Optimizing Army Base Realignment and Closure

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In April 1997, the United States Army announced that savings had finally overtaken costs in closing or realigning 803 of its installations worldwide. This milestone occurred in the ninth year of a 13-year program approved by Congress and Presidents Reagan, Bush, and Clinton. The cost of this program is $5.3 billion, and when complete, the army expects annual savings of $996 million in perpetuity. A mixed-integer linear program, BRACAS (base realignment and closure action scheduler), helped the army budget for the 29 closures and 11 realignments approved by Congress and President Clinton in 1995. The army used BRACAS to schedule optimally the $2 billion in BRAC costs for these 40 installations over the six-year period mandated by Congress; associated annual savings will be $360 million.

The post-Cold War United States Army is smaller than its predecessor; 30 percent smaller than the force of 1989, the current active force of 495,000 is the smallest since 1939. A smaller force requires fewer installations, and reducing the number and changing the use of army installations increase efficiency and reduce costs. An army installation is much like a small city, in that maintenance and operating costs continue even when its population decreases. Closing an installation and relocating its inhabitants is costly, but the benefit accrues forever once the

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MILITARY—COST-EFFECTIVENESS
PROGRAMMING—INTEGER

installation is finally closed.

Closing an army installation is easier said than done. Overcoming the political and economic ramifications of removing a large tax-supported employer has proven daunting. A complex, politically insulated process for closing and realigning military installations was provided by Title XXIX of Public Law 101-510 (the National Defense Authorization Act for Fiscal Year 1991) as amended. This act established an independent Defense Base Closure and Realignment Commission and set in motion a process known as Base Realignment and Closure (BRAC) for 1991, 1993, and 1995, to be applied to installations in the United States. BRAC95 [Defense Base Closure and Realignment Commission 1995] decided to close 29 army installations and realign 11 others. The total estimated one-time cost for implementing these decisions is approximately $2 billion. The army expects annual savings of approximately $360 million when all actions are completed.

A mixed-integer linear program, BRACAS (base realignment and closure action scheduler), helped the army determine the way to allocate the $2 billion over the six-year period mandated by Congress. Understanding BRACAS' role requires some background.

How BRAC Nominations Must Be Made

Public law prescribes the way the Department of Defense (DoD) must pursue closures, and DoD guidelines for the army and other DoD institutions changed little during the 1991, 1993, and 1995 rounds. The Defense Secretary's Commission on BRAC [1988] and the United States General Accounting Office (GAO) [1989] offer good summaries of the political climate leading up to Public Law 101-510. Additional guidance appears in the Defense Base Closure and Realignment Commission reports to the president [1991, 1993, 1995], GAO reports [1991a, 1991b, 1993a, 1993b, 1995a, 1995b], Department of the Army reports [1991, 1993], and a Department of Defense report [1995].

The United States Air Force, Army, Navy, Defense Logistics Agency, and other institutions involved in BRAC95 were each allowed to develop a separate BRAC95 plan, but the secretary of defense [Defense Base Closure and Realignment Commission 1995, p. x] required that every institution's plan include the following eight core criteria (Figure 1):

(1) The current and future mission requirements and the impact on operational readiness of DoD's total force;
(2) The availability and condition of land, facilities, and associated airspace at both existing and potential receiving locations;
(3) The ability to accommodate contingency, mobilization, and future total force requirements at both existing and potential receiving locations;
(4) The cost-of-manpower implications;
(5) The extent and timing of potential costs and savings, including the number of years beginning with the date of completion of the closure or realignment for the savings to exceed the costs;
(6) The economic impact on communities;
(7) The ability of both the existing and potential receiving communities' infrastructure to support forces, missions, and personnel; and
(8) The environmental impact.

The first four criteria regarding military

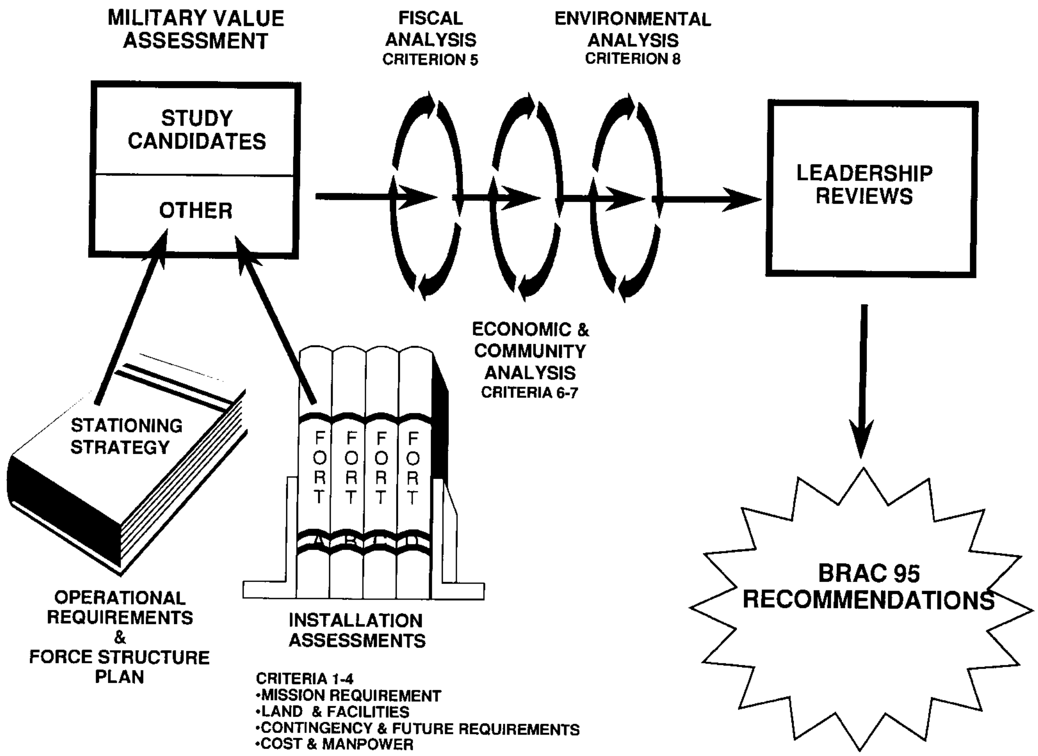

Figure 1: In developing its BRAC95 nominations, the army establishes a stationing strategy that specifies what units it needs and their operational requirements. It assesses installations to gauge, in terms of military value, the ability of each candidate installation to house units. This assessment suggests candidates for realignment and closure, but the army must also evaluate these installations for fiscal, economic, community, and environmental impacts before making a recommendation to leadership. The army and other affected institutions must use the COBRA (cost of base realignment actions) model to analyze costs and savings. After final reviews, the army leadership makes BRAC95 recommendations to the DoD. (Figure adapted from a Department of the Army presentation [1995].)

value are paramount in selecting closures but have little to do with implementing them. (Fletcher [1996] gives details on the army's military-value assessment.) Criterion 5, on the other hand, plays a critical role in implementation.

