CHAPTER 16

Personnel Survivability Methodology

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16.1 INTRODUCTION

Survivability is the ability to exist and function through and after exposure to hostile situations or environments. This can apply to both personnel and equipment. With personnel survivability, the application is focused on the human. In the civilian sector, a realistic example would be living through an automobile collision even though the participants may have received major injuries. In the military sector, survivability can be illustrated in many different ways, from living through pitched battles on land, on and under the sea, and in the air to exploring hostile regions of the world. While survivability is an issue for the system designer in both civilian and military environments, this chapter concentrates on the military environment because of its critical need to include survivability in designing of equipment and training personnel and the existence of formal survivability analysis programs within the U.S. Department of Defense (DoD) that are not present in civilian environments.

16.1.1 Definitions

Within the DoD, *Mandatory Procedures for Major Defense Acquisition Programs (MDAP) and Major Automated Information System (MAIS) Acquisition Programs* (U.S. Department of Defense, 1999, p. 6-F-2) defines survivability as "the capability of a system and crew to avoid or withstand man-made hostile environments without suffering an abortive impairment of its ability to accomplish its designated mission." The army defines the characteristics for survivability more specifically in both system and personnel terms:

- *System* *Survivability of Army Personnel and Materiel* (U.S. Army, 1995) states it as "the characteristics of a system that can reduce fratricide, as well as reduce detectability, prevent attack if detected, prevent damage if attacked, minimize medical injury if wounded or otherwise injured, and reduce physical and mental fatigue." (p. 7)

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- *Personnel Survivability of Army Personnel and Materiel*, (U.S. Army, 1995) states it as "those characteristics of humans that enable them to withstand (or avoid) adverse military action or the effects of natural phenomena that would result in the loss of capability to continue effective performance of the prescribed mission." (p. 7)

16.1.2 MANPRINT Domain

The U.S. Army established 'soldier survivability' (SSv) as the seventh domain of its Manpower and Personnel Integration (MANPRINT) program in 1994 (see U.S. Army. 1994). As an institutionalized concept, the U.S. Army SSv program is referred to extensively throughout the chapter since the U.S. Navy, U.S. Air Force, and U.S. Marine Corps do not yet have a specific, cohesive area of human systems integration (HSI) for personnel survivability coverage. However, examples from each of the services and civilian life are used frequently to show the universal applicability of incorporating personnel survivability into equipment design and strategies for system operational utilization.

The military personnel survivability domain is built around the following six components:

- Reduce fratricide.
- Reduce detectability.
- Reduce probability of being attacked.
- Reduce damage.
- Minimize injury.
- Reduce mental and physical fatigue.

In the personnel survivability domain, it is assumed the warfighter is integral with his or her equipment during combat. Damage to that equipment or improperly functioning component due to an enemy or fratricide action may endanger the warfighters' well-being and place them immediately into a life-threatening situation. The effects on the equipment are then evaluated to determine the potential further effects on the personnel manning the specific system. Although personnel and equipment appear to be separate areas in the real world, they both fight together as a single intertwined unit, and reality dictates that they be evaluated together.

Fratricide is the unforeseen and unintentional death or injury of personnel (and of damaged and destroyed equipment systems) resulting from friendly forces employment of weapons and munitions. Personnel systems and weapons systems should contain improved antifratricide systems, such as identification of friend or foe (IFF) and situational awareness (SA) systems.

Reducing detectability considers a number of issues to minimize and possibly eliminate detectability of friendly personnel and equipment by confounding visual, acoustic, electromagnetic, infrared/thermal, and radar signatures and methods that may be utilized by enemy equipment and personnel. Methods of reducing detectability could include camouflage, low-observable technology, smoke, countermeasures, signature distortion, training, and/or doctrine.

Reducing probability of attack concentrates on a number of issues revolving around two primary concepts: (1) avoiding the appearance of similarity to a high-value target and (2) actively preventing or deterring attack. For a hardware system or personnel manning the system, these issues can range from determining whether there are warning sensors to assessing the ability to deflect attack by use of active countermeasures.

Reducing damage if attacked addresses many issues to answer the following concerns: (1) the system's ability to protect the operator(s) or crew member(s) from attacking weapons, (2) the effects of the methods and tactics of the system's field operation on the system's and unit's survivability, (3) the system's ability to protect the crew from on-board equipment (e.g., fuel, munitions, etc.) hazards in the event of an attack, and (4) the system's ability to minimize the risk to supporting personnel if the system is attacked. Subject matter experts (SMEs) in areas such as nuclear, biological, and chemical (NBC) warfare, ballistics, electronic warfare (EW), directed energy, medical treatment, human factors, and information assurance can add additional issues.

Minimizing injury explores (1) combat enemy weapon-caused injuries, (2) the system's potential sources and types of injury to both its crew and supported troops as it is used and maintained in the field, (3) the system's ability to prevent further injury to the fighter after being attacked, and (4) the system's ability to support treatment and evacuation of injured personnel. Combat-caused injuries or possible injuries are addressed in this portion of personnel survivability, along with the different perspectives on potential mechanisms for reducing damage.

Reducing physical and mental fatigue considers tasks that may have a direct bearing on the occurrence of combat-related mistakes. The primary thrust is reducing the complexity of combat-related or combat support tasks, where negative effects by operator error can be directly traced to fatigue. Associated human factors-related tasks need to be simple and not mentally fatiguing, knowing that stress and sleep deprivation make the mental processes for operating equipment increasingly difficult while mistakes in processing and judgment become more prolific.

16.2 PARAMETER ASSESSMENT LIST

When SSv was established in 1994, a parameter assessment list (PAL) (Tauson et al., 1995) was developed to provide a common tool for diverse individuals to perform SSv assessments. The PAL comprises approximately 170 different issues associated with soldier combat survival. Provision is made to maximize flexibility by allowing removal of those issues that do not apply to the particular program/project/product being assessed while providing for addition of other system-specific issues that may apply. The PAL was developed to aid a multidisciplinary approach using a number of subject matter authorities. A thorough understanding of SSv issues is necessary to do a competent job. The PAL can be used by the combat developer to construct a set of potential issues to be considered for inclusion in an operational requirements document.

When the SSv assessor is notified of a program start, the first step is to assign required system performance criteria for each issue. These criteria should result from consensus among the assessors, program manager (PM), proponent agency, and user community. Sources of required system performance levels may come from operational requirements documents, the system's concept of employment, and the evaluation of SMEs. Once required system performance levels are defined, they are compared to actual (testing, experimentation, technical analysis, etc.) system performance for each issue. Sources of information on system performance may include modeling output, performance from similar or predecessor systems, engineering plans, task analysis and crew workload data, and test data. In earlier milestones, this may constitute a best guess, with more substantive information becoming available later in the acquisition cycle.

The comparison of the required and the actual system performance leads to a rating for each issue. An issue may be assigned a deficiency rating of critical, major, minor, none, or does not apply. The rating is based on the magnitude of the difference between required and actual performance and the potential effect on injury to the soldier, mission completion, loss of the system, inability of the system to complete its mission, probability of occurrence, and unacceptable impact on other HSI domains.

The primary difference between personnel survivability and other HSI domains is that personnel survivability addresses issues involving enemy and friendly combat weapons-induced injuries and the inherent hazards to the human under threat/combat conditions. Under normal noncombat environment operating circumstances, some related issues would be considered in the human factors engineering, systems safety, and health hazards domains of HSI. When potential combat weapon-induced threat exposure is included, these issues are reevaluated differently as part of the survivability domain.

For the U.S. Army, the SSv assessment provides a service to the materiel and combat developers by providing an overall integrated technical review of the hardware/human system, the combat weapon-induced threat, the resulting program survivability issues, participation in resolving those issues, and technical support for milestone decisions. This SSv assessment assists in providing coverage and assurance that issues will be or are being addressed in such diverse areas as EW, NBC survivability, individual ballistic protection, directed-energy weapons, smoke/obscurants and atmospheric effects, physiological effects, and heat stress. Survivability work performed on a program can immediately be incorporated into addressing the SSv issues and efforts. The personnel survivability specialist can assist a program team in producing a survivability outline and strategy as well as creating developmental and operational test plans, live-fire test plans, and issues to be undertaken by threat working groups, while providing valuable information and insights for the combat developer.

16.3 SURVIVABILITY ANALYSIS PROCESS

Survivability analysis is a process that evaluates personnel susceptibility to attack and physical injury. It focuses on the effects of threats that might reduce the ability of a friendly system to complete its mission. Part of the survivability analysis determines if a potentially destructive matter (i.e., bullet, fragment, high-powered energy device, chemical/biological agent, environmental situation, etc.) can affect the system and to what extent. A survivability program and analysis should be established for every new equipment program that may be used in combat situations or indirectly affected by such effects.

A typical survivability analysis is diagrammed in Figure 16.1. The need for the system, its operational requirements and specifications, and types of missions are first reviewed. The combat or small-scale contingency threat(s) to the system are also reviewed. From this information, survivability system requirements are established. A complete understanding of the development through production hardware/human operator system is acquired, and the computerized target solid geometry of the system is prepared for simulation testing, if necessary. A susceptibility analysis is then performed to identify the inability of the system or its components to avoid the weapons (present, anticipated, potential, and creative usage) and other elements that make up the hostile environment (Ball, 1985). About the same

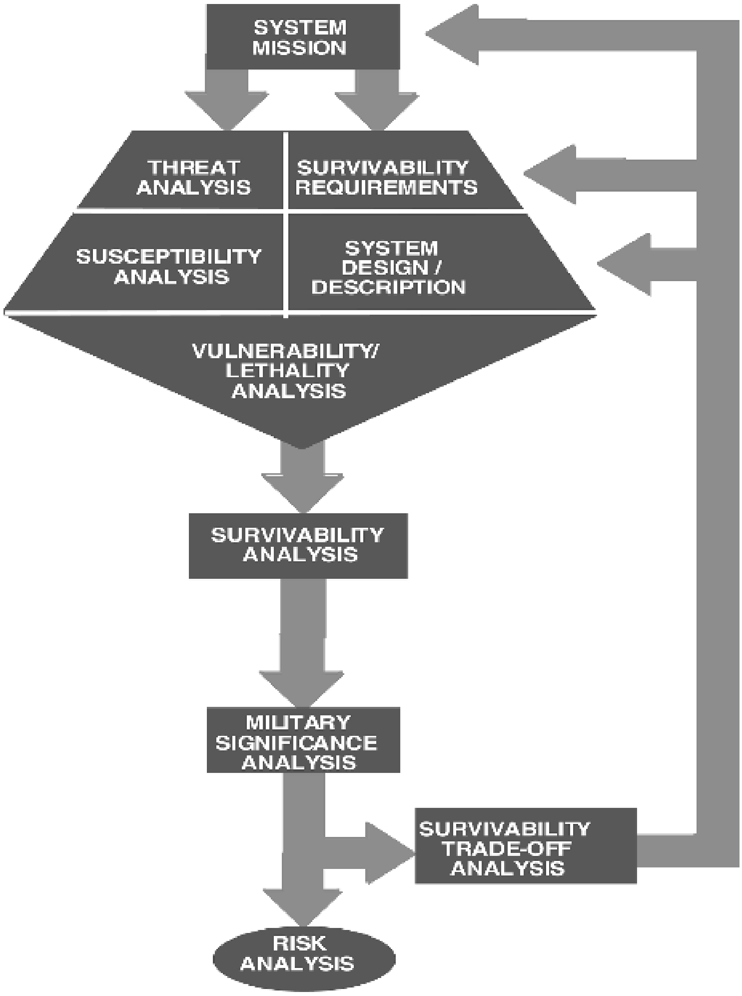

Figure 16.1 Survivability analysis process.

time a vulnerability/lethality analysis is performed to determine the inability of the system and components to avoid or withstand the damage caused by the hostile environment. The vulnerability and susceptibility analyses together examine the criticality of each component and the effect of any degradation of a component to the overall system as well as determine the degraded condition or remaining capabilities of the system after it is attacked. The basic data to conduct these analyses can be generated from a variety of sources to include computer models, laboratory, hardware-in-the-loop investigations, or field experiments.

