Chapter 2

ASSESSING THE EFFECTIVENESS OF CONVENTIONAL WEAPONS

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INTRODUCTION

Karl von Clausewitz observed that "war is an act of violence intended to compel our opponent to fulfill our will."[1] Historically, compelling opponents "to fulfill our will" has meant that one group of people uses weapons and physical force to injure or kill another group of people, and therefore intimidates the survivors into compliance. While the specific mechanisms of ballistic, blast, and burn injuries and their medical and surgical treatments are considered in the following sections of this textbook, this chapter considers (in the broadest sense) the ability of the weapons that are used violently in conventional land warfare to inflict physical harm. Describing the outcome when weapons are employed—weapons effectiveness in the broadest sense—utilizes concepts including: *(a) lethality* (that is, the observed probability that a casualty will die if injured by a given weapon; *(b) casualty generation* (which has two definitions: the observed fraction of the total at-risk population that was injured by a given weapons system, or alternatively, the probability that a weapon's single use will generate casualties); *(c) incapacitation* (that is, the probability that an injury resulting from a weapon's single use will prevent the casualty from performing a soldier's duties); and *(d) injury severity* (that is, the observed probability that a weapon's single use will produce a certain degree of morbidity in a casualty).

Several features of these definitions require elaboration. First, they deal with probabilities. Unlike physicians who treat individual patients, medical officers who seek to understand weapons effectiveness and to predict (for planning purposes) the number of casualties that are probable need to become familiar with the concept of *conditional probability*, which can be defined as the probability (P) that a given outcome (O) will result from a specific event (E), and which can be expressed as P(O|E). For example, the probability that a casualty will die given an injury made by a weapon's single use is a conditional probability. Probability is usually expressed as a ratio: the observed number of specified outcomes divided by the population at risk of that outcome. Thus, there is a need to precisely define not only those outcomes but also, even more importantly, the at risk population.

Second, the apparent precision and simplicity of the definitions above are deceptive. For example, all four include the concept of a *casualty*. But what exactly must happen before a soldier is classified as a casualty? Officially, the U.S. Army defines a casualty as "any person lost to his organization because he is killed, wounded, missing, captured, or interned if such a loss is incurred in action."[2] From of assessing weapons effectiveness, only the casualties who are killed and wounded are relevant, but here too, precise definitions are required. What must happen for a soldier to be classified as wounded? The official definition is: "Battle casualties who require admission to a Medical Treatment Facility (MTF) or who die of their wounds after reaching any MTF are reported as Wounded in Action."* However, many soldiers sustain such minor injuries that they do not require admission to an MTF. During the Vietnam War, the largest group of officially recognized casualties were soldiers who were not admitted to MTFs but were *carded for record* only (that is, even though the soldiers' injuries were trivial and they did not require admission, their names were recorded on cards for record-keeping purposes), and therefore they were not casualties at all according to the official definition.[3] Including these soldiers—who were carded for record only—in data used to assess weapons effectiveness has led to misleading conclusions.

And third, military surgeons recognize *wounds* as a category of *injuries* (that is, a wound is specifically a penetrating injury caused by a projectile) and distinguish wounds from other injuries such as those caused by blasts and burns. Note that the official definition of a casualty uses the word "wound" in the sense that this textbook uses "injury."

Such seemingly minor semantic problems may limit the validity of some of the conclusions that can be drawn from some of the data presented in this chapter. Not only do some of the original sources use some of these terms interchangeably, but their definitions may also vary from war to war, from army to army, and even from one data collector to another.

Casualty generation and lethality will be discussed at great length, but medical commanders and staff officers will find other indices of weapons effectiveness to be useful, also. The concept of injury severity as an index of weapons effectiveness should be immediately appealing to medical officers. This approach is limited, however; little data exist that directly relate injury severity to specific weapons, and the assessment of severity is almost in purely qualitative terms (trivial, medium, serious) that are incompletely defined.

Certainly from the military standpoint, the probability that a casualty will be *incapacitated* (that is, unable to perform his or her soldierly duties) if a weapon is used has great practical importance. Precise definitions exist delineating a soldier's duties. Thus it is possible to state what a weapon must **do** to prevent a soldier from functioning; that is, it is possible to quantitate the violence required to cause a casualty to become incapacitated. In fact, some ers during the second half of the twentieth century have predicated their work upon the goal of incapacitating—not killing—the enemy.

METHODOLOGY: DISTINGUISHING BETWEEN LETHALITY AND CASUALTY GENERATION

Death is an outcome that is recognized by all, and lethality—the probability that a casualty will be killed if injured by a specific weapon—should be one of the most commonly used indices of weapons effectiveness. Thus, lethality should be a good discriminator among weapons: The probability that a casualty will be killed if wounded by a bullet fired by an assault rifle should differ from the probability of being killed if wounded by a pellet from a BB gun. Unfortunately, however, weapons designers frequently refer to the ability to generate casualties as a weapon's "lethality." This usage is misleading. A weapon that is very likely to kill may not normally cause many casualties, and a relatively inefficient weapon may generate many nonfatally wounded casualties.

Rarely, sources can be found that document the number of casualties that a single use of a weapon will make.[4,5,6] These allow one to contrast lethality defined as casualty generation (the weapons designers' sense of the term) with lethality defined as the probability that a casualty will be killed if injured by that weapon's single use (this textbook's definition, because it is the more medically relevant). Three weapons and their effects illustrate the shortcomings of using the terms "casually generation" and "lethality" as if they were synonyms: *(a)* the Japanese model M 97 hand grenade that was used in the Bougainville Campaign during World War II, *(b)* the 17-kilnfon(kt) atomic bomb that was used at Hiroshima during World War II, and *(c)* the sword as Homer described its use in his *Iliad* and Virgil in his *Aeneid* (Table 2-1). Obviously, a properly used sword can be very lethal, but no one would suggest that a battlefield dominated by cutting weapons is a more lethal place than **a** city under nuclear attack. Furthermore, the relatively inefficient hand grenade is militarily more useful than the very deadly sword, because a hand grenade's single use can wound more soldiers. A weapon such as a 12-kt atomic bomb can injure vast numbers (its casualty generation) even though the fraction of the total number of injured who were actually killed (its lethality) is less than that of a weapon such as the sword, which has a very high lethality but injures only one at a time. While both definitions of lethality may have their uses, for purposes of this textbook, medical officers must carefully distinguish lethality—the fraction of the total number injured who have a fatal outcome—from casualty generation—the number of individuals in the target population who are injured by a single use of the weapon.

Lethality

Data on the lethality of historical weapons are not readily available. To calculate a weapon's lethality (that is, the probability that the casualty will die after being injured by the weapon in question), one needs to know the number of casualties produced by the weapon

TABLE 2-1

THE TWO DEFINITIONS OF LETHALITY

Weapon	Number Injured by a Single Use of the Weapon	Probability of Being Killed if Injured by the Weapon
Grenade	6–8	0.06
Atomic bomb	–144,000	–0.5
Sword	1	0.95

Source: References 4, 5, and 6

and, of these, how many died.

Two major sources of error cloud lethality assessments: missing data and the effect of medical care. Inadequate sampling and inaccurate data are common for the category "killed in action." Even during this century, only a small fraction of those killed in action have been accurately diagnosed at autopsy, with an accurate assessment of the wounding agent made by an ordnance expert. Even when this has been attempted, the difficulty of deciding which weapon made the wound is frequently so great that even an ordnance officer (to say nothing of field medical personnel, who are expected to fill out a field medical tag specifying the weapon) cannot make an accurate determination. Explosive munitions make the problem of identifying the wounding weapon especially difficult. For example, wounds made by a mortar bomb may not be distinguishable from wounds made by an artillery shell. Frequently all the data collector can do is to indicate that the wound was made by an explosive munition and not by a bullet. And complicating the matter, some casualties will have wounds made by both bullets and fragments, or combined injuries from burn, blast, and ballistic weapons.

Medical care can change the likelihood that a casualty will die from a wound and therefore can decrease the weapon's lethality. For example, during the Civil War, the hospital mortality rate for open comminuted femoral-shaft fractures caused by bullets was more than 50%.[7] The same injury in the Vietnam War was associated with a hospital mortality rate of 1.4%.[8] But one would be quite wrong to conclude that this dramatic fall in mortality resulted from less-lethal bullets being used in Vietnam.

There are several ways to avoid the errors that the effect of medical care can introduce. First, lethality should be calculated only for **those** casualties who are actually killed in action (that is, those who die before they receive any medical care). Unfortunately, this is not always possible; original source material may list only the total mortality and not distinguish between the categories "killed in action" and "died of wounds." Second, if only total mortality data are available, one should attempt to compare lethalities only for wars of the same era, which will minimize the effect of greatly differing medical capabilities.

Casualty Generation

The Requirement for an Operational Definition. The index of a weapon's effectiveness that a soldier thinks of first—the weapon's ability to kill or injure—is, unfortunately, not usable for several reasons. First, the number of casualties generated by the single use of a weapon will depend not only on the characteristics of the weapon, but also on the number of potential casualties (the at-risk population) that are available. Second, in order to generate casualties, the weapon must be used effectively. (Firing into the ground is less **likely** to **cause** casualties than firing into **a** crowded room.) Third, almost no data exist that tell how many times a weapon was used to generate the observed number of casualties. Nuclear weapons are an exception (only one atomic bomb was used at Hiroshima), but for most weapons these data are not known. For example, the conventional wisdom is that at least 10,000 rounds were fired from small arms for every casualty wounded by a bullet in World War II. But little understanding would be gained by referring to the casualty generation of military small arms as 1/10,000. (Snipers can achieve better results with bullets; data from the Vietnam War indicate that one casualty was caused by every 1.5 bullets fired by snipers.') Given these limitations, an alternative definition of casualty generation is required. This textbook defines casualty generation as that fraction of the total casualty population produced by a given type of weapon. Ample data do exist from a variety of wars, campaigns, and battles that allow this definition to be used.