Cost of Base Realignment Actions (COBRA) Model

The army and all other affected institutions have adopted the COBRA model [Richardson and Kirmse 1994] as the mandatory tool for evaluating BRAC costs and savings (Criterion 5). COBRA was first used in this role in 1988 by the Defense Secretary's Commission on BRAC. Brown [1989] offers the best explanation of COBRA.

COBRA estimates the essential costs and savings of a proposed installation closure or realignment using data that military staff organizations can assemble without extensive field studies; this is a lot of data. Table 1 shows the diversity and detail of the cost data collected in one of COBRA's four standard-factor tables.

COBRA calculates the net present value of costs from three categories for a proposed scenario:

—Old cost: The annual cost of operations at the existing location(s) includes personnel costs (such as salaries and variable housing allowances) and overhead costs (such as the costs of base-operation support, real-property maintenance, and administrative support).

—New cost: The annual cost of operations at the proposed new location(s) after BRAC actions also includes personnel costs and overhead costs.

—BRAC cost: The cost of the move to the receiving location(s) includes construction costs (for new construction and renovations), PCS (permanent change of station) costs (PCS is military jargon for moving personnel), transportation costs (for freight, vehicles, and special equipment), and personnel costs (such as severance pay and early retirement).

If the old cost is higher than the new cost, the difference is an estimate of the recurring yearly savings; BRAC cost is the one-time cost required to achieve these

Standard Personnel Factors

Officers married	(%)	Civilian retired pay factor	(%)
Enlisted married	(%)	Priority placement	(%)
Enlisted housing construction	(%)	PPS placement involving PCS	(%)
Officer salary	($/year)	Civilian PCS cost	($)
Officer BAQ with dependents	($)	New hire cost	($)
Enlisted salary	($/year)	National median home price	($)
Enlisted BAQ with dependents	($)	Home sale reimbursement rate	(%)
Average unemployment cost	($/week)	Maximum home sale reimbursement	($)
Unemployment eligible	(weeks)	Home purchase reimbursement rate	(%)
Civilian salary	($/year)	Maximum home purchase reimbursement	($)
Civilian turnover	(%)	Home ownership rate	(%)
Civilian early retirement	(%)	HAP home value rate	(%)
Civilian regular retirement	(%)	HAP receiving rate	(%)
Civilian RIF pay factor	(%)	RSE home value rate	(%)
		RSE receiving rate	(%)

Table 1: This list of the items on one of COBRA's four standard-factor tables shows the diversity and detail of COBRA cost data. The percentage of officers and enlisted personnel who are married helps COBRA refine housing and transportation costs. The percentage of new housing for enlisted personnel further refines housing costs. The average salaries for officers, enlisted personnel, and civilian employees help COBRA calculate savings from eliminating positions. The military savings or costs include basic allowances for quarters (BAQ) for both officers and enlisted personnel. The civilian savings or costs include adjustments for retirement (civilian early retirement and civilian regular retirement), natural attrition (civilian turnover), severance for lost jobs (unemployment and a civilian RIF (reduction in force) pay factor), finding new government employment for affected civilian employees under the PPS (priority placement system) adjusted for PCS (permanent change of station), and new hires. The Homeowners Assistance Program (HAP) and the Relocation Service Entitlement (RSE) entitle (under specific conditions) military and government personnel who are homeowners and are affected by BRAC to reimbursement of home losses incurred as a consequence of a BRAC action.

savings.

Because, by law, DoD must clean up all installations, not just those closed or realigned, the costs of environmental restoration are excluded from BRAC economic analyses and ignored by COBRA. Although excluded from economic analyses, these costs are an implementation reality. For BRAC95, just for the army and just over the first six years, the cost of environmental restoration is $1 billion; environmental restoration may cost more and continue longer. In contrast to environmental restoration, environmental impact (Criterion 8) includes such issues as BRAC impact to endangered species, wetlands, and historic sites.

COBRA calculates net present values for all the actions on a completely predefined scenario timetable. For example, COBRA requires as input the personnel, equipment, and vehicles moving in each of the scenario years between each pair of installations. Similarly, COBRA needs the amount of all one-time costs, such as construction costs, to be spent in each of the scenario years. COBRA does not seek a good solution to any closure or realignment scenario but rather serves as a cost calculator. COBRA can be used to show that the economic viability of a proposed action can be influenced merely by changes to a timetable. COBRA's limitations offer opportunities for improvements. A mixed-integer linear program, BRACAS, is such an improvement.

BRACAS (Base Realignment and Closure Action Scheduler)

BRACAS suggests timetables for BRAC actions that both satisfy yearly budget constraints and maximize net present value. During BRAC93, army analysts had many opportunities to manually adjust timetables in stubby-pencil drills with COBRA. Manually massaging a complex BRAC schedule just once is experience enough to make the need for an automated decision aid absolutely clear. Free [1994] developed a prototype that evolved into BRACAS, and Wong [1995] developed variations on the model. The appendix contains a sample BRACAS mathematical formulation.

BRACAS either uses COBRA data and mimics COBRA's assumptions, or it enforces more conservative assumptions:

(1) The average tour length for military personnel on an installation is 26 months. Therefore, 12/26 or 46 percent of the costs to move military personnel in a given year can be considered natural rotation and not attributable to a BRAC action. Regardless of the timetable adopted, COBRA and BRACAS assume that only 54 percent of the total costs to move military personnel is a BRAC expense.

(2) BRACAS recognizes future dollars and discounts to a net present value. BRAC95 used a 2.75 percent discount rate. COBRA can embellish the discount rate with a true inflation rate added for future activities, but this was not done for BRAC95.

(3) BRACAS assumes conservatively that any civilian RIF (reduction in force) necessitated by the closure of an installation occur in the last year the installation is open.

(4) BRACAS assumes by default that military construction paid for in year t is not completed until year $t + 2$. This allows for planning and construction time. The army may direct that construction be accelerated or delayed from this default rate. For

instance, repeated use of standard construction plans can accelerate completion.
(5) BRACAS restricts moving a given portion of personnel and equipment to a receiving installation until the installation's new construction is complete.
(6) BRACAS recognizes some recurrent savings even before all personnel complete their moves to receiving installations: one-quarter of savings accrue when at least one third, but less than two thirds, of personnel have moved, and one half accrue when at least two thirds, but not all, have moved.

