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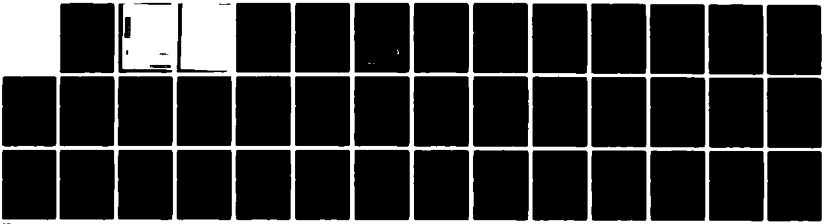

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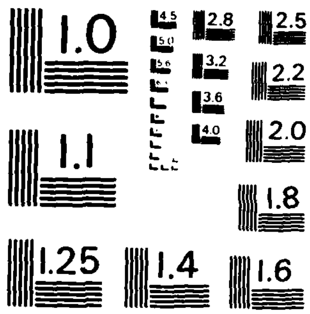

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Documents a methodology for analyzing problems incurred in planning an Air Force Medical Service serving complementary and conflicting functions. The Note describes a mathematical programming model called the physician workforce design model, which complements the Provider Requirements Integrated Speciality Model (PRISM) developed by the Air Force. The model and methodology indentifies and compares options for improving the wartime capabilities of active duty physicians without compromising the peacetime delivery of health care. By pursuing the more promising options, the Air Force can improve its readiness to respond in a sudden conflict within the constraints of a workable peacetime health care system. The Note describes the dual purpose workforce design model, the wartime capability assessment model, and defines the workforce model inputs.

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A RAND NOTE

A METHODOLOGY FOR EVALUATING AIR FORCE PHYSICIANS' PEACETIME AND WARTIME CAPABILITIES

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PREFACE

This Note documents a methodology for analyzing problems incurred in planning an Air Force Medical Service serving complementary and conflicting functions. The Medical Service sustains the health of active duty personnel in peacetime and maintains a wartime medical capability. However, in peacetime, the primary day-to-day activity is to offer health care to military beneficiaries, most of whom are not active duty personnel. These functions demand a different mix of medical services and therefore a different resource mix. Wartime casualties require more surgery than peacetime patients, and most peacetime patients require either more routine care or the skills of nonsurgical specialists.

Rand has developed a methodology to identify and compare options for improving the wartime capabilities of active duty physicians without compromising the peacetime delivery of health care. By pursuing the more promising options, the Air Force can improve its readiness to respond in a sudden conflict within the constraints of a workable peacetime health care system.

Rand is undertaking this project for the Air Force Surgeon General as a complement to the Provider Requirements Integrated Specialty Model (PRISM). PRISM has been designed over the past several years to provide meaningful estimates of the medical provider manpower required in peacetime and in wartime. Rand's study will offer some suggestions for narrowing the differences in the two PRISM physician requirements estimates and analyze the effect of beneficiary benefits changes and other peacetime policy changes on medical readiness.

The Rand research project, entitled "Air Force Medical Resource Planning," is being conducted under the Project AIR FORCE Resource Management Program. The project is also studying issues concerning the supply of Air Force physicians. Other project publications include: G. A. Goldberg, *Israeli Military Medical Experience: Ideas for the U.S. Air Force's Medical Service?* N-1924-AF, August 1982; S. D. Hosek, *Procurement of Air Force Physicians: Scholarship or Direct Recruiting?* N-1968-AF, July 1983.

SUMMARY

This Note describes a mathematical programming model, called the physician workforce design model, useful in evaluating:

- Workable wartime substitutions of one physician specialty for another in the performance of specified tasks,
- The benefits of peacetime expansion in those services requiring specialists most useful in wartime,
- The comparative readiness of alternative specialty mixes that can handle the current peacetime workload,
- The size of the gap between wartime workload and active duty workforce capability (by type of activity needed) after all workable substitutions have been made, and
- Weaknesses in active duty physicians' training and experience relevant to casualty treatment.

The evaluation is based on varying assumptions about military manpower planning priorities and constraints, and about future physician supply conditions. The flexibility of the model can handle alternative wartime scenarios, once their associated workloads are specified.

The workforce design model prespecifies: (1) The peacetime and wartime workloads, defined in categories and measured in units of required physician time. (2) The maximum time that each available physician specialty can provide. (3) The maximum total physician time consistent with the physician manpower authorization. (4) The set of workload categories typically performed by each specialty. (5) The wartime specialty substitutions considered feasible. (6) The penalty the Air Force pays for not having sufficient capacity in each workload category or using less preferred specialty substitutes.

The model then jointly assigns the peacetime and wartime workload to a single group of physicians and to peacetime and wartime overflow categories. The objective in making these assignments is to meet all prespecified constraints and most closely reflect the Air Force's

priorities. Although the workforce design model is technically an optimizing model--it selects the "best" workforce, given the workload requirements and constraints--we use it to provide information regarding the desirability of alternative physician workforces, to evaluate the options for improving joint capability in the peacetime and wartime missions, and to identify the constraints on achieving greater capability.

We have structured this manpower analysis to fit into the simplified framework of a network model, which can consider large numbers of variables without sacrificing computational efficiency. Here, we describe the full peacetime-wartime model and a more limited model, called the wartime capability assessment model that deletes the peacetime component. The more limited model facilitates initial development of the data inputs and permits preliminary insights into a portion of the workforce design problem. The two models have the same mathematical formulation, but the variable definitions change.

The workforce design model is an aggregate model. It allows us to consider the physician manpower implications of a wide range of policies and exogenous factors. However, in facilitating these aggregate workload comparisons, it ignores problems arising because casualties do not occur evenly through time and in one place. We recognize that additional staffing needs result from the decentralized health care delivery system and the sporadic arrivals of many simultaneous casualties at a facility and that these can be handled only approximately within our analyses.

In constructing inputs for the workforce design model, we are relying on information embedded in the Provider Requirements Integrated Specialty Model (PRISM). To complement PRISM III, which estimates the Air Force's peacetime physician requirements, we define the peacetime workload by clinic service category. To accommodate the greater variety of specialty substitutions, we define the wartime workload by physician task.

The penalties in the model derive from many sources, including one or more of the trauma severity indexes that have been developed to aid research and triage in the civilian sector, a survey to determine Air Force physicians' assessments of potential wartime substitutions, and discussions with experienced Air Force medical personnel.

ACKNOWLEDGMENTS

We would like to thank Lt. Col. Tom Schumann and Major Steve Jones for their help in understanding the tri-service wartime planning models and data sets around which this project is designed. Major Bill Tufte guided us through the Air Force's PRISM III peacetime planning model. Advice from Jan Chaiken and Warren Walker guided our design of the methodology. We are particularly indebted to Jim Kakalik for a thoughtful review of an earlier version.

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I. INTRODUCTION

The demands for physician skills in peacetime and wartime differ sharply. The peacetime workload encompasses routine medical care for active duty and retired family members; in wartime, the volume of surgical cases rises dramatically. Historically, U.S. involvement in combat has developed gradually, allowing time to build a wartime medical service. The military medical services can no longer count on a long transition period. This research concentrates on the early stages of conflict before civilian physicians can be mobilized, trained, and transferred overseas. Without sufficient time for full mobilization, the peacetime physician force would have to treat wartime casualties without assistance from reserve or drafted physicians. In this context, the goal of peacetime manpower planning is to design an efficient, high quality peacetime physician force with maximum wartime capability.