Changes in the Distribution of Casualties by Weapon. Although penetrating trauma caused by fragmentation munitions and especially explosive shells have been the major source of casualties on the modern battlefield, this is a rather recent development. During most of the nineteenth century, infantry weapons dominated battlefields, first smooth-bore muskets and then rifles. The predominance of small arms is quite apparent in casualty data from the

TABLE ***2-2***

SOURCES OF UNION CASUALTIES IN THE CIVIL WAR

Weapon or Missile	Casualties
Rifle or smooth-bore musket	124,000
Fragments from shells	12,500
Cannonball or grapeshot	359
Cutting weapons	7,002

Source: Reference *5*

American Civil War (Table 2-2).[5]

The casualties in the Franco-Prussian War of 1870–1871 were similarly distributed: Rifles were responsible for 92% of German wounded and 91% of German killed.[10] But by the end of the century, technological changes (such as smokeless powder and mechanisms for controlling recoil, which made the artillery that dominated World War I battlefields possible) had occurred. The proportion of the World War I casualty population that was caused by fragmentation weapons had changed dramatically since the late nineteenth century (Table 2-3).[10]

While small arms were the source of 39%–51% of German casualties, they were responsible tor only 8%–14% of American casualties. Such major differences raise important questions that illustrate some of the limitations of analyzing historical sources.
validity of one or both sets of data must be questioned, or the two sides fought with fundamentally different tactics. Perhaps the German commanders utilized artillery in both attacking and defending, or the Americans depended more upon infantry weapons. Regardless of the reason for these differences, these data suggest that the proportion of the total casualty population that is generated by a given weapon can be quite variable.

Methodological problems that result from data-collecting protocols must also be considered. Published data on the sources of casualties by weapon frequently fail to state whether the data pertain to the total casualty population (that is, those killed outright, plus those who died later of their wounds, plus those who were wounded but survived) or only to those casualties who were hospitalized. Uncertainty in assessing the data also arises from the data collectors' inability *(a)* to count all the dead and *(b)* to accurately identify the weapons that were the cause of death. Assessments of the causes of death are sometimes based upon surprisingly small samples. The German history of World War I upon which Table 2-3 is based states that 39% of German casualties who were killed were victims of bullets, based upon the analysis of 14,486 casualties.[10] Although an impressively large number, it is less than 1% of the total German battle deaths in World War I.

That errors in counting are responsible for some of the variation from war to war seems certain, but comparing German and American data from World War I almost certainly reveals two more important factors: *(a)* the technological state of weapons design and construction, which determines the weapons that are available, and *(b)* the tactics and the military operational situation, which determine the weapons that are used and how they are deployed.

ASSESSING WEAPONS EFFECTIVENESS IN MODERN WARS

Of the modern sources pertaining to weapons effectiveness in recent wars, ten contain information that was gathered with enough precision to be considered here. Although they will be used to assess weapons effectiveness, only two of them — the Bougainville and Wound Data and Munitions Effectiveness Team (WDMET) studies — were specifically designed for that purpose. The others **must** be considered in light of the constraints (misleading definitions, missing data, effects of medical care on the casualties, and so forth) that were discussed above. In all cases, the lethalities, based on information contained in the

TABLE 2-3

SOURCES OF ARMY CASUALTIES IN WORLD WAR I

Missile	German 1914–1917		English (no dates given)	American 1918		French 1918
	wounded	killed	wounded	wounded	killed	wounded
Bullet	51%	39%	39%	14%	8%	30%
Fragments*	46%	56%	61%	85%	92%	58%

*Shells, grenades, and mortar bombs

Source: Reference 10

tables or their original source material, were calculated especially for this chapter.

The German-Russian Front, 1944

German data, analyzed at the German Central Archives for Military Medicine in Berlin, include clinical records, roentgenograms, and hospital and field sick-report books that were collected during World War II. Little is known about the methods used in the field to obtain the original data. Apparently, statisticians at the Central Archives in 1944 took random samples known as spot-checks but "unfortunately, the exact figures for these spot-checks, which were made on a very wide scale, are no longer available."" Although the data were compiled in 1944, they almost certainly pertain to actions fought on the **eastern** front during the preceding ***3*** years (Table 2-4).

These data are valuable insofar as they are categorized by weapon. Since the absolute number of casualties is not known, however, a calculation of the casualty generation is impossible, although some of the entries such as wounds caused by bayonets, blows from rifle butts, and being run over by a tank must describe rather unusual events. Some weapons are more lethal than others. Antitank shells are very likely to kill; therefore, they cause few minor wounds. Hand grenades and mortar bombs cause few deaths but proportionately many casualties who need medical care. The most important fact is that wounds made by explosive projectile munitions used against personnel (not against tanks) were fatal 8% of the time for mortar shells and 19% of the time for artillery shells. Their calculated lethalities were 0.08 and 0.19. Bullets were fatal 30% of the time; their lethality was 0.30.

The Bougainville Campaign, February-April 1911

American data collected during the Bougainville Campaign constitute a unique study valuable for its essentially prospective organization, comprehensive

TABLE 2-4

GERMAN CASUALTIES ON THE RUSSIAN FRONT

Wounding Weapon	Percentage of Casualties		
	Killed in Action	Seriously Wounded	Slightly Wounded
Armor-piercing and antitank shells	69	22	9
Bayonet	***64***	14	22
Blow from rifle butt	62	**31**	**7**
Run over by tank	34	**33**	**33**
Infantry projectiles (rifles, machine guns, submachine guns, and pistols)	30	31	3Y
Land mine	***22***	40	38
Aircraft bomb	20	37	43
Artillery shell	19	29	52
Hand grenade	17	18	65
Mortar shell	8	31	61

Source: Reference 11

coverage, and depth of detail. For example, the data collectors took great care to assure that the casualty's *disposition* was known (that is, they determined whether the casualty returned to duty and, if *so,* from what echelon of care). Their depth of detail included using ordnance officers to identify weapons and requiring that complete autopsies be performed on the dead. Unfortunately, the original data probably no longer exist, but the study contains detailed descriptions of the methods that were used to organize and collect the data.[4] Althoughabsolutely authoritative in its description of low-intensity, light-infantry actions, this study has little applicability to high-intensity warfare, in which thc battlcficld is dominatcd by artillcry, aircraft, and armor (Table 2-5).

The term "dead" as it is used in this study applies both to casualties who were killed in action and those who died later of their wounds. The extent to which medical care altered the lethality is probably very small, since the study reports that over 90% of the mortality was killed in action.

Data were collected separately for casualties wounded by bullets from rifles and machine guns, and bullet wounds were tallied separately from fragment wounds. The calculated lethality of a wound made by a rifle bullet was 0.32 and for machine guns, 0.58. The higher lethality for machine guns probably indicates multiple bullet wounds. Bullets from both sources caused 34% of the total number of casualties, but because bullets are likely to kill, they caused a disproportionately greater number of those fatally wounded (62%). Only 25% of the casualties who required treatment were wounded by bullets, but 72% were wounded by fragments.

Mortars alone caused about 38% of the total casualties, but their lethality was only 0.12. The lethality of fragments from all explosive munitions (that is, mortars, grenades, artillery, and mines) averaged 0.11. In view of the difficulty in deploying conventional artillery in an overgrown, triple-canopy jungle island **like**

TABLE 2-5

AMERICAN CASUALTIES IN THE BOUGAINVILLE CAMPAIGN: CASUALTY GENERATION AND LETHALITY BY WEAPON

Weapon	Total Casualties	Living	Dead	Lethality of Weapon
Mortar	693	611 (43%)	87 (22%)	0.12
Rifle	445	302 (21%)	143 (38%)	0.32
Grenade	224	210 (15%)	14 (4%)	0.05
Artillery	193	172 (12%)	21 (6%)	0.11
Machine gun	152	64 (4%)	88 (24%)	0.58
Mine	**34**	21 (2%)	13 (3%)	0.38
Miscellaneous*	47	35 (3%)	12 (3%)	0.26
Totals	1,799	1,415	373	
			Average Lethality:	0.21

'Aerial bombs, pistols, bayonets, and similar weapons

Source: Reference 4

Bougainville, it is interesting to note the important casualty-generating role that mortars played. In this tactical milieu, bullets did most of the killing, but fragment wounds constituted most of the military surgeons' work, similar to the situation that was occurring at the same time in the European theater.

Although this study is far and away the most authoritative on weapons effects, the tactical situation that existed in Bougainville does not describe tank-heavy mechanized operations such as those that have occurred in Europe and the Middle East.

British Data from the Invasion of Normandy, June-July 1944

One of the British operational research groups who studied the Normandy invasion obtained these data retrospectively by analyzing field, medical, and hospital records. Since the data are based upon 3,609 of the approximately 50,000 casualties sustained by the British over the 6-week Normandy campaign, the sampling methodology is a variable that might limit the data's usefulness (Table 2-6).[12]

Although the invasion of Normandy was discrete in time and place, these data were collected from a heterogeneous assortment of tactical deployments including an amphibious invasion, several urban battles, and an enormous armor engagement (Operation Goodwood). About two-thirds of the hospitalized casualties had fragment wounds and one-third had bullet wounds. The percentage of bullet wounds shown in Table 2-6 is about 50% greater than the overall American rate in Europe, but a direct comparison of the two rates is not appropriate; the American experience in all European theaters was even less homogeneous than the British experience was at Normandy. Interestingly, Table 2-6 shows a distribution of casualties by type of projectile (bullet versus fragment), but not by weapon, that is similar to the distribution observed for hospitalized casualties in Bougainville (Table 2-5).