BRACAS and COBRA both recognize the net present value of one-time savings in Year 1 of a scenario—savings for such things as military construction avoided, family housing costs avoided, land sales, canceled moves, environmental mitigation, and one-time unique savings.

BRACAS classifies all COBRA costs into one of four categories: costs with fixed yearly schedules, costs with somewhat flexible schedules, cost with completely flexible schedules, and costs at completion.

Costs with fixed yearly outlays include program costs, civilian early retirements, and construction costs. BRACAS program costs include COBRA overhead and the cost of planning the program. The total amount paid (Y) is allocated over four years such that an initial amount is discounted 25 percent yearly (that is, $Y = \Sigma_{t=1}^{4} (1.0 - 0.25)^{t-1} * X$, where X is the amount spent in Year 1, (0.75) X in Year 2, $(0.75)^2X$ in Year 3, and $(0.75)^3X$ in Year 4). BRACAS allocates COBRA early-retirement costs for civilians evenly over the first three years of any action. BRACAS construction costs include COBRA costs for military construction, family-housing construction, and information management. BRACAS schedules the first year of each construction project and allocates nine percent of costs to that year; it spreads the remaining 91 percent evenly over the rest of the project.

BRACAS has some flexibility to schedule the costs of hiring new civilians and of moving civilians, military, and freight. In particular, one third of these costs must be paid before the action is one quarter complete, and two thirds before the action is half complete.

BRACAS has complete flexibility to schedule COBRA costs for household assistance, environmental mitigation, one-time unique costs, mothball (maintaining an inactive installation), and shutdown.

BRACAS charges for civilian RIF during the last year of the BRAC action.

The army first used BRACAS in November 1994 as it prepared its initial BRAC95 recommendations for DoD (Figure 2), but the army did not adopt the initial schedules BRACAS recommended. Because the army viewed BRAC95 as its last chance for the foreseeable future to close major installations, it concentrated on individual recommendations with minimal concern for resulting yearly implementation costs.

In April 1995, the army used BRACAS again; this was just a warm-up.

Implementing BRAC Decisions

The president received the Defense Base Closure and Realignment Commission report on July 1, 1995 (Figure 2). Figure 3 shows part of what he saw. The army supported its recommendation for each installation with information similar to that shown for Fort McClellan, Alabama, in

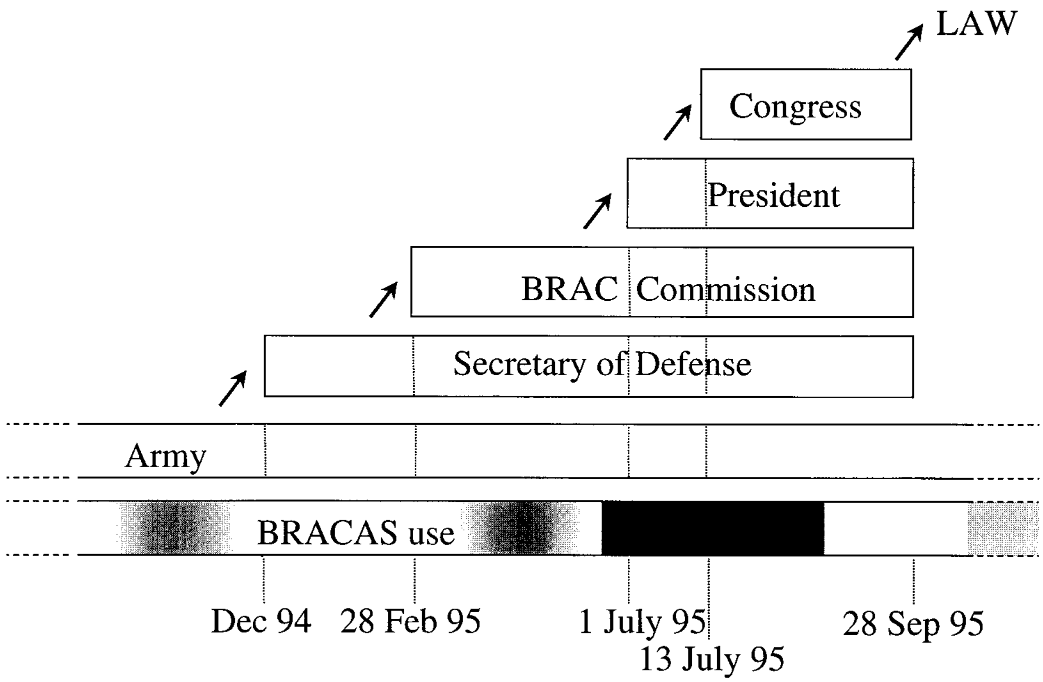

Figure 2: The army first tested BRACAS in November 1994 as it prepared its initial BRAC95 recommendations, but the army did not adopt the initial schedules BRACAS recommended. BRAC95 recommendations migrated up the chain of command, with the dates distinguished when each higher authority assumed responsibility. During this period, the army needed to answer questions about its proposals. The intensity of the use of BRACAS peaked when the president and Congress joined the deliberations.

Figure 4 and Figure 5. Figure 6 summarizes the army's COBRA-estimated costs and savings. The president approved the recommendations on July 13. Congress then had 45 legislative days to issue a joint resolution of disapproval or the recommendations would become law. The recommendations become law on September 28.

Paradoxically, to meet a September 15 deadline, the army had already submitted its budget request to the secretary of defense; the request had to include all costs for BRAC95. BRACAS was used intensely.

The secretary of defense planned to give the army $182 million in fiscal year 1996, $298 million in 1997, and $393 million in 1998 to implement BRAC95. The BRAC95 COBRA schedules would have costs that significantly exceeded the approved level in 1997 (Figure 6). The major army commands started refining COBRA cost estimates when the BRAC95 proposals were released to the public in March 1995. The army needed to find the best levels of expenditures to complete BRAC95.

In July 1995, field data from the major commands were not yet available, so BRACAS runs used BRAC95 COBRA costs and savings estimates. BRACAS' advice (Figure 7) provides recommended expenditures and resulting savings when constrained to a fiscal year 1996 DoD budget of $182 million (costs minus savings), but unrestricted thereafter. BRACAS prioritized actions with the greatest benefit and found savings of about $400 million more than COBRA-estimated savings over the six-year planning horizon; the additional savings derived primarily from accelerating about $60 million of future expenditures into 1996. The army relied on its experience in past BRAC actions to ensure that it could implement BRACAS' advice.

