APPENDIXES

APPENDIX A

DESCRIPTION OF THE DYNAMIC MODEL USED IN THIS STUDY

The dynamic model used in this study was based on one developed by Joshua M. Epstein of the Brookings Institution.1/ Epstein's model, which attempts to simulate the conduct of a conventional war of attrition, is based on the premise that both the attacker and defender will accept some level of attrition to their forces in an effort to attain some objective. For the attacker, the objective might be to gain territory, and the defender's goal might be to repel the attacker without losing ground. Epstein has assumed, however, that there is some level of attrition beyond which each side is willing to abandon its objective, at least temporarily; that is, when losses become too high, the aggressor might stop pressing the attack. Likewise, the defender might be willing to withdraw to a new position to avoid further losses, at least for the moment.

Epstein attempts to capture these phenomena through mathematical equations describing each side's starting position and losses for each day of a theoretical war. When hostilities begin, each side's total forces can be assigned a numeric value, such as the weapon effectiveness index/weighted unit value (WEI/WUV) score described in Chapter II. In addition, each side might start out with a specific number of ground-attack aircraft with which it can inflict losses on the other side's ground forces. As the war progresses, each side loses ground combat capability and aircraft as determined by the equations Epstein has developed. The defense, in order to maintain its losses at an acceptable level, gives up ground. The mathematical process of removing ground and air assets can continue for a specified number of days or until one side is decimated.

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1. Joshua M. Epstein, *The Calculus of Conventional War: Dynamic Analysis Without Lanchester Theory* (Washington, D.C.: Brookings Institution, 1985).

DETAILED DESCRIPTION

The Congressional Budget Office modified the model, as described in Epstein's 1985 publication, to make it more useful in analyzing the subjects pertinent to this study. In particular, modifications were incorporated to allow the addition of reinforcements and the use of weapons for follow-on forces attack. The model was also expanded to accept attrition rates that vary over the course of the war.

Epstein's model requires the definition of variables and constants, which are listed in Table A-1. Several equations are used to compute each side's losses at the end of each day of combat. Specifically, the equations that govern the conduct of ground combat are:

$$A(t+1) = A(t)[1-AGL(t)] - ACASL(t)$$

and

$$ATOT(t) = A(t) + AREINF(t).$$

Similarly,

$$D(t+1) = D(t) - \frac{AGL(t)A(t)}{XCHNG(t)} - DCASL(t)$$

and

$$DTOT(t) = D(t) + DREINF(t)$$

where

$$AGL(t) = APROS(t)\left(1 - \frac{W(t)}{WMAX}\right)$$

and

$$W(t) = 0$$

if $DTL(t-1) \leq DMAX$, or

TABLE A-1. VARIABLES AND CONSTANTS USED IN THE DYNAMIC MODEL

Symbol	Definition
	Ground Forces
A(t)	Attacker's ground force value surviving at the start of day t
AREINF(t)	Attacker's reinforcements available on day t
ATOT(t)	Attacker's total ground forces available on day t
APROS(t)	Attacker's prosecution rate on day t
AGL(t)	Attacker's losses to ground combat (measured in attrition rate) on day t
ATL(t)	Attacker's total ground force loss rate on day t, to both air and ground forces
AMAX	Attacker's threshold attrition rate
D(t)	Defender's ground force value surviving at the start of day t
DREINF(t)	Defender's reinforcements available on day t
DTOT(t)	Defender's total ground forces available on day t
XCHNG(t)	Exchange rate for ground combat on day t (that is, attackers lost per defenders lost)
DMAX	Defender's threshold attrition rate
DTL(t)	Defender's total ground force loss rate on day t, to both air and ground forces
W(t)	Defender's rate of withdrawal in kilometers per day
WMAX	Defender's maximum rate of withdrawal in kilometers per day
t	Time in days, t = 1, 2, 3, . . .
	Close Air Support Forces
AAC(t)	Attacker's close air support (CAS) aircraft on day t
AACL	Attacker's CAS aircraft attrition rate per sortie
ASRTY	Attacker's daily sortie rate per CAS aircraft
ASRTYPK	Defender's armored fighting vehicles killed per attacker CAS sortie
ACASL(t)	Attacker's ground forces lost to defender's CAS on day t
DAC(t)	Defender's CAS aircraft on day t
DACL	Defender's CAS aircraft attrition rate per sortie
DSRTY	Defender's daily sortie rate per CAS aircraft
DSRTYPK	Attacker's armored fighting vehicles killed per defender CAS sortie
DCASL(t)	Defender's ground forces lost to attacker's CAS on day t
NUMAFV	Number of armored fighting vehicles per armored division equivalent (ADE)
L	Lethality points (or WEI/WUV score) per ADE