As the German data collectors had done (Table 2-4), the British data collectors made an effort to stratify

TABLE 2-6

BRITISH CASUALTIES IN THE NORMANDY INVASION

Weapon	Percentage of Total Casualties	Severity of Injuries: Trivial	Medium	Severe	Lethal	Calculated Lethality
Mine	4	34	42	33	25	0.19
Bomb	4	64	22	26	35	0.24
Shell	39	450	303	281	356	0.27
Mortar	21	184	228	199	134	0.18
Grenade	1	13	10	8	5	0.14
Gunshot	31	177	235	284	439	0.39
Bayonet	—	3	4	2	4	0.31
Multiple	—	—	3	6	—	—
	Total Wounded	925	847	839	998	

Source: Reference 12

the casualties by the degree of severity of their Injuries. Injuries classified as *minor* probably did not require admission to a medical treatment facility; those classified as *medium* may incapacitating (like fractures), but were unlikely to cause death; those classified as *severe* were probably critical life-threatening injuries (like penetrating head wounds); and *lethal* refers to the total mortality (that is, both the casualties who were killed outright and those who died later of their wounds). This study's potential weakness lies in its using the total mortality, because the effect of medical care cannot be gauged. The error, however, is likely to be small, because about 83% of the total British combat mortality during the campaign were killed outright.

Casualties wounded by shells appear to be distributed bimodally, with peaks occurring at both ends of the injury-severity curve. The distributions of gunshot and mortar wounds each show a single peak, skewed toward less-serious injuries for mortar wounds and more-serious injuries for bullet wounds. The data clearly show that a gunshot wound was more likely to be serious than a wound made by any other weapon.

Grenades played a dt overall lethality for fragmentation weapons is calculated to be 0.23, which is significantly less than the 0.39 lethality associated with bullets **A** grenade's range was determined then solely by the distance that a soldier could throw it—obviously much less than the ranges of guns.

TABLE **2-7**

ESTIMATED LETHALITY OF WEAPONS USED AGAINST THE U.S. ARMY DURING WORLD WAR II

	Lethality	
Wounding Weapon	Killed	Killed and Died
Small arms	**0.34**	0.38
Explosive projectile shells	0.22	0.26
Rockets and bombs	0.22	0.26
Grenades	0.05	0.08
Mines	0.18	0.22

Source: Reference 13

U.S. **Army** Casualties **in** World **War** II

Nearly 25 spent analyzing statistical samples obtained from medical field cards, unit operational records, and hospital records of the nearly one million American casualties of World War II. Of the problems inherent in analyzing such an enormous mass of raw data, the most serious potential threat to the accuracy of these data is the questionable validity of the original records that were entered in the field, especially those casualties in the "killed" category (Table 2-7).[13] The unfortunate need to pool together data from differing campaigns, battles, time frames, and even different services (that is, the army's land forces and air corps) created another weakness in the database.

These data suffer from two serious potential defects. First, the diagnosis of the cause of death and the identification of the ordnance responsible for those casualties who were killed in action depended upon the accuracy of the field medical tag or the death certificate. **A** recent analysis of the WDMET database of casualties from **the** Vietnam War suggests **that** the weapons were misidentified in at least 25% of the cases; it is safe to assume that these determinations were made no more accurately during World War II than they were during the Vietnam War.[8]

The second potential source of error stems from the manipulation of the data that needs to be performed in order to obtain the figures shown in Table 2-7. Published data give the percentages of casualties who were wounded by weapons of various types and who were classified as *(a)* **killed** in action, *(b)* died of wounds, and *(c)* wounded in action but survived. To calculate the percentage of casualties wounded by a given weapon, statisticians must necessarily weight the outcome categories by their observed frequencies. The required data in this instance are the percentages of the total casualty population in each of the outcome categories. These data for the U.S. Army in all theaters of World War II are: 24.5% killed in action, 3.4% died of wounds, and 72.1% wounded but survived.[13] Bearing in mind that multiplying two sets of data—each of which is subject to error—will compound the error, the calculated lethalities of 0.34 for small-arm wounds and 0.21 for fragment wounds are, surprisingly, quite similar to those observed in the British study of Normandy casualties (Table 2-6). The database also treats the fatal (killed in action) and nonfatal (hospitalized) wounds suffered by U.S. Army casualties separately (Tables 2-8 and 2-9).

Overall, the U.S. Army in World War II sustained about one-third of its battle deaths and about one-fifth

TABLE 2-8

U.S. ARMY CASUALTIES KILLED IN ACTION IN WORLD WAR 11, BY MUNITION

Casualty	Total	Theater of Action* EUR	MED	SWP	POA
		Numbers and Percentages of Known Killed**			
Killed	192,220	120,043	35,185	19,426	12,361
Killed by known munition	90,975	53,553	18,809	11,940	4,278
Bombs	1%	1%	2%	2Yo	2Yo
Shells***	50%	52%	65%	28%	40%
Bullets	32%	33%	20%	52%	44%
Mines	2%	2%	4%	2%	2%
Grenades	—	—	—	1%	1%

*EUR: European Theater
MED: Mediterranean Theater
SWP: Southwest Pacific
POA: Pacific Ocean Area
**Sums are less than 100% because combat losses sustained in aircraft and armored fighting vehicles were excluded
***Shell: artillery and mortar

Source: Reference 13

of its hospitalized wounded from bullet wounds. The great majority of the remainder in both categories sustained fragment wounds. When viewed theater-by-theater, the only significant deviation from this pattern is the higher proportion of casualties with bullet wounds in the Southwest Pacific Theater; this no doubt reflects the tactical realities of jungle warfare. Comparing the relative importance of small arms as a source of casualties in Europe in the two world wars (Tables *2-3* and 2-9) reveals the unexpected finding that small arms were more significant during World War 11. One might have expected that the highly mechanized campaigns in Europe during 1944–1945 would have deemphasized the importance of the infantryman and his rifle. Apparently this did not happen, perhaps because much of the actual fighting was done by mechanized or motorized infantry. Of course, the logic of speculating about the impact of American tactics by studying American casualties is flawed; we need to know the sources of casualties in the German army in France and Germany but, unfortunately, such data no longer exist.

U.S. Army Casualties in the Korean War, **1950-1953**

The official U.S. Army medical historian of the American experience in Korea required nearly 15 years to analyze the data obtained from the more than 100,000 American army casualties of the Korean War. This database is considerably more valuable to medical officers seeking to understand the nature of combat injury and field medical care in general than the same author's World War II medical-statistics volume.[14] Not only was the database from Korea a more manageable size than the World War II database, but the statisticians also recognized that lumping together data from diverse time frames and tactical postures was unsatisfactory. Once again, the accuracy of data recorded in the field must not be taken for granted, and an independent source did not specify the proportion of casu-

TABLE 2-9

U.S. ARMY CASUALTIES HOSPITALIZED IN WORLD WAR 11, BY MUNITION

Casualty	Total	EUR	MED	SWP	POA
		Theater of Action*			
	Numbers and Percentages of Total Hospitalized Population*"				
Hospitalized	599,724	393,987	107,323	59,646	33,556
Munitions involved					
Bombs	2%	1%	2%	3%	3%
Shells***	57%	59%	62%	41%	49%
Bullets	20%	19%	14%	32%	29%
Mines	4%	4%	5%	2%	1%
Grenades	2%	2%	2%	7%	2%

*EUR: European Theater
MED: Mediterranean Theater
SWP: Southwest Pacific
POA: Pacific Ocean Area

**Sums are less than 100% because combat losses sustained in aircraft and armored fighting vehicles were excluded
**'Shell: artillery and mortar

Source: Reference 13

alties in each outcome category. Nevertheless, the lethalities of the weapons employed (Table 2-10) can be computed. The sample population contained about 42% of the total American soldiers killed in action in Korea; 19.7% were killed in action, 2.1% died of their wounds, and 78.2% were wounded but survived. The lethality of small arms during the Korean War (0.26) is about one-third below that calculated for all previous wars, but the overall lethality for fragmentation weapons (0.22) is similar.

Table 2-11 presents the actual numbers of U.S. Army soldiers who were wounded during the Korean War. When the data are examined by weapon, the large number of soldiers whose deaths could not be definitely attributed to a specific weapon makes the implausibly low lethality calculated from the crude data suspect (for example, for grenades, 0.01 and for bullets, 0.11). However, if we assume that the sample of those killed for whom the causative weapon has been assigned accurately reflects the whole, then bullets killed 33% and fragments 62%.

We are on more solid analytic ground when examining the data for those casualties who were wounded: Bullets wounded 28% and fragments wounded 66%. One of the most valuable aspects of this database is its description of how the tactical situation alters the mix of wounding weapons. The data (available for wounded only) indicate that small arms caused almost one-half the wounding in operations such as pursuits and withdrawals. When soldiers were engaged in static defensive operations from fixed lines, however, bullets accounted for only about 15% of the casualties. These differences undoubtedly arise from the fact that concealment and cover are much more difficult for soldiers to obtain when they are either advancing or retreating. Furthermore, since whole campaigns can be so characterized, it is not surprising to find that during the period July-November 1950, when the front rapidly shifted back and forth, small arms accounted for 37% of the casualties. Conversely, only 11% of them

TABLE 2-10

ESTIMATED LETHALITY OF WEAPONS IN KOREA

	Lethality	
Wounding Weapon	Killed in Action	Total Killed in Action and Died nf Wnunds
Small arms	0.23	0.26
Explosive projectile	0.20	**0.22**
Shells, rockets, and bombs	0.17	0.34
Grenades	0.03	0.04
Land mines	0.22	0.25
Other fragmentation munitions	0.50	0.54

Source: Reference 14

sustained bullet wounds during the period October 1951-July 1953. During this time, as truce talks proceeded, the tactical situation was defensive and conducted behind well prepared fortified lines, reminiscent of World War I trench warfare.

TABLE 2-11

AMERICAN SOLDIERS KILLED AND WOUNDED IN KOREA, BY WEAPON

Missile	Killed	Wounded
Bullet	2,584	19,833
Shell	3,859	36,379
Mine	305	2,401
Grenade	97	***6,557***
Unknown	10,643	1,377

Source: Reference 14

U.S. Army and Marine ***Corps*** Casualties in Vietnam, **1965–1970**

Although the official medical statistical history of the Vietnam War has not yet been published, information exists on weapons effects.[15, 16] The most authoritative and useful database on the nature of combat injury extant was compiled by WDMET in Vietnam. It **consists nf** **(written records and** photos) of *(a)* the tactical posture, *(b)* the nature of the wound (including autopsy results for those killed), *(c)* the wounding weapon, *(d)* the field care, and *(e)* the hospital care for nearly 8,000 U.S. Army and Marine Corps casualties during 1967–1969. Ironically, the WDMET database describes the same type of warfare—low-intensity, that the Bougainville study covered. No database that specifically applies to understanding the nature of combat injuries in high-intensity warfare with its abundance of armor, aircraft, and artillery exists.

