Operational Test and Evaluation. Any new helmet development program fell under operational testing oversight to approve the testing protocols used to ensure the requirements were met. Director, Operational Test and Evaluation also provided an independent assessment of the helmet's operational effectiveness and suitability for soldiers to Army senior leaders and documented that assessment in reports to Congress. Colonel Harry Crisp had years of experience as a tester and evaluator of Army systems. The importance, influence, and visibility of operational tester's independent assessment were increased by the recent congressional and public concerns calling into question the adequacy of soldiers' protective equipment.

Colonel Smith knew that each of the stakeholders was passionate about a new helmet program. He realized that his role as the project manager was not to advocate for a new program but to give advice about the underpinning technological possibilities; additionally, he needed to lay out the cost, schedule, and performance implications of various strategies for the development, testing, and procurement of the new helmet.

Two important determinants of program success were requirements definition and alignment of those requirements against capability gaps. Simply put, poorly defined requirements set a project's initial trajectory that would be difficult to fix later in the development cycle. Project initiation was sometimes the result of a need from the warfighters generically called *capability pull*. Alternatively, a project resulted from an innovative new technology without a specific identified warfighting application generically called *technology push*. The question of technology push or capability pull at program initiation often delayed efforts and created perception challenges among key stakeholders. The ECH effort was driven by the urgent need for a new helmet to address protection for soldiers against rifle threats in combat, and enabled by the maturation of high-molecular-weight polyethylene technologies. The helmet requirements had to balance acceptable minimum risk versus maximum safety for protective equipment, and weight reduction (soldier load) versus protection (ballistic and blunt force). Colonel Smith knew that this balance would not be an easy compromise for any of the stakeholders.

During the meeting hosted by the Hon Cho, Colonel Johnson was adamant that the ECH had to address the rifle threat, be fielded as quickly as possible, and reduce the weight on soldiers in combat. Colonel Smith laid out the basic options that he had discussed with Dr. Suchez; the ECH would not be able the address the rifle threat and also reduce the helmet weight. Colonel Johnson was not happy, and doubted the validity of the technology assessment. He stated that, just a week prior, he received an industry brief from a company that claimed they could develop a helmet at reduced weights that also addressed increased threats. Dr. Suchez, also in attendance, spoke up and said that it was not unusual for industry to make claims that they could not back up, and that the application of a new technology into helmets is technically challenging from a manufacturing perspective. "It's one thing to produce a prototype helmet in a controlled laboratory," he said, "but completely different to produce many helmets from a manufacturing line that consistently perform against rigorous testing requirements."

To address the schedule aspect of the program, Colonel Smith next laid out the options of pursuing a formal program of record through the deliberate acquisition process versus pursuing a rapid acquisition process supported by a directed or urgent requirement. Establishing a formal ECH program involved a four-year time period of contracting, development, and testing. Year one allowed for the refinement, analysis, and approval of formal requirement documents and the development of testing protocols. Year one also allowed for the Army to request development and procurement funding from Congress in the Army's base budget for the program. Years two and three involved the development and testing of helmet prototypes resulting from competitively awarded contracts (cost-plus type contracts) to be awarded to industry companies. Year four allowed for the Army to award procurement contracts to the successful companies for the manufacture and production of helmets. Again, Colonel Johnson was not happy that it would take four years to get the new helmet to soldiers. The alternative to a program of record was to use the rapid acquisition process. In rapid acquisition, the Army wrote a directed requirement (within a month) for the ECH, and the Army awarded competitive contracts (fixed-price contracts for certain quantities with production options) to industry within six months. A rapid acquisition effort could be funded with money from overseas contingency operations accounts (separate from the Army's base budget approved by Congress), which was limited to procurement money and no development money. Another six months would be required to test the helmets. So, ECHs could be on soldiers in just over a year. Colonel Johnson was much happier with the second strategy. Colonel Crisp was quick to point out that for the rapid acquisition options, the new helmet's requirements would not be underpinned by analysis, and the test protocols had to rely on the protocols for current helmets because there would be no time to develop test protocols specifically for the ECH. Colonel Crisp noted this was particularly important for the ECH, which would rely on thermoplastic polymers. A helmet based on polyethylenes might perform much differently than the current para-aramid based helmets. For example, ECHs had the potential to lose their rigidity after being shot once and offered much less protection from multiple shots. Also, the ECH may deform excessively, leading to head trauma and skull fractures. There were legitimate testing and safety concerns that would have to be addressed.

Colonel Smith tried to remain neutral. Both strategies had advantages and disadvantages. Decision making involved defining and analyzing alternative approaches and came down to the level of risk the Army was willing to accept. The ECH project initiation decision also encompassed setting future funding levels and procurement quantities, as well as addressing industrial base concerns, competition, and testing implications. From past experience, Colonel Smith understood that stakeholder management was key to the success of the ECH program and that proper communication and collaboration increased the chances of program success.