SOURCE: Congressional Budget Office based on Joshua M. Epstein, *The Calculus of Conventional War: Dynamic Analysis Without Lanchester Theory* (Washington, D.C.: Brookings Institution, 1985).

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$$W(t) = W(t\text{-}1) + [WMAX - W(t\text{-}1)] \left(\frac{DTL(t\text{-}1) - DMAX}{1\text{-}DMAX}\right)$$

if DTL(t-1) > DMAX.

Furthermore,

$$DTL(t\text{-}1) = \frac{DTOT(t\text{-}1) - D(t)}{DTOT(t\text{-}1)}$$

and

$$XCHNG(t) = 3 - 0.5[ATOT(t)/DTOT(t)]$$

if ATOT(t)/DTOT(t) < 5.5, otherwise

$$XCHNG(t) = 0.5.$$

The attacker's daily prosecution rate--denoted by APROS(t)--according to Epstein "represents the rate of attrition to ground combat that the attacker is prepared to suffer in order to press the attack at his chosen pace." By setting W(1) = 0 and the first day's prosecution rate, APROS(1) < AMAX, then

$$APROS(t) = APROS(t\text{-}1) - \left(\frac{AMAX\text{-}APROS(t\text{-}1)}{AMAX}\right)[ATL(t\text{-}1)\text{-}AMAX]$$

and

$$ATL(t\text{-}1) = \frac{ATOT(t\text{-}1) - A(t)}{ATOT(t\text{-}1)}$$

For the treatment of each side's aircraft and ground losses to the enemy's close air support (CAS) aircraft,

$$DAC(t) = DAC(t\text{-}1)(1\text{-}DACL)^{DSRTY}$$

and

$$AAC(t) = AAC(t\text{-}1)(1\text{-}AACL)^{ASRTY}.$$

To determine the daily losses to each side's CAS aircraft,

$$DCASL(t) = \frac{L}{NUMAFV} ASRTYPK \bullet AAC(t) \sum_{i=1}^{DSRTY} (1\text{-}AACL)^{i-1}$$

and

$$ACASL(t) = \frac{L}{NUMAFV} DSRTYPK \bullet DAC(t) \sum_{i=1}^{ASRTY} (1\text{-}DACL)^{i-1}.$$

(The model accommodates nonintegral sortie rates by appending an additional term to represent the fractional sortie, for both attacking and defending aircraft.)

The output of the model, of course, depends largely on the values assigned to the variables and constants used in the model. The same initial values and constant values were used for all the dynamic analyses in this study (see Table A-2).

ADVANTAGE OF DYNAMIC MODELS

Dynamic comparisons take into account each side's ability to destroy the other and the effect of attrition over time. Such models, however, require much of the same quantitative information included in static balances--and more. Dynamic comparisons can be viewed as starting where static comparisons end. In addition to counting each side's equipment, dynamic models also simulate the destruction of the opposing side's weapons, depending on the ability of each side's systems

to do so. Thus, the ability of each combatant's weapons to find and destroy the enemy's weapons and the rate at which this can be done determine the outcome of a force comparison. In this way, dynamic models can, based on numerous assumptions and inputs, simulate the interaction of many different types of weapons, the impact of different strategies, and the contribution of logistic support.