The analysis of the wounded in Vietnam shown in Table 2-12 shares the problems that analyses of other databases have—the accuracy of the field data and the need to specify the proportion of casualties in the outcome categories—with the added difficulty that the actual number of American casualties in the Viet-

TABLE **2-12**

U.S. ARMY CASUALTIES IN VIETNAM: OUTCOME BY TYPE OF WEAPON

	Outcome		Lethality Assumptions	
Wounding Weapon	Deaths	Survivors	**A***	B**
Small arms	51%	16%	0.49	0.30
Fragmentation munitions	**36%**	65%	0.14	0.07
Mines and booby traps	11%	15%	0.15	0.08

*Assumption ***A.*** excluding those carded for record only, 23% were fatally wounded
Assumption B: including those carded for record only, **12% were fatally wounded
Source: Reference 15

nam War is still disputed. Data shown under Assumption A excluded those casualties who were carded for record only, while Assumption B included them.[3]

It is intriguing to compare the American experiences in France in 1918 with those in Vietnam 1965–1970. If the wounding weapon were the sole criterion, surgeons might have difficulty telling the two wars apart. Yet, a comparison of the casualties who did not leave the battlefield alive tells a different story. In Vietnam, 51% of those killed (Table 2-12) sustained bullet wounds, while in France in 1918, fewer than 10% of those who were killed were hit by bullets (Table 2-3). The tactics and weapons employed in both wars must be incorporated into a of both the similarities and dissimilarities. Small-unit actions with frequent, deadly firefights characterized the action in Vietnam. When the enemy used fragmentation weapons, they did not employ conventional artillery of the type that made the massive barrages that occurred in World War I possible, but rather they used mortars and grenades: low-lethality but high-casualty-generating weapons. Most soldiers and marines were killed by assault rifles during firefights, while most casualties were wounded by mortars and rocket-propelled grenade attacks on base camps (Table 2-13).[15] These data are perhaps the best twentieth-century examples showing that the tactical situation determines the casualty proportions that various kinds of weapons cause. During the search-and-destroy missions that were conducted in 1966, assault rifles were the weapons most likely to be used against American troops. By 1970, American forces were confined to base camps, and the only way the enemy could attack them was to employ rockets and mortars.

TABLE 2-13

U.S. ARMY CASUALTIES IN VIETNAM: TACTICAL POSTURE AND TYPE OF MISSILE

Projectile	Casualties" per Tactical Posture	
	Search and Destroy (1966)	Base Defense (1970)
Bullets	42%	16%
Fragments	50%	80%

*Wounded in action only
source: Reference 15

In the particular sample of the WDMET database from which these data were gleaned (Table 2-14), the data collectors were nearly certain whether individual wounds were inflicted by bullets or by fragments from explosive munitions. Fifteen percent of the total group wounded by bullets and 29% of those killed by bullets had multiple wounds. About 75% of those with fragmentation wounds had multiple injuries. Since the 290 casualties sustained a total of 426 bullet wounds, the probability that **a** casualty would be fatally wounded

TABLE 2-14

U.S. ARMY CASUALTIES IN VIETNAM: OUTCOME BY TYPE OF PENETRATING MISSILE

Missile	Fatal	Nonfatal	Lethality
Bullets	124 (36*)	166 (7*)	0.43
Fragments	56	320	0.15
Both bullets and fragments	4	7	

*Multiple wounds
Source: Reference 8

by a single bullet can be calculated to be about 0.30.[8,16]

The data contained in Table 2-15 are drawn from two WDMGT sources: *(a)* one that **lists** 7,964 casualties (essentially all of the WDMET casualties) both killed and wounded, caused by nineteen different types of weapons;[17] Table 2-15 records only the seven most common (which caused 91% of the total injuries); and *(b)* another that lists 5,329 wounded casualties.[18] Although the difference between these two casualty totals should equal those killed in action, the two sources of data comprising Table 2-15 do not exactly correspond. The second source lists more than thirty wounding-weapon categories; therefore, calculating lethality in this instance is inappropriate.

The WDMET database reflects the overall American casualty rate in the Vietnam War. Forty-six percent of those killed and 27% of those who **survived** long enough to be evacuated from the battlefield sustained bullet wounds. This distribution of casualties by weapon represents low-intensity or counterinsurgency actions in general. Most of those killed had been hit by small-arms fire and most of the surviving wounded had been injured by fragments produced by lower-lethality weapons including mortars, booby traps, and hand grenades. (An unknown fraction of the total casualty population, but almost **certainly** more than 10%, **were victims** of friendly fire.) Among those casualties not injured by bullets, the proportion of those fatally wounded may increase in the future, if weapons using shaped-charge warheads

TABLE 2-15

U.S. ARMY IN VIETNAM: CASUALTY GENERATION BY WEAPON

Weapon	Killed	Wounded	Percentage of Total
Bullets"	926	1,455	30
Mortars	187	1,299	19
Booby traps	388	734	14
RPG series**	396	561	12
Hand grenades***	115	786	11
Antipersonnel mines	30	239	3
Artillery	59	180	3

'About one-half were caused by AK47s; M16s caused 10% of the killed and **12% of** the wounded.

'Shaped-charge warhead weapon of Soviet design, of **which the** RPG **2 and** RPG **7** were the most common, used against both materiel and personnel

***Excluding rifle grenades and grenades that were used as booby traps

Source: **References 17 and 18**

TABLE 2-16

BRITISH CASUALTIES IN NORTHERN IRELAND

Wounding Weapon	Outcome: Fatal	Nonfatal	Lethality
Low-velocity bullets'	35	430	0.08
High-velocity bullets'"	152	261	0.37
Fragmentation munitions	5	33	0.13
Homemade bombs	10	164	0.06
High-explosive devices	79	281	0.22
Hand-thrown missiles	0	304	—

*Of the 465 casualties with low-velocity bullet wounds, ninety were known to have wounds made by 0.22-inch, 0.38-inch, 0.45-inch, or 9-mm bullets. Lethality in this subgroup was 0.24.

'"'Of the **413** casualties with high-velocity bullet wounds, **169** casualties were known to have wounds made by 0.303-inch, 0.30-inch, M1 Garrand, 5.56-mm, or 7.62-mm bullets. Lethality in this subgroup was 0.46.

Source: Reference 19

such as dual-purpose submunitions become more widespread.

Of course, we do not know the distribution of casualties by type of wounding weapon for the Viet Cong and North Vietnamese. The percentages of both those killed and those who survived their bullet wounds were probably quite low. The great majority of their casualties probably sustained fragmentation wounds from both conventional artillery and from rockets and bombs delivered by tactical air strikes?

British Casualties in Northern Ireland, 1969-Present

Using computerized data-entry forms, the British in Northern Ireland have compiled a state-of-the-art databank, and the information it contains is probably typical of the weapons effects seen in urban terrorist incidents (Table 2-16).[19] The data clearly show that small arms of military design killed by far the most casualties **(54%)**. Overall, bullets caused a much higher proportion of the total wounded population than is commonly found on battlefields. This study is especially valuable because it permits comparison between the lethalities of typically military (0.37, the high-velocity bullets) and typically civilian (0.075, the low-velocity bullets) small arms. Furthermore, while 9% of the survivors of the low-velocity bullet wounds were found to be unfit for duty, 21% of survivors of high-velocity bullet wounds were considered unfit. The blast effects from high-explosive devices were second only to bullets as a cause of death.

Israeli Casualties in the Israeli-Lebanon War, 1982

While no official study applying to weapons effects and the nature of combat injuries in the Israeli-Lebanon War has yet been published by the government of Israel, two sources of information do exist. First, an entire issue of *Israeli Journal of Medical Science* was devoted to medical problems encountered in Lebanon.[20] The method of collecting data was rather interesting: Medical students on active reserve military status were assigned the task of preparing the data-collection forms, which frequently included interviewing surviving casualties (Table 2-17). And second, an Israeli medical officer collected data comparing the nature of combat injuries by weapon (Table 2-18) and in two distinctly different tactical postures: urban fighting and rural armor operations (Table 2-19).[21]

TABLE 2-17

WEAPONS EFFECTS IN THE 1982 ISRAELI-LEBANON WAR: I

Wounding Weapon	Percentage of Total Wounded	Hospitalized (N)	Killed (N)	Lethality
Shells (mortars, cannons, rockets)	77	827	80	0.11
Bullets	23	181	86	0.31

Source: Reference 20

These two sources probably include some of the same casualties; thus, information from the two databases cannot be added together.

Whether or not the data in Table 2-17 includes those casualties who died of their wounds is not specified, but the data in Table 2-18 definitely excludes this category. The data in the "hospitalized and "killed' categories in Table 2-17 are from different researchers and may not be samples from the same original population of casualties. Table 2-17 indicates that only 11% of casualties wounded by fragmentation weapons were killed, but in Table 2-18, 25% of all casualties who were injured by fragments were killed. This large discrepancy seems unlikely to be an artifact of the data-collecting methodologies. About 20% of the data included in Table 2-17 pertains to casualties killed by antitank weapons, but whether their deaths were directly due to the weapons or to indirect causes such as secondary explosions cannot be determined.

