A new paradigm for measuring military readiness

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Abstract

Current measures of military readiness are inadequate. Their only incentive is "more is better." They are subject to gaming between subordinates and superiors. They can mislead planners even when they are accurate. They do not tell precisely *when* a unit can be ready, nor *which* units to send to a conflict. They give no information about *how much* readiness we can buy with another dollar.

We propose a new paradigm with the potential to give *operational* readiness information that can inform and guide defense decision-making and policy, from the lowest level to the highest. Our methods rely heavily on operations research analysis. It is already possible to measure accurately the readiness of a small unit such as a tank battalion, but soon it will also be possible to measure accurately the readiness of a large unit such as a division – in *dollars.* Furthermore, it may be possible to *prescribe* optimal levels of readiness.

Why readiness measurement is important

Ask a military commander whether his soldiers are ready to go to war, and he will tell you they can fight *now* and they can win. And you believe him. Then ask him how much time he would *like to have* to train his soldiers for a conflict, and he will press for as much time as possible. His duty to uphold the Constitution conflicts with his responsibility for the lives of his soldiers. In the words of a retired Navy captain (Bloch 1997), "Measuring readiness is like nailing jello to a wall."

We want the military to be ready for anything. More ready always seems better than less ready. At the same time, we know we cannot afford the highest possible level of readiness (whatever "readiness" means) for every unit all the time.

Although the task is difficult, readiness measurement must get done. The primary purpose of this paper is to draw the attention of the operations research community to this interesting, difficult and important task. Our contributions here only scratch the surface. Second, we propose criteria by which to judge a given measure of readiness; we propose models to measure and improve readiness at low organization levels; and we propose models to scale up readiness measurement to higher organizational levels. While not fully developed, these promising models provide a new paradigm for studying readiness. In Raffensperger & Schrage (1997), we studied a tank battalion, but that method may not work for other types of small units. Much work remains to be done.

Readiness measurement affects many complex policies of national defense. For example, reserve forces cost less than active forces, but reserves cannot fight if they cannot prepare quickly enough. The question of the ratio of actives to reserves leads to the question of capacity. A large reserve force requires adequate preparation capacity; given a certain force structure, do we have sufficient capacity to prepare for a conflict in the time required? To answer these and other readiness questions, we need to find the Holy Grail of readiness measurement: a way to calculate *the cost to raise readiness* and the savings from relaxing it. Suppose we give the Pentagon an extra billion dollars, or suppose we give a tank battalion an extra quarter million dollars. How much more readiness do we get? How much larger a conflict can we engage in for this extra money? What are the readiness consequences of less money?

Such questions have the attention of Congress:

> The Secretary of Defense shall submit to the Committees on Armed Service of the Senate and the House of Representatives a report containing an assessment of a wide range of alternatives relating to the structure and mix of active and reserve forces appropriate for carrying out assigned missions in the mid- to late-1990s…
>
> …(B) for each mix of active and reserve forces, conduct an analysis of the ability of the resulting alternative base-forces to successfully prosecute a range of military operations and focus on the time that would be required to prepare such forces for combat, the cost of training, and maintaining such forces in peacetime, and the sustainability of reserve recruiting and retention… (National Defense Authorization Act for Fiscal Years 1992 and 1993, U.S. 1991).

Researchers have successfully attacked pieces of the readiness puzzle, but few have attempted a comprehensive approach to measuring and improving readiness. Journal papers fall into two types, assignment models and class scheduling (timetabling) models. Bausch *et al.* (1991) described a system to assign Marine Corps officers to billets for mobilization. Sweeny (1993) developed a system to assign Marine Corps officers to job positions. Krass