TABLE A-2. VARIABLES AND VALUES USED IN THE DYNAMIC MODEL

Variable	Value
APROS(1)	2.0 percent
AMAX	7.5 percent
DMAX	5.0 percent
WMAX	20 kilometers per day
DAC(1) a/	330 aircraft
AAC(1) b/	250 aircraft
DSRTY c/	2 sorties per day, 1.1 sorties per day
ASRTY	1 sortie per day
DACL c/	4 percent, 1 percent
AACL c/	4 percent, 1 percent
DSRTYPK	.50 armored fighting vehicles per sortie
ASRTYPK	.25 armored fighting vehicles per sortie
NUMAFV	1,800 armored fighting vehicles per armored division equivalent (ADE)
L	130,458 lethality points per ADE

SOURCE: Congressional Budget Office based on Joshua M. Epstein, *The Calculus of Conventional War: Dynamic Analysis Without Lanchester Theory* (Washington, D.C.: Brookings Institution, 1985); and Department of Defense, Office of the Assistant Secretary for Program Analysis and Evaluation, *NATO Center Region Military Balance Study, 1978-1984* (July 1979).

a. Number of NATO close air support (CAS) aircraft assumed to be assigned to each corps sector facing a main attack.

b. Number of Pact CAS aircraft assigned to each main attack corridor.

c. The two numbers represent the value used for the first week of combat and the value used thereafter, respectively.

Calculation of dynamic balances, however, requires many detailed inputs; many assumptions about the interactions of individual weapons, the general conduct of war, and the mathematical equations governing it; judgments concerning the behavior of commanders on each side; and, generally, large computers to process the numbers. Furthermore, since dynamic assessments of force balance depend on the conduct of war, they are highly dependent on local force concentrations. They are therefore more useful for examining the course of the battle in smaller sectors of the battlefield than across the whole theater. Finally, the outputs of such models typically describe the amount of territory a military unit has ceded to its attacker after so many days of war, or the number of enemy tanks and aircraft destroyed by each side.

Limitations of Dynamic Models

Although dynamic models attempt to quantify and take into account many aspects of war that static balance comparisons do not, they must necessarily rely on many assumptions concerning the conditions under which a war would be fought. Some of these conditions cannot be predicted, thus placing the credibility of such models' outcomes in question. Questions also arise concerning the equations used in the models, whether the model or the scenario is biased for or against a particular side, and the sensitivity of the model to different assumptions. Thus it would appear that a dynamic model may have as many disadvantages as advantages and does not necessarily offer a more reliable method for evaluating relative combat capability than some less sophisticated static models.

Epstein's model, like any quantitative method for evaluating the relationship between two military forces, cannot be used to predict the outcome of an actual conflict. No mathematical model, even one that attempts to capture the dynamics of warfare, can replicate all the factors that determine the course of a battle. Indeed, some factors that have a large impact on the outcome of a conflict--such as leadership, morale, tactical competence--cannot be quantified. Others, such as location of the attack, weather and other conditions at the time of attack, and the element of surprise cannot be predicted.

APPENDIX B

NATO'S EMPHASIS ON SUPPORT STRUCTURE AND ITS EFFECT ON THE BALANCE OF FORCES

Despite the parity in the number of active-duty personnel of NATO and the Warsaw Pact in the central region (1.4 million and 1.2 million, respectively), NATO combat divisions are outnumbered by Warsaw Pact divisions by approximately 1.7 to 1.0. This discrepancy stems primarily from NATO's greater emphasis on support structure and tactical air power.

NATO's ground combat divisions, though they contain roughly the same number of fighting vehicles as Warsaw Pact counterparts, are manned at much higher levels. A typical U.S. armored division has about 16,500 soldiers, whereas a Soviet tank division in eastern Europe would be at full strength with 10,500--or more than one-third fewer--people. A U.S. division would have more people involved in support activities such as vehicle maintenance, ammunition and fuel resupply, and general logistics activities than its Soviet counterpart. This difference in unit size accounts for the greater number of Warsaw Pact combat units, even though the Pact has roughly the same number of people as NATO.

Two basic reasons account for this significant discrepancy in support structure between Pact and NATO forces. The first is a difference in replacement philosophy: the Pact replaces entire units that have been depleted with fresh ones, whereas NATO replaces individuals within units. Second, the Soviet style of administration is much more centralized. Unlike NATO units, which include administrative organizations at all levels, only Soviet and Pact units at higher levels, such as divisions and armies, include large command structures.