The central component of our analysis is a workforce design model that, conditional on prespecified priorities, simultaneously assigns peacetime and wartime medical workloads to particular specialties in a single physician workforce. These assignments are constrained by various factors, including physician supply and the total number of physicians authorized in peacetime. The workforce design model uses a specialized form of linear programming called a network model. The simple structure of a network model decreases the cost of obtaining solutions and allows us to use the model to explore various workload and constraint issues. For example, we plan to vary the wartime workload estimates, recognizing wartime scenarios may differ. In this manner, we can observe how a workforce performs the different workloads and also how the the desired workforce design responds to the workload changes.

The workforce design model is an optimization model; it selects the most capable physician workforce, or specialty mix, and specifies how it should be used in both peacetime and wartime. The optimal workforce depends on previously specified peacetime and wartime physician demands, specialty substitutions, physician supply constraints, and a penalty scheme that incorporates the Air Force's priorities. We plan to actually use the model to evaluate how alternative workforces perform and to understand whether potential changes in physician manpower planning policies, military health care benefits, physician supply, and other policy variables would enhance or detract from the active duty physicians' joint peacetime/wartime treatment capabilities.

In late 1980 the Air Force began development of PRISM (Provider Requirements Integrated Specialty Model), which represents a considerable improvement in physician requirements determination. When complete, PRISM will estimate the physician requirements to accomplish the wartime and peacetime missions. PRISM III[1] identifies peacetime active duty provider requirements from estimated peacetime patient needs. PRISM II[2] bases wartime requirements on estimated wartime workload and relies heavily on tri-service readiness planning models, described below.

A series of issues outside the current capability of PRISM still need to be addressed for effective planning of the active physician force. First, because of sharp differences in the wartime and peacetime caseloads, PRISM II and III will inevitably call for different physician skills. Rand's physician workforce design analysis is intended to help evaluate alternatives for approaching a reconciliation. Second, since the draft ended a decade ago, obtaining the required number and mix of physicians has been difficult at best. The Air Force is not recruiting enough surgeons to meet the needs of its peacetime patient population, much less the larger wartime needs. The interactions among physician supply, peacetime care, and readiness can be understood only if they are analyzed jointly. Most military medical decisionmakers understand intuitively that the delivery of peacetime health care benefits both

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[1] The development of PRISM III is the responsibility of Manpower Division, Directorate of Medical Plans and Resources, Office of the Surgeon General, Department of the Air Force, Bolling Air Force Base, Washington, D.C. "PRISM I, allocates resources in a balanced health care program constituted by the Five Year Defense Program (FYDP)."

[2] PRISM II is the responsibility of the Medical Readiness Division, Directorate of Medical Plans and Resources, Office of the Surgeon General, Department of the Air Force, Bolling Air Force Base, Washington, D.C.

supports and limits wartime medical capabilities. Systematic evaluation of policy alternatives enables a more concrete assessment of this relationship.

The workload specifications for the workforce design model are being developed directly from the PRISM III data base for peacetime needs and PRISM II for wartime needs.

PRISM II relies on new tools for determining wartime resource requirements, developed over the past several years by the Army, Navy, and Air Force. A series of computer models[3] (some still in the development phase) and the data bases to support them provide a common tri-service readiness planning methodology to determine wartime requirements, especially for physicians. These models derive personnel requirements for a specified time period from greatly improved descriptions of theater medical workload and the medical personnel inputs needed for each patient. When complete, the models will also simulate theater medical facility operations and medical evacuation. The simulations will allow each Medical Service to design a workable combat medical system and to validate resource requirements generated by the more aggregate models. Alternatively, the models will enable readiness planners to evaluate the wartime capabilities of the medical resources on hand in the active or reserve forces.

The peacetime component, PRISM III, calculates the number of physicians and other providers by specialty required at each hospital and clinic, without regard to readiness or wartime needs. These peacetime requirements are based on the estimated caseload for the beneficiary population residing within forty miles of each Air Force hospital and clinic.

The workforce design is presented in Section II. Section III describes a more limited wartime capability assessment model that we will use to develop and refine some crucial model inputs. To help illustrate the methodology, this section also contains some examples using the limited model. In the final section, we discuss the model inputs, including the penalties that guide the optimization procedure.

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[3] Requests for additional information on these models should be directed to Operations Analysis Office, Combat Developments and Health Care Studies, Academy of the Health Sciences, Department of the Army, Fort Sam Houston, Texas.

II. A DUAL PURPOSE WORKFORCE DESIGN MODEL

GENERAL DESCRIPTION

We wish to study how a single active duty physician specialty mix can serve the Air Force's peacetime patient population but also be capable of responding rapidly in the event of a future conflict. In particular we want to compare alternative joint allocations of the peacetime workload and the expected wartime workload among physician specialties. The total volume of work allocated in either time period is limited by the total number of physicians authorized in the Air Force. In addition, allocation to certain specialties may be limited by the supply of physicians in these specialties.

This workforce design problem is pictured in Fig. 1. Peacetime cases are defined by diagnosis and depicted in the left column, and the wartime workload is given on the right. By defining the wartime workload by task instead of diagnosis, we can allow different physician groups responsibility for patients at different treatment stages. For example, we can substitute medical specialists for scarce surgeons in preoperative and postoperative care, if such substitutions are medically feasible. By switching to tasks, we reflect case management contingencies arising from wartime scarcities, unnecessary in peacetime. Tasks are also differentiated by echelon or facility level when facility level affects the choice of specialties available. The lines connecting cases and tasks to the physician groups in the middle column indicate which physician groups can treat the case or task. When more than one physician group is connected to a case or task, specialty substitution is feasible.

The system may be thought of as a large accounting scheme. All components are measured in time units. The two workloads are specified as the demands for provider time to treat peacetime cases and perform wartime tasks. To fully account for all available physician time and required work, several additional categories are appended. In each workload column, we add an 'unassigned' category and, in the physician group column, we add a 'CHAMPUS[1]/shortage' category.

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[1] Civilian Health and Medical Program for the Uniformed Services.