A briefing about the $400 million increase in savings caught the attention of Major General Robert T. Howard, who was deputy assistant secretary of the army for budget. He questioned a number of modeling assumptions and ordered another BRACAS run on the spot, but with different ground rules: "Suppose moves were allowed without waiting for construction to be completed?" Within an hour, I reformulated and solved BRACAS, which showed that this could save an additional $60 million (over the $400 million). This fortuitous exchange was the first test of BRACAS in an exigent what-if role, and it partially explains why the army accepted BRACAS as an integral tool for implementing BRAC95.

Reconciling Estimates of Costs and Savings

By August 1995, the major commands had provided detailed field estimates of BRAC95 costs and savings. Their six-year cost estimates, excluding environmental restoration, totaled about $1.7 billion, whereas COBRA had estimated about $1 billion. They estimated annual savings after completing BRAC95 at only $270 million, compared to a COBRA estimate of $480 million. These are significant differences.

The army conducted a vigorous audit of the field estimates and reduced the estimate of $1.7 billion in costs to about $1.3

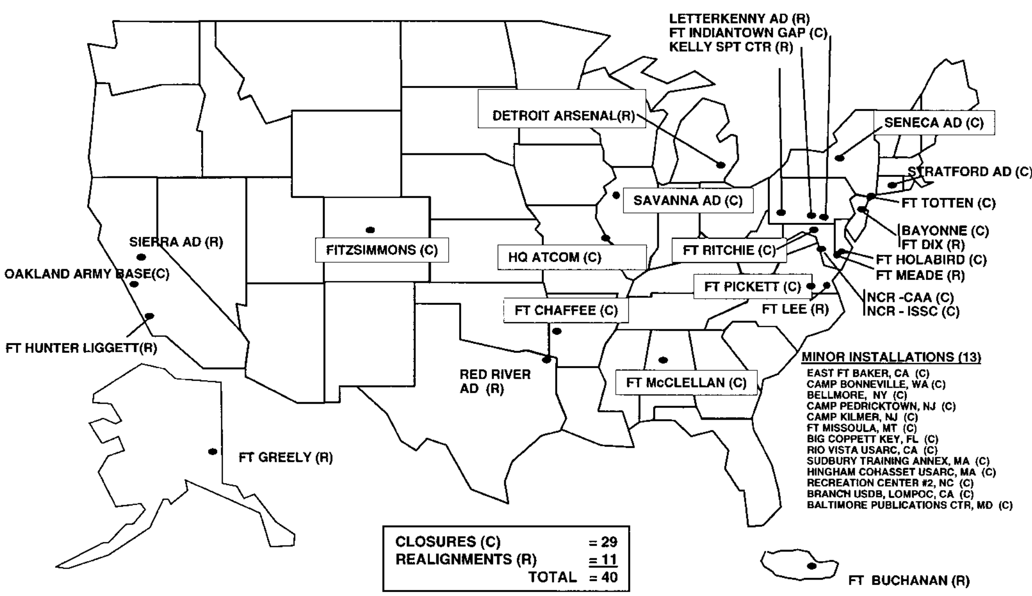

Figure 3: The army recommended closing the installations marked (C) and realigning those marked (R) for BRAC95. (Figure adapted from a Department of the Army presentation [1995].)

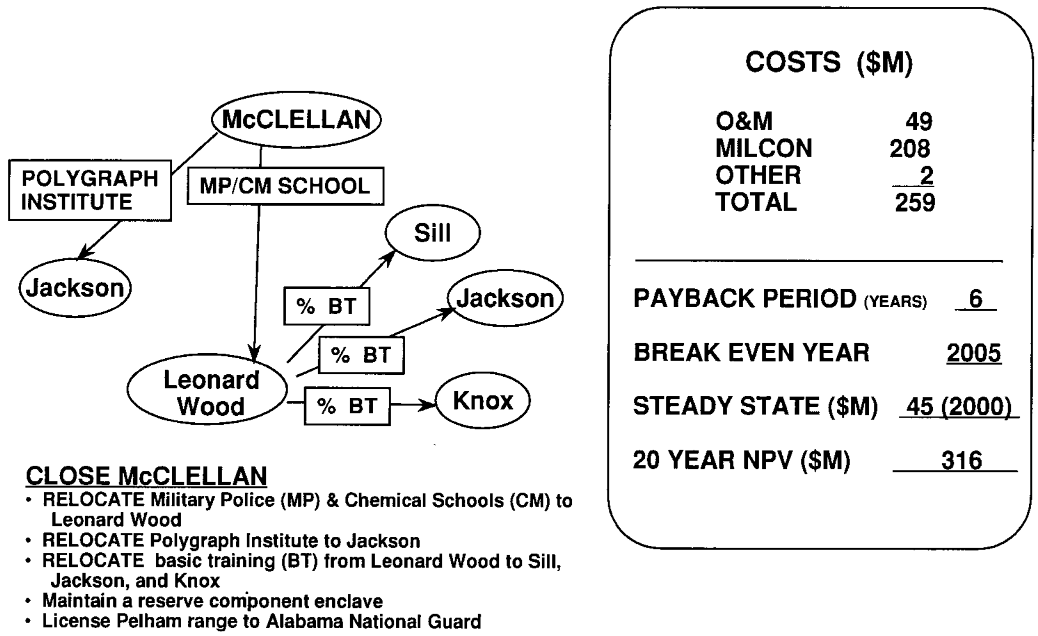

Figure 4: An army BRAC95 summary for closing Fort McClellan, Alabama, provides an overview of the movements and the resulting costs and savings. Costs come in three budget categories: O&M (operations and maintenances), Milcon (military construction), and other. The army developed a similar summary for each nominated installation. (Figure adapted from a Department of the Army presentation [1995].)

billion. Even with these refinements, BRAC95 has been more expensive to implement than any other prior BRAC round (Figure 8).

Obtaining reliable estimates of future savings is not easy [GAO 1996]. The army decided to use COBRA estimates in lieu of the lower aggregate projections by its major commands. It has since revised the COBRA estimate of annual savings down to $360 million [Jones 1997].

With refined cost and schedule estimates and an additional billion-dollar, six-year environmental restoration effort to plan, the army needed just the tool BRACAS turned out to be. It modified BRACAS many times and employed it heavily at this stage of BRAC95.

Because COBRA ignores environmental restoration costs, BRACAS initially did too. However, although this billion-dollar cost is not discretionary, it is such a large budget item that it had to be incorporated into BRACAS. The environmental restoration does not have to be completed within the six-year limit imposed on other BRAC costs. Installation plans for environmental restoration covered only initial studies and essential preliminary work that could not be delayed. There was no easy way to realistically reschedule these funds, and the army couldn't afford to delay planning. BRACAS just fixed expenditures for the initial work at the levels recommended by the installations.