Some experts have argued, however, that Warsaw Pact units would not be effective in combat over long periods of time because they

lack sufficient logistical support.1/ For example, Pact units might not have the mechanics to fix broken-down vehicles or the supply-truck drivers or handlers to pass forward the necessary food, fuel, and ammunition. One Department of Defense (DoD) study estimated that the Pact might be able to keep its units in intense combat for only five to six days.2/ NATO's combat units, on the other hand, are assumed to be more capable of sustained combat because of their superior support structure. (The same DoD study suggests that U.S. units could maintain intense conflict indefinitely if supply stocks were adequate.) In addition, because each individual NATO unit has its own command structure, the units will be better able to operate independently and flexibly. If the United States and its allies have invested so much of their military capital in support, it is reasonable to believe that NATO's military planners expect a payoff in terms of increased effectiveness in combat.

NATO's greater investment in support structure is not reflected in its armored division equivalent (ADE) scores, however. If increased support results in higher combat effectiveness, then, arguably, NATO's ADE scores should be increased proportionately to reflect that increased efficiency. Some analysts have suggested that efficiencies as high as 50 percent could translate into a 50 percent increase in NATO's ADE score.3/ Such an increase would radically affect the balance of forces (see Figure B-1). Indeed, if NATO's investment in support structure produces a return proportional to its investment in manpower, then under conditions outlined in the middle-range case defined in Chapter II, the Pact/NATO force ratio in the central region would be roughly equal to 1.0 during the 90 days after mobilization. Most important, however, is the fact that NATO's support structure could offset, to some extent, the Warsaw Pact's numerical advantage in combat troops and equipment.

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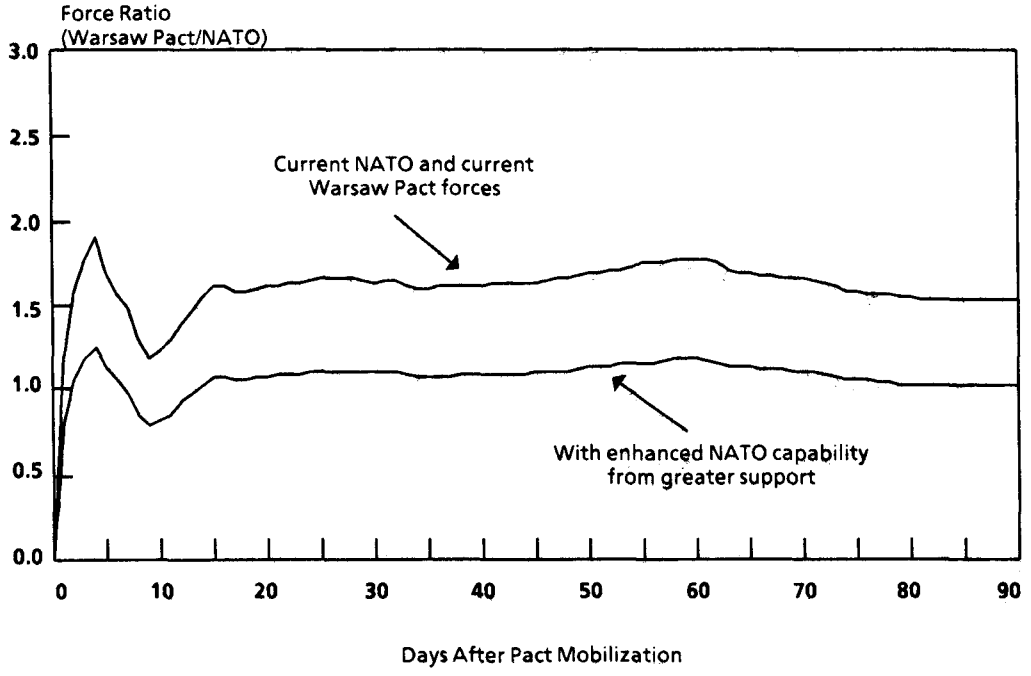
1. See William P. Mako, *U.S. Ground Forces and the Defense of Central Europe* (Washington, D.C.: Brookings Institution, 1983), p. 60.

2. Department of Defense, Office of the Assistant Secretary of Defense for Program Analysis and Evaluation, *NATO Center Region Military Balance Study, 1978-1984* (July 1979), Appendix D, p. 8.

3. Barry R. Posen, "Measuring the European Conventional Balance," *International Security*, vol. 9 (Winter 1984-1985), pp. 66 and 67; and Department of Defense, *NATO Center Region Military Balance Study, 1978-1984*, p. I-22.