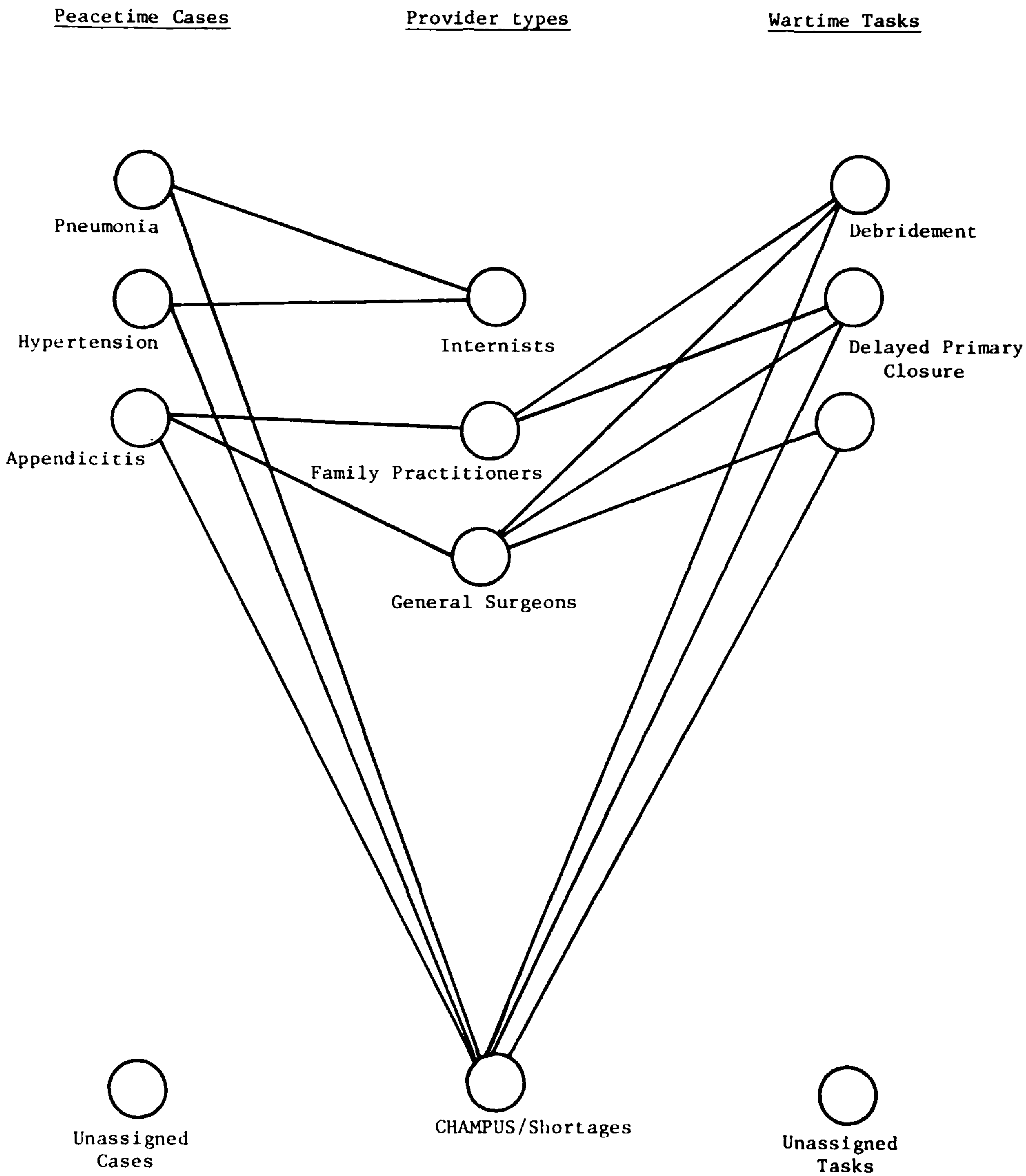

Fig. 1--Model of provider workforce design

The unassigned categories recognize that some physicians can be underemployed in peacetime or wartime. These categories also serve another purpose. Like any accounting scheme, the workforce design model keeps track of all workload and provider time by requiring that the three columns have the same total time. To balance the total times in the peacetime and wartime workload categories, we add time in the unassigned category.

The CHAMPUS/shortage category receives all workload that cannot be assigned to active duty physicians, either because the peacetime manpower authorization is too small or because supply in one or more specialties is inadequate. Peacetime workload assigned to this category is referred to other military facilities or performed in the civilian sector under differing payment mechanisms. The Air Force directly pays for civilian care for active duty personnel. Other beneficiaries are eligible for reimbursement under the CHAMPUS insurance program, but many opt to leave the military health care system.

Wartime tasks assigned to "shortage" represent combat medical needs for which no appropriately skilled active duty physician can be made available. At a minimum, Air Force Reserves when mobilized should be able to relieve these shortages. We do not mean to imply that, in wartime, Reserve physicians should work only in the active duty shortage areas. This project can identify only the minimum Reserve requirement; determining the proper split of wartime responsibilities between active and Reserve physicians will require further research.

Whenever work must be allocated to the CHAMPUS/shortage category or, in wartime, to less appropriate substitute specialties, the model imposes predetermined penalties, which indicate how much using alternative providers or not having active duty physicians to perform the work are undesirable outcomes. The best workforce design minimizes the sum of these penalties.

The Air Force must plan within some tight constraints, the most important of which we will reflect in our analysis. These constraints, which can make designing the workforce a difficult chore, include:

- Mandatory assignment to active duty physicians of active duty workload.
- A ceiling on the number of active duty physicians.
- Limited physician supply, especially in certain specialties.
- Prohibition of greatly underemployed physicians in peacetime.

In the model the constraints, like the penalties, are predesignated. By changing the constraints, we learn how they alter the feasible workload assignments. For example, we can increase the total number of active physicians above the current number and discover what these added physicians can do in peacetime and wartime if the specialty mix is adjusted to achieve the best mix of capabilities. Similarly, raising the supply ceilings on individual specialties will indicate whether joint capability would improve and whether the total workforce would increase.

RESTATING THE PROBLEM AS A NETWORK MODEL

To efficiently handle the numerous workload categories and maintain the flexibility to explore the dual workforce design by varying the model's inputs, we have formulated the problem as a network model. Network models are specialized linear programming models with decision variables that may be visualized as directed flows along "arcs" connecting "nodes." These are roughly comparable to the lines and circles in Fig. 1. The specialized mathematical structure within network models greatly facilitates the solution procedure, enabling us to economically solve much larger problems than would otherwise be possible.

Network models have only two types of constraints, one set bounding the amount of flow along each arc to fall within lower and upper limits and the other set constraining the flow into and out of each node. The latter are termed "conservation of flow" constraints. A node is classified as a "source" node when all its flow is directed outward, as a "sink" when all its flow is directed inward, and as an "intermediate" node when its flow is both inward and outward. The conservation equations then require that total outward flow equal total inward flow for intermediate nodes, that all supply flow out of source nodes and that all demand flow into sink nodes, and that total inflow (demand) equal total outflow (supply) in the network as a whole.

Representing the workforce design problem in a network framework is fairly straightforward. A new node identifies each peacetime case type, each physician group, and each wartime task type. Arcs connect physician groups with peacetime cases (wartime tasks) and represent the capability of the physician group to treat the case (task) type. To depict substitution possibilities, multiple arcs emanate from a peacetime case to alternative physician groups or enter a wartime task from alternative physician groups. The flow of decision variables now represents the time providers of each type devote to the associated peacetime case (wartime task). To direct the flow as required for a network model, we adopt the convention that time flows from peacetime cases through physician group nodes into wartime task nodes.

The decision variables represent time allocations. For any set of inputs, the associated workforce size and specialty mix is obtained by summing across the cases assigned to each physician group. For example, one decision variable will show the amount of time needed to treat those pneumonia cases expected to occur within our time frame and assigned to internists. Other variables show the amount of pneumonia case time assigned to family practitioners and general medical officers. Summing over all case type times assigned to internists (pneumonia, diabetes, etc.) gives the total internal medicine workload for the time frame. A measure of work minutes per physician may be used to convert this to a staffing figure. The conservation of flow equations insure that the same number of internists are available for peacetime and wartime. Data transformations, described in more detail below, allow us to reflect any increases in working hours during wartime.