Having committed to the approved

BRAC95 actions, the army wanted to reschedule yearly budgets to maximize returns. Since it was already too late to change the 1996 budget, many what-if analyses focused on changes to cost estimates, inflation and discount rates, and ad-hoc rescheduling for later years. For instance, we added hypothetical increments to the $298 million 1997 budget of $100, $200, and $300 million from later years, which yielded respective additional savings of $290, $380, and $425 million. Helped by these what-if analyses, the army approved a $100 million addition to the 1997 budget, with revised BRACAS advice that this would lead to savings in excess of $230 million.

Sticking to a Fixed Budget

In February 1996, each army installation affected by BRAC95 provided a revised schedule of its planned annual and environmental costs to complete BRAC95 actions. Aggregation of these independent installation-by-installation estimates revealed budget overruns in early years (Figure 9). Clearly, the installation budgets had to be revised to be consistent with the amounts approved by Congress.

The army could reallocate BRAC95 funds among categories within years, but not among years. Unfortunately, in their BRAC95 cost estimates, the target installations provided little guidance about how they might reallocate funds. BRACAS, with enhancements to encourage "persistence" [Brown, Dell, and Wood 1997], provided a model to reallocate yearly BRAC95 budgets across categories and installations. Estimated savings guided the reallocation, while constraints ensured that

OPERATIONAL:

- **DoD's recommendation to close rejected by Commission during BRAC 91 and BRAC 93**
- **Collocates Engineer, Military Police, and Chemical training schools in accordance with Stationing Strategy**
- **Rebuilds Chemical Defense Training Facility (CDTF) at Leonard Wood for $30 million**

PERSONNEL:

	MILITARY	CIVILIAN	STUDENTS
REDUCTIONS	230	543	
REALIGNMENTS	2384	764	7620

ENVIRONMENTAL: **CDTF requires expedited permitting**

ECONOMIC: **Assuming no economic recovery, this recommendation could result in a maximum potential reduction of 10,720 jobs (8,536 direct jobs and 2,184 indirect jobs) over the 1996 to 2001 period in Anniston, AL area, which is 17.3% of the area's employment.**

OTHER SERVICE/DOD FACTORS: **None**

ALTERNATIVES CONSIDERED **Close Leonard Wood and realign Engineer School to McClellan and BT to Sill, Knox and Jackson.**
Cost = $ 612M / 8 yrs.

Figure 5: An army BRAC95 impact summary for closing Fort McClellan, Alabama, provides the rationale for closing this installation, including a number of operational and other considerations in addition to costs. The army submitted a similar summary to DoD for each nominated installation. (Figure adapted from a Department of the Army presentation [1995].)

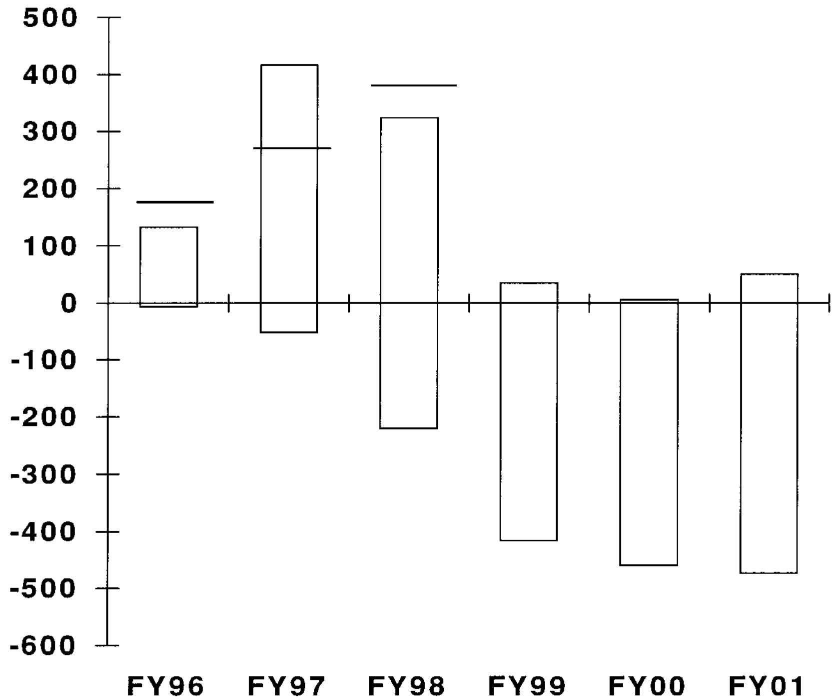

Figure 6: Initial army BRAC95 cost and saving schedule from COBRA. Six years of army costs (positive) and savings (negative) were estimated using COBRA. The costs in fiscal years 1996 and 1998 were less than authorized by DoD, while 1997 exceeded budget (about $300 million, shown by the bar) by over $100 million.

spending stayed within yearly budget totals.

Within "persistent BRACAS," a ranged persistent constraint provides upper and lower limits (ranges) for each target budget category by installation. We again fixed environmental restoration expenditures; that is, we set upper and lower ranges in the associated persistent budget constraints equal to established values. Construction plans are difficult to change, so if an installation had requested more than a million dollars, BRACAS ranged the reallocation within 10 percent of plan. Operating and maintenance and "other" BRAC costs are somewhat more flexible. We allowed yearly operating-and-maintenance requests above $2 million to range from an 80-percent decrease to a 150-percent increase. We allowed requests below $2 million to be increased to 35 percent of the total six-year operating-and-maintenance amount the installation requested. We set the range for "other" requests above $2 million between −90 and +150 percent and permitted requests for lower amounts to increase to 35 percent of total. Persistent BRACAS also constrains budget totals in each year to the level approved by Congress exactly.

The army is following the persistent BRACAS advice.

The Future of BRAC and BRACAS

BRACAS has enabled the army to see quickly the effect of schedule and budget changes and to prioritize and exploit funding flexibility within fixed budgets to obtain the greatest potential savings. BRACAS is a valuable tool that may be needed for future BRAC rounds.

The 1995 Defense Base Closure and Realignment Commission [1995] recommended further reductions because over the last decade the defense budget has declined in real terms by almost 40 percent, the DoD has reduced the size of the military by 30 percent (the army has eliminated 45 percent of its divisions, the air force 44 percent of its tactical fighter wings, and the navy 37 percent of its ships), but reduction to domestic base infrastructure will be only 21 percent after all BRAC95 actions are complete.