Additional data apply to the effects that tactical posture and terrain have on the distribution of injuries caused by specific types of weapons (Table 2-19). The Israeli medical officer who collected these data sought to determine if differences existed between the distribution of wounds by weapon (the "epidemiology" of combat casualties) in urban and nonurban (open-terrain) warfare. Data were collected from two groups of Israeli casualties: *(a)* those injured while fighting in Beirut and several other cities and towns and *(b)* those injured while fighting in armor and mechanized operations in the field (especially the Bekka valley), which has characterized previous Israeli wars. Surprisingly, the Israeli findings do not conform to the picture of urban warfare that developed from the World War II experience. In Stalingrad, for example, small groups of assault troops, armed with grenades and automatic weapons, engaged in savage room-to-room and building-by-building fighting, interspersed with one side or the other calling in artillery or air strikes to demolish an enemy's position. Rather than showing the expected high incidence of casualties with wounds made by small arms, these data actually show the opposite. The major differences seen between the two groups are *(a)* the higher incidence of fragmentation injuries caused by explosive projectiles from artillery and mortars found in urban fighting and *(b)* the higher incidence of casualties injured by aerial bombs and antitank guns found in nonurban fighting. Rocket-propelled grenades (RPGs), the ubiquitous shaped-charge warheads, were commonly used in both tactical postures.

TABLE 2-18

WEAPONS EFFECTS IN THE 1982 ISRAELI-LEBANON WAR II

Wounding Weapon	Wounded (N)	Killed (N)	Calculated Lethality
Artillery*	264	69	0.21
Small arms	198	77	0.28
Bombs	83	24	0.22
Rockets	77	25	0.24
Grenades	62	10	0.14
Mines	52	6	0.12

*Includes mortars

Source: Reference 21

TABLE **2-19**

DISTRIBUTION OF ISRAELI CASUALTIES IN THE 1382 ISRAELI-LEBANON WAR BY WEAPON AND TERRAIN

Wounding Weapon	Terrain Urban (N) = 580*	 Nonurban (N) = 820*
	Percentage of Total Casualties	
Artillery and mortars	33	17
Small arms	18	21
Rocket-propelled grenades (RPGs)	19	10
Antitank weapons	3	10
Bombs	2	12
Rockets	5	9
Grenades	6	4
Mines	4	4
Booby traps	2	1
Miscellaneous	9	12

*Casualty count includes both killed and nonfatally wounded.
Source: Reference 21

ASSESSING LETHALITY

All sources agree that the probability that a bullet wound will have a fatal outcome is about one in three, except for the notably different findings from the Korean War. It is probably safe to say that this means that a bullet striking the human body at random will kill about one-third of the time. The lethality of multiple bullet wounds (assuming that the individual wounds are randomly distributed) should approximately equal $1 - (1 - p_1)(1 - p_2) \ldots (1 - p_n)$, where p is the lethality of the *nth* hit. Thus the probability of being fatally wounded by two gunshot wounds, either one of which has a lethality of one-third, should be 0.55. For three wounds, the probability should be 0.70.

Aimed fire by snipers should be more lethal because the head and chest are the usual targets. However, recent data compiled by the British army in Northern Ireland, against whom sniping is common, do not indicate a significant increase in lethality for bullets. Death occurred in 152 of 413 (37%) soldiers hit by high-velocity bullets (mostly 5.56-mm and 7.62-mm), not greatly different from the lethality calculated from other databases.''

The databases that permit calculations of lethality to be made indicate that the lethality of fragmentation munitions appears to range between 0.10 for mortar bombs and grenades to about 0.20 for conventional artillery shells. It is unclear to what extent, if any, data reported from the Vietnam and Israeli-Lebanon wars reflect the lethality of improved-fragmentation munitinns (Tables 2-12 through 2-15 and 2-17 through 2-19) A recent analysis of the WDMET data suggests that the lethality of 105-mm random-fragmentation shells (0.21) is slightly, but not significantly, higher than the lethality of 105-mm improved-fragmentation shells (0.16).[8] Injuries that antitank and antiaircraft weapons make on crews of armored fighting vehicles, ground-support aircraft, and helicopters are generally more lethal than injuries that result from small arms and fragmentation munitions (their lethalities range between 0.4 and 0.8), but since these crews normally constitute only a small fraction of the total force, the infantry ground casualties dominate the overall mortality.

It is possible that a useful measure of the lethality of a battlefield (but not the number of casualties) could be obtained by appropriately weighting the established lethalities of the deployed weapons by the observed number of casualties generated by type of weapon. For example, the probability of being killed if wounded on a battlefield in which only small arms are used should approach one in three. At the other extreme, a battlefield on which only hand grenades were used would perhaps yield one out of ten of those wounded being killed. For any historical battle, the probability of being killed if injured should fall between these two (or similar) limits, and would depend upon the mix of weapons. This approach, if valid, suggests that, in the sense of the probability of being killed if injured, Vietnam was the most lethal battlefield for Americans.

Future dcvclopmcnts will probably not alter thcsc conclusions. If anything, ordnance design is evolving toward *(a)* assault rifles that fire even more rapidly and *(b)* improved fragmentation munitions that create more numerous—but less lethal—fragments, which will increase the tendency for small arms to be the most lethal weapons on conventional battlefields.

ASSESSING CASUALTY GENERATION

The proportion of combat casualties caused by specific types or classes of military weapons has varied widely in the wars of this century. Even if the analysis is confined to the population of those who are killed, the observed proportion of casualties with bullet wounds to casualties with fragment wounds has varied from 1:10 to 1:1. Although the primary determinants of no doubt *(a)* the tactics that are employed and *(b)* the state of weapons technology, simple formulations seem unlikely to explain the observed variations in nf wounds hy their causative weapon. The best that can be said is that fragmentation munitions—whether artillery shells, mortar bombs, or grenades—account for most of the living wounded and those who are killed. Bullets are more lethal than fragments, but fragments injure—and kill—more casualties.

Attackers are likely to sustain a higher proportion of casualties from small arms when they assault a fortified position or move across terrain that offers poor concealment For example (although the actual data do not exist), it would not be surprising to find that the great majority of the German parachutists killed during their airborne assault on Crete in 1941 were hit by small-arms fire. Defenders are likely to be subjected to artillery and rocket bombardment, as well as to airstrikes made with explosive munitions in preparation for an assault. Thus the proportion of fragment wounds will be greater relative to bullet wounds, at least in the early stage of the battle. (Verdun is a case in point. Estimates of French casualties during the first German attack, in February 1916, indicate that artillery caused 80% or more of the wounding.)

But this assessment is too simplistic if it fails to consider other relevant variables. If, as is likely, most German battle casualties in Ci-ete were caused by small arms, it is also likely that the reason why is complex. While the attacking Germans were very exposed as they jnmped frnm their aircraft, the fact that their opponents had only small arms with which to defend their positions is equally important. Comprehending the observed distribution of casualties by weapon requires knowing both the tactical posture and the nature of the deployed weaponry on both sides. The data (both for casualties and weapons) included in this chapter almost exclusively describe the winners of the battles. But understanding why the Israelis observed the types of casualties that they did in Beirut, for example, than a superficial knowledge of how their enemies fought. Perhaps the generally accepted view of them as aggressive street fighters armed with a plentiful supply of AK47s is inaccurate. If so, then the observed percentage of Israeli urban-warfare casualties who were wounded by small arms might not be so unexpected.

MEDICAL CRITERIA FOR ASSESSING WEAPONS EFFECTIVENESS

Quantifying the expenditure of medical resources per casualty by class of weapon is an attractive but little-used operational definition of weapons effectiveness. Theoretically, the use of medical resources can be quantitated by counting the man-days spent caring for each casualty, the number of surgical operations performed per casualty, the money expended, and so forth, but except in isolated instances, such data do not exist. Surrogate measurements such as the average time a soldier spends in a noneffective status per class of weapon, changes in a soldier's physical condition, and the probability that the soldier will be discharged for a medical reason following a combat injury made by a specific class of weapon are both useful and practicable, however.

Data on *(a)* man-days lost and *(b)* the percentage of soldiers discharged, both as functions of the class of injuring weapon, were collected during World War II (Table 2-20).[13] Judging from the days soldiers were noneffective and the probability that they would require separation from the army for medical reasons, injuries caused by land mines and bullets have consumed more medical resources per casualty than injuries that were caused by any other weapon system. About **30%** of those who were shot received disability discharges. If we remember that about one-third of those who were shot were fatally wounded, then it becomes apparent that shooting a soldier will effectively remove him as a combatant. Clearly, however, within the entire casualty population, those with fragmentation wounds from explosive shells utilize medical resources more than casualties from any other weapon category do.

One of the uniquely valuable aspects of the Bougainville study is its detailed determination of the echelon of the medical system that casualties reached before they returned to duty (Table **2-21).** Because Bougainville is a small island and the combat zone included most of it, all casualties requiring more than a few weeks of care were evacuated to safe offshore islands. Furthermore, because the logistics of supporting extensive medical facilities in so isolated an area proved difficult, casualties whose recoveries would require months were promptly evacuated to the continental United States (CONUS). The Bougainville study recognized three levels of care, which modern terminology designates: *(a)* the combat zone, *(b)* the communication zone, and *(c)* CONUS. Bullets were much more likely to cause a wound requiring evacuation to CONUS (implying a serious wound). Conversely, most survivors of fragmentation-munition wounds returned to duty from the combat zone (implying that their wounds, particularly those made by grenades, were of modest severity).

TABLE **2-20**

U.S. ARMY, ALL THEATERS IN WORLD WAR 11: DISCHARGE AND NONEFFECTIVE DAYS AS FUNCTIONS OF WOUNDING WEAPONS

Weapon or Missile	Total Wounded	Disability Discharge	Percentage of Wounded Discharged	Days Non-effective
Shell	**340,651**	**73,158**	**21**	**123**
Bullet	**120,455**	**36,240**	30	**158**
Land mine	**25,529**	**8,267**	**32**	**174**
Grenade	**14,929**	**3,063**	**21**	**105**
Bomb	**10,484**	**1,704**	16	**94**

Source: Reference 13

TABLE 2-21

US. ARMY, BOUGAINVILLE CAMPAIGN: DISPOSITION OF SURVIVING WOUNDED BY CAUSATIVE WEAPON

Weapon	Casualties (N)	Returned to Duty From		
		Combat Zone	Communication Zone	CONUS
Rifle	306	37%	31%	32%
Machine gun	64	34%	17%	49%
Mortar	611	53%	28%	19%
Artillery	150	56%	26%	18%
Grenade	210	63%	14%	18%

Source: **Reference** 4

Data from the Korean War tell a similar story: 37% of survivors with land-mine injuries were evacuated to CONUS, and about one-half of those evacuated were given disability separations. One-third of casualties with wounds made by small arms required evacuation, and one-third of these evacuees were separated. As in World War II, the greatest claim on medical resources came from the large population who had been wounded by shell fragments.“ No data analyzing noneffective days by class of weapon exist from the Korean War.