Formal Statement of the Network Model

The model may be stated formally as a capacitated transshipment problem. Nodes are defined for each peacetime case type and wartime task type (including unassigned times), for the CHAMPUS program and the physician shortage group and for each physician specialty. Arcs represent the physician groups' capabilities to perform cases and tasks, potential assignments to the CHAMPUS and shortage categories, potential idle time, and residual flows. If i indexes the node set and j the arc set, then the problem is to select the x_j that will:

$$\text{Minimize} \quad \sum_{j=1}^{J} p_j x_j$$

$$\text{subject to} \quad \sum_{j \varepsilon A_i} x_j - \sum_{j \varepsilon B_i} x_j = c_i \qquad i = 1,\ldots,I$$

$$l_j \leq x_j \leq u_j \qquad j = 1,\ldots,J$$

where p_j is the penalty on arc j,

x_j is the physician time flow along arc j,

A_i is the set of arcs leading out of node i,

B_i is the set of arcs leading into node i,

l_j is the lower bound on arc j time,

u_j is the upper bound on arc j time;

for peacetime nodes, $c_i = +S_i$ = total minutes needed to perform case type i for all occurrences;

for wartime nodes, $c_i = -D_i$ = total task minutes needed for task i for all occurrences;

for other nodes, $c_i = 0$.

Dual Problem

Every mathematical programming problem has an associated dual problem. In this case, the dual problem is to maximize the valuation of care delivered. The dual solution may be used to identify: (1) which physician supply constraints are most limiting, given the assignment pattern and the specified mission priorities; and, therefore, (2) which physicians' groups it would be most advantageous to increase. Some wartime substitution possibilities require training in peacetime to introduce or reinforce the physicians' substitute skill. The dual solution also enables us to identify which of the new substitution possibilities are most productive in increasing wartime capabilities. To choose among potential substitutions requires a separate assessment of how adequately the substitutes can be trained.

Time Flow Assumptions and Adjustments

The model ignores dynamic considerations, particularly those created by the uneven distribution of patient arrivals.[2] Inputs for the model include the amount of time needed to treat each peacetime case or perform each wartime task and the amount of time supplied by each physician. In wartime, twelve hour shifts, seven days a week would increase the workload capacity per provider. Since the model cannot directly incorporate the increase in worktime per physician from peacetime to wartime, we need to convert the wartime demands to peacetime equivalent minutes. If C_p denotes peacetime and C_w wartime patient care minutes per physician, the time demanded for each wartime task is expressed in peacetime equivalent minutes after the following transformation:

$$D'_k = D_k \cdot \frac{C_p}{C_w}$$

D_k is the actual total time demanded for task k.

Peak load demand may then be introduced by increasing the wartime workload demands uniformly by some percentage or by using lower figures for patient care minutes per provider, C_w.[3]

[2] This project looks at the resolution of conflicts in total peacetime and wartime physician staffing needs. We do not deal with dynamic problems at the micro level because the Air Force, together with the other services, has developed the capability to analyze these problems. The tri-service micro simulation model HOSPITALS simulates the treatment of wartime casualties in an individual hospital. It is used to assess the ability of a hospital to treat its expected workload with the staff determined by the macro requirements determination model (CZAR). The Operations Analysis Office, Combat Development and Health Care Studies Academy of the Health Sciences, Department of the Army, at Fort Sam Houston, Texas, oversees these models.

[3] This adjustment procedure is analogous to introducing or revising productivity factors common to most industrial engineering studies on workload capacity. By decreasing a productivity factor, more slack time is introduced in the system. This slack time is necessary to accommodate uneven demand.

Arc penalties for arcs connecting provider groups to cases (tasks) are expressed as penalties per (peacetime equivalent) minute for the physician group handling that case (task).

The Constraint Set

In designing its physician workforce, the Air Force faces a supply constraint, representing the availability of physicians by specialty, and a budget constraint on the total number of active duty physician slots. Recall that, in a network model, we can bound the flow across individual arcs and we can conserve the total flow into or out of the nodes. To represent the above constraints on Air Force manpower planning, we need to expand the network from the framework shown in Fig. 1.

If supply constraints limit the number of physicians the Air Force can employ in some specialties, the total workload capacity of those specialties, defined in time units, is correspondingly limited. In the network model, constraining a physician group's capacity is conceptually equivalent to constraining the total flow into or out of that group's node. However, in a network framework, we cannot bound this total flow. Therefore, to introduce supply constraints, we have controlled the flow along each individual arc by dividing each provider group node into two nodes and introducing a new arc between them. To limit the total time assigned to a particular specialty group, first we require that all flow into the original node for that group flow out along the new arc and into the new node, and then we bound the flow along this new arc. As illustrated in Fig. 2, arcs flowing to the wartime tasks now emanate from the second node. The total flow across these arcs must be equal to the bounded flow between the double provider group nodes.

The second major constraint, which limits the number of active duty physician slots, is equivalent to an active duty workload capacity constraint. Recall that the total peacetime workload, including any unassigned physician time, must be allocated between the active duty physician workforce and the CHAMPUS program. Similarly, the wartime workload must be fully allocated to the physicians and the shortage category. Therefore, to limit the workload that will be assigned to

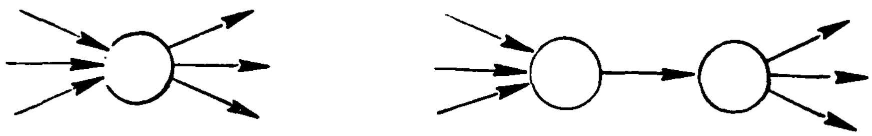

Fig. 2--Expanded physician group node

active duty physicians, we place a lower bound on the flow from the CHAMPUS workload plus residual balancing time node. From the technique illustrated in Fig. 2, we implement this lower bound by separating the CHAMPUS program plus residual balancing time node from the physician shortage group node with an arc between them. The expanded network is illustrated in Fig. 3.

We also use upper and lower bounds on the arc flows to impose some additional constraints on the workforce design. The law requires that the Air Force be directly responsible for providing active duty health care. Since active duty patients are rarely transferred to non-Air Force facilities, we want to limit the assignment of active duty workload, excluding only highly specialized care, to active duty physicians. To impose this constraint, we identify the active duty caseload and then place corresponding upper bounds on the amount of each case type sent to the CHAMPUS category. Lower bound constraints may also be used to insure that, in peacetime, patients whose treatment would sharpen the active duty physicians' wartime skills are not needlessly diverted to CHAMPUS. Alternatively, we can more heavily penalize assignment of these cases to CHAMPUS.

In the absence of physician supply and total manning constraints, the model could accommodate completely disjoint physician staffing for peacetime and wartime by letting physicians employed in one setting be idle in the other. At the other extreme, arcs connecting the physician

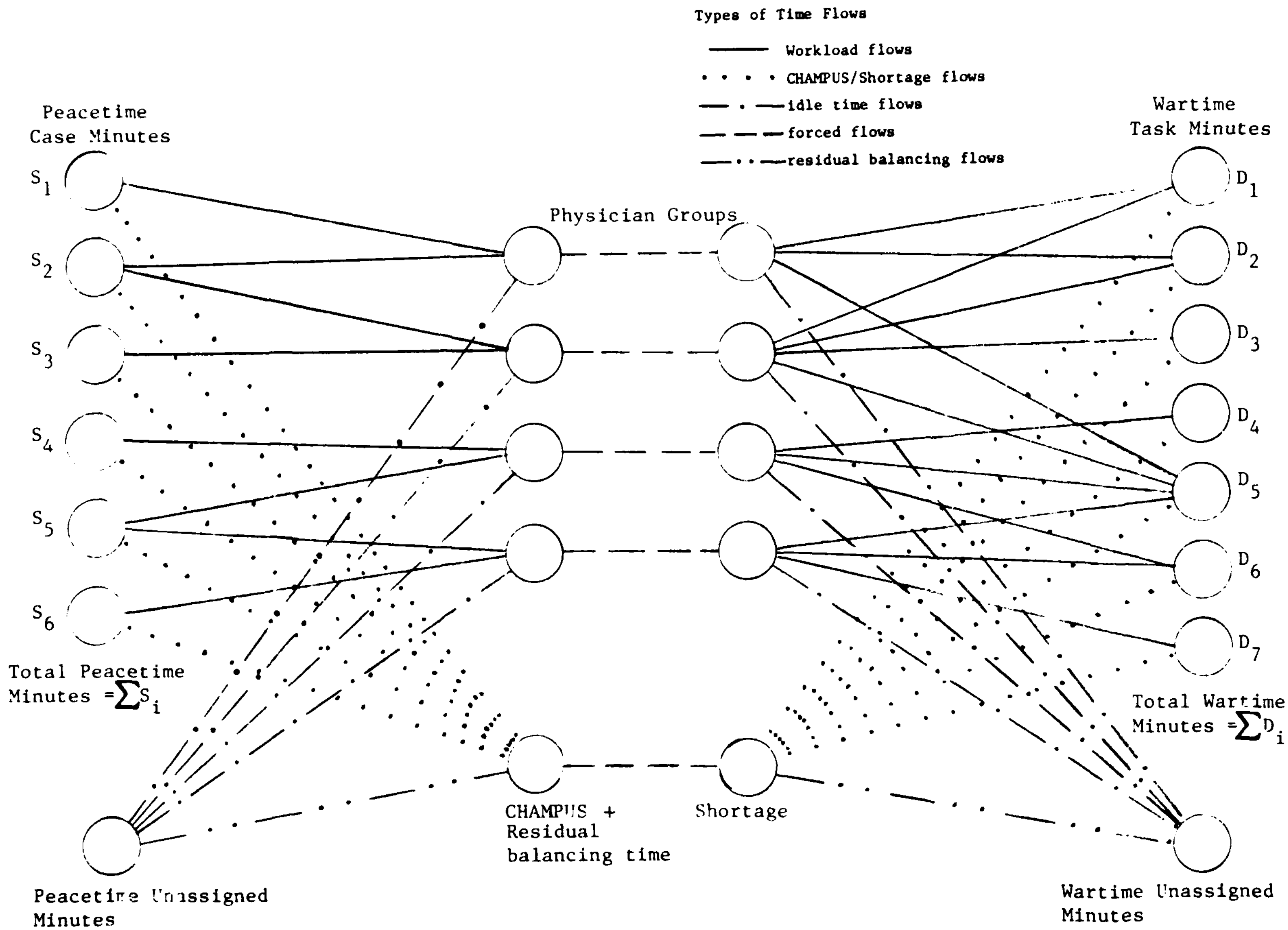

Fig. 3--Physician workforce design network

groups to the unassigned categories could be eliminated or heavily penalized, forcing active duty physicians to be fully employed in both settings. In Sec. III we further explore how penalties can be used to learn about system flexibility.

Aggregate Nature of the Output

A single solution of the model provides the following information: (1) total minutes of each task assigned to each specialty group, (2) total minutes of each task that no active physician can cover, (3) utilized physician time by specialty, (4) total peacetime case minutes assigned to each specialty, and (5) CHAMPUS case minutes. To obtain the provider staffing selected by the model, we simply sum the task or case minutes assigned to each specialty and divide by the total time each individual can work.

We have designed the workforce design model to facilitate aggregate workload capability comparisons. In doing so, we have necessarily ignored stochastic elements and indivisibilities resulting from the actual decentralized delivery system. Instead, the model illustrates how the peacetime caseload and wartime task needs interplay in physician workforce design. We are especially interested in identifying the aggregate flexibility that substitution possibilities offer when both peacetime and wartime roles are considered. In network terms, time flows that emanate from peacetime cases may occupy various physician workforces that ultimately provide the resources to meet wartime needs expressed as task demands. The physician workload assignments produced by our analysis should be viewed as approximations rather than precise estimates. For example, we might solve the network model to estimate the physician time in each specialty needed during the first six weeks of a conflict to handle wound debridement at third echelon facilities. However, the number of minutes of surgeons' time allocated to this task may not represent an integral number of repetitions. Similarly, summing the surgeons' time allocated tc all tasks may not represent an integral number of physicians. These technical limitations of the model should not affect the validity of policy conclusions based on our solutions.

III. THE WARTIME CAPABILITY ASSESSMENT MODEL

Although linking the peacetime and wartime components is integral to the value of our research, we feel that development of data for the two pieces differs sufficiently to warrant undertaking one piece at a time. Working with a more limited context will also facilitate the development and understanding of the penalty assessment scheme. To take advantage of a highly suitable wartime data base already developed by the Army and modified by the Air Force (described in Sec. IV), we are first developing the wartime component.

The questions analyzed by a wartime capability assessment model are more limited than those analyzed by the full model. We can operate this wartime model in two modes. The first structures the physician workforce based on prespecified wartime demands, total manning constraints, and specialty supply limitations. The resulting workforce would probably not suit the peacetime medical service. The second mode prespecifies a physician workforce and then allocates wartime tasks according to the penalty scheme, or alternative schemes. In this mode, we can compare the capabilities of the current and alternative workforces to handle various wartime workloads.

The limited model is pictured in Fig. 4. The mathematical formulation is identical to the full model, although some of the node and arc definitions change. It uses a single set of physician specialty group nodes and replaces the peacetime caseload nodes by a single source leading to a manpower supply node and a shortage node. An upper bound on the arc from the source to the manpower node constrains the overall size of the active duty workforce. Upper bounds on arcs from the manpower node to each specialty group node constrain specialty supply. To prespecify a particular workforce, we equate the upper and lower bounds along these arcs.

Here we investigate a hypothetical planning problem to demonstrate how the wartime capability assessment model works. We have constructed an example for this simpler model, rather than the full workforce design model, to show how workload, physician supply, and priorities (as

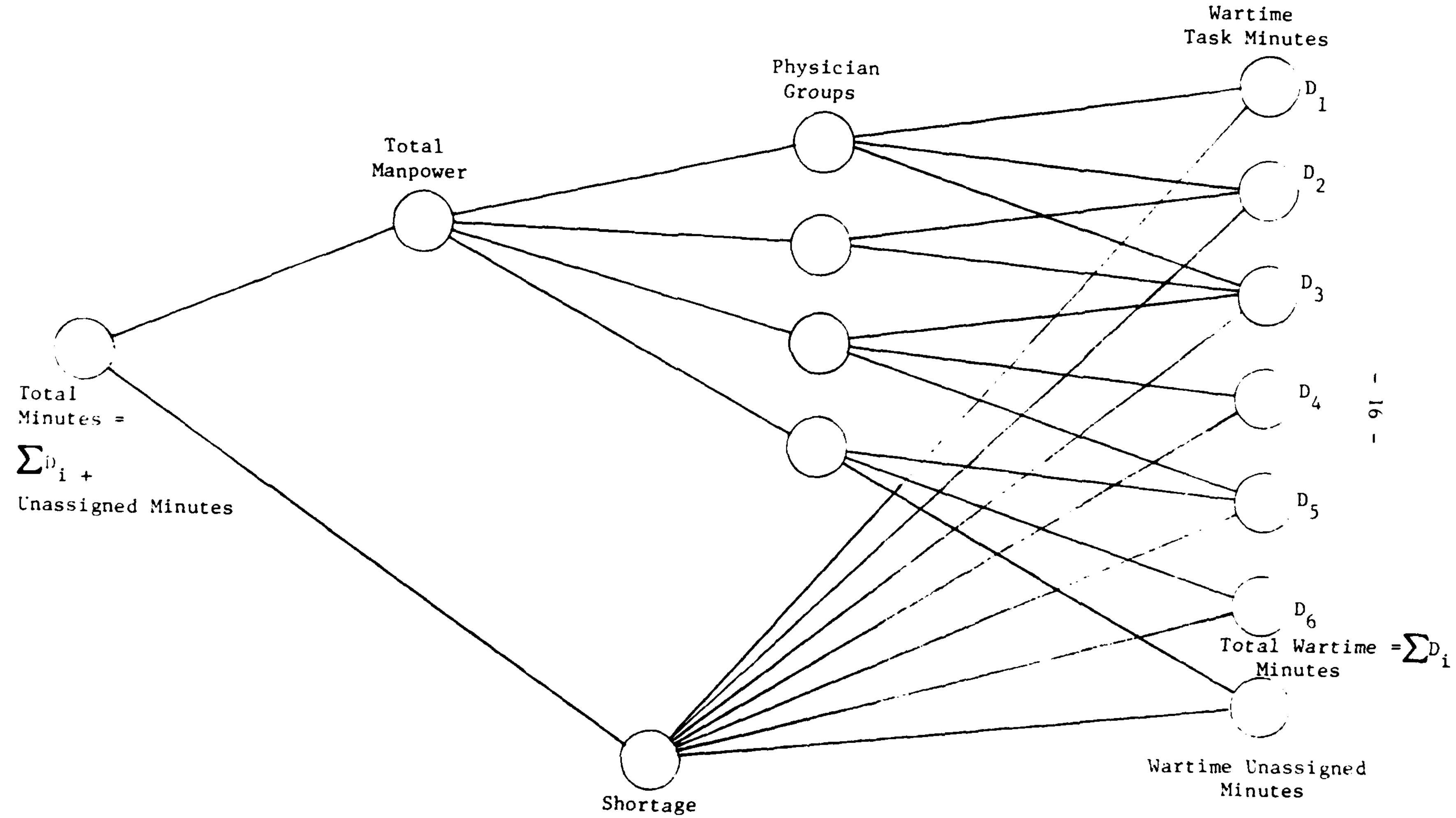

Fig. 4--Wartime capability assessment network

represented by the workload and substitution penalties) can interact in different ways to produce workload assignments by specialty.

Suppose there are only two types of physicians, internists and general surgeons. These physicians are asked to perform four tasks: (1) interpretation of an electrocardiogram (EKG), (2) endoscopy, (3) "cut-down" catheter insertion, and (4) emergency tracheostomy. Internists are preferred for tasks 1 and 2, and surgeons are preferred for tasks 3 and 4. However, suppose that internists and surgeons can substitute for one another in all tasks. When internists insert a catheter or perform an emergency tracheostomy, we impose penalties. Similar penalties are incurred when surgeons interpret EKGs or perform endoscopy.

For the purposes of this example, we assume that the social costs of death and disability can be monetarized. Suppose we assess each preventable death with a penalty of $350,000 and each preventable permanent disability with $200,000. If we know the probability of death and of disability for each task, penalty development would be straightforward. Assume that the probabilities of bad outcomes given in Table 1 are realistic, then the penalty when an internist performs a tracheostomy is calculated as

$$(.3)(350,000) + (.1)(200,000) = \$125,000.$$

If we further assume that tracheostomies require 10 minutes, then the penalty per minute is $12,500. This last conversion is necessary because the times to perform tasks differ. Using these hypothetical data, we see that in 20 minutes an internist can perform either one endoscopy or four EKGs. The penalty for one uncovered endoscopy is $210,000, and four nonperformed EKGs total $440,000 in penalties. These relative penalties are reflected in the calculated penalty per minute figures. Table 2 displays these values.

Suppose the physician force can supply 300 minutes of internists' time and 200 minutes of general surgeons' time. Task minute demands are 100 minutes for interpreting EKGs, 200 for cut down catheter insertion, 200 for endoscopies, and 300 for emergency tracheostomies. Total task demand exceeds total physician supply by 300 minutes, so 300 task minutes will be assigned to the shortage category. Solving the wartime model tells us how internists and surgeons should each allocate their

Table 1

PROBABILITIES OF BAD OUTCOMES

Task	Internists		Surgeons		Shortage	
	Death	Disability	Death	Disability	Death	Disability
EKG	0	0	.1	.1	.2	.2
Endoscopy	0	0	.1	.2	.2	.5
Catheter	.2	.1	0	0	.8	.2
Tracheostomy	.3	.1	0	0	1.0	0

Table 2

PENALTIES PER ASSIGNMENT
(PENALTIES PER MINUTE)

Task	Internists	Surgeons	Shortage
EKG (5 minutes)	0 (0)	$55,000 ($11,000)	$110,000 ($22,000)
Endoscopy (20 minutes)	0 (0)	$75,000 ($3,750)	$210,000 ($10,500)
Catheter (15 minutes)	$90,000 ($6,000)	0 (0)	$320,000 ($21,333)
Tracheostomy (10 minutes)	$125,000 ($12,5000)	0 (0)	$350,000 ($35,000)

time--that is, what tasks they should perform. It also tells us what tasks remain uncovered. Table 3(a) presents the solution; internists do not perform endoscopies but divide their time evenly among the remaining tasks, and surgeons spend all their time doing tracheostomies; endoscopies and some catheter insertions are uncovered.

The solution in Table 3(b) is based on a different staffing mix, one richer in surgeons. Internists now constitute only 40 percent of the workforce (down from 60 percent), and general surgeons provide 60 percent of the time input. Notice the total available staffing remains unchanged at 500 minutes.

With this physician mix, internists no longer substitute for surgeons in performing tracheostomies. The total penalties are lower for this staffing mix than for the internist-rich staffing mix. In other words, the physician workforce with more surgeons is preferable. In this example, the preference for surgeons is consistent with the higher priority on surgical tasks reflected in the penalty scheme.

As a final example, consider the effects of changing the mix of task demands. Suppose we decrease the demands for endoscopies and catheters equally and increase the demands for electrocardiograms and, to a lesser extent, tracheostomies. Tables 3(c) and 3(d) show how the time allocations and total penalties change to reflect the new workload. Internists spend their time interpreting EKGs and performing tracheostomies; endoscopies and catheter insertion are not performed. Surgeons still devote all their time to tracheostomies. These solutions reflect the interaction of performance time, provider availability, and the severity of the outcome. The lack of a needed catheter has a much higher risk of death within this example than an omitted EKG interpretation; however, it also requires longer to perform. The interpretation of three EKGs is preferred over one catheter insertion. Once again, the surgeon-rich staffing mix is preferable (results in lower penalties). But, as reflected by higher penalty levels, this workload stresses the capabilities of both specialty mixes more than the first scenario. These examples are purely illustrative; this type of consistency--where one staffing mix is clearly preferable--need not occur.

Table 3

ILLUSTRATIVE TASK ASSIGNMENTS FOR
ALTERNATIVE SPECIALTY MIXES, AND WORKLOADS

(a) Workload I
Specialty Mix I: 300 Internist Minutes, 200 Surgeon Minutes

Task	Minutes Needed	Penalty Scheme 1 — Minutes Provided: Internist	Surgeon	Shortage
1. Interpret EKG	100	100		
2. Endoscopy	200			200
3. Insert Catheter	200	100		100
4. Tracheostomy	300	100	200	
Total Penalties			6,083,300	

(b) Workload I
Specialty Mix II: 200 Internist Minutes, 300 Surgeon Minutes

Task	Minutes Needed	Penalty Scheme 1 — Minutes Provided: Internist	Surgeon	Shortage
1. Interpret EKG	100	100		
2. Endoscopy	200			200
3. Insert Catheter	200	100		100
4. Tracheostomy	300		300	
Total Penalties			4,8[illegible],300	

(c) Workload II
Specialty Mix I: 300 Internist Minutes, 200 Surgeon Minutes

Task	Minutes Needed	Penalty Scheme 1 — Minutes Provided: Internist	Surgeon	Shortages
1. Interpret EKG	300	100		200
2. Endoscopy	50			50
3. Insert Catheter	50			50
4. Tracheostomy	400	200	200	
Total Penalties			8,491,650	

(d) Workload II
Specialty Mix II: 200 Internist Minutes, 300 Surgeon Minutes

Task	Minutes Needed	Penalty Scheme 1 — Minutes Provided: Internist	Surgeon	Shortage
1. Interpret EKG	300	100		200
2. Endoscopy	50			50
3. Insert Catheter	50			50
4. Tracheostomy	400	100	300	
Total Penalties			7,241,650	

IV. WORKFORCE MODEL INPUTS

The full workforce design (or network) model requires a large input data set. Major items include:

- Wartime workload by task (and facility) level
- Physician time requirements for each patient requiring each task category
- Peacetime workload by diagnostic category, with a separate estimate of the active duty workload
- Physician time requirements for each patient in each diagnostic category
- Primary specialties for each peacetime case and wartime task category
- Specialties capable of substituting for the preferred specialty for each wartime task category
- Measures of all penalties for specialty substitution and work not assigned to active duty physicians
- Estimates of physician supply and total manpower authorization ceilings plus any minimum peacetime workload constraints the Air Force wishes to impose.

In this section, we specify these inputs more fully and describe how we plan to quantify them. As we stated in the Introduction, our analysis complements the Air Force's efforts to develop PRISM, the family of provider requirements models. Therefore, we are adapting the PRISM data for use in the workforce design model. PRISM II, the wartime component, relies on the tri-service wartime medical requirements models, notably the aggregate CZAR model, that are operated at the Army's Academy of Health Sciences (Combat Development Division). CZAR calculates the resources--manpower, beds, and supplies--needed in each period of time at each level of care for a specified level of combat casualties. CZAR uses a Clinical Data Base developed for eventual use in all tri-service planning models. The Clinical Data Base contains three major components:

1. The Patient Condition List specifies 309 wartime diagnoses and stipulates the incidence of each diagnosis.
2. The Clinical Task List identifies the clinical tasks necessary for treating the 309 patient conditions, the time in minutes to perform each task, and up to five provider types allowed to perform each task, in order of preference.
3. The worksheets describe, for each patient condition at each level of care, the course of hospital treatment, including the tasks to be performed, length of stay, and evacuation procedures. The Air Force has modified these worksheets to reflect its wartime system of four echelons of care in the combat theater.

PRISM III, developed independently by the Air Force to estimate peacetime physician requirements, contains data on the population served by each Air Force hospital and clinic, the populations' utilization of health care services, and the manpower required to provide each service.

DEFINING AND QUANTIFYING THE WORKLOAD CATEGORIES AND TREATMENT TIMES

Wartime Task Categories

The wartime task list and the associated provider time requirements come directly from the Clinical Task List, as modified by the Air Force. We have dropped all tasks not normally performed by a physician or physician substitute, such as a physician assistant or podiatrist. In the original Clinical Task List, some tasks--for example, task B3, "perform physical inspection/assessment"--are too general. The appropriate specialty or substitute specialties for patient assessment may differ, depending on when and where the assessment is done. Therefore, the Air Force modification differentiates some of the more general tasks by specialty. Task B3 has been redefined as a series of tasks, each calling for the specialist appropriate to a diagnostic category. We have further divided this task into four components: initial assessment, follow-up assessment by the specialist for post-operative and nonsurgical patients, and periodic patient monitoring.

In the network model, all work falling in a single task category can be assigned to any specialty group connected by an arc to the task category. If we want the acceptable substitute specialties for a given task to differ by patient condition, we must separate the task categories for conditions with different substitution patterns.

The same task may also require different skills according to the level, or echelon, of facility in which the task is performed. Certainly, the range of specialties likely to be available varies by echelon. The Air Force would not place surgical subspecialists in a 25 bed triage facility. To differentiate echelons in the network model, we define separate tasks for each echelon. Then we create arcs between each specialty group and appropriate task nodes only at echelons that can effectively use the specialty.

The volume of work in each task category equals the total number of patients multiplied by the proportion of patients needing the task. From the Clinical Data Set worksheets, we know which patient conditions require a given task and the incidence in the patient population of each condition. Thus, the expected number of patients requiring the task can be calculated by multiplying the proportion of patients suffering conditions calling for the task by the total expected number of patients. If there are I conditions and J tasks, the number of times task j is expected to be performed in time period t, N_{jt}, equals:

$$N_{jt} = P_t \sum_{i=1}^{I} e_i d_{ij} R_{ijt}$$

where P_t = the number of patients in time period t, e_i = the incidence of the ith condition, d_{ij} = a dummy variable equal to 1 if the ith condition requires the jth task, and R_{ijt} = the number of repetitions of the jth task for patients with the ith condition in time period t. The CZAR version of the Clinical Data Set does not allow a task to be repeated within a facility, although the worksheets do specify daily repetitions of the previously discussed B3 task. To incorporate these repetitions, we can increase the demand for the appropriate component tasks.

Peacetime Diagnostic Categories

The peacetime workload categories, defined by diagnosis rather than task, need not be so detailed as the wartime workload categories. All diagnoses that are treated by the same specialty or set of specialties and that receive the same priority can be combined in a single category. In peacetime, the diagnoses treated by each physician specialty are well defined, although specialties do overlap. For example, family practitioners treat many common conditions that are also treated by internists, pediatricians, or gynecologists. Diagnoses for which specialties overlap must be categorized separately from otherwise similar diagnoses belonging to a single specialty. Because the penalty scheme assigns a single priority to each category, diagnoses with different priorities also need to be separately classified. As we describe below, peacetime priorities depend on the type of care and the beneficiary category of the patient.

Ideally, then, we might define the peacetime workload categories by diagnostic group, specialty, and patient type. From PRISM III, we can get needed information on workload and treatment times by beneficiary type and clinic service, which is roughly equivalent to specialty. PRISM III inputs include the following information: (1) the beneficiary population living within 40 miles of each Air Force hospital and clinic; (2) outpatient utilization rates, measured in monthly visits, for each clinic service; (3) physician workload factors, measured as the number of outpatient visits per month a full-time physician can handle; (4) substitution rates of nonphysicians for physicians; and (5) various minimum staffing rules. The PRISM III output lists the number of physicians required to satisfy patient demands, with and without the staffing rules.

Therefore, in PRISM III, workload is measured in outpatient visits; differing inpatient workloads are recognized by lowering the number of visits some specialists can handle in hospitals with over 100 beds. The outpatient utilization rates predict visits to all health care facilities; the data set assumes that all active duty families and 40 percent of the retired families living in the 40-mile catchment area use the Air Force facility. Note that the data exclude beneficiaries living more than 40 miles from a facility; in some heavy retirement areas, many military retirees travel more than 40 miles to Air Force hospitals. Finally, the data do not cover most subspecialties, which are modeled outside the PRISM III framework.

The PRISM III data must be recalibrated to units of provider time for use in the workforce design model. If we estimate the number of minutes a full-time physician provides in a month, we can calculate the average minutes per visit implied by the PRISM III workload factors for each clinic service. This calculation provides us with average treatment times that can vary by clinic service but not by beneficiary group. The volume of work in each workload category, defined by clinic service and beneficiary type, then equals the number of outpatient visits multiplied by the treatment time for that category. For the subspecialties omitted by PRISM III, the Air Force's Uniform Chart of Accounts data include the number of outpatient visits seen in each hospital offering subspecialty care. By comparing the number of visits with the number of full-time equivalent physicians, we can crudely estimate workload factors. If we assume that beneficiaries demand the same proportion of their subspecialty care from these hospitals as they do other care, we can inflate the Report of Patients outpatient visit figures to estimate total utilization of each subspecialty service.

Physician Specialty Groups

Physicians are categorized by medical specialty and subspecialty, according to the Air Force's occupational specialty codes. We also include categories for nonphysician providers who: (1) are currently included in the active duty force in reasonable numbers; (2) are trained to perform physician tasks; and (3) in wartime, would not be in short supply for crucial nonphysician tasks. Thus, we omit operating room nurses and intensive care nurses, who could relieve physicians of some wartime tasks, because they are needed in their primary nursing roles. Potential nonphysician candidates for the analysis include physician assistants, nurse practitioners, nurse-midwives, nurse anesthetists, podiatrists, optometrists, psychologists, dentists, and oral surgeons. We may want to exclude nurse practitioners because they might be needed in wartime for nursing duty. We have omitted specialty-trained corpsmen, such as orthopedic technicians, because they, like specialized nurses, are in short supply relative to wartime demand. For nonphysicians who also must perform nonphysician tasks in wartime, we limit their supply to the proportion of time likely to be available for physician tasks and assign this time to the unassigned category in peacetime.

DESIGNING A PENALTY SCHEME

The workforce design model selects the physician specialty mix that minimizes a set of penalties. These penalties are incurred when less capable physician groups are assigned tasks, when physician groups are underemployed in either peacetime or wartime, and when the active duty medical system lacks sufficient physician resources to treat either cases or tasks. Thus, in the network model, the penalties result when time flows along certain arcs.

Figure 3, which portrays the workforce design network, uses five different line patterns to distinguish five conceptually different arc types. All arcs that are associated with forced and residual flows bear no penalties. The forced flow arcs, represented in Fig. 3 by dashed lines, connect the duplicate physician group modes introduced to constrain physician supply. The dash-double-dot patterns represent the residual flow arcs connecting the peacetime unassigned case node to the CHAMPUS program node and the shortage group to the wartime unassigned task category. The other three arc types all may carry penalties.

Penalties for Workload Assigned to CHAMPUS/Shortage

The dotted lines in Fig. 3 represent the assignment of workload to the CHAMPUS and shortage categories. The penalties assigned when peacetime workload must be diverted to CHAMPUS (or outside the system) should reflect the real cost to the patients of obtaining this care elsewhere, the risk that these patients will leave the direct care system altogether, and the difference in government costs. We will develop approximate measures of these relative costs based on previous Rand research on military retirees' outpatient care demands and other existing literature.

Wartime shortage penalties--also indicated by dotted lines--should reflect the threat of permanent health loss or death with treatment delay and the penalty for failure to return all injured personnel to needed duty as soon as possible. We are using existing indexes of trauma severity as an initial measure of the consequences to the patients of delayed or no treatment. Unfortunately, the best of these indexes provides imperfect information.[1] In addition, we must work from an index that is based solely on ICD-coded diagnosis, such as the Revised Estimated Survival Probability (RESP) Index described by Levy et al. (1982), and by Levy, Goldberg, and Rothrock (1982). The RESP index reflects only measured mortality rates. Finally, because none of the indexes covers all wartime diagnoses, we will have to develop consistent estimates of severity for omitted diagnoses.

Once the severity measures are complete, we must estimate the importance of returning wartime patients to duty, comparing that outcome with saved lives and prevented disabilities. The assignment to the shortage category of wartime tasks associated with patients who would return to duty with prompt treatment will incur a uniform penalty. We can then vary this penalty, which is the weight the model assigns to treating these patients rather than more seriously injured patients.

All penalties are measured on the same scale. Therefore, after developing independent penalty schemes for the two workloads, we must weigh their importance relative to each other and to substitutions among specialties in wartime. The difficulty of quantifying these priorities argues against using the network model to select a single, optimal workforce. Therefore, rather than attempt to determine the relative weight or priority given by the Air Force to accomplishing the peacetime workload versus the wartime workload, we plan to solve the workforce design model for several different weights. In this way, we will learn the effects of different Air Force priorities, and to what extent the workforce can adequately respond to various different priorities. If the analysis demonstrates that such flexibility does exist, the model solutions will indicate, for each set of mission weights, the

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[1]The indexes are evaluated in Gustafson, Hiles, and Taylor (1980), Gibson (1981); and Krischer (1976).

appropriate physician workforce and its peacetime and wartime capabilities.

Penalties for Specialty Substitution and Underutilized Physicians

In Fig. 3, penalties along the solid arcs connecting physician groups to tasks and cases reflect the quality of provider substitutions. Ideally, the penalties would represent the relative improvement obtained (the decreased likelihood of poor outcomes) by having one substitute versus another substitute or leaving the task undone. Assigning tasks to the preferred specialty carries no penalty. The penalties for assigning substitutes will be estimated by surveying Air Force physicians. The survey asks each physician whether he is currently qualified to perform a series of tasks and, if not, how much training he would need to become qualified. The physician may also indicate that he would never see himself performing the task. Physicians in each specialty are asked about tasks that, although within their specialty, are infrequently encountered in peacetime, and about tasks outside their specialty.

Penalties for underutilizing physicians in either peacetime or wartime (dash-dot arc patterns) are assessed in the model indirectly as well as directly. Indirect penalties are incurred because leaving physician time unassigned requires an equivalent increase in the workload assigned to the CHAMPUS or shortage category; resulting assignments to CHAMPUS or shortage incur penalties.

Direct penalties for unassigned physician time may be introduced in the model to represent other disadvantages of leaving physicians idle. For example, physicians with a small peacetime workload may run the risk of depleting their skills. Physicians may also find a limited practice in either peacetime or wartime unrewarding. However, one should recognize that there are wartime demands for physicians that are not represented in the Clinical Data Base and underutilized physicians could be assigned to these.

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