The survivability analyst uses information from these previous analyses to assess the battle damage of components and the entire hardware/human system. Also essential in conducting a survivability analysis are studies of battle damage assessment and repair (BDAR) capabilities, spare-parts availability, and logistics support provided for that system. Survivability deficiencies must be determined not only on the basis of individual system but also on a more global perspective. This includes the effect of system degradation on the surrounding equipment and overall missions, whether it is a long-range reconnaissance mission or a full-scale battlefront.

No system can be made invulnerable to all threats. When survivability deficiencies are identified, a military significance analysis is conducted to determine whether these deficiencies are mission critical. If the deficiencies are mission critical, a trade-off analysis may be recommended to determine if they can be rectified by changing doctrine, tactics, training, introducing survivability enhancements, redesigning the basic system, or developing an entirely new system. The effectiveness of the various alternatives is analyzed. In other cases, where the cost to correct the survivability deficiency is unacceptably high, with respect to the level of operational effectiveness gained, the army may decide to accept the deficiencies. Therefore, the ultimate value of the survivability/lethality/ vulnerability analysis is that it provides decision makers with the quantified technical information to understand and effectively manage systems.

Survivability efforts in the acquisition process are the key to maintaining a fighting force's size and effectiveness when going from one combat mission to the next. Highly trained personnel are key to all manned weapon systems performing effectively. Improvements in combat capabilities will occur by improving/enhancing personnel survivability in two primary ways: (1) by designing and producing increasingly combat-effective systems for land, sea, and air operations and (2) by ensuring all weapon systems incorporate systems design characteristics to enhance personnel survivability. The survival of a soldier, sailor, marine, or airman and his or her equipment depends on the type of mission conducted, the amount of friendly support available, and the effectiveness of the hostile combat environment encountered.

To perform a thorough survivability analysis of both the hardware system and the personnel using that system, the interrelated considerations diagrammed in Figure 16.2 must be evaluated iteratively. For example, the type of military mission must first be selected and then one of the military and natural fighting environments must be determined. Knowing the mission and fighting environment, an analysis is then conducted to determine the likely physiological and psychological states of the warfighters as well as how well they will be protected. After that analysis, the same mission is performed with a different military and natural environment, physiological and psychological state of the personnel, and availability of the protective equipment. This iterative process is continued until all combinations are considered and analyzed. Although this seems like a daunting task, it is really not that difficult, because many of the considerations may not apply for each system. However, before discarding a consideration, a rationale to discard it must be developed. By doing this type of analysis on each human/hardware system, a thorough understanding of that system's capability, limitations, and survivability will be established. This will make it easier for the materiel developer and the combat user to understand the system's functional boundaries and limitations.

16.4 PERSONNEL SURVIVABILITY COMPONENTS

Each of the six focal components for the personnel survivability analysis will now be considered in more detail, in light of the iterative review process. Note that all six components are interlinked in the real world of survivability. For clarity, they have been separated artificially in a continuing time sequence. All the components are based on

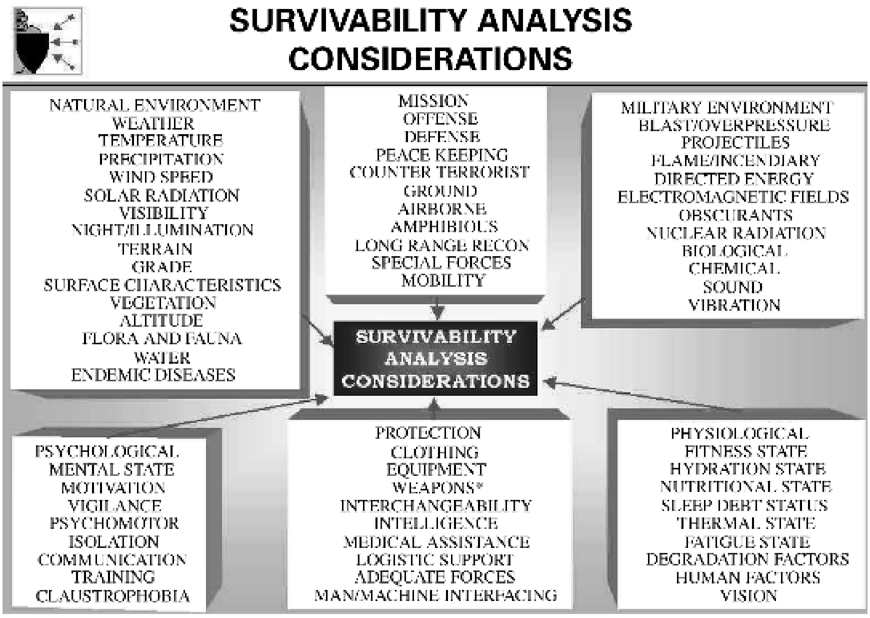

Figure 16.2 Survivability considerations.

avoidance or minimization of an event and the correcting activities if the avoidance activity fails.

16.4.1 Reduce Fratricide

Unfortunate as it is, fratricide does occur under the normally less-than-perfect conditions of combat. Example 16.1 illustrates some historic battles where fratricide events played significant roles.

Example 16.1 Fratricide in Historic Battles During the Battle of Waterloo, the late afternoon approach of the Prussian allies to link up with the Duke of Wellington's left wing resulted in fratricidal situations because the Dutch–Belgian forces could not be recognized. Having fought with the French forces under Napoleon until his abdication the year before, the Dutch–Belgians still retained their blue and white uniforms, which the Prussians incorrectly recognized as French. However, those Prussians that arrived slightly later in the same vicinity as the Scottish troops had no recognition problems when they saw the kilts, feather bonnets, and scarlet coats. Well-known incidents occurred during the Civil War when Confederate Lieutenant General (LTG) Thomas "Stonewall" Jackson was returning from a quick night reconnaissance on the Chancellorsville battlefield after collapsing the Federal army's right flank. Hand and arm wounds inflicted by his own troops forced him from the battle and eventually led to his death. A year later, Confederate LTG James Longstreet was similarly hit in the arm by Confederate soldiers during daylight while returning from a reconnaissance after successfully attacking on and rolling up the Federal army's left flank during the Battle of the Wilderness.

Numerous attempts have been made in this century to reduce the risk of fratricidal incidents as evidenced by the large national insignias on aircraft of the world wars, multicolor roundels on the wings and fuselages of the British, French, and American aircraft, and crosses on German aircraft. Other nationalities used various markings, such as the Poles with their four white and red alternating squares. One of the more memorable attempts at reducing fratricidal risk were the big black and white "invasion stripes" on allied aircraft for D-Day and beyond.

The 2 Percent Rate There have been several studies (Shrader, 1982; Dupuy, 1990) on casualties, with a commonly referred to 2 percent rate of fratricidal casualties compared to combat casualties. The following paragraph is intended to illustrate that fratricide can be a serious problem for the force strength overall. It is not intended to indicate what an "acceptable" percentage rate is for fratricidal casualties.

Although there was undoubtedly a great deal of research involved in arriving at the 2 percent figure, there is some question as to the accuracy of the data used. (See Example 16.2 for studies showing higher rates.) World War I is a good example since generally only the coarsest types of casualty information are reported and large portions of records were lost through time.

Example 16.2 Studies Showing Greater Than 2 percent Fratricide Rate An excellent article, entitled "Dealing Realistically with Fratricide," by Steinweg (1995) reveals some very detailed studies providing results at much different fratricidal rates. During World War II, battalion surgeon Captain James Hopkins of the 5307th Composite Unit (Merrill's Marauders) was interested in the effects of body armor and thus maintained very detailed records of wounds and interviews with patients, obtaining a figure of 14 percent of total casualties resulting from fratricide. For Vietnam, over 125 personnel were involved in a wounds data and munitions effectiveness team (WDMET). This team produced an evaluation of wounds data and munitions effectiveness in Vietnam from a 1967 to 1969 study of over 7800 casualties that showed fractricide accounting for 14 percent of total killed in action through rifle fire, 11 percent of total killed in action through fragments, and 11 percent of total wounded.

Five Fratricide Issues How does one apply "reduce fratricide" to personnel survivability? The PAL (Tauson et al., 1995) provides a list of fratricide-associated issues that serve as a guide in evaluating the equipment and the soldiers in this regard. Examples of some of these issues are as follows:

1. Is the related IFF or target identification system effective to ranges at least as long as the weapons' ranges?
2. Is the system's signature (visible, electromagnetic, etc.) similar to potential threat vehicles? Is the system compatible with IFF receiver or identifier systems, such as active (question-and-answer) IFF receivers?
3. Is the IFF system a noncooperative target recognition system (i.e., if an enemy tries to target you to find your position, does the system refuse to cooperate so as not to give any information to the enemy)?
4. Does the self-location equipment provide sufficient resolution to reduce fratricide?
5. Is the system's ability to distinguish between friendly and enemy targets compatible with mission-oriented protective posture level IV (MOPP IV) (NBC individual protective equipment) conditions?

Elaboration of these five issues provides insight into how vulnerable the warfighter may be to fratricidal incidents and will provide the impetus to raise and correct noted deficiencies.

The first issue concerning weapon range being greater than identification (ID) capability is a constant struggle. Most sights are currently not capable of providing enough detail of a potential target at a great enough range for a gunner to positively identify friend or foe. Moving close to a potential target to provide positive ID is normally out of the question in combat situations (see Example 16.3).

Example 16.3 The Chevron ("V") ID Sign The chevron, or V, used in Operation Desert Storm was an attempt at positive ID. (It could be applied in several ways: horizontally laying on its side, vertical, and up-side down.) But, if the chevron were not large enough or not made of the recommended material, it would be nearly impossible for the platform sight's pixels to pick up the sign and provide it to the gunner to positively identify. In addition, if a platform's chevron were on the sides of the platform but not on the front, there would be an angle of approach to the targeting sight where it would not be able to pick out the ID sign.

As for the weapon ranges, although the tank gunner's primary sights can pick out targets at long ranges, they cannot (by themselves) pick up enough identifying features to positively identify friend or foe at extended ranges, which are increasing rapidly. During Operation Desert Storm, an ABRAMS tank's 120-mm cannon scored a kill at 3.4 km (Carhart, 1994), well beyond normal long-range gunnery expectations, while during Britain's equivalent, Operation Desert Sabre, a CHALLENGER tank scored a kill even further, at 5.1 km (Houck, 1994).

For the second issue, a friendly weapons platform having a signature(s) similar to or identical to a potential enemy's platform signature(s) can place the friendly platform and its crew in danger due to chaotic imperfect conditions, round-the-clock operations, and aggressive friendly forces (see Example 16.4).