INDICES OF INCAPACITATION

For more than 100 years, weapons designers and military medical scientists have striven to develop concepts of weapons effectiveness that go beyond such simple outcomes as death and wounding. Their goal has been to find a projectile's measurable property that can be correlated with the probability that it will cause a measurable, functional, militarily relevant disability. More often than not, the projectile's ability to incapacitate has been related to mechanical properties such as the projectile's mass, velocity, and such derived parameters as its momentum or kinetic energy, but contemporary computer-simulation techniques allow a more sophisticated approach.

Historical Attempts to Quantify Incapacitation

One of the first attempts to quantify a projectile's ability to incapacitate occurred during the nineteenth century and concluded that delivering 58 foot-pounds (equivalent to 83 joules in today's nomenclature) of kinetic energy would probably put a soldier out of action. This figure's origin is shrouded in mystery, and its validity is **dubious.** Thought by some to have originated in Germany, it is said to have been derived from experiments in which one-ounce lead balls were shot at horses. Others say that the experiments were done in France, with half-inch balls shot at cadavers.[22]

Whatever its derivation, this approach's obvious weakness lies in the fact that the damage done by 58 foot-pounds depends upon the body part that is hit. (To put 58 foot-pounds of kinetic energy in perspective, a beanball thrown by a major-league pitcher will deliver about 90 foot-pounds, an uppercut by a heavyweight boxer several hundred foot-pounds, most rifle rounds more than 1,000 foot-pounds, and a typical kinetic energy antitank projectile over 1 million foot-pounds.) Obviously, the outcomes when 58 foot-pounds are delivered to a finger and to the brain stem will be quite different. This conceptual deficiency, and the need for a more functional test that recognized the different vulnerability of body parts to injury, has been recognized by several authorities, including the American military surgeon Louis A. La Garde, whose textbook *Gunshot Injuries* was the standard on ballistics and war surgery for many years.[23]

La Garde's involvement in assessing weapons effectiveness dated back to the Spanish-American War and the ensuing Philippine insurrection. Then as now, some ballisticians believed that a bullet striking almost anywhere on the body could cause immediate incapacitation due to shock. The shock itself was thought to make the victim fall down and stop fighting. The pathophysiology of this mysterious phenomenon was believed to be related to an indirect effect of the bullet on the nervous system, and this attribute was referred to as the bullet's stopping power or its knockdown power. Military handguns then in use were found to have inadequate stopping power, since the enemy did not fall down unless the bullet fractured a leg bone or hit a vital organ such as the heart.[24]

La Garde and members of the U.S. Army Ordnance Corps were assigned the task of testing existing pistol ammunition and finding a pistol round with the desired stopping power. Working in the Chicago stockyards in 1904, they shot unanesthetized cattle with various weapons, assessing incapacitation by recording the number of bullets required to knock the animal down. Recognizing that a shot into the heart would have similar stopping power regardless of the ammunition they used, they tried to hit only body parts that would not cause immediate death. In a typical experiment, they shot one animal for each type of ammunition tested and reported:

> .45 Colt 220-grain lead bullet with small flat on *[sic]* point
> **720 fps, 288 foot-pounds**
> 7th animal Bull, 10 years old, 1,300 lbs
>
> Shot through lungs. At 1 minute, shot again through lungs. At 2 minutes 35 seconds, shot through abdomen and fell. At 2 minutes 45 seconds, shot again through abdomen, got up, then fell again—tried to regain his feet for 70 seconds—and was killed by hammer blows to the head.[24]

The sad truth about wound-ballistics research is that much information that could be relevant and important is gathered under conditions that are barbarous as well as scientifically unsound, and information that is more esthetically pleasing and scientifically elegant often consists of esoterica that are meaningful in a laboratory but irrelevant to battlefield conditions. While La Garde's Chicago-stockyard experiments fall into the relevant-but-barbarous category, they showed that no shock, stopping-, or knockdown power was observable beyond that directly attributable to the effect of the bullet at the site of wound. His official report stated the only reasonable conclusion regarding handguns: "[They] offer no hope of stopping an adversary by shock."[24] Inexplicably, not only did La Garde not restate this firm conclusion in *Gunshot Injuries*, he also misquoted his own official report, and suggested that he had actually observed shock. Because of this misinformation, for the past 70 years ballisticians have continued to search for a mathematical explanation of the shock that La Garde said he observed in bullet wounds made by handguns.

Wounds made by military rifles and machine guns are frequently incapacitating, however. One of the specific goals of the WDMET study was to collect information on the behavior of soldiers after they were wounded. The database also includes the soldiers' (and their buddies') recollections of their behavior just before they were wounded. Almost every casualty who was shot—whether in the head, trunk, legs, or arms—immediately stopped his pre-wounding behavior. In fact, most casualties fell to the ground and lay there, suggesting that assault rifles and machine guns do indeed have stopping power.[8]

Modern Concepts of Personnel Vulnerability: Computer Man

The U.S. Army has led efforts to find a scientific basis for predicting the effects of ballistic injury on a soldier's performance. The effort is distinguished by: *(a)* emphasizing fragments rather than bullets, *(b)* recognizing that some body regions are more vulnerable to ballistic injury than others, *(c)* establishing concrete criteria for incapacitation, based on well defined soldier tasks required to complete a given mission, *(d)* quantitating the wounding effects of missiles by their mass, velocity, and shape, *(e)* expressing results in terms of probability, and *(f)* using sophisticated computer technology.

The need to optimize the wounding potential of preformed fragments has driven the emphasis on fragmentation injury. What is the combination of mass and velocity most likely to wound? A random-fragmentation munition such as an 81-mm mortar bomb breaks into a wide range of different-sized fragments, but only the heaviest—those weighing 1–10 g and constituting about 10% of the total number of fragments—are likely to retain sufficient velocity beyond 50 m to wound. The smallest fragments—those weighing less than 100 mg—will not even travel 50 m, although their initial velocities may be 4,000–5,000 fps. So fragments ranging in weight from several hundred milligrams to one gram (the median fragment mass in the WDMET study is 200 mg) and with velocities of several thousand feet per second seem to be reasonable values for the desired mass and velocity.[8]

But how can this conjecture be tested short of war? Modern mathematical modeling can address such problems. Researchers "shoot" a fragment of specified mass, velocity, and shape at a random target on a "Computer Man."[25]

The fragment's mass, velocity, and shape determine the depth and lateral extent of the wound tract. For any given hypothetical wound, these parameters are known from a well-documented body of knowledge derived from experimentation on animals and the tissue-simulant gelatin. (This is discussed at length in Chapter Four of this textbook.) The researchers select a computerized simulation of the external projection of the human body as the target. Next, they superimpose the depth of the fragment's penetration and the lateral extent of damage (the width of the permanent cavity plus several millimeters around the permanent tract) caused by the fragment's passage on an axial section of the computerized target. Then, the researchers medically assess how the injured structures lying along the wound tract might affect the performance of the limbs "[b]ecause of the intimate dependence of perfomance on the behavior of the limbs."[25] This prediction of incapacitation assumes that no medical care is given. **of** incapacitation is then related to **four** tactical roles (assault, defense, supply, and reserve) at six post-wounding times (30 seconds to 24 hours). The researchers then repeat the procedure for many different fragment masses, velocities, and trajectories through the Computer Man. Although this was not part of the original methodology, the effects of fragments with oblique trajectories (that is, trajectories that traverse two or more axial cross sections) can now be studied.

The computer generates a diagram similar to the one shown in Figure **2-1.** The probability of incapacitation can be understood as an expected value. For example, a 75% probability of incapacitation means that there is a 100% probability that a soldier will be unable to perform 75% of the tasks required to carry out a given mission. It does *not* mean that there is a 75% probability that 100% of the tasks cannot be performed. One limitation of the original Computer-Man methodology is that the computer is not programmed to include a medical reason for the soldier's incapacitation. For example, we are not told whether a soldier who is incapacitated because he cannot move his arm has a soft-tissue wound of the arm, a fractured humerus, a transected brachial plexus, or some other injury.

Incapacitation is predicted to be a function of not only the fragment's mass (M), but also its velocity (V) raised to the **3/2** power. Thus incapacitation is not directly related to either kinetic energy (1/2 MV^2) or momentum (MV). While the biophysical explanation for this function seems intuitively obvious to some ballisticians, others disagree. This line of reasoning holds that, other factors being unchanged, the greater the fragment's mass, the larger the fragment will be, **and** therefore, **the** larger the **hole** that it makes as it penetrates will be. Similarly, other factors being equal, the greater the fragment's velocity, the greater its depth of penetration, and the greater the probability that it will strike a body part whose function is necessary for performing a soldier's tasks. Finally, we might expect other than a linear function because biological phenomena are notoriously complex. The point in Figure 2-1 indicated by the X is satisfied by such combinations of fragment mass and velocity as 2 g and 1,000 fps, 693 mg and 2,000 fps, and 377 mg and 3,000 fps. Since the corresponding calculated kinetic-energy values for these combinations of mass and velocity are 69, 95, and 117 foot-pounds, respectively, the historical value of 58 foot-pounds for incapacitation may not be all that dubious.

The subtlety, sophistication, and complexity of this methodology has only been suggested in this chapter's introductory treatment, and interested readers should consult the primary source for a detailed discussion of

and staff officers should also be aware that similar analyses have been performed for blast and blunt traumas and for burns.