The 1995 commission recommended a BRAC round in 2001 similar to the 1991, 1993, and 1995 rounds. The six-year delay allows for BRAC95 to be completed. In 1995, the commission changed 27 prior BRAC decisions and recommended that Congress enable it to revise the 1995 recommendations during this six-year period.

If no new legislative authority appears that is similar to Title XXIX of Public Law 101-510 (the National Defense Authorization Act for Fiscal Year 1991), the military services could proceed with a new BRAC

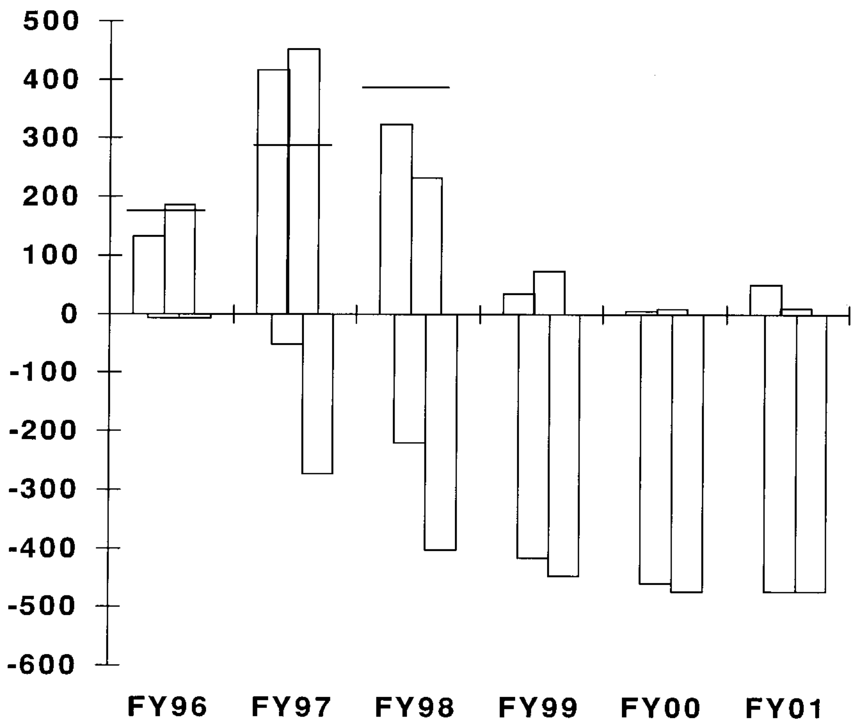

Figure 7: Initial army BRAC95 cost and saving schedule from COBRA (left; see also Figure 6) compared with army BRAC95 costs rescheduled by BRACAS (right). BRACAS was given a fiscal year 1996 DoD budget goal (about $182 million, shown by the bar), but was unrestricted thereafter. BRACAS accelerated spending to use all of the 1996 budget and suggested an overexpenditure for 1997. BRACAS found savings of about $400 million more than COBRA over these six years.

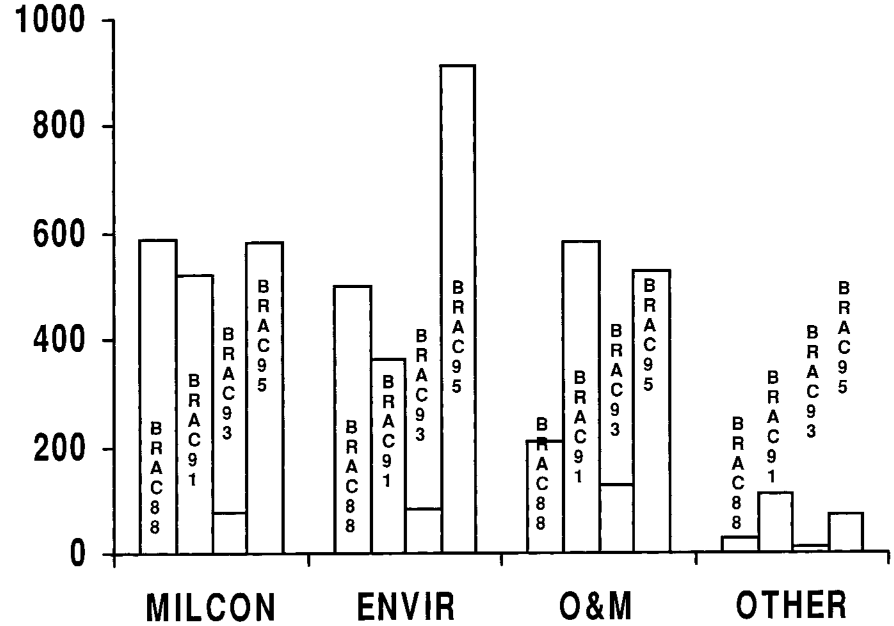

Figure 8: Six-year implementation costs for army BRAC88, 91, 93, and 95 shown in four budget categories: Milcon (military construction), Envir (environmental cleanup), O&M (operations and maintenance), and other. BRAC95 is the most expensive army BRAC ever.

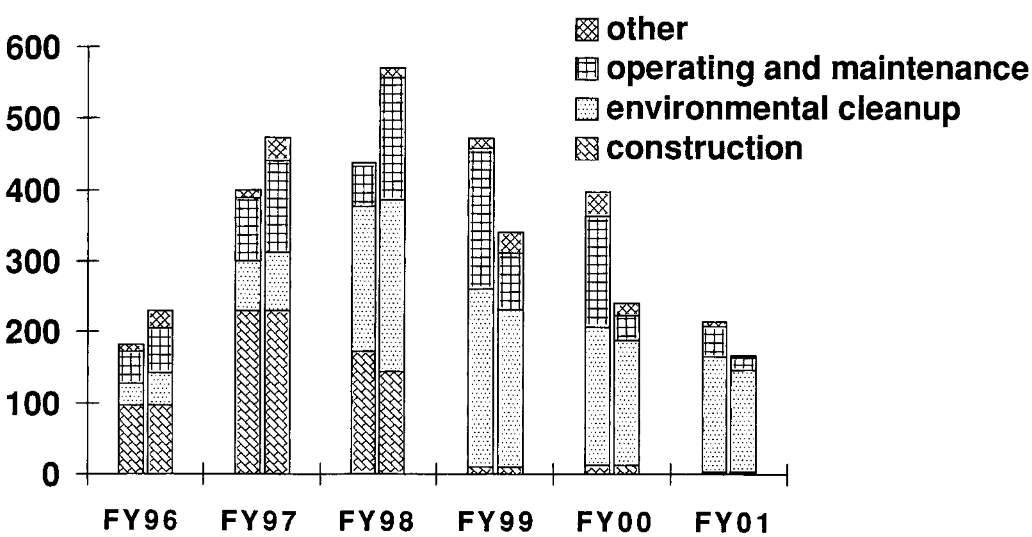

Figure 9: In late 1995, the army published an approved six-year plan for spending about $2 billion to close and realign military installations (left-hand bars). Soon after, the affected installations submitted detailed individual revisions to this schedule that agree with the published plan in total amount but not in timing (right-hand bars). The army used BRACAS to reschedule the revisions at the affected installation to comply with the plans Congress had approved.

round governed by current authority (section 2687 of Title 10, United States Code), the same authority that existed prior to Title XXIX of Public Law 101-510.