Example 16.4 Similar Tanks of Opposing Forces During Operation Desert Storm, the Syrian and Kuwaiti contingents of the coalition forces employed T-series (Syria, T-62's and T-72's; Kuwait, M-84 Yugoslav-built T-72-design tanks) (DeBay, 1991) main battle tanks that were practically identical to those of the opposing Iraqi forces. During the coalition drive into southern Kuwait, the Syrians were to be assigned to align between U.S. 2nd Marine Division on their right and the Egyptians and Kuwaitis on their left (U.S. News and World Report, 1992). After a number of tense and frustrating meetings between the U.S. Marines and Syrians about how the marines would recognize the Syrian T-62's and T-72's to be friendly forces, the Syrians "refused to assume their assigned position and had then moved west to follow the Egyptians and Kuwaitis into Kuwait." The marines' left flank was open throughout the ground war, although the army's 1st Cavalry Division's Tiger Brigade was caused to be assigned to strengthen the 2nd Marine Division's left flank due to this potential fratricidal situation. Here, even positive visual ID of the type of tank (T-62 or T-72 series) would still leave one wondering as to whether it is a friend or foe. Unfortunately, a "friend" firing at you while you hesitate to fire to get confirmation of friend or foe is still a dangerous situation, no matter how friendly the opponent may be in other circumstances.

The Desert Storm coverage and publicity via television coverage of fratricidal incidents—giving rise to the third and fourth issues—have provided impetus to the U.S. Army to develop IFF systems, similar in concept to those available to the U.S. Air Force and U.S. Navy. The difficult part will be designing these systems to be noncooperative with potential enemy detection systems and to maintain security on them. This can be a very tough proposition; for example, fighter pilots and helicopter pilots on covert missions would be reluctant to turn on an active IFF system that broadcast a "Here I am!" signal to the world. In addition, making an IFF system small and light enough to be carried by dismounted soldiers will be one of the ultimate design challenges.

The fifth issue on MOPP IV addresses one of the potentially most confusing and frightening scenarios, where a soldier, marine, or air police may undergo an NBC attack with smokes and obscurants with very limited visibility (it is worse at night). In a close-combat situation, the individual will potentially be faced with situations where any other individuals in their protective clothing must be immediately recognized. Limited visibility, increased personal stress, and heat retention are situations that will have to be addressed for successful combat and survival. If available, increased SA capability can help the individual with orientation, personal location, and locating friendly forces.

16.4.2 Reduce Detectability

Detectability is an important issue of survival during wartime. Reducing the range at which an enemy can finally detect an individual or weapon system often improves the chances of surviving an engagement or performing a mission. If a combat sniper's position is detected at long range, he or she is immediately placed in danger; therefore, snipers are taught carefully conceived camouflage and concealment techniques that require an enemy force to approach to within a very short distance before the sniper can be detected. The same is true for other platforms. The moment that a combat aircraft or ship is detected by an opposing force, the specific platform and its crew members are both immediately placed into a state of vastly increased danger.

Personnel survivability is a vital concern and must be addressed to reduce detectability for both personnel and weapon systems in a wartime setting. A weapons system's signature is a function of its inherent characteristics and/or its interaction with the physical environment. All weapons systems and personnel possess signatures in the visible part of the electromagnetic (EM) spectrum and emit and/or reflect EM radiation (see Fig. 16.3). To the extent that these emissions or reflections can be associated with the existence of and ID of the person or system, they are referred to as a "signature."

What issues can be directed at reducing signatures while simultaneously reducing detectability and the dangers associated with both? The SSv PAL lists 21 probable issues for army systems, and SMEs are likely to raise more issues depending on the system's characteristics. Issues that would have to be studied and addressed for either a helicopter or a dismounted soldier system include the following:

- Is the system likely to be detected by threat forces because of its visible static signature?
- Is the system likely to be detected by threat forces because of its thermal (infrared) signature?
- Is the system likely to be detected by threat forces because of its radio-frequency signature?
- Have any electro-optical or optical components on the system been hardened to reduce optical cross-sectional measurements that are the cause of wide-angle and at-range detection?

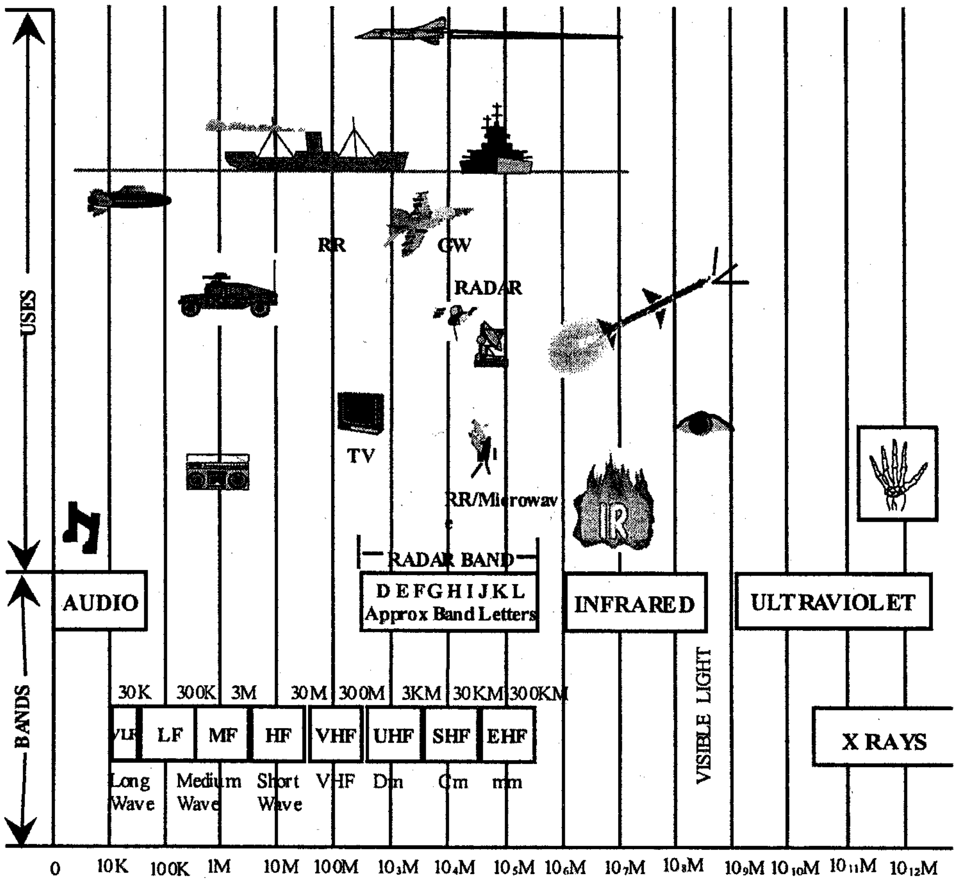

Figure 16.3 Electromagnetic spectrum and representative sources for specific signatures.

- Will threat forces' use of obscurants prevent the system from detecting approaching enemy systems?

Failure to knowingly address these and other issues during the acquisition process will probably cause combat danger to the weapon system and put the military personnel in or near the system in potentially mortal danger. Environmental effects such as the diurnal temperature cycle can make the difference whether the combatant will become a casualty (see Example 16.5).

Example 16.5 Diurnal Temperature Cycle The diurnal temperature cycle (U.S. Army Research Laboratory, 1999) was a topic of concern during Operation Desert Shield, with many military personnel concerned about the potential signatures of enemy forces and their equipment. The diurnal cycle is a daily cycle where twice during the day (see Fig. 16.4) objects that change temperatures faster than the background sand will become the same temperature as the sand for a short period of time. For example, a cool tank's temperature will rise in the morning and become hotter than the desert, and the tank will then cool down faster during evening than the sand so that it is colder at night. The difference in temperature is the method used in thermal sights to find targets. The danger for systems (i.e., tanks, helicopters,

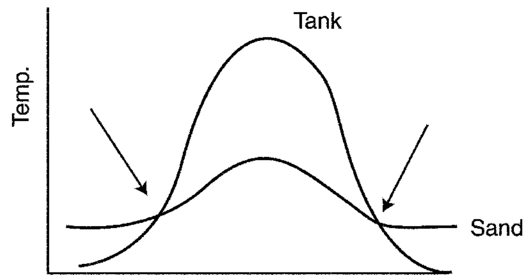

Figure 16.4 Desert ambient temperature cycle (imposed on generic tank signature to show points where vehicle can "disappear" for short periods of time during 24-hour day).

aircraft, etc.) using thermal sights in their fighting is that once in the morning and once in the late evening thermal sights will not be able to see an opposing tank because its temperature will be indistinguishable from the background sand and therefore "disappearing." The Battle of 73 Easting in Operation Desert Storm (Carhart, 1994) was affected by this phenomenon when the lead U.S. tanks crested a ridge and stopped because they could not see expected enemy forces. What they could see appeared to them as "bowling balls" in the distance. As the lead troop studied the bowling balls, and as the other tanks came up alongside their position, one of the bowling balls moved upward, revealing arms and a torso. With that signature identified, the guidance was given to aim below the enemy tank commander's thermal signatures given off by their heads and thus fire at what would be armored vehicles below. The U.S. forces could have been in mortal danger when they could not see the enemy force, but fortunately they found and used the unintended enemy signatures to their advantage. The diurnal cycle itself can vary with wind speed, temperature, relative humidity, and turbulence, but it can be determined and provided to those combatant forces who need to know when it will affect their gun sights.

Signatures Detection Technology Friendly weapons systems and military personnel throughout the combat theater will be subject to continuous enemy efforts to locate and identify them for deception, destruction, or avoidance. In this effort, the enemy will employ a variety of intelligence, surveillance, and reconnaissance (ISR) techniques, special operations forces teams, devices, and platforms oriented toward exploiting the signatures of individual weapons systems. (The dismounted soldier is now also being considered as a weapons system.) Acoustic, radar, sonar, infrared, and visual detection, tracking, and guidance devices are designed to sense EM radiation emitted or reflected from the system. Using counter-ISR means, such as camouflage, concealment, deception, and emission control, places an additional burden on soldiers and may reduce their operational effectiveness.

Detection avoidance includes technologies and methods used to suppress sights, sounds, and images associated with friendly weapons systems and military personnel. Suppressing these signatures, so that personnel and their weapon systems are indistinguishable from their background, provides the weapon systems with the ultimate advantages of battlefield surprise and protection. Making weapon systems harder to find increases their survivability. While some of the greatest gains in survivability may be achieved through detection avoidance technologies, they can sometimes be the most expensive to develop and integrate. Technology programs that apply to detection avoidance include acoustic, radar, seismic, thermal, and visual signature reduction and/or masking achieved by using advanced materials and coatings and materials that distort the apparent shape of the equipment.

Obscurants Adverse atmospheric and obscurant conditions (U.S. Army Research Laboratory, 1998) (see Fig. 16.5) can be valuable battlefield countermeasures for defeating or degrading threat detection, acquisition, tracking, and terminal guidance functions. Early knowledge concerning atmospheric and obscurant parameters in developing a weapon system can provide decisive advantages in that system's use. Similarly, studying threat systems' vulnerabilities to meteorological conditions and atmospherics can help defeat those threat systems.