The ability to predict the magnitude of the treatment problem that results from a combat casualty's missile wound will probably interest medical officers more than predictions of soldier-incapacitation will. The Computer-Man methodology is also well-suited for this purpose.[26] An extensive body of experimental data exists showing that kinetic-energy expenditure along a missile's trajectory through the tissue simulant gelatin correlates with the permanent tract's cross-sectional area or volume made by the same missile in living soft tissue. After researchers determine the kinetic energy that will be expended along the trajectory of a fragment of specific mass, velocity, and shape, they superimpose the resulting energy-deposit contour along the missile's trajectory onto a randomly selected axial cross section of the computer-simulated body. Then they assess the severity of the injury, based upon the interaction of the missile and the organs in its path.

This approach recognizes two degrees of injury severity: lethal and serious. ***Lethal*** wounds are those

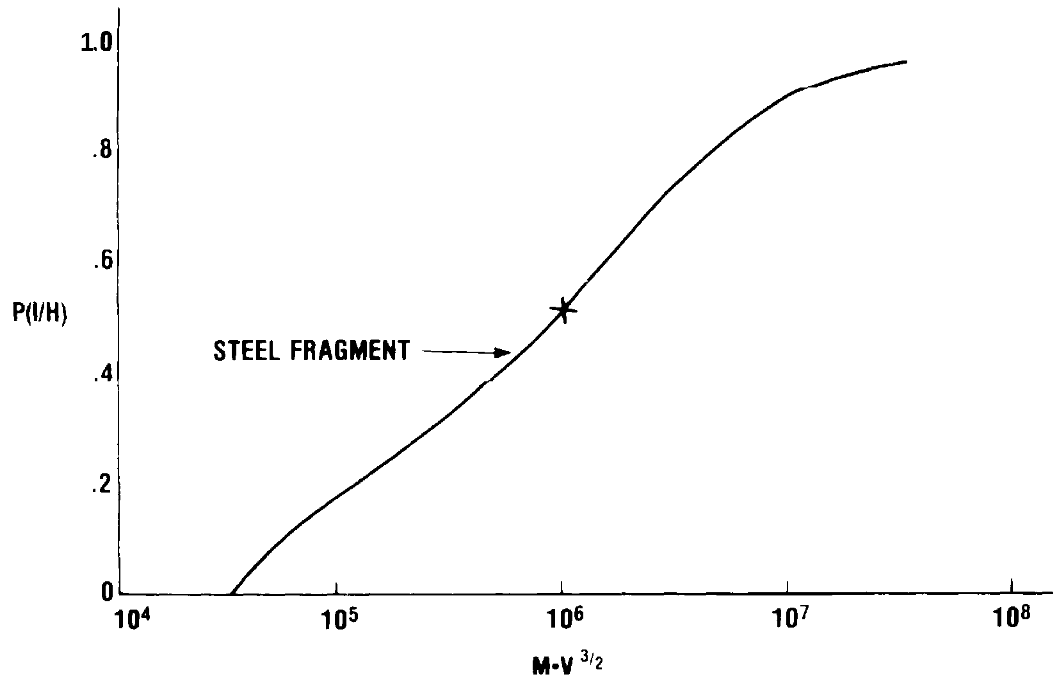

Fig. **2-1.** The probability that a steel fragment will incapacitate a soldier. P(I|H) represents the probability of incapacitation if the soldier is wounded; M, the fragment's mass in grains; and V, its velocity in fps. Notice that the relationship is semilogarithmic: The point labelled X can be interpreted to mean that an irregular steel fragment with mass and velocity such that $M \times V^{3/2} = 1 \times 10^6$ striking a soldier at random will prevent him from performing **50%** of his duties in an assault that began 5 minutes after **he** was wounded.
Source: Redrawn from reference 25

of the heart, large blood vessels, lung hilum, the midline central nervous system, and certain abdominal structures such as the hepatic hilum. In this computer program, lethal does not necessarily mean that death is certain, only that it is probable even with optimal care. ***Serious*** wounds, those that make it unlikely that a soldier will return to duty, are those of the cranial, pleural, or peritoneal cavities in general (excluding wound tracts that involve organs whose injuries would be lethal), large muscular wounds, and bony and neurovascular wounds of the extremities. While modern computer technology makes the study of multiple trajectories produced by many missiles of different masses, shapes, and velocities possible (Figure 2-2), the computer does not tell us anything about the pathophysiology of the casualty's hypothetical injury. For example, judging from the missile's trajectory and the computer's assessment of the degree of injury severity, the simulated casualty described in Figure 2-2 might have a tension pneumothorax, a massive hemothorax, or an open sucking chest wound.

Of course, a computer's predictions are only as good as its program. Although there can be little doubt that this technological approach is the correct one to solve the physical aspect of this biophysical problem, the same is not necessarily true of its medical aspect. As proponents of Computer Man frankly admit:

> [o]f crucial significance to the study are the judgments made by the medical assessors on the relationships between behavior of the limbs and the ability of the wounded "enemy" soldier to carry out his assigned task.[25]

A similar concern applies to the injury-severity assessment. Nevertheless, evidence strongly suggests that the Computer-Man methodology may have validity. A recent analysis of the WDMET database found that 382 casualties with penetrating wounds of the thorax had an observed mortality of 65%.[8] About two-thirds of these casualties had been wounded by 7.62 x 39-mm rounds, for which $M \times V^{3/2}$ equals about 1.0×10^7. According to the Computer-Man predictions, this bullet's lethality is about 0.70 (Figure 2-2).

The casualty's behavioral or psychological status, especially immediately after being wounded, remains

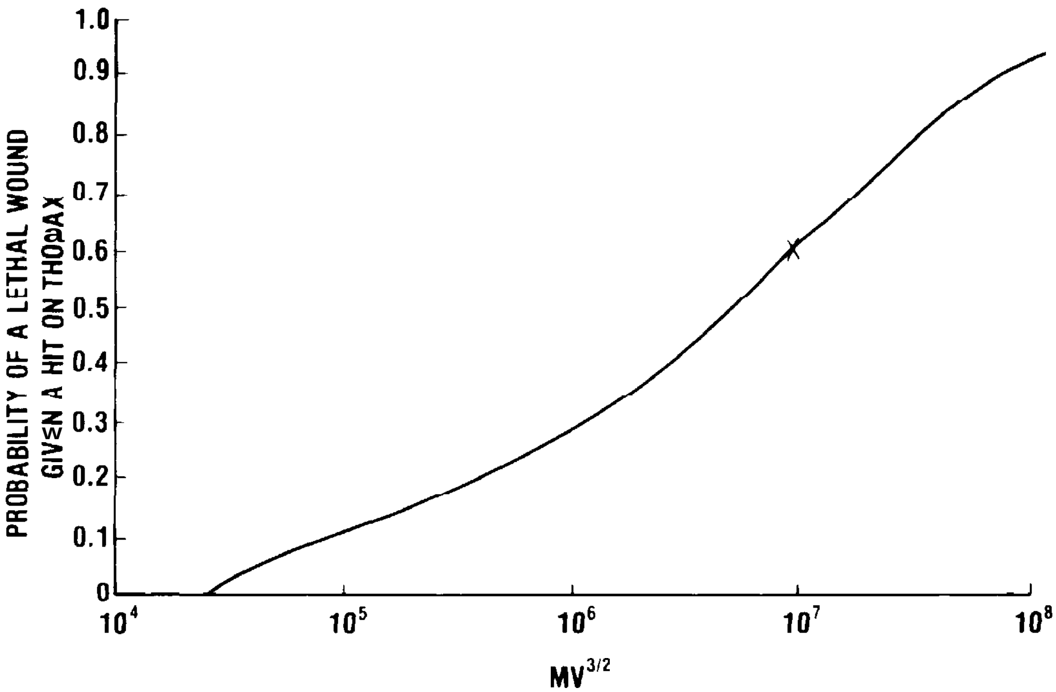

Fig. 2-2. This graph shows a predicted relationship between the probability that a projectile will create a lethal wound in the thorax and its physical parameters (that is, the product of mass and velocity raised to the 3/2 power). When $M \times V^{3/2} = 1 \times 10^7$, which corresponds to a typical M43 ball (marked x on the graph), the probability that a thoracic wound will be lethal approaches two out of three.
Source: Redrawn from **reference** 26

inscrutable. The WDMET data clearly demonstrate that the great majority (about 90%) of casualties who were wounded by exploding munitions immediately fell to the ground and frequently remained lying there for some minutes. Whether this behavior resulted from their sudden absorption of some critical number of foot-pounds of kinetic energy, a self-preserving reflex induced by a bright flash and a loud noise, or the fact that there was no need to move is not so clear. Of course, incapacitation that begins, or continues for, hours after wounding is a different matter, not being so subject to intangibles.

An important related problem is how to predict the effect of multiple wounds. How should the potential synergistic interaction of many wounds in a casualty be assessed? This problem remains to be solved. Thus, even Man in its present state has great practical use and considerable heuristic value, it needs further refinement.

Relative Incapacitation Index

Although it uses much of the same methodology that Computer Man does, the Relative Incapacitation Index (RII) has a different focus and emphasizes a different aspect of the projectile-target interaction.[27] The focus has come from civilian law-enforcement agencies such as the Federal Bureau of Investigation (FBI), who want to arm their agents with weapons capable of immediately stopping a felon who is committing a crime. There must also be little risk to bystanders. This proviso precludes the FBI from using military weapons such as submachine guns or hand grenades; their only practical alternative weapon is the handgun. Thus, the FBI's need for optimal performance from its ammunition and weapons has allowed the old question of stopping power to be reassessed with the entire armamentarium of modern computer-oriented ballistic modeling.