The Hon Cho was pleased with the frank dialog between the key stakeholders and stated that enough information was presented for an informed decision on whether or not to initiate the ECH program. Before prioritizing resources for the ECH program, the ECH had to be considered through the lens of the Defense Acquisition institutional framework (see Figure 4). The project manager had cost, schedule, and performance responsibilities, and managed the effort with the Defense Acquisition Management System. The project manager's official chain of command was in the executive branch, but the project manager also reported to Congress with program status updates and worked through contracts with industry. The requirements generation system provided requirements and the resource allocation system provided funding. Depending on the program, the public and media perceptions became important considerations.

The warfighters in combat wanted a new lighter helmet that also protected soldiers against rifle bullets—soldiers were dying in combat. Colonel Smith knew that the Hon Cho wanted a follow-up meeting with him before deciding what the Army should do. He gathered his thoughts and wrote down what he thought were the key questions he had to consider:

- Who are the key stakeholders in the ECH program initiation decision and how does he manage their expectations?
- Would the ECH program be considered a "technology push" or "capability pull" program, and what are the implications?
- How should the ECH requirements be set? Should increased protection or weight reduction be emphasized?
- What is the right balance between reductions of soldier load (combat weight) versus greater soldier protection?
- How does the Army set testing protocols for the ECH prior to development and manufacturing of a helmet based on a new technology?
- What are the advantages and disadvantages of various acquisition approaches for the development, testing, procurement, and fielding of the ECH? What are the criteria used to compare the alternative approaches?

## The ECH Program

The ECH program began in early 2009 (as shown in Figure 5). The Army and the U.S. Marine Corps approved urgent requirements based on combat operations and the need for increased protection against enemy rifle threats. The overseas contingency operations account funded the ECH program. The acquisition procurement objectives were set based on the predicted numbers of deploying soldiers. The Army set broad requirements to include a 35% increase in fragmentation protection, increased 9-mm pistol protection, and rifle threat protection—all at the same weight of the current Advanced Combat Helmet. The acquisition strategy was a single step development in which competition was encouraged among industry manufacturers. The original request for proposal asked for each vendor to deliver test data validating their claim that their design met the combat helmet test protocols used at the time and the new ECH requirements for rifle protection. Four vendors submitted proposals; however, only one vender's design was acceptable. At the end of 2009, this vendor received a contract to produce ECHs to undergo government developmental testing with contract options for production deliveries after successful first article tests. In late 2010, after successful developmental testing, the Army approved the program milestone to enter into low rate initial production with the selected vendor. The decision permitted


**Figure 4:** U.S. Defense Acquisition Institution.

the production of a small number of helmets to undergo testing in order to validate that the contractor could successfully produce the helmets to performance requirements.

In late 2011, the ECH passed the second round of first article testing. To meet an aggressive production schedule for the Army, the vendor submitted an engineering change proposal for second and third production lines. It took all of 2012 for the vendor to successfully pass the third round of first article testing for all three production lines after working through issues between test sites, the U.S. Army Test Center, and the National Institute Justice laboratories, as well as issues with the source of testing rifle rounds (Winchester versus Hornady versus Remington).

The testing results demonstrated that the ECH met its requirements and offered soldiers the potential for greater protection compared to the current helmet. Against a requirement for a 35% increase in fragmentation protection, the ECH demonstrated an average increase of 53%. For the 9-mm pistol deformation requirements, the ECH demonstrated an average increase in performance of 10% over the current helmet. Finally, against the chosen test rifle threat, the ECH demonstrated an over 153% increase in protection for resistance to penetration; of note, was the fact that there was no backface deformation requirement against rifle threats for the ECH. The current helmet 9-mm pistol backface deformation requirements were too restrictive for rifle threats, and there