Figure B-1.
Potential Effect of NATO's Support Forces on Theaterwide Force Ratios (Middle-range case)



SOURCE: Congressional Budget Office based on Department of Defense data.

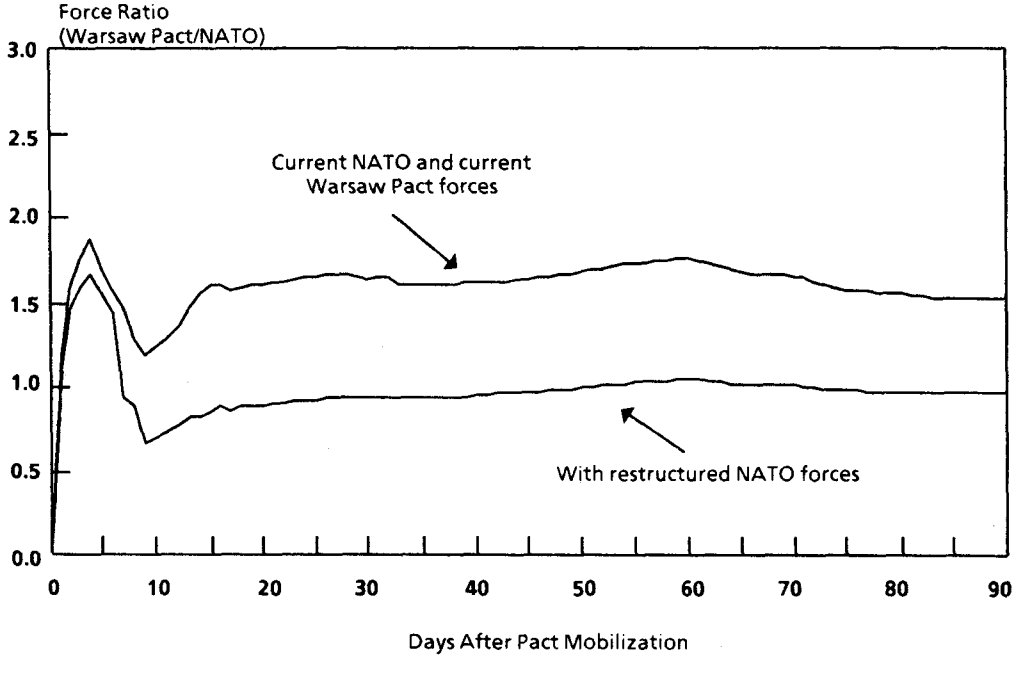
Some analysts have suggested that by restructuring its forces, NATO could, with the same manpower, create more combat divisions and thus more evenly match the Pact's combat power.4/ This, of course, would be a drastic departure from NATO's current strategy and structure. If NATO's military planners conclude that their past strategy was wrong and decide to shift support personnel to combat roles and to reorganize NATO along the same line as the Pact's current structure, many more combat divisions could be created.

4. William Mako cites several discussions of this kind of restructuring, including those by Steven Canby, *The Alliance and Europe*, part 4: *Military Doctrine and Technology*, Adelphi Paper 109 (London: International Institute for Strategic Studies, 1974), pp. 21-22; William S. Lind, "Some Doctrinal Questions for the United States Army," *Military Review* (March 1977), pp. 54-65; and Edward N. Luttwak, "The American Style of Warfare and the Military Balance," *Survival*, 21 (March-April 1979), pp. 57-60.

Theoretically, NATO countries that currently provide forces to the central region could add 36 heavy combat divisions to their current force structure without increasing the number of soldiers in the ground forces. About half of these new divisions could be fielded by the United States, with one of the additional divisions being formed from the 217,000 Army personnel currently stationed in Europe.