The aspect of the projectile-target interaction that RII emphasizes is temporary cavitation. As a projectile passes through a target with viscoelastic properties—such as the human body—energy transfer is manifested in two ways: *(a)* laceration of tissue along the projectile's pathway, which usually is the major determinant of the size of the *permanent wound tract*, and *(b)* radial displacement, with stretching and tearing of the tissue surrounding the projectile's pathway, which

TABLE 2-22

STOPPING POWER OF PISTOL AMMUNITION

Result of Firing	Pistol Ammunition: Sheriff RII = 13.3	Pistol Ammunition: Police RII = 6.4
Felons shot	*28*	*32*
Felons killed	14	18
Felons killed instantly	4	5
Rounds fired per officer	1.6	1.7
Number of organs hit per felon	3.1	3.2

Source: Reference 28

creates the *temporary cavity.* (These phenomena are discussed in great detail in Chapter Four.) RII assumes that temporary cavitation is the major wounding mechanism.

To assess RII, researchers first shoot potentially useful bullets into gelatin blocks to determine the physical characteristics of the temporary cavity that the bullet creates. Next, they determine the contour of the maximum instantaneous temporary cavity for that bullet. In simulated handgun shootouts, they select the body sites most likely to be hit by experienced law-enforcement officers. Then they superimpose the contour of the maximum temporary cavity onto those selected axial cross sections of Computer Man and medically assess the degree of incapacitation likely to result from damage done at each increment of the projectile's path through the tissue. After the incremental incapacitations have been added together, they repeat the process until all cross sections corresponding to likely hits have been studied. The individual results are averaged and the final product is a number, the RII, specific for each type of ammunition. The higher the RII, the likelier the ammunition should be to cause a felon's immediate incapacitation. Relative Incapacitation Indices range between 1.2 (for the .38 special lead round-nose bullet) to 67.3 (for the .44 magnum jacketed hollow-point bullet). RIIs for common military rounds are 11 for the 9-mm parabellum fired by the Beretta M9 and 3.6 for the .45 ACP (better known as the Colt .45).

Fortuitously, actual field testing of RII predictions regarding handgun ammunition—and in a sense, the validity of the mathematical approach to assessing weapons effects—occurred. During 1978–1979, the Los Angeles Police Department and the Los Angeles County Sheriff's Office used 0.38-caliber pistol ammunition of different designs. The police used 150-grain Winchester round-nose bullets and the sheriff's office used 110-grain Federal jacketed hard-point bullets, with the sheriff's bullets having a much higher RII.[28] All other factors being equal, one might predict that to achieve their goal, the sheriff's officers fired fewer rounds per felon or, alternatively, killed more felons. The actual results are shown in Table 2-72

Clearly, the superiority that the RII methodology predicted for the sheriff's ammunition was not seen. Whether or not this indicates a fallacy that might invalidate the entire mathematical-modeling approach is unclear, but readers should not forget that RII differs from the military applications of Computer Man in two ways: (*a*) the civilian sector requires immediate incapacitation, while the military modelers have emphasized both immediate and delayed incapacitation (that is, from 5 seconds to 24 hours) and (*b*) the RII methodology's assumption that temporary cavitation determines the outcome. What this field test clearly demonstrates, however, is that computer predictions need to be subjected to realistic tests.

PREDICTING THE EFFECTS OF FOREIGN WEAPONS

Predicting the nature of the next major war is a problem of compelling importance for military leaders. Modern computer technology holds the promise that the diverse factors that determine events at the tactical and operational levels can be successfully modeled. Medical commanders will be especially interested in two such simulations: *(a)* predicting casualty rates and *(b)* stratifying combat injuries by their anatomical location and severity. Computer-Man methodology can supply the information on stratification, and, together with an approach that couples a knowledge of weapons effects with the likelihood of their employment, will make a comprehensive prediction of the medical workload probable. Organizations such as the Armed Forces Medical Intelligence Center, the Army Materiel Systems Analysis Activity, and the Foreign Science Technology Center have adopted this approach.

Given a knowledge of the following factors, it is theoretically possible to predict the maximum number of casualties that will result from a given weapon's use:

- the weapons effects, including *(a)* the munition's characteristics such as the size, shape, and velocity of fragments; *(b)* the rate of fire; *(c)* the range required to hit the target, and the angle of impact for explosive munitions; and *(d)* the weapon's reliability
- the target's vulnerability, including *(a)* the tactical posture (for example, defending from a prepared position); *(b)* the terrain and the weather (for example, the forest in winter); and *(c)* the protective equipment available, individual (for example, helmets) and collective (for example, bunkers)

Calculating the mean area of effectiveness (also known as the lethal area) presents the results of com-

TABLE 2-23

CALCULATED MEAN AREA OF EFFECTIVENESS
FOR SOVIET 160-mm HIGH-EXPLOSIVE HOWITZER SHELLS

P(CC I H) = 0.9

Environment: Open Burst Height: 3 m Burst Velocity: 400 m/s Angle of Impact: 50°		Troop Posture and Area of Effectiveness (m^2)		
		Standing	Prone	Foxhole
Casualty categories (CC) are assessed in terms of the probability of 90% incapacitation:				
Defense	30 sec	600	350	70
Assault	5 min	900	600	80
Supply	12 hr	1,100	600	90
Casualty categories (CC) are assessed in terms of medical consequences:				
Lethal		450	350	40
Both serious and lethal		1,200	800	60
All wounds		1,500	1,000	100

Source: Reference 21

puter simulations in a conceptually useful way. The mean area of effectiveness is defined as the area in whicha given munition has a specific probability (P) of causing a given casualty outcome or casualty category (CC), for example, a serious wound, given that the weapon actually causes an injury or hit (H). These factors can be expressed mathematically as P(CC|H), and can yield the information, for example, that there is a 90% probability that a serious wound will result if a casualty is injured by a given weapon. The source document detailing the mean areas of effectiveness and their associated medical implications for foreign weapons is classified.[29] However, in order to acquaint with an unclassified example describing a *notational* weapon (that is, one that is feasible but presently nonexistent), has been prepared (Table 2-23).

The methodology used to generate Table 2-23 predicts, among other outcomes, that a soldier standing in an open field devoid of any cover has a very high probability of being fatally wounded if a shell with the specified characteristics bursts within 12 m of his position. **A** foxhole would appear to offer substantial protection: The lethal radius **is** reduced to ***3.6*** m. Clearly, if a medical commander knew all the relevant factors describing the troop concentration—including the total number present in the target area—a prediction of the medical workload could be made for a given action. By adding all the individual actions for a given battle, commanders or their staff officers could theoretically estimate both the total number of casualties and their requirements for medical care.

What should the military medical officer's attitude bc towards this grand synthesis? There seems to be little doubt that accurate predictions of the wounding characteristics of a given munition can be made. Facts such as the number of fragments produced by a shell, their velocity and the distance they will travel, and the probability that they will hit a soldier are readily available. What a given hit will do to a soldier is perhaps less well established, but predictions of injury severity based on Computer-Man simulations may nevertheless be taken as a useful first approximation. The aspect of this approach that is moat questioned (and most suspect) is that it requires a detailed knowledge of how the deployed weapons will be used in battle. This is no small problem. For example, operational research during World War II found that only one rifleman in ten was likely to fire his weapon in battle. Predicting the number of casualties on the basis of the number of rifles present will overestimate the number of casualties by a factor of ten.[30]

The probability that the weapon will hit its target is even harder to predict. Predicting what will happen if a munition hits within a certain distance of a target is one thing. It is much more difficult to accurately predict the number of times the weapon will have to be employed to hit within the selected distance from the target (Table 2-24).[31] (These data might apply to the performance of the notational munition described in

TABLE 2-24

EXPECTED FRACTION OF CASUALTIES FOR SOVIET 152-mm HOWITZERS FIRING HIGH-EXPLOSIVE MUNITIONS*

Radius of Target (m)	Number of Volleys/Shells	Expected Fractional Incapacitation for Assault Posture		
		Standing	Prone	Foxhole
100	1/18	*0*	0	0
	10/180	0.34	0.26	0.04
	20/360	0.48	0.39	0.08
200	20/360	0.43	0.36	0.07
350	20/360	0.26	0.21	0.04

*12-km range, proximity fuse, indirect fire by map coordinates
Source: Reference 31

Table 2-23.)

The following extreme example may help both to interpret Table 2-24 and to suggest the considerable difficulty inherent in predicting casualty rates. Assume that a single soldier stands at the center of a circle with a radius of 100 m, which is the target for a battery of 152-mm howitzers that are 12 km away. To be 100% certain to cause a 48% reduction in that soldier's ability to assume an assault posture, the howitzers would have to fire no fewer than 360 shells! This datum reflects artillery's well-known lack of pinpoint accuracy when used indirectly, and especially when firing conventional munitions. As the diagram in Figure 1-34 (in Chapter One) clearly shows, using cluster munitions greatly increases the probability that a hit will be made. These highly probabilistic assessments, together with the degradation of weapons effectiveness caused by the vagaries of human performance in battle (a factor that is more than a little refractory to computer modeling), requires that predicted casualty rates be assessed cautiously.

SUMMAKY

Once casualty generation and lethality are defined so they can be applied to the data that are available, two generalizations emerge that apply to the wars of this century: Bullets kill people more effectively, but fragment wounds predominate on modern battlefields.

Incapacitation and injury severity, both logical endpoints of descriptions of weapons effectiveness, can certainly be rigorously defined. Mathematical models that relate incapacitation and injury severity to measurable properties of the wounding agent can also be developed. Military medical officers need to be conversant with this modern approach toward estimating personnel vulnerability on the battlefield—typified by the Computer-Man methodology—if for no other reason than to avail themselves of its considerable heuristic power. Furthermore, because it focuses attention on developing—and by implication, using—munitions that are designed to incapacitate rather than to kill, the Computer-Man methodology unexpectedly introduces ethical considerations that the military needs to ponder. Unfortunately, no evidence suggests that contemporary designers of small-arms ammunition have also been motivated by similar humanitarian considerations.

All too often, modern munitions are used in the spirit of the celebrated Confederate General Nathan Bedford Forrest's reputed declaration: "Fightin's fer killin'."

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