> Under section 2687, the closure of any military installation in the United States with at least 300 civilian employees, or the realignment of any installation involving a reduction of more than 1,000 civilian employees or of more than 50 percent of the installation's civilian work force, cannot take place until the Secretary of Defense carries out "an evaluation of the fiscal, local economic, budgetary, environmental, strategic, and operational consequences of such closure or realignment." If the Secretary concludes as a result of these evaluations that the closure or realignment should proceed, the Secretary must notify Congress of the proposed closure or realignment and wait 30 legislative, or 60 calendar, days before proceeding. [Defense Base Closure and Realignment Commission 1995, p. 3–1]

The 1995 commission commented that section 2687 was unworkable. However, the deficit-phobic political climate today is quite different from the deficit-immune climate that necessitated Title XXIX of Public Law 101-510. If the services develop new BRAC recommendations using the current authority, this might also convince Congress of a need for future legislation like Title XXIX of Public Law 101-510.

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APPENDIX: BRACAS (Base Realignment and Closure Action Scheduler)

Indices:

- t,t' year ($t = 1,2,\ldots,20$);
- l installation losing unit(s); and
- g installation gaining unit(s).

Index sets:

- G_l set of all installations gaining unit(s) from installation l; and
- L_g set of all installations losing unit(s) to installation g.

Losing installation cost and saving data in constant (1996) dollars:

- $CONSAV_l$ procurement and construction costs avoided at installation l;
- $RECSAV_l$ yearly savings after completing actions at installation l;
- $RETIR_l$ yearly civilian early retirement cost at installation l attributable to its realignment;
- $SEVPAY_l$ cost for civilian reduction-in-force (RIF) attributable to realigning installation l; and
- $UNIQCOST_l$ unique costs attributable to realigning installation l.

Gaining installation cost data:

- $MILCON_{t'tg}$ cost of construction at installation g in year t (year t dollars) when construction is started in year t' (i.e., $MILCON_{t'tg} = 0$ for all $t < t'$); and
- $NEWHIRE_g$ cost (1996 dollars) of all civilian new hires at installation g.

Transfer cost from losing to gaining installation in 1996 dollars:

- $CIVPCS_{lg}$ cost to move all civilians from installation l to installation g;
- $FREIGHT_{lg}$ cost to ship all office and special equipment from installation l to installation g; and
- $MILPCS_{lg}$ 54 percent of the cost to move all military personnel from installation l to installation g.

Additional data:

$CYEAR_g$ years required to complete construction at installation g (i.e., $MILCON_{t'tg} = 0$ for all $t \geq t' + CYEAR_g$);

$DEVPEN_t$ the penalty for exceeding the budget in year t;

DIS_t the discount applied to a dollar in year t for net present value (in COBRA, $DIS_t = 1/(1 + d)^{t-0.5}$ where d is the COBRA discount rate);

INF_t the inflation to a dollar in year t (in COBRA, $INF_t = (1 + i)^{t-0.5}$ where i is the inflation rate; standard DoD inflation rates for BRAC actions were used in BRACAS);

$IINF_t$ ($IINF_t = 1/INF_t$);

NET_t ($NET_t = DIS_t * INF_t$);

REQ_g the fraction of personnel that can move onto installation g without completing construction at g; and

$WEDGE_t$ total funds available for BRAC actions in year t (in year t dollars).

Binary decision variables:

$1third_{tl}$ one if at least one third of all required personnel move from installation l during year t (zero otherwise);

$2third_{tl}$ one if at least two thirds of all required personnel move from installation l during year t (zero otherwise);

$build_{tg}$ one if construction at base g begins during year t (zero otherwise); and

$done_{tl}$ one if all actions at installation l are complete during year t (zero otherwise).

Continuous decision variables:

$civmove_{tlg}$ spending in year t (year t dollars) for civilian movement from installation l to g;

$civrif_{tl}$ spending in year t (year t dollars) for civilian RIF at installation l;

dev_t spending in year t (year t dollars) exceeding $WEDGE_t$;

$hire_{tg}$ spending in year t (year t dollars) for hiring at installation g;

$milmove_{tlg}$ spending in year t (year t dollars) for military movement from installation l to g;

$ship_{tlg}$ spending in year t (year t dollars) for shipping from installation l to g; and

$uniq_{tl}$ spending in year t (year t dollars) for unique one-time costs at installation l.

maximize

$$
\begin{aligned}
&\sum_{t=7}^{20} \sum_{l} RECSAV_l * NET_t - \sum_{t=1}^{3} \sum_{l} RETIR_l \\
&\quad * NET_t + \sum_{l} CONSAV_l * NET_1 \\
&\quad + \sum_{t'=2}^{6} \sum_{t=2}^{t'} \sum_{l} \left(\frac{1}{4}\, RECSAV_l\right) * (NET_t) \\
&\quad * (2 * done_{t-1,l} + 1third_{t-1,l}\; 2third_{t-1,l}) \\
&\quad - \sum_{t=1}^{6} \sum_{l} DIS_t * (uniq_{tl} + civrif_{tl}) \\
&\quad - \sum_{t=1}^{6} \sum_{g} DIS_t * (hire_{tg}) - \sum_{t=1}^{6} \sum_{l} \sum_{g \in G_l} DIS_t \\
&\quad * (ship_{tlg} + civmove_{tlg} + milmove_{tlg}) \\
&\quad - \sum_{t=1}^{6} \sum_{t'=1}^{t} \sum_{g} DIS_t * (MILCON_{t'tg} * build_{t'g}) \\
&\quad - \sum_{t=1}^{6} (DEVPEN_t * dev_t)
\end{aligned}
$$

subject to

$$
\begin{aligned}
&\sum_{l (if\ t \leq 3)} RETIR_l * INF_t + \sum_{l} (uniq_{tl} + civrif_{tl}) \\
&\quad + \sum_{g} hire_{tg} + \sum_{t'=1}^{t} \sum_{g} (MILCON_{t'tg} * build_{t'g}) \\
&\quad + \sum_{l} \sum_{g \in G_l} (ship_{tlg} + civmove_{tlg} + milmove_{tlg}) \\
&\quad \leq WEDGE_t + dev_t \quad \forall t \leq 6, \qquad (1)
\end{aligned}
$$