Of course, NATO would need more than people to create new divisions. According to the ADE method of comparison, divisions with personnel and no equipment are worth nothing. The equipment alone for a new heavy division could cost about $3.6 billion; the cost of munitions and reserves of munitions and spare parts could add another $1.4 billion. Furthermore, the additional U.S. divisions based in the States

Figure B-2.
Effect of Restructuring NATO's Forces on Theaterwide Force Ratios (Middle-range case)



SOURCE: Congressional Budget Office based on Department of Defense data.

would be able to reach Europe shortly after mobilization only if each had an additional set of equipment prepositioned in West Germany. This would cost an extra $3.6 billion for each of the 17 divisions formed. Thus, the total cost to the United States alone could be as high as $90 billion to $150 billion, just to buy the equipment, war reserves, munitions, and prepositioned sets for these new divisions; the total cost to NATO could be up to $240 billion.

Creating these new divisions would enable NATO to match the Pact almost 1 to 1 on the basis of combat divisions, with a similar result in the force balance analysis (see Figure B-2 on preceding page). If NATO's investment in support forces has a payoff roughly equivalent to its cost in people, however, then increased capability can be achieved by increased efficiency without expenditures on equipment and added divisions, as was illustrated in Figure B-1.

APPENDIX C

GROUND FORCES AND TACTICAL AIRCRAFT IN THE CENTRAL REGION

Although the countries included in the NATO and Warsaw Pact alliances encompass essentially all of Europe, CBO's study was limited to those forces that would participate in a conflict within the central region. This area includes most of the inter-German border and specifically comprises the Federal Republic of Germany (also referred to as West Germany), Belgium, the Netherlands, Luxembourg, the German Democratic Republic (also known as East Germany), Poland, and Czechoslovakia.

Many other countries currently have forces stationed in the central region, including several NATO members--the United States, Great Britain, and Canada--France, and the Soviet Union. These conventional forces have been the subject of most discussions concerning the Warsaw Pact/NATO balance and will be examined in more detail in this appendix.

GROUND FORCES

Each alliance has large numbers of ground combat units permanently stationed in the central region (see Tables C-1 and C-2). In addition, countries in each alliance, most notably the United States for NATO and the Soviet Union for the Warsaw Pact, are capable of providing large numbers of reinforcing units. The time at which these reinforcing units could be available to either side is a function of many variables, including combat readiness, peacetime location, and the rapidity with which each side starts to mobilize.

Warsaw Pact

Although the Department of Defense, in its publication *Soviet Military Power*, describes all of the Warsaw Pact combat units as being of

TABLE C-1. WARSAW PACT COMBAT DIVISIONS AVAILABLE FOR A CONFLICT IN THE CENTRAL REGION

National Army and Location in Peacetime	Category I Divisions			Category II Divisions			Category III Divisions a/		Total
	Tank	MRD	Air-borne	Tank	MRD	Air-borne	Tank	MRD	
East Germany	2	4	0	0	0	0	0	0	6
Czechoslovakia	3	3	0	0	0	0	2	2	10
Poland	5	3	0	0	2	2	0	3	15
Soviet Forces in:									
East Germany	11	8	0	0	0	0	0	0	19
Czechoslovakia	2	3	0	0	0	0	0	0	5
Poland	2	0	0	0	0	0	0	0	2
Soviet Union									
Baltic MD	0	0	2	1	3	0	2	2	10
Byelorussian MD	0	1	1	3	1	0	6	0	12
Carpathian MD	1	0	0	1	6	0	0	3	11
Kiev MD	0	0	0	0	0	0	7	4	11
Moscow MD	0	0	1	0	0	0	2	4	7
Ural MD	0	0	0	0	0	0	1	2	3
Volga MD	0	0	0	0	0	0	0	3	3
Central Asian MD	0	0	0	1	1	0	0	5	7
Total	26	22	4	6	13	2	20	28	121

SOURCE: Congressional Budget Office based on data from William P. Mako, *U.S. Ground Forces and the Defense of Central Europe* (Washington, D.C.: Brookings Institution, 1983), p. 44; and Gunter Lippert, "GSFG, Spearhead of the Red Army," *International Defense Review* (May 1987), p. 559.

NOTE: MRD = motorized rifle division; MD = military district.

a. The Warsaw Pact has no Category III airborne divisions in these locations.

"active" status, they are not all maintained at the same level of readiness.1/ Pact divisions are typically divided into three categories, with only Category I divisions actually being kept in "ready" condition. The International Institute for Strategic Studies defines the categories as follows:

1. Department of Defense, *Soviet Military Power, 1987* (1987), p. 17.