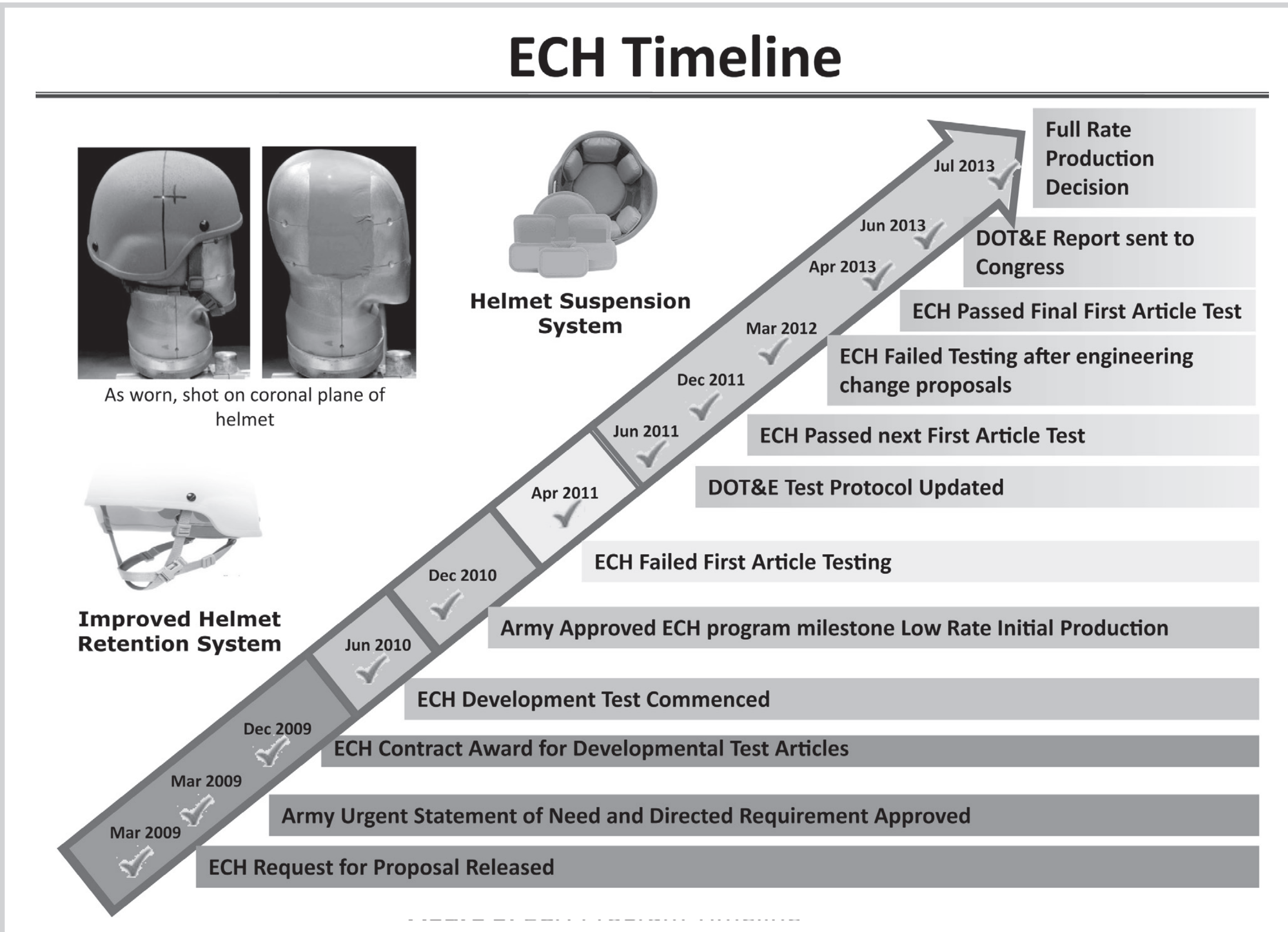



**Figure 5:** ECH program timeline.

was no basis to assign these requirements to rifle threats without injury data, which did not exist. To avoid jeopardizing the program due to unachievable or unrealistic requirements, rifle backface deformation testing occurred for government reference purposes only.

## Part Two: ECH Procurement and Fielding Decision, Summer of 2013

After passing testing and four years since program initiation, in the summer of 2013, the ECH was ready for a full rate production decision. Subsequently, the ECH would be produced as quickly as possible to the approved acquisition objective quantity. Each production lot of helmets would undergo lot acceptance testing to verify continued compliance to specification requirements. Finally, after passing lot acceptance testing, the Army could field helmets to soldiers deploying into combat.

The full rate production decision involved significant procurement money (US$35 million) to buy and field the ECH. Despite testing results in which the ECH demonstrated superior performance against the requirements over current helmets, Army leaders, specifically the Hon Cho and Colonel Smith, faced a difficult decision. Not all key stakeholders interpreted the test results similarly, raising significant concerns about the safety of soldiers who might wear the ECH in combat. The Director, Operational Test & Evaluation issued a congressionally mandated "Beyond Low Rate Initial Production Report" recommending that the ECH not be fielded to soldiers. The operational testers believed that the cost per helmet (roughly 2.5 times the current helmet) did not justify the minimal performance increase, and were also concerned that the Army did not test the ECH against the most stressing or most prevalent enemy rifle threats. Additionally, and more importantly, the testers stated that soldiers wearing the ECH in combat would face an unacceptable risk of head injuries due to excessive backface deformation caused by rifle rounds. The medical community, through the Army Surgeon General, supported the Director, Operational Test & Evaluation conclusions that ECH would put soldiers in unacceptable risk of head injuries. These concerns put the Hon Cho and Colonel Smith in a difficult position. To further complicate matters, the Hon Cho had just spoken to the Director, Operational Test & Evaluation, who emphatically stood behind their recommendation.

Again, the Hon Cho convened the same Council of Colonels that met four years earlier to discuss the decision to initiate the ECH program. Colonel Smith admitted the ECH program had not met the original timelines, but emphasized that the helmet had finally successfully passed testing and met its performance requirements. Colonel Smith also stressed that US$35 million was at risk if the procurement decision passed the end of the fiscal year, which was nearing. Colonel Crisp noted that he understood the program history well and understood the challenges. He reiterated that, in operational testers' opinion, the ECH was not operationally effective or operationally suitable for fielding to soldiers. The risk of injury to soldiers was unacceptable; in the testers' and the Army Surgeon General's opinions, soldiers wearing the ECH could suffer life-threatening skull fractures from excessive backface deformation from threat rifle rounds. Additionally, Colonel Crisp noted that the ECH was not tested against the most stressing threats, bringing into question the validity of the requirements. Colonel Johnson was livid that there was even a question about the requirements. The entire community and all stakeholders had agreed to the original requirements more than four years earlier. Everyone had accepted the program risks. Now, three years later than planned, when the ECH finally passed testing, concerns were raised. Colonel Johnson stated that the warfighter community strongly recommended getting the ECH to soldiers as quickly as possible.

Colonel Smith again tried to remain neutral to avoid the appearance that the project manager was biased toward buying the ECH. He was compelled to provide the complete picture to the Hon Cho for the most informed decision. His program office was also charged with the collection and analysis of battle-damaged helmets from soldiers who had been shot in the head while wearing their helmets. Analysis of those helmets indicated that no soldiers had died or suffered major injuries as a result of excessive backface deformation of the helmet. The average deformation observed was 35% of the 9-mm pistol requirement of 25.4 mm (or coincidentally, exactly 1 inch). Colonel Crisp interrupted and stated that the operational testers placed no value on the results because they were not statistically robust, and were not done under strict testing conditions where the variables were controlled. Colonel Crisp also pointed out that the government's own reference testing indicated that the backface deformation observed from the test rifle threat was 18% to 89% higher than the 9-mm pistol requirement. Colonel Smith concurred with those numbers but indicated that he was not finished presenting the rest of the field data results, which indicated that nearly 74% of soldiers died if the threat round completely penetrated the helmet. Again, Colonel Crisp dismissed that data, and again brought up the rifle threat round used in testing. Colonel Johnson asked a question about the operational safety margin built into the testing. Colonel Smith replied in the affirmative that the chosen rifle round was fired at the ECH at muzzle velocity and at 0% obliquity, operationally providing soldiers a safety margin, because in combat, rounds are fired at considerable distance, slowing down in flight and striking at non-direct angles. Therefore, even though the chosen test round was not the most stressing rifle threat round, the ECH still provided considerable protection and 153% more protection from penetration than the current helmet against the rifle threat.

The Hon Cho realized that the meeting of the Council of Colonels was probably at a point of agreeing to disagree. He understood each of the positions clearly and thanked everyone for their candid and articulate input. Colonel Smith understood well what that meant. Again, he had to recommend a path forward for decision with the major stakeholders not on the same page. Colonel Smith wrote the following questions that he knew he would have to address with Hon Cho before any decision was made:

- Who were the key stakeholders and how would he manage their expectations?
- How does the Army balance the importance of development test data versus field data from helmets that were battle damaged? Should developmental test results or field data carry more weight in decision making? How can the same development test data be interpreted differently by stakeholders?
- Are the concerns of the testing and medical communities warranted?
- How does the Army address these concerns with Congress, the media, and the American public?
- What are the advantages, disadvantages, and second order implications of various courses of actions for the path forward? What are the decision criteria?
- How do you quantify benefits such as saving a soldier's life and compare these benefits with long-term, potential health problems like concussions or musculoskeletal neck injuries from the weight of helmets?

## Suggested Readings

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**Program Manager Soldier Protection and Individual Equipment, Program Executive Office Soldier. (2002, October).** *Ballistic testing basics* [PowerPoint presentation]. Fort Belvoir, VA: James Q. Zheng.

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## Appendix 1: U.S. Defense Acquisition Institution—Decision Framework

Within the U.S. Defense Department, the development, testing, procurement, and fielding of capability for the warfighter operates within a decision-making framework that is complex. Within the private sector, similar frameworks exist. The U.S. Defense Acquisition Institution has three fundamental support templates that provide requirements, funding, and management constraints. The Executive Branch, Congress, and Industry work together to deliver capability with the program manager as the central person responsible for cost, schedule, and performance. Figure 6 depicts this framework.

The government project manager is at the center of Defense Acquisition, which aims to deliver warfighter capability. The project manager is responsible for cost, schedule, and performance (commonly referred to as the "triple constraint") of assigned projects—usually combat systems within the Defense Department. The Executive branch of government provides the project manager a formal chain of command in the DoD. The project manager typically reports directly to a program executive officer, who reports to the Service Acquisition Executive (an Assistant Secretary for that Service—either Army, Navy, or Air Force), who reports to the Defense Acquisition Executive (the Under Secretary of Defense for Acquisition, Technology, and Logistics). Depending on the program's visibility, importance, and/or funding levels, the program decision-making authority is assigned to the appropriate level of the chain of command.

Programs within Defense Acquisition require resources (for funding) and contracts (for execution of work) with industry. Congress provides the resources for the Defense programs through the annual enactment of the Defense Authorization and Appropriation Acts, which become law and statutory requirements. The project manager, through warranted contracting officers governed by the Federal Acquisition Regulations, enters contracts with private companies within the Defense industry. Other important stakeholders include actual warfighters, the American public, the media, and functional experts (like engineers, testers, logisticians, cost estimators, etc.), as well as fiscal and regulatory lawyers.

As a backdrop to this complicated organizational structure for Defense project managers, there are three decision-making support templates: one for the generation of requirements, a second for the management of program milestones, and a third for the allocation of resources. Each of these decision support systems is fundamentally driven by different and often contradictory factors. The requirement generation system is driven primarily by a combination of capability needs and an adaptive, evolving threat. The resource allocation system is calendar-driven by Congress writing an appropriation bill—providing control of funding to the Congress and transparency to the American public and media for taxpayer money. The Defense Acquisition Management System is event driven by milestones based on commercial industry best practices of knowledge points and off-ramps supported by the design, development, and testing of the systems as technology matures. Often integration and manufacturing challenges occur.

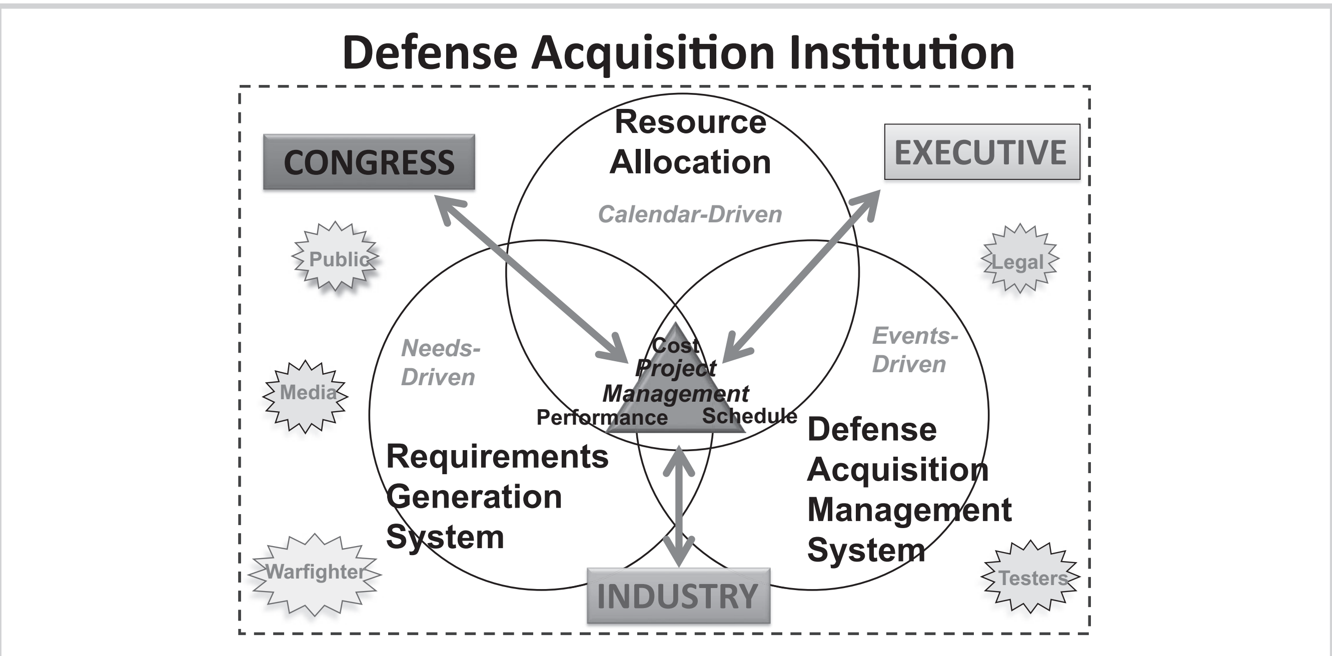


**Figure 6:** Defense Acquisition Institution.

## Appendix 2: Helmet Testing Basics

The Army rigorously tests combat helmets worn by soldiers against protocols to ensure they conform to stringent requirements to protect soldiers against both blunt trauma and ballistic threats. Typical battlefield ballistic threats include fragments from explosive devices, and bullets from handguns and rifles. Within the Department of Defense, System Threat Assessment Reports document relevant and existing helmet threats and these threats are validated by the National Ground Intelligence Center. With respect to fragmentation, the Army Research Laboratory proved that five fragment simulators represent 95% of the range of threat fragments soldiers expect to face from exploding munitions. Fragment threats used in testing include the 2, 4, 16, and 64 grain right circular cylinders, as well as 17 grain fragment simulating projectile. Handgun threats include the 9-mm full metal jacket 124 grain, 0.357 Sig full metal jacket 125 grain, and the 44 Mag 240 grain. These threats are defined by the National Institute of Justice (NIJ). Rifle threats include eight different rounds to include 5.45-mm, 5.56-mm, and 7.62-mm rounds (both armor piercing and non-armor piercing varieties).

Helmet testing is a form of destructive testing because the helmets are non-recoverable after the testing. Generally, testing can focus on physical properties (like density or melting point), mechanical properties (like tensile strength or impact strength), and ballistic properties. Three ballistic properties particularly important for helmets are complete penetration (the bullets goes completely through the helmet), partial penetration (the bullet does not go completely through the helmet), and backface transient deformation (a measure for the amount the round's impact indents the helmet material).

Depending on the materials selected and the manufacturing process, each helmet will demonstrate a ballistic testing curve, represented in Figure 7. The frequency of complete penetration can be plotted against the striking velocity of the round. A striking velocity of $V_0$ is the highest velocity at which no rounds completely penetrate the helmet shell. A striking velocity of $V_{100}$ is the velocity at which all rounds completely penetrate the helmet shell. The $V_{50}$ striking velocity represents the velocity at which 50% of the rounds completely penetrate and 50% partially penetrate the helmet. Figure 7 labels the zones of variation and non-variation. The variation zone represents a performance area for the helmet in which the helmet may provide the different levels of protection but demonstrate the same $V_0$ and $V_{100}$ characteristics.

$V_0$ is the "protection parameter" because it identifies the warfighter's guaranteed protection level. It is an important parameter in production quality and control; however, it does not completely measure material performance and depends greatly on the production process. Generally, helmet manufacturers want to make the actual $V_0$ demonstrated by a helmet higher than the $V_0$ required to ensure a helmet passes testing (see Figure 8). $V_{50}$ is the "material parameter" because it does not represent a guaranteed level of protection but is important in the optimization of the helmet design. There is

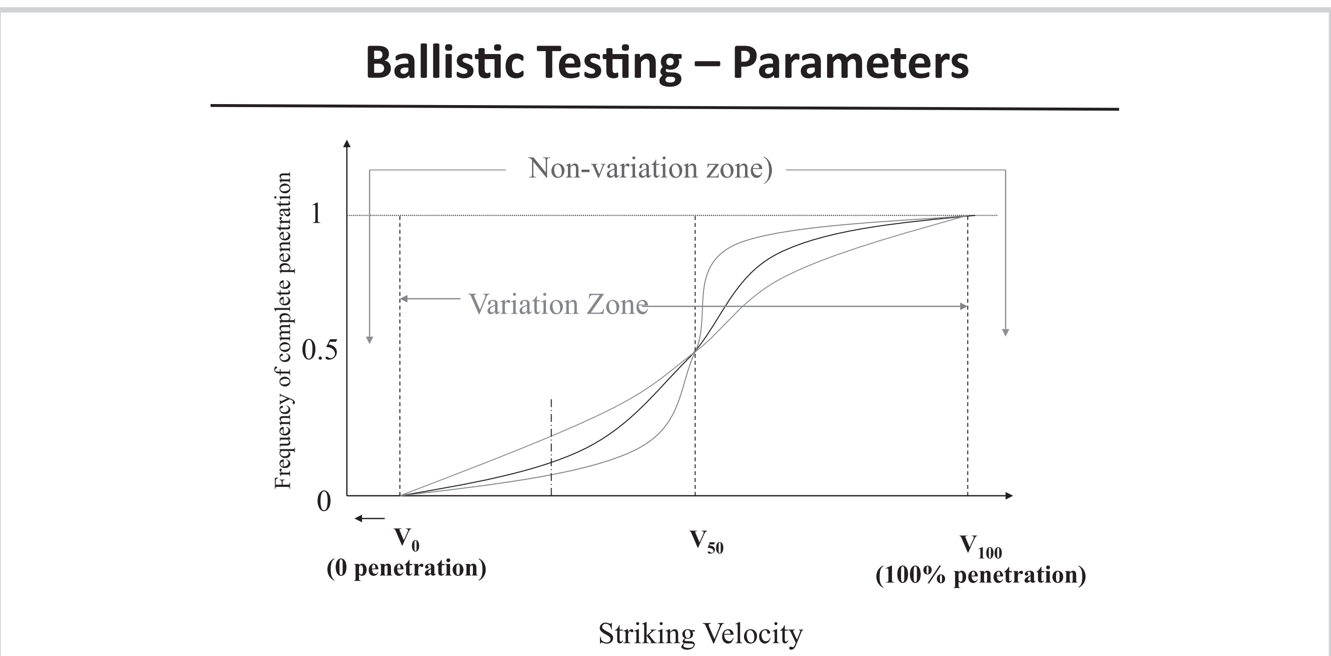


**Figure 7:** Ballistic helmet testing—Penetration.

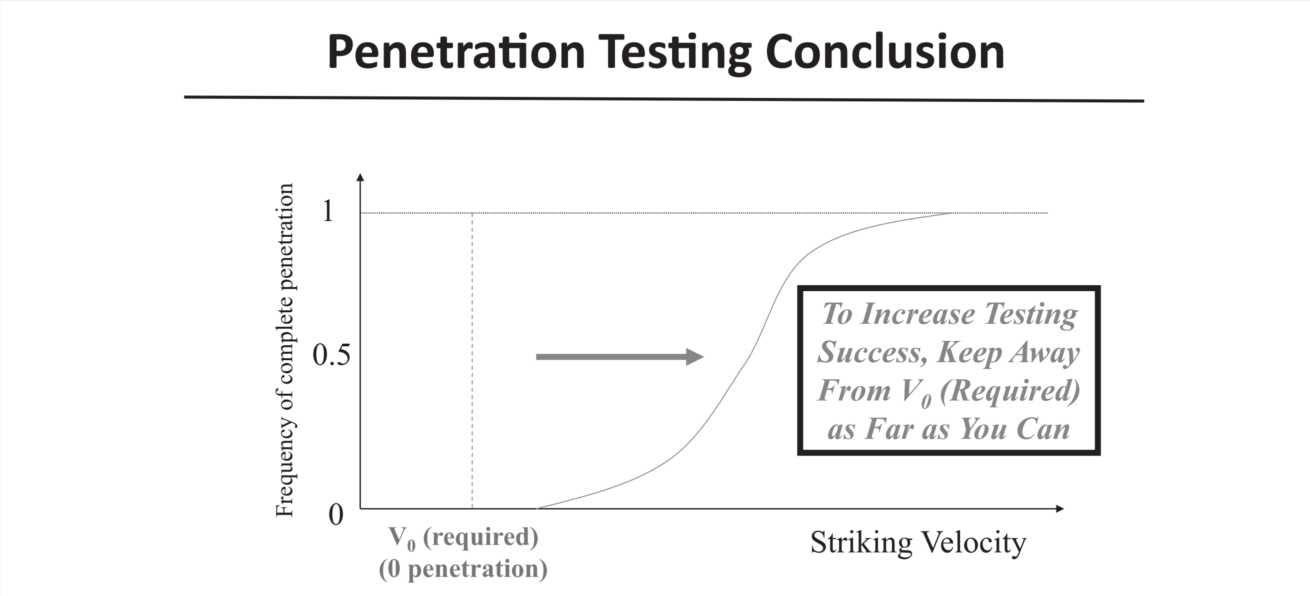


**Figure 8:** Penetration testing conclusion.

a unique $V_{50}$ for each helmet design. Generally, the design goal is to make $V_{50}$ as high as possible and as close to $V_{100}$ as possible.

During ballistic testing, if a bullet only partially penetrates the helmet, testers measure the backface deformation using calipers or laser techniques. The lower the deformation exhibited by a helmet in testing, the lower the potential for injuries to the wearer's head. Figure 9 is a pictorial representation of a sample backface deformation measurement. After a series of tests, testers plot the observed backface deformations for a helmet. This results in a distribution of values around an average value (Figure 10). The lower the average measured backface

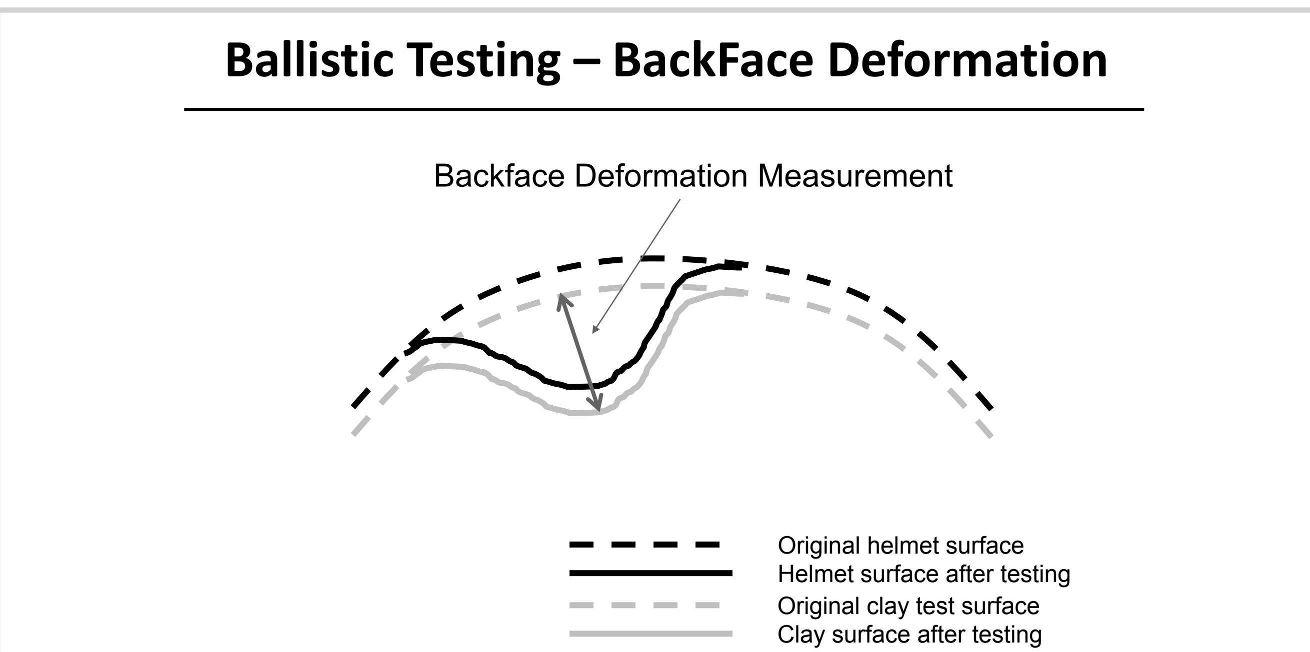


**Figure 9:** Ballistic testing—Backface deformation.

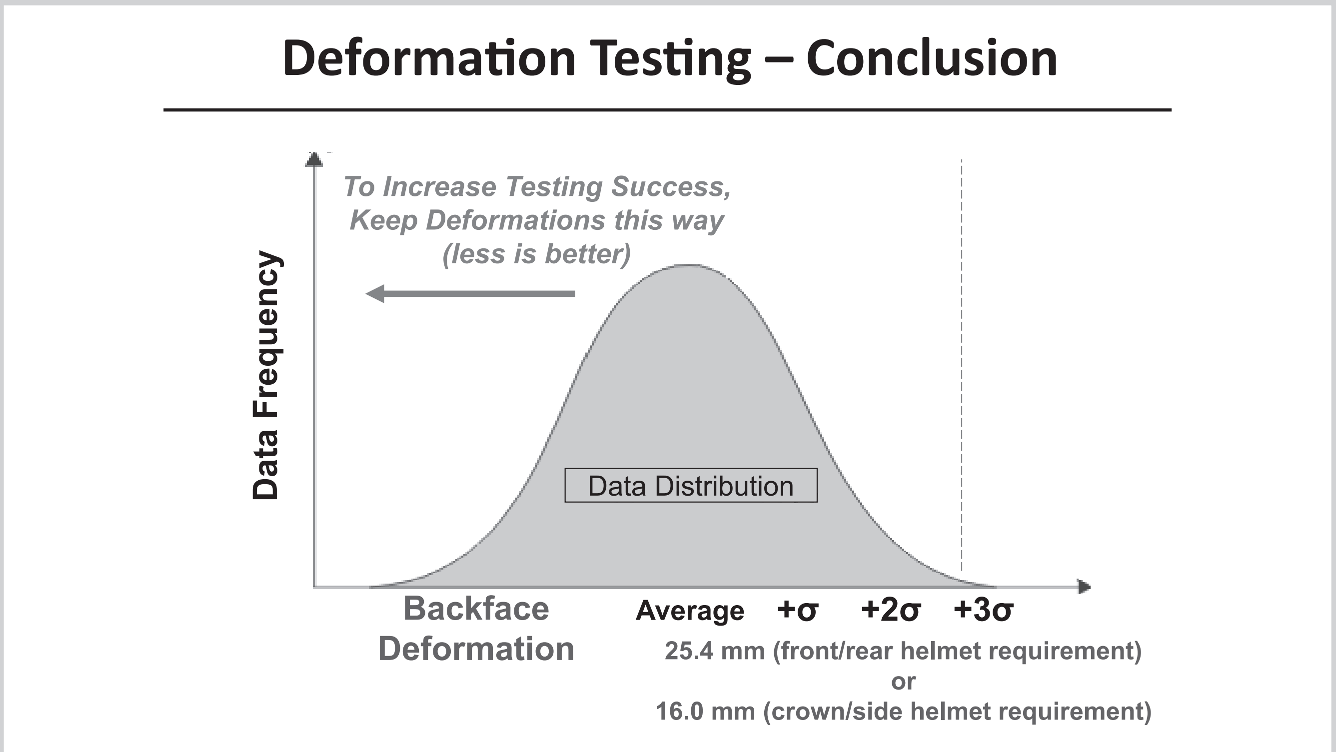


**Figure 10:** Deformation testing—Conclusion.

deformation compared to the required value, the more protection the helmets offers and the greater the testing success rate for the design and manufacturer (see Figure 10).

There is an additional important point to understand about helmet testing with respect to battlefield operational relevance. In testing, the Army performs $V_0$ resistance to penetration and backface deformation testing with the threat rounds fired at the helmet at speeds representing threat weapon muzzle velocity and at angles of 0% obliquity. This represents a worst-case condition that is representative of extremely close combat scenarios. Under these conditions, the round strikes the helmet with the maximum force and the highest chance for penetration, but during combat, the enemy fires at various distances from their targets. Over these distances, bullets slow down and strike their intended targets at various angles. Therefore, in combat, bullets strike soldier helmets at speeds significantly lower than muzzle velocity speeds and from non-perpendicular angles.