$$\frac{\sum_{t=1}^{t'} \sum_{g \in G_l} (IINF_t * (civmove_{tlg} + milmove_{tlg}))}{\sum_{g \in G_l} (CIVPCS_{lg} + MILPCS_{lg})} \geq \sum_{t=1}^{t'} \frac{1}{3} * 1third_{tl} \; \forall t' \leq 6, l, \tag{2a}$$

$$\frac{\sum_{t=1}^{t'} \sum_{g \in G_l} (IINF_t * (civmove_{tlg} + milmove_{tlg}))}{\sum_{g \in G_l} (CIVPCS_{lg} + MILPCS_{lg})} \geq \sum_{t=1}^{t'} \frac{2}{3} * 2third_{tl} \quad \forall t' \leq 6, l, \tag{2b}$$

$$\frac{\sum_{t=1}^{t'} \sum_{l \in L_g} (IINF_t * (civmove_{tlg} + milmove_{tlg}))}{\sum_{l \in L_g} (CIVPCS_{lg} + MILPCS_{lg})} \leq \frac{\sum_{t=1}^{t'} (IINF_t * hire_{tg})}{NEWHIRE_g} \; \forall t' \leq 6, g, \tag{3a}$$

$$\frac{\sum_{t=1}^{t'} (IINF_t * (civmove_{tlg} + milmove_{tlg}))}{(CIVPCS_{lg} + MILPCS_{lg})} \leq \frac{\sum_{t=1}^{t'} (IINF_t * ship_{tlg})}{FREIGHT_{lg}} \; \forall t' \leq 6, l, g \in G_l, \tag{3b}$$

$$\frac{\sum_{t=1}^{t'} \sum_{l \in L_g} (IINF_t * (civmove_{tlg} + milmove_{tlg}))}{\sum_{l \in L_g} (CIVPCS_{lg} + MILPCS_{lg})} \leq REQ_g + (1 - REQ_g) * \sum_{t=1}^{t' - CYEAR_g} build_{tg} \quad \forall t' \leq 6, g, \tag{3c}$$

$$\frac{\sum_{t=1}^{t'} (IINF_t * uniq_{tl})}{UNIQCOST_l} \geq \sum_{t=1}^{t'} done_{tl} \quad \forall t' \leq 6, l, \tag{4a}$$

$$\frac{\sum_{t=1}^{t'} \sum_{g \in G_l} (IINF_t * (civmove_{tlg} + milmove_{tlg}))}{\sum_{g \in G_l} (CIVPCS_{lg} + MILPCS_{lg})} \geq \sum_{t=1}^{t'} done_{tl} \quad \forall t' \leq 6, l, \tag{4b}$$

$$\sum_{t=1}^{t' - CYEAR_g} build_{tg} \geq \sum_{t=1}^{t'} done_{tl} \quad \forall t' \leq 6, l, g \in G_l, \tag{4c}$$

$$(IINF_t * civrif_{tl}) = SEVPAY_l * done_{tl} \quad \forall t \leq 6, l, \tag{5}$$

$$\sum_{t=1}^{6} done_{tl} = 1 \quad \forall l, \tag{6}$$

$$\begin{aligned} &1third_{tl} \in \{0, 1\}; 2third_{tl} \in \{0, 1\}; \\ &done_{lt} \in \{0, 1\} \; \forall t, l; \\ &build_{tg} \in \{0, 1\} \; \forall t, g; \\ &civmove_{tlg} \geq 0; milmove_{tlg} \geq 0; \\ &ship_{tlg} \geq 0 \; \forall t, l, g; civrif_{tl} \geq 0; \\ &uniq_{tl} \geq 0 \; \forall t, l; hire_{tg} \geq 0 \; \forall t, g; \\ &dev_t \geq 0 \; \forall t. \end{aligned} \tag{7}$$

The objective function expresses the discounted total savings achieved over a 20-year period accounting for one-time costs, one-time savings, and the annual recurrent savings produced by BRAC actions. The first line of the objective is a constant to make BRACAS consistent with COBRA. The objective function value is in net present dollars when $dev_t = 0$ for all t.

Constraints (1) seek to keep yearly expenditures within budget. The elastic variable dev_t allows its budget constraint to be violated at a per-unit penalty of $DEVPEN_t$.

Constraints (2) credit recurrent savings at installation l only after a sufficient number of personnel have moved.

Constraints (3) link personnel movement to prerequisites. Constraint sets (3a) and (3b) ensure the cumulative percentage of support personnel hired and equipment shipped to an installation is at least as great as the cumulative percentage of personnel moved. Constraint (3c) ensures the cumulative percentage of personnel moved to an installation does not exceed the amount allowed prior to completion of construction. This constraint accounts for the lag between construction start and completion.

Constraints (4) ensure a BRAC action is not complete until all actions that generate one-time costs are complete.

Constraints (5) ensure all civilian reduction-in-force actions occur in the last year of the transition period for each BRAC action.

Constraints (6) ensure all actions from installation l occur by year 6.

Constraints (7) specify variables as binary or continuous.

The General Algebraic Modeling System (GAMS) [Brooke, Kendrick, and Meeraus 1992] was used to generate BRACAS instances and XA [Sunset Software 1992] to solve them on either a notebook personal computer with a 66 megahertz processor at the Pentagon or an IBM RS/6000 Model 590 workstation in Monterey. An instance had about 2,500 equations, 1,500 continuous variables, 1,500 binary variables, and 15,000 non-zero elements.

Solution time was usually within 10 minutes using the notebook when accepting the first integer solution guaranteed to be within three percent of optimal. Use of the IBM workstation usually provided guaranteed optimal solutions within an hour. See Free [1994] and Wong [1995] for additional computational experiences.

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Frank L. Miller, Major General, US Army, Assistant Chief of Staff for Installation Management, 600 Army Pentagon, Washington, DC 20310-0600, writes: "Professor Dell impressively demonstrated initiative and academic skill in applying an optimization model known as BRACAS, developed in a research effort with the Naval Postgraduate School. The army used this model to optimize annual funding levels while developing the BRAC budget.

"Because the president did not accept the commission's recommendations until mid-July, very little time was available to design a budget enabling the army to achieve the greatest possible savings with a careful allocation of resources. Professor Dell's model demonstrated we could reap additional savings by adjusting annual budgets. In the end, the army's senior leaders approved an increase of $100 million in the FY97 budget in order to produce an additional $233 million in savings over a six-year period."