Obscurant materials, ranging from visual to the far infrared, are a valuable battlefield countermeasure for defeating or degrading threat detection equipment. An atmospheric and obscurant analysis would include subanalyses such as the diurnal temperature cycle, far-infrared attenuation, and weather effects analysis.

16.4.3 Reduce Probability of Being Attacked

This section addresses hit avoidance and countermeasures instituted to frustrate an enemy attempt to attack friendly forces. It is generally accomplished by reducing opponent target acquisition and guidance systems' ranges of operation and sometimes is accomplished by intimidation. This is a critical area, as failure will likely increase the numbers of casualties. The SSv PAL lists 17 probable issues for army systems, and SMEs are likely to raise more issues depending on the system's characteristics. A few of the issues that would have to be studied and answered, whether for a helicopter or for a dismounted soldier system, are as follows:

- Is the system able to deflect attack by the use of electronic jamming or spoofing of a munition's sensors?
- Is the system able to deflect attack by the use of active ballistic interdiction to deflect or destroy incoming munitions?
- Has any microprocessor code on the system been protected from the presence or insertion of malicious code ("back-doors," viruses, etc.)?

Figure 16.5 Use of smoke/obscurants to hide battle field movement.

- Does the system present a unique or highly recognizable signature (visual, thermal, etc.)?

Hit Avoidance Hit avoidance refers to technologies that reduce the probability of being hit by a weapon after being detected by the enemy. Hit avoidance includes both avoiding acquisition and tracking by enemy fire control and avoiding being struck by enemy weapons that have been fired. Hit avoidance technologies protect with sensors and countermeasures. The sensors detect incoming threats, and the countermeasures confuse, physically disrupt, deflect, or destroy those incoming threats. Examples of hit avoidance technologies and doctrinal countermeasures are early warning systems, such as missile and radar warning receivers, smoke and obscurants, jammers (optics, laser, and radar), decoys (laser, flares, and chaff), rapid mobility, and counterfire.

Detection of Susceptibility System performance evaluators, decision makers, materiel and combat developers, and the eventual users of these systems benefit from knowing any limitations of these systems in degraded environments before they are fielded. Detecting susceptibilities early enables better management of a program and greatly reduces the risk of surprise findings in any developmental and operational testing or, more importantly, during actual combat. Proactively identifying potential counter-countermeasures that will negate or reduce these susceptibilities is also a benefit to these programs and to the combat forces that will use them.

The common infantryman's signature amid technology changes is an intriguing but easily understood example of reducing the probability of being attacked (see Example 16.6).

Example 16.6 Military Clothing and Equipment Concepts of military clothing and equipment have changed greatly over the last 100 years. During the Anglo-Boer War of 1899 to 1902, the British Army learned at great human expense the value of khaki-colored uniforms that allowed them to blend into the terrain. This was in stark contrast to the brilliant and colorful multicolor uniforms with shiny metal accoutrements that were the style used in most western armies of the time and up through the first months of World War I. During the Russo–Japanese War of 1904 to 1905, the Japanese Imperial Army (Burnett, 1913) learned the value of uniforms and equipment that would reduce acoustic noise down to almost nothing. This improvement in uniforms was especially effective for surprise when conducting mass night attacks against Russian positions and for the night "Banzai" attacks used later during World War II. The German Waffen SS and Wehrmacht units of World War II developed the flecks-of-spots (flecktern) camouflage patterns for battle-dress smocks and uniforms to help them blend in more with the surrounding terrain and growth during daylight. The starlight scopes of the U.S. forces in Vietnam started to take away the opportunity and advantage for infantry to close with an enemy without being detected during the dark of night. Image intensifiers and now thermal weapon sights are becoming prolific to the extent that the advantage of night movement, and even hiding under camouflage in daylight, is removed to some extent.

Electronic Warfare Successful EW is a carefully integrated program of actions and countermeasures. Reconnaissance, firepower, communications, signal intelligence, jamming, direction finding (DF), and deception elements can be used by an enemy to attack priority networks, nodes, and links to nullify, limit, or delay command, control, communication, and computer (C4) systems while protecting their own operational capability. Airborne, sea-based, and ground-based platforms can allow an enemy to intercept, locate, and jam tactical communications systems from the high-frequency (HF) to superhigh frequency (SHF) portions of the radio-frequency (RF) spectrum. The EW threat will continue to grow as technologies are employed to affect low probability of intercept.

Knowing the susceptibility and vulnerability of combat and combat support systems to the full spectrum of EW effects is critical to the survival of soldiers and to their ability to fight effectively on the battlefield.

16.4.4 Reduce Damage

The personnel vulnerability component of "reduce damage" is one area where the life and death of military personnel are most directly affected. This component recognizes the moment when an attack is made, and the last line of defense of system and operators' personal equipment must stand up to this attack. Complicating this realization is the fact that weapon overmatch of system defenses often occurs, and efforts to minimize or preclude injury are very important. In PAL for SSv, there are 33 listed potential issues. This is the area where SMEs are most likely to raise a large number of additional system-specific and threat-related issues affecting survival of the system and the military personnel operating it. Some issues are as follows:

- Does the system adequately protect the crew from direct- and indirect-fire munitions through the specific damage mechanism of spall?
- Does the system provide crew protection from secondary explosions of on-board munitions if the system is attacked, by means of separation of ammunition storage in a compartment isolated from the crew?
- Does the system provide adequate crew protection from directed-energy weapons such as lasers?
- Does the system provide adequate warning and protection for the crew in a chemically or biologically contaminated environment?
- Will the system be able to operate in the presence of external electromagnetic environmental effects without affecting crew members and other military personnel?

Ballistics Protection The ballistic impact of an overmatching munition of any type occasions significant effects behind the armor of a weapon system. If the projectile perforates, a residual of the penetrator or some portion of a shaped-charge jet (see Fig. 16.6) will exit behind the armor. Behind-armor debris (BAD) is then also generated. This may include residual penetrator pieces, armor plug, scab, small pieces of these objects if they break up, many armor fragments, and a fine spray of metallic particles referred to as spall. The result is the BAD cloud of fragments being projected forward at high speed, generation of blast overpressure, potential fire hazard, and combustion by-products, causing a great deal of damage and injury. In many cases, most of the lethality from a ballistic impact is caused by BAD. In addition to casualty-producing effects, debris often kills not only primary but redundant components and systems as well. A major success story has been the development of spall liners that are often attached to the interior walls of armored vehicles. These spall liners tremendously reduce the number and narrow the cone

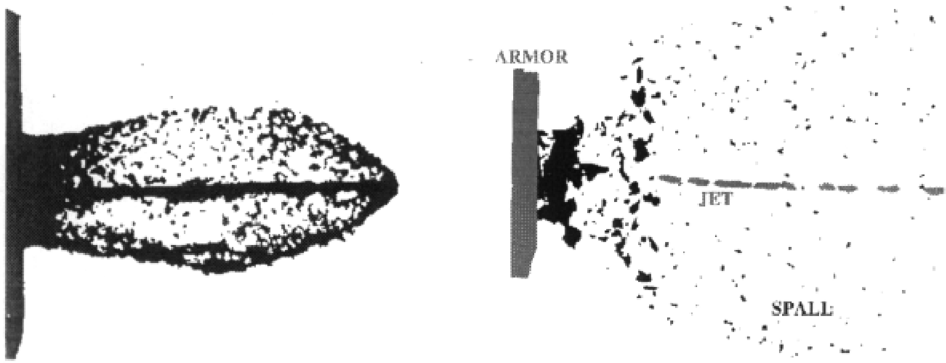

Figure 16.6 X-ray photographs of shaped-charge weapon's molten metal jet penetrating armor and propelling spall armor fragments at very high velocity into a vehicle interior.

angle of spall fragments that can harm both onboard operating personnel and materiel systems within the vehicle.

Federal law (U.S. Code, Title 10, Section 2366, n.d.) directs that military survivability testing shall begin at the component, subsystem, and subassembly level, culminating with tests of the complete major system or program, or major product improvement, configured for combat. This means that live-fire test and evaluation (LFTE) is really a process, rather than a discrete event. A major system, major munitions, a missile program, or a product improvement to any of these programs may not proceed beyond low-rate initial production (LRIP) until realistic survivability or lethality testing is completed, and the report required by statute is submitted to the prescribed congressional committees. *Realistic survivability testing* means testing for vulnerability of the system under combatlike conditions by firing various weapons and munitions.

Fully dressed and equipped mannequins representing soldiers are often placed in the LFTE systems to determine injuries. They are placed to measure stress and strain effects and to note injuries that may be inflicted upon crew members. If a test munition is anticipated to overmatch a platform's armor to penetrate into the crew compartment, the mannequins will be constructed of wooden forms to hold the soldier-worn equipment in proper locations. If the personal equipment and the mannequin are penetrated, the mannequin will then act as a "witness" for examination and analysis in showing the shot-lines of any munition, spall, and associated fragments that hit it.

Directed Energy Electronic equipment can be defeated or impaired by irradiation from directed-energy weapons (DEWs). Degradation can range from temporary upsets in electronics subsystems, permanent circuit deterioration, or permanent destruction due to burnout or electrical overload. Humans can be wounded, impaired, and, in extreme cases, killed by DEWs. These weapons produce casualties and upset or damage equipment by focusing energy on the target. The three principal divisions of DEWs include lasers (low and high energy), high power radio frequency (HPRF), and particle beams (charged and neutral).

- *Lasers* The presence of laser devices in the inventories of major armies is increasing, and any device, such as a target designator or a laser range finder, can be employed as a weapon if it is pointed at a target it can damage. In the near term, the most probable targets of laser weapons are electrical and electro-optical systems (specifically, fire control devices such as sights and the person behind the sights) and personnel. Most systems that contain optical components, including direct-view optics such as vision blocks, periscopes, laser protection goggles, and telescopes, along with cameras (television), laser range finders, image intensifiers, forward-looking infrared (FLIR) systems, trackers, or seekers are potentially susceptible to laser threats currently fielded or under development. At a minimum, protection of the soldier is required, and depending upon the particular system, hardening with regard to laser jamming susceptibility may be required for the system to pass a milestone III (production) decision.

- *Particle Beam* The particle beam weapon is the newest of the developing threats, using radiation in the form of accelerated subatomic particles focused on a target by magnetic fields. A particle beam weapon can inflict damage on a target by removal of material in the proximity of a hit, by detonation and ignition of explosives and fuel, or by radiation damage to vulnerable critical components.

Weapons of Mass Destruction Weapons of mass destruction are an increasing threat against the U.S. military and civilian population and institutions. DoD Directive 5000.1 (U.S. DoD, 1996), U.S. Army Regulation AR 70-75 (U.S. Army, 1995), and many requirements documents require PMs to make their systems NBC survivable. These documents include requirements for nuclear, biological, and chemical contamination survivability (NBCCS) and nuclear weapons effect (NWE) survivability.

NBC Contamination The NBCCS requirements encompass three areas: hardness, compatibility, and decontaminability. Hardness is defined as the ability of a system to withstand both an NBC attack and the decontamination process without mission-essential equipment functioning unacceptably or failing. Compatibility is the ability of equipment to be operable by personnel wearing NBC-protective clothing and equipment. Decontaminability is the ease and degree of ability to restore equipment to safe levels of cleanliness so that personnel may remove burdensome protective equipment without fear of ill health from residual agent effects. Incomplete NBCCS processing of the system may cause casualties at a later date when crew members or maintenance personnel are maintaining the system.

Nuclear Weapons Effects The NWEs (see Fig. 16.7) include blast (overpressure), thermal, electromagnetic pulse (EMP), and initial nuclear radiation (INR). An EMP is a secondary effect of a nuclear weapons detonation.

Initial nuclear radiation consists of both neutrons directly emitted from a nuclear detonation and ionizing radiation (rays) caused directly or indirectly by the nuclear detonation. The INR ends within seconds of the detonation and affects both personnel and equipment. For tactical situations (e.g., the effects of a nearby detonation on ground equipment), semiconductor parts can be upset or burned out, and optical materials can have a significant temporary or permanent change in optical properties.

The thermal pulse consists of visible, infrared, and ultraviolet radiation emitted from the fireball. Thermal radiation can cause severe burns and flash blindness to soldiers and can cause many effects on materials, including melting of material, charring of surface

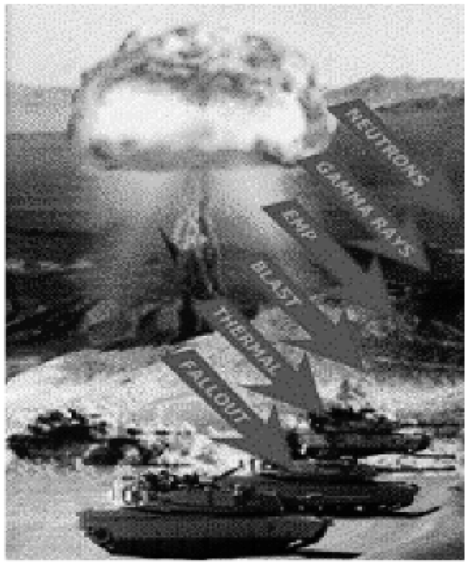

Figure 16.7 Nuclear weapons effects can damage/destroy systems in many ways.

coatings, ignition of materials, debonding of laminates, optical obscuration, and degradation of material properties.

Information Operations Information operations (IO) is defined as actions taken to achieve information superiority by affecting adversary information, information-based processes, information systems, and computer-based networks while defending friendly information, information-based processes, information systems, and computer-based networks (U.S. Army, 1999). The threats to the information infrastructure come from individuals and groups motivated by ego, curiosity, military, political, social, cultural, ethnic, religious, or personal or industrial gain. The information warfare (IW) threat focuses on intercepting, exploiting, corrupting, and/or destroying data in existing databases or data being exchanged between databases. Attacks can be designed with a delayed effect, such as corrupting a database or controlling program, as well as immediate actions to degrade or physically destroy. Examples include the following:

- unauthorized access to classified or sensitive military information;
- insertion of malicious software to cause a computer to operate in a manner other than that intended by its users (this category includes computer viruses, worms, logic bombs, and programs designed to bypass protective programs);
- corruption of data through use of malicious software or alteration of data;
- sowing disinformation;
- lengthening the command-decision cycle;
- misdirection of U.S. forces, weapons or sensors;
- delay or prevention of the development or deployment of military information systems;
- withholding battlefield or other situational information.

Electromagnetic Environmental Effects Electromagnetic environmental effects (E3) is a broad term used to define the general effects of several diverse EM phenomena. The E3 address the performance, safety, and reliability of a system to be stored, transported, and operated in an EM radiation environment without suffering any detrimental effect. The E3 encompass that portion of the EM spectrum from very low frequencies (VLF band) to extremely high frequencies (millimeter-wave band).

The E3 can range from simple static interference or upset to permanent damage or burnout of electronic components and possibly catastrophic system failure. Examples of different effects in a military environment that can be caused by undesired EM energy are as follows:

- temporary or permanent injury of personnel;
- corruption of stored computer instructions or data;
- performance degradation of receiver signal processing circuits;
- ignition of electrically initiated devices, flammable materials, or explosives;
- operation of electromechanical equipment, electronic circuits, or components; and
- burnout or voltage breakdown of electronic components, antennas, or circuit cards.

Example 16.7 illustrates the need for emphasis on E3.

Example 16.7 U.S.S. Forrestal Fire An example from military experience illustrates the need for emphasis on E3. This incident occurred aboard the aircraft carrier *USS Forrestal* (U.S.S. Forrestal Museum, Inc., n.d.) in 1967 (see Fig. 16.8). During rearm and refuel activity for a strike operation over Vietnam, a 5-inch-diameter Zuni missile mounted under the wing of an F-4 Phantom that was preparing to fly its second strike of the day was accidentally launched up-deck and struck and knocked off the fuel tank and a 1000-lb bomb of an A-4D Skyhawk. The ensuing fire and explosions of ordnance resulted in 134 dead, 27 aircraft destroyed, and over $70 million damage to the carrier. The accident investigation concluded that the inadvertent coupling of EM energy from either a ship-mounted transmitter or a power generator located next to the aircraft wing most likely caused the accident. This E3 accident remains today as the greatest single incident of loss of life in the U.S. Navy since World War II.

16.4.5 Minimize Injury

Medical injury is one of the major components affecting the probability of survival. Figure 16.9 shows the percentage of wound cases and their anatomical distribution for some major wars fought in the twentieth century. Fragmentation and bullets accounted for 85 percent of the wound cases. These wounds were generally received in the upper body regions (upper extremities, head and neck, and chest and abdomen). The greatest percentage of wounds in a single region was inflicted in the lower extremities. The type of mission and the prevailing equipment used dictated the susceptibility of wound location. During the trench warfare activities of World War I, soldiers standing in those trenches exposed the head and neck, upper torso, and upper extremities to rifle fire and artillery fragmentation barrages. The only protection provided for an infantryman was a thin steel helmet that did not always stop a bullet or fragment. During the Vietnam War, most of the soldiers in the field were issued torso-covering body armor that provided good protection

Figure 16.8 Fire aboard the carrier *U.S.S. Forrestal* resulting from an E3 incident.

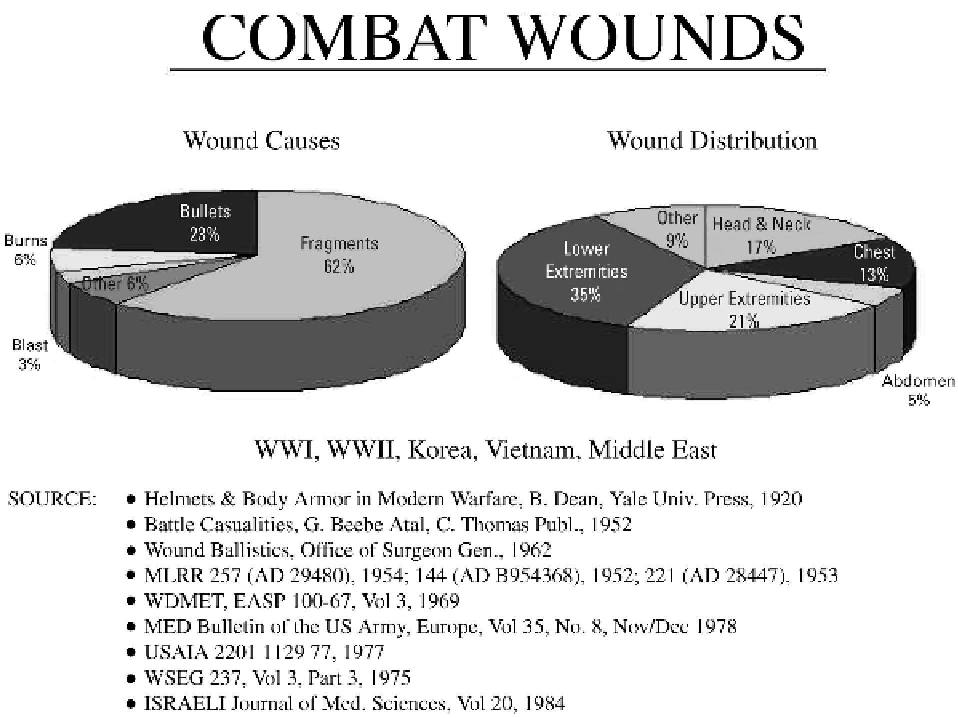

Figure 16.9 Causes and anatomical distribution of wounds compiled from some major conflict studies.

against fragmentation weapons but not against bullets. Lack of protection of the extremities and lower torso still led to the many fragmentation wounds in those areas.

Today's scientific and highly technical battlefield environment encompasses much more than bullets and shrapnel. Air assault, both in the dark and in daylight, can result in broken bones due to falling from heights. Moving vehicles such as tanks, wheeled vehicles, and helicopters can produce skeletal injuries when detonating buried mines or accidents when the vehicles roll over or crash. Radiation injury may result from exposure to nuclear material. The use of chemical and biological warfare materials can produce nerve and soft tissue damage and possibly death. Directed-energy weapons can generate eye injuries, blindness, and burns. Electromagnetic effects, electric shock, and burns are potential medical injuries from short-circuited, capacitor-discharged, and ungrounded electronic equipment. In many cases, these injuries may be prevented or ameliorated when survivability is addressed in the initial hardware design and development stages.

The SSv PAL focuses on three general areas of minimizing medical injury to improve survivability:

- Identify the potential sources for personnel injury in the system design and when the soldier and equipment are functioning in the field.
- Assess the system's ability to prevent further injury to the soldier after being attacked or exposed to a hostile environment.
- Assess the ability of the system to support treatment and evacuation of the injured.

Bail-Out Ejection Bail-out ejection from a high-performance aircraft illustrates how a system analysis using a PAL could identify both potential sources of medical injury from ejection and requirements to prevent further injury after leaving the aircraft (see Example 16.8).

Example 16.8 Bail-Out Ejection Analysis The purpose of the ejection seat is to get the aircrew member as far away as possible from a damaged/troubled aircraft to avoid injury to the crew member. Ejection is required because the speed and potential attitude of these modern aircraft precludes jettisoning the canopy and stepping on the wing to jump clear of the aircraft to execute a parachute jump. The design of the aircraft must include a method of rapid, complete removal of the canopy prior to ejection to avoid crew member injury as the rocket- or mortar-propelled seat or system moves up its guide rails and out of the aircraft. After leaving the aircraft, the seat must be thrust sufficiently high above the vertical stabilizer and horizontal tail surfaces to prevent them from striking the crew member or the seat to which the crew member is attached. In some aircraft, the instrument panel is immediately above the rudder pedals, feet, and lower legs. To prevent contact injury to the feet and lower legs by striking the underside of the instrument panel during ejection, the crew member must wear straps on his or her flying boots that will automatically retract the lower legs and feet against the seat and out from under the panel when the ejection process is activated. The seat pan must be sufficiently long to preclude the momentum "G" force of ejection and the weight of the crew member's legs from breaking both thigh bones during the rapid upward acceleration. The activation mechanism of the ejection system must be placed in a position so it can easily be reached and activated by one hand, if necessary, without placing the spinal column or the arms in a position where they can be injured. A timing mechanism must be in the seat design so that, once the ejection propellant is activated, enough time will elapse to clear the tail plane surfaces and separate the seat away from the crew member to preclude further seat contact injury when descending and landing.

During canopy separation and crew member/seat separation, depending on altitude and air speed, the crew member must have an eye shield and an oxygen mask that are functional. The eye shield is necessary to prevent facial injury from exposure to wind blast, rain, and particulates in the air traveling at speeds up to several hundred knots per hour. Depending on altitude, an easily activated oxygen bottle connected to the flight mask must be part of the survival kit to prevent hypoxia during the several-minute parachute descent. If the descent is into water or onto rocky terrain, a means of quickly disconnecting the parachute must be available to prevent bodily injury from being entangled in the parachute that is collapsing around the crew member or being dragged over the ground. If the crew member becomes entangled in the chute when in the water, he or she may not find their way out of the entanglement and drown. The crew member should also be wearing some sort of flotation device to keep the head above water until rescue is achieved.

While the potential sources of medical injury described in Example 16.8 will cover most high-performance aircraft, several other potential medical injury situations must be considered. If ejection is required at zero speed/zero altitude while the plane is sitting on the runway, hovering, or initiating take-off, this same ejection sequence must be used to clear the aircraft and fully open the parachute before the crew member comes in contact with the ground to minimize injury.

In some aircraft, emergency positional stability requires full-time monitoring and control. The slightest distraction may result in the aircraft rolling upside down. In this event, time is not available to sequentially jettison the canopy and eject. Ejection must go through the closed canopy. To prevent head and neck injury by having the crew member's head serve as the canopy penetrator, the back of the seat is higher than the tallest crew member using it. This seat back then absorbs the impact of canopy penetration rather than the head, neck, and body. In some cases, a pointed spike is mounted on the seat top to facilitate penetration. In the past, some preliminary tests of this mode of ejection using dummies indicated the potential for breaking and/or amputating shoulders and arms because the hole created in the canopy by the seat was not sufficiently large to allow the body to pass through cleanly. This led to canopies being scored in several places to facilitate canopy penetration by the seat and breakage of an adequate hole to allow crew member ejection through it without injury.

In the event of a crew member bailing out and landing with injuries involved, the ability to provide rescue and treatment must be considered. If the incident happens near a fixed installation, fire engines, ambulance, and emergency medical crews may be available to provide these services. If this same event happened over water or in a remote location, trained helicopter rescue teams and special equipment may be necessary to find, treat, and evacuate the downed crew member. Methods (procedures, equipment, and trained personnel) must be strategically located to minimize contact time.

Fire Suppression Another example of minimizing injuries by designing soldier and system survivability into the hardware system can be illustrated with the fire suppression subsystem installed in a small enclosed compartment such as a barge engine room, tank turret, or vehicle crew compartment. In each situation, a fire detection system must be present to detect that a fire is actually present and give warning to unsuspecting occupants to leave the area. The detector must be functional for that particular environment. A combination of a thermocouple and sensor to observe the EM spectrum for specific flame signatures is often required to detect fires in these environments without false alarms. Once an alarm is given, the occupants of the compartment must quickly understand it. An acoustic signal must be heard over background noise, and a visible alarm light must be observed and recognized from any location in the compartment. More than one exit route must be available to flee the fire and potential explosion. In many systems, it is not possible to provide an easily accessible escape exit for each individual. [For example, the ABRAMS tank has two turret hatches on top, one each for loader and track commander (TC). The gunner is seated in front of the TC, and in an emergency, the gunner must wait for the TC to go through the hatch before being able to escape. If the tank has flipped over onto the top of its turret, the turret basket side screens and some equipment on the basket floor will have to be removed before the three turret crew members will be able to escape through the driver's hatch in the hull glacis plate.] The choice of fire-extinguishing material must be quick and effective (desired speed of extinguishments is measured in milliseconds for armored combat vehicles) on the burning material and non toxic to the crew or ample escape time must be provided to minimize toxic exposure. If a built-in fire suppression system is utilized, means to minimize compartment air exchange during the fire suppression treatment are needed for the treatment to work most effectively.

Under ordinary circumstances, halogen gas in high concentration would be used to suppress a fire by both reducing oxygen concentration and lowering the temperature of the ignited material. For short exposures during flight to safety, the gas is safe to breathe in high concentrations (Sass-Kortsak et al., 1985). Typical symptoms reported in confined spaces are light headedness, headache, and disorientation. These are all symptoms usually found with breathing low-oxygen concentrations and retaining carbon dioxide, not specific toxic materials. Because of the ban on the use of halogens due to ozone depletion, other agents must be used. Carbon dioxide in concentrations from 25 to 62 percent by volume (dependent upon the fuel source) is effective against fire in most situations. Unfortunately, these concentrations are extremely toxic to the crew within the compartment or confined space (see Example 16.20). Only a few breaths of these high concentrations can incapacitate the crew to the extent that they may not be able to make it out of the area on their own. If the fire must be fought with hand-held extinguishers, safety masks with carbon monoxide filtering materials must be used to protect those fighting the fire. Water as a fire suppressant cannot be used around electrical fires because the water will short out other electrical equipment and cause electrical shock hazards for the crew as they fight the fire.

Once the fire is out, how can the crew safely reenter the compartment to determine the extent of the damage and their ability to repair it? If either the suppressing substance did not sufficiently cool down the burning material or the cause of the fire was not isolated and shut off (e.g., leak of flammable hydraulic fluid, overloaded electric circuit, etc.), the action of a crew member opening the hatch to take a look could reignite the fire from the renewed supply of oxygen. The person opening this hatch could be severely burned by this flashback. Toxic combusted substances such as carbon monoxide and nitrous oxide may be present in the air within the confined space. These substances must be flushed out of the space before reentry can be safely attempted. Unless instruments are available to determine the presence of adequate oxygen to support life and toxic materials are absent or present in sufficiently low acceptable levels, reentry should not be attempted without a self-contained breathing apparatus.

Evacuating the Wounded If the crew is injured in the confined space, how can they be extracted rapidly and safely? The use of loops attached to the shoulder area of their crew members' uniforms can assist in the lifting of injured, unconscious, or nonmobile crew members through narrow hatches. After a fire, pure oxygen breathing apparatus must be available to flush the crew members' lungs of soot particles and restore blood hemoglobin oxygen saturation levels. Where should the extracted personnel be laid out for examination, treatment, and recuperation until they can be evacuated to a more substantial medical treatment facility? In one situation, it was determined that the black plastic surface of a barge deck ordinarily was so hot from absorbing a solar heat load that sailors working on that surface periodically had to go inside to cool their feet. If injured personnel were laid directly on that hot surface, they could suffer additional burns and dermal injury beyond what they had been exposed to in the confined space during the fire.

Injuries resulting in loss of mobility or loss of utilization of the hands and arms can drastically limit the chances of survival if the soldier is alone, even though sometimes the tactical situation calls for the wounded to fend for themselves for a period of time before they can be retrieved, such as what occurred during the British campaign in the Falkland Islands. Besides the inability to travel safely, soldiers sometimes cannot get to water and food to sustain or protect themselves until rescue. Loss of blood and burns over large areas of the body would put individuals in shock and increase their dependence on water and nutrient electrolytes.

Overall mission performance degradation as the result of physical and mental wounds must also be considered. Potential combat-caused injury or the possibilities of injury are generally not addressed in the HSI health hazard assessment and system safety analysis. However, they are included in the reduction of the medical injury component of SSv.

Wearing Protective Equipment There are a number of different needs for combatants or other personnel to wear specially designed protective equipment. Example 16.9 describes some of these special needs. Example 16.10 describes helmet design in particular.

Example 16.9 Special Needs for Protective Equipment When soldiers are in combat, they will usually wear protective equipment to minimize personal injury when engaged with an opponent. This will usually include helmet and body armor. In some cases, a face shield may be worn. If a chemical attack is anticipated, the soldier may also wear a chemical respirator mask and protective clothing that will completely enclose and separate the body from the ambient environment. Also, the combatant as well as those not engaged in combat, working or residing in areas where biological weapons may be employed, may be inoculated with a vaccine against a specific potential threat. During assembly of bridges to cross wide bodies of water, engineers will wear life vests to protect themselves from drowning if they fall into the water.

An operational "cost" is associated with each of these protective systems. For example, wearing chemical protective clothing may reduce the potential exposure to chemical injury but increases the opportunity for heat stress injuries that may pose medical problems and death. Breathing through a gas mask will limit the ability to perform heavy work at a rate equal to doing it without a mask. Body armor capable of protecting against rifle and small arms fire is very heavy. To limit the amount of extra weight while still maintaining near-normal body mobility, it is generally only used to cover the upper torso (chest and back). Flexible body armor can protect most of the torso, but this protection is limited to shrapnel and fragmentation protection. The extremities are not protected from any of these ballistic projectiles.

Example 16.10 Helmet Design The current Army Personal Armor System for Ground Troops (PASGT) helmet was a design improvement over the World War II plastic helmet liner and steel outer shell by offering more protection to the ears, side of the head, and neck while making it lighter and more impervious to shrapnel. By covering the ears of some troops, however, a reduction of the ability to hear sounds (and their direction) occurred, jeopardizing their survival on patrols. Mounting night vision goggles and heads-up displays on the helmet requires that the helmet be anchored tightly by a chin strap to prevent "motion sickness" when looking through these devices. During World War II, it was found (Beyer et al., 1962) that when a helmet was held in place by a chin strap and artillery rounds or bombs exploded nearby, the resulting shock waves would get under the helmet, lifting it upward at some angle. Since the strap held the helmet fast to the head, the upward and angled motion could break the wearer's neck. Once this was learned, the soldiers during that war and the Korean War did not fasten helmet chin straps. Because artillery and bombs were seldom used in heavy concentration against our troops during the Vietnam and Desert Storm wars, and most of our current group of military designers have never really been exposed to combat, this lesson of certain combat medical injuries may have been forgotten.

16.4.6 Reduce Mental and Physical Fatigue

The component for the reduction of physical stress and mental fatigue was developed to address tasks that may have direct bearing on the occurrence of combat-related mistakes. Emphasis of this component is on the ID and reduction of complexity of combat-related or combat-support tasks, where negative effects by operator error can be directly traced to stress and fatigue. Associated human factors–related tasks need to be made simple and not mentally tasking, considering that stress and sleep deprivation make the mental processes for operating equipment increasingly difficult as time goes on while mistakes in processing and judgment become more prolific.

Stress Stress can have both positive and negative effects on personnel. Both the anticipation as well as the experience of exposure to a hostile environment can cause a toll on functional ability. Personnel in a defensive position waiting for an attack to come will experience the "fight-or-flight" reactions described physiologically by Cannon (1932) and psychologically by Selye (1956). To some personnel, primarily those who have previously experienced the situation, their senses are sharpened and movements made more fluid, making them more prepared to protect themselves, defeat their attacker, and survive the event. Other personnel, generally new and inexperienced to the event about to unfold, will be frightened to the point of near panic and/or paralysis when protecting themselves and may wish to flee as the only method of survival.

For at least the last half century, military organizations have tried to place their recruits through training that simulated realistic fighting environments the individual was likely to experience in order to reduce personal fear and stress when the individual would be exposed to the same condition in a combat situation. The experience of being fired upon, going through unfamiliar/hostile territory at night, and then fighting the enemy according to a prearranged plan and timetable (with alternate courses of action in case of unforeseen circumstances), with a group of friends they have come to rely on to protect one another, is all training to condition the troops that the event is not that difficult if one does not let fear get the best of the mind. Stress should never be completely eliminated because stress is required to develop the mental "edge" needed to survive.

Fatigue *Military combat is extremely fatiguing.* Those who have experienced this environment have learned to take their rest when and where they can. While fire-fights are short (usually less than an hour), the troops may be required to be on alert for long periods extending to days. It is not unusual for a patrol to be on the move all day long, and then while most of the group is trying to rest, some of the troop must remain awake as sentries. They frequently resume the patrol the next day before the sentries have had a chance to rest or sleep. Even though the next night sees different sentries remaining awake, eventually all of the patrol becomes fatigued from lack of sleep. The situation of being constantly on the alert is dangerous due to fatigue causing an individual to lose focus on his or her objectives.

Stress and Fatigue Examples The SSv parameter assessment list initiates a review of a hardware system and the personnel who will operate the system in combat by focusing on the following five stress and fatigue areas:

- the physical constraints and workload placed on the soldier by this system,
- the cognitive constrains and workload placed on the soldier by this system,
- the system's ability to minimize the effect of the environmental stressors on the soldier,
- the system's ability to minimize the effect of mechanical (system-produced) stressors on the soldier, and
- the system's compatibility with crew life support and continuous operations.

Several examples of routine military and civilian activities that are very stressful and fatiguing in themselves are provided to illustrate how the additional stress of combat or lack of sleep can change the activities into life-threatening situations (see Examples 16.11 to 16.14).

Example 16.11 Weapons Operations The physical constraints placed on a weapon operator can be severe. Several decades ago, a weapon was developed for infantry reconnaissance platoons to protect themselves against helicopter attacks. Once an approaching enemy helicopter was identified by sound, the crew carrying the weapon was to stop, unpack the weapon, assemble its many component parts, acquire, aim, and fire it as the helicopter came within the crew's line of sight. To do all these tasks before the helicopter was able to find, identify, and destroy them and their weapon required about 1.75 min under the best of circumstances by crewmen who were in the upper 10 percent of their high school graduating class. The battery was only good for one firing. If the weapon misfired or the fired projectile missed, a second electric battery and missile had to be unstowed, attached, and checked and the weapon fired again. The speed of the workload on the crew and the knowledge and skill required to maintain and operate the weapon as well as the weight of the weapon created such a stress on the soldiers that an analysis of the fielded system provided an example that went to Congress and became part of the impetus in developing the MANPRINT program in the army.

Example 16.12 Deep-Sea Diving One civilian and military occupation that places very high cognitive and physical restraints on an individual is that of a deep-sea diver. The individual is confined to an ambient isolating suit that is only slightly larger than his or her body. The diver depends on a crew of knowledgeable people up to half a mile away to provide a blended mixture of breathing gas at a pressure equal to the diver's changing ambient pressure. This gas must be supplied in sufficient quantity to allow the diver to do heavy work without causing the diving suit to balloon and preclude the individual's movement. It must be passed through a 0.5-in.-diameter line that can be easily snagged and cut by features of the diver's surrounding work site. Beyond the 100-ft depth, the working environment is so dark that the diver must use a high-powered light to be able to see a distance as short as 3 ft away from the face. One method of communication with the top-side crew is a two-way wired telephone to enable the diver to clearly hear and understand the top-side crew. The diver, unfortunately, cannot be heard distinctly below approximately the 150-ft depth because the breathing gas mixture distorts the sound as it flows over the vocal cords so that the voice is changed in pitch and speed. The backup communication method is tugging on the lifeline a given number of pulls in a coded format. In many cases, the length of line damps out the communication being sent in either direction. The ambient environment contains predatory creatures, unseen currents to prevent the diver from staying at the workstation, and uneven working areas preventing standing or functioning in a comfortable position. The diver must usually work alone because of the danger involved. He or she must be skilled at several different occupations, including plumbing, welding, naval architecture, oceanology, and respiratory physiology. The diver knows that a cut or crimp in the breathing hose, a cut in the suit, loss of neutral buoyancy by the intentional or unintentional dropping of a weight, improper use or loss of tools can immediately cause death. Every body movement must be considered and the consequences weighed for the diver to survive.

When the diver attempts to return to safety upon the completion of work, the process must be very slow if he or she is to live. If the descent was to below 200 ft of depth for more than 12 min, the diver must ascend at the rate of only 1 ft of depth every 20 min in accordance with U.S. Navy diving tables. A dive to 900 ft to fix an oil well "Christmas Tree" can take more than 12 days to return to the ocean surface. To ease the return ascent, allow the diver to drink and eat, and protect the body from the constant extremely cold water (usually about 32°F), a diving chamber is sent near the bottom to provide a refuge during the return. Although isolated from other personnel for the full ascent time, there is access to food, water, warmth, and personal hygiene needs. Such an occupation can produce sensory overload and increased physiological and psychological fatigue. Unless the individual puts complete trust in his or her own ability, the ability of both the supporting top-side crew and the equipment, and the stability of the ambient environment above and below the ocean where the individual is working, the deep-sea diver may not survive the mental and physical stresses to which he or she is subjected.

Example 16.13 High Climatic Temperatures High climatic temperatures affect the ability to perform many different tasks, both military and civilian. Pepler (1958) measured the performances of British soldiers receiving Morse code, detecting simulated radar signals, tracking a moving pointer, and making decisions from rapidly changing visual displays. Performance started to deteriorate in temperatures above 81°F. The accuracy of West African soldiers conducting Morse code communication duties and tracking mission activities for 3-hour periods also deteriorated above 86°F according to Watkins (1956). Bursill (1958) conducted experiments to determine heat fatigue on simulated tracking. He had the men sit in both a 65 and a 96°F environment for 2 hours and then had them respond to small randomly timed lights appearing erratically in their peripheral field of view while they were tracking a moving target and point immediately in front of them. More peripheral lights were not observed in the higher temperature than in the lower temperature, suggesting that fatigue produced by heat, repetitive task, and possible boredom focused their awareness toward the central visual field. It is well known that a pilot looking directly ahead through the cockpit window without any cloud variation or ground to focus on for a period of time will gradually focus on a point of ocular convergence and miss any object in the surrounding visual field.

Example 16.14 Heat and Sleep Deprivation Pepler (1959) also conducted studies on serial tracking tasks associated with combinations of heat and lack of sleep. The effects of lack of sleep alone were different from the effects of heat alone. Loss of sleep reduced the subject's responsiveness to the required tasks but not the accuracy. The elevated temperature reduced the accuracy but not the responsiveness to the task.

16.5 SOME "LESS-THAN-OBVIOUS" EXAMPLES

For those working in the areas previously described, it is normal for many to make a studied observation of a given system based upon their expertise, list the issues of concern, and then work hard at addressing those particular issues without continually looking further. Periodically, issues arise after the equipment has been fielded, causing concern and potential disruption. A few examples are presented to suggest that an assessor continually needs to watch for the "flaw" that is often not obvious.

16.5.1 NBC-Protective Equipment

A person who has performed any physical task in a MOPP IV chemical protective ensemble and NBC-protective respirator immediately recognizes that this set of protective equipment attempts to address simultaneously survivability, human factors, and health hazards issues. Looking beyond the obvious concerns when individual protective equipment is used in the usual temperate environment, there are some potentially serious issues (see Examples 16.15 to 16.18).

Example 16.15 Arctic Clothing in NBC Environment Consider use with Arctic cold-weather clothing in below-freezing conditions. In the recent past, NBC protection was to be worn *under* the troops' Arctic clothing. This is not an obvious consideration until one realizes that after a chemical exposure the soldiers must remove their contaminated cold-weather clothing and MOPP clothing and equipment prior to entering a shelter. While going through the decontamination process outdoors, the soldiers could suffer severe hypothermic injury before entering the protective shelter. Once inside, the soldiers are not able to go back out into the contaminated environment unless the shelter has supplies of cold-weather clothing and MOPP protective equipment. Even if the environment is decontaminated, clean, cold-weather clothing must be provided for activity outside the shelter.

Example 16.16 Shaving While Wearing NBC Mask To properly utilize an NBC respirator, the male military person must take extra care when shaving and do so on a daily basis since NBC mask seal (as presently designed) leakage can be caused by a single whisker.

Example 16.17 NBC Clothing and Stevedoring Another NBC tangential issue can be that stevedoring (loading and unloading ships' cargoes) in the tropics may cause serious concerns. When under threat of missile attack with chemical weapons, the wearing of MOPP IV can be a big "monkey wrench" in normal personnel requirements. Working in MOPP IV in the tropics may limit work performed by personnel down in ships' holds to as little as 15-min/hr shifts, due to the existing intense humidity and temperature being severely intensified within ships' holds.

Example 16.18 NBC Clothing and Reading Wristwatch For a simpler example, consider the front-line leader wearing MOPP IV. Combat-related movements and actions are to be made at specified times. Has the leader realized that one cannot pull back the sleeve under contaminated conditions to look at the wristwatch for the time? Will the leader be thinking ahead and wear a favorite wristwatch over the sleeve and be willing to dispose of it if exposed to chemical/biological agents? Has logistics considered stocking replacements in sufficient quantity to meet the anticipated demand?

16.5.2 Single-Eye Viewer

Another example to consider is an opaque heads-up display for use by only a single eye (see Example 16.19).

Example 16.19. Single-Eye Viewer The display is periodically pulled down in front of that primary eye while the other eye is intended to maintain surrounding situation awareness (SA) in a ground or aviation environment. A display of this type, when put into position, is in the visual field of only the primary eye. Unrealized by many, this concentrated active utilization of one eye affects the vision of the other eye, causing this other eye to "shut down" its visual activity over a very short time period. This situation can tremendously reduce a soldier's visual awareness of his peripheral surroundings until the display is repositioned away from the single eye and both eyes are again to be used to view the surroundings. The soldier will then experience a short time lapse before the shut-down eye fully reactivates.

16.5.3 Fire Extinguisher Agents

Another less-than-obvious concern comes from a past consideration for fire-extinguishing agents. Due to environmental concerns for ozone effects, Halon manufacture was discontinued in the United States. One version of Halon was used in the automatic fire suppression systems of military vehicles due to its ability to quickly extinguish fires at a low concentration in crew compartments while simultaneously allowing the crew to breathe. Carbon dioxide was proposed as a substitute for Halon. (See Example 16.20 for the limitations of carbon dioxide as a fire-extinguishing agent.)

Example 16.20 Carbon Dioxide as Fire-Extinguishing Agent in Closed Quarters On the surface, carbon dioxide seems like a good candidate due to its common use in fire extinguishers and its ability to extinguish many sources of fire. Unfortunately, although common carbon dioxide fire extinguishers can be used to good effect in large rooms, outdoors, or in compartments without personnel, carbon dioxide does have serious effects on the human body when used in heavy concentration. Carbon dioxide needs to be in a concentration of 25 percent (minimum) to 62 percent (Cote, 1997) of total air volume dependent upon fuel source(s) to put out flame. Consider the little-known physiological fact that if humans are in a closed compartment (whether in a cockpit, ship, or armored vehicle), a lower than required (for extinguishing a blaze) 10 percent by volume atmospheric level (Bender et al., 1994) of carbon dioxide is subjectively intolerable to breathe, while slightly higher (12 to 15 percent) carbon dioxide levels produce unconsciousness and, eventually, death. For those personnel successfully evacuating the high-carbon-dioxide environment to fresh air, they experience severe headaches, nausea, vomiting, the smell of ammonia (which may lead a military person to believe that a chemical attack is underway), and potential loss of consciousness. At a carbon dioxide level of 25 percent or greater (minimum required to extinguish flame in a closed compartment), the crew members may immediately experience effects such as impaired mental ability, violent respiratory movements and convulsions, inability to take steps for self-preservation, loss of consciousness, and potentially stopping of the heart. These human body responses to high levels of carbon dioxide may only allow a three- to four-breath reaction time before collapse. Used in combat, a vehicle might be saved from a fire during combat, but members of the crew would likely perish from the extinguishing agent named in this example.

Personnel survivability investigations must constantly consider many diverse possibilities to find the lesser known and hidden issues until they are detected and pointed out. The effective use of the survivability considerations presented in Figure 16.2 by knowledgeable multidisciplined SMEs should minimize the less-than-obvious concerns if this information is incorporated in system design during the concept and development stage of a new or modified program.

16.6 CASUALTY ASSESSMENT TOOLS

Combat mathematical and computerized models are often used to project probabilities of war-fighting outcomes. At this level, combat models are used to feed assumptions into the analysis of alternatives (AOA). Although these models are used to project personnel casualties as well as weapon system losses during combat, they are unlikely to have utilized human performance data or taken into consideration SSv factors. For example, soldiers operating a tank in actual combat may become casualties even though the tank survives an attack.

16.6.1 The ORCA Model

In the past, casualty assessments relied on separate applications of several stand-alone models, each of which dealt with a specific battlefield insult (injury mechanism). These tools serve a crucial function by permitting the computation of human vulnerability measures for personnel serving as individual combatants or as "components" who contribute to the overall vulnerability of a weapon system. For example, the army's ComputerMan (Clare et al., 1980; Saucier, and Kash, 1994) model was often used to evaluate penetrating injuries, while BURNSIM (Knox, and Perry, 1993), an air force code, was frequently used to assess the likelihood of skin burns from thermal exposures. The Operational Requirements-based Casualty Assessment (ORCA) model (Neades et al., 1999) incorporates the best features of these and several other existing models and combines them in a way that allows consistent assessment of casualties across virtually all platform, task, and threat types (see Fig. 16.10). It provides a new methodology for assessing the antipersonnel effects associated with various munition-produced mechanisms. Development of this model was prompted by concern at the Office of the Secretary of Defense (OSD) level over the lack of standardized service methodology for computation of user casualties.

The ORCA computer code allows the analyst to calculate anatomical damage and the effect on individual performance as a result of exposure to kinetic energy threats. It will also tell what happens with other insults such as thermal, chemical, directed-energy (laser), blast, and accelerative loading threats, but, at the time of this writing, ORCA does not yet incorporate pressure–time histories for these latter threats. In each case, the effect of a computed injury is characterized by the predicted impairment of each of 24 human

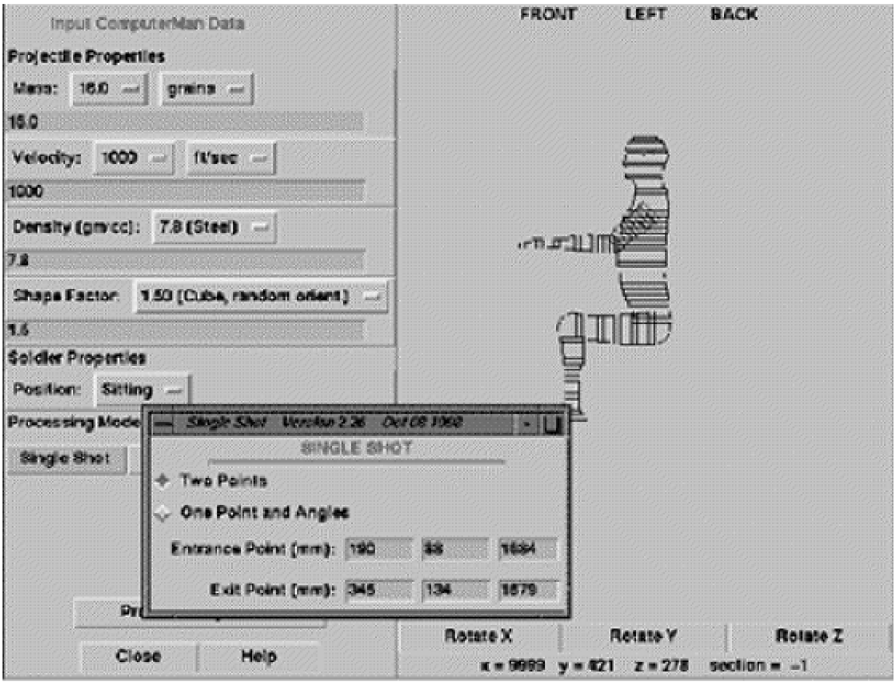

Figure 16.10 ORCA analysis—computer screen showing areas of inputs and the human figure in one of the available aspects and configurations.

elemental capabilities (e.g., vision, cognition, and physical strength) as a function of time after injury. Postinjury capability is then compared to capability requirements associated with the individual's military job task or mission to determine if he or she is an operational casualty. ORCA has code outputs for the following: (1) discrete exposures (e.g., a single fragment impact) including a physical damage summary; (2) details of any deleterious processes (e.g., blood loss); (3) abbreviated injury score (AIS) (American Association for Automotive Medicine, 1998); (4) elemental capability status; and (5) remaining performance capability (comparable to incapacitation) as a function of time after wounding (six time periods ranging from immediate to 72 hours). In addition to addressing discrete simulations with single threats, ORCA can also be run in grid or batch mode to produce results that reflect a range of exposure conditions. ORCA users can specify the operational requirement for a military job, task, or mission by selecting from a database library of 20 army, navy, air force, and marine military occupational specialties, specific military tasks, or predefined mission scenarios. Although the determination of medical casualties is not within the charter of the DoD Joint Technical Coordinating Group for Munitions Effectiveness' Crew Casualty Working Group, it is essential, to the degree that medical and operational casualty factors are common, that ORCA be consistent with the needs of the combat casualty analytical medical community. To this end, significant care has been taken to define and record injuries in a way that serves future medical analysis needs. In particular, ORCA determines and tracks each injury's AIS severity score, an injury characterization system common throughout the civilian medical community.

16.6.2 Weapons Systems Effects Models

Beyond modeling of human effects, it is vitally important in SSv to understand effects of weapons on combat systems and equipment. What affects the platform or equipment provides the analyst with information on what to protect the human against. For example, a tank commander may have his head and shoulders out of his hatch to observe and give movement commands to avoid being hit by incoming SAGGER antitank guided missiles (ATGM). Based upon actual occurrence, the tank commander in this position will experience tremendous heat and overwhelming pressure from the detonation of the missile against the tank, at a minimum. The analyst must be knowledgeable of the potential weapon's and the platform's interaction effects to understand what the human being will potentially experience. An analyst must realize that soldiers by themselves would almost never be the targets of an ATGM, but, because of the tanks they are manning, they may be exposed to the ATGM's weapon effects upon a tank and its armor. Therefore, SSv must be viewed as interwoven with system survivability.

There are a fairly large number of computerized models that provide invaluable insights as to weapon system effects (U.S. Army Natick Research, 1992; National Defence Research Establishment, n.d.; U.S. Army Research Laboratory, 1996, 1997). Generally, they incorporate algorithms based upon actual test data and provide quite accurate outputs.

16.6.3 Current Limitations

A word of caution is due on the use of models and simulations. Models and simulations have limited value, depending upon their accuracy in the codes and the data used. For example, one particular chemical-related model does not take into consideration the heat stress on the body due to wearing MOPP IV clothing and its weakening effect before the chemical attack is even applied. This same model does not take into consideration the dehydrated state of the soldier in a hot desert environment or the fact that the individual may have taken pyridostigmine as a prophylactic before exposure. It completely escapes the analyst using the model that pyridostigmine will cause the soldier to have a hard time aiming a rifle to protect him- or herself unless the user is familiar with the pharmacology of the prophylactic. The model does not incorporate the protective layers of clothing and their stopping action. In many cases the models have been looking at the wrong route of entry for bioagents according to epidemiological studies. That said, models and simulations can add a great amount of value in an analysis and as guides useful in applying knowledgeable insight and experience.

An additional cautionary note is on time limitations of some models, as they may use 5-to 10-minute minimum time intervals. An illustrative example would be improving the breathing resistance of a gas mask. A soldier under fire is taught never to expose her- or himself to the enemy for more than 15 seconds when running from protective cover to protective cover. If the breathing resistance of the mask is improved 200 percent, the soldier will be able to get to protective cover faster (less than 15 seconds). This improvement is important for survivability but will not show any improvement in a simulation model where the shortest time segment is 5 minutes. This interval may often be too long to notice major technical improvements in individual equipment. Also, a wounded military person's variability of his or her physiological and psychological state sometimes causes extreme responses, different than those predicted. Models generally do not take into consideration the excited state of the body (being pumped up for trouble before the event), as they generally use model data of an individual physiologically at rest.

16.7 SUMMARY AND CONCLUSIONS

Personnel survivability most often deals with an inseparable combination of equipment and personnel. If military communications or other equipment becomes a target of a threat force, the personnel manning that equipment are also parts of the target. If a terrorist places a bomb in a plane, the personnel occupying the plane are also targets. There often is no simple means to disconnect the human from the machine for combat effects investigation and analysis. Therefore, personnel survivability must view man–machine interaction and effects as a whole with the ultimate focus on the survival of the human. For good investigations to occur, a number of different disciplines are required. A good personnel survivability assessment can bring together a medical combat care provider, an EW SME, an NBC assessor, a human factors professional, and a materiel developer. They may *all* be needed to make one integrated, threat- and combat-oriented HSI assessment.

A personnel survivability assessment may furnish a valuable service to the materiel developer and others by providing an overall integrated technical review of the hardware/human system. This includes appreciation of the combat weapon–induced threat and the resulting program survivability issues while encouraging HSI participation in resolving those issues. This type of assessment assists in providing coverage and assurance that issues will be, or are being, addressed in such diverse areas as EW, ballistics, DEWs, NBC warfare, physiological effects, and heat stress. A comprehensive personnel survivability list of issues can be tailored to assist a materiel development team in producing a survivability outline and strategy while simultaneously providing valuable information and insights for the combat developer.

The HSI practitioner should be able to utilize this method with some modifications to help the civilian who fights in hostile environments as well. The personnel survivability examples provided in the chapter on fire-extinguishing agents, deep-sea diving, high climatic temperatures, heat and sleep deprivation, single-eye viewers, and wearing protective clothing in hostile environments are as applicable for civilians as for military combatants. The kinds of civilian operations where personnel survivability becomes especially critical are situations such as bombs in airplanes and trains, chemicals placed by terrorists in water supplies, mask and special clothing utilization in NBC civilian environments, police firearms and armor, and fire fighter protection.

It is important to distinguish those human factors that might be routinely addressed in the systems safety and health hazards domains from those in the personnel survivability domain, which adds a new dimension to the general HSI arena. Whether a warfighter or a civilian, personnel survivability applies to those situations where the environment is so hostile that those to be protected are working on the outermost edge of their physical and cognitive abilities where at any moment they could become casualties. It is believed that the methods and examples described provide information that can play a positive role in reducing the likelihood of such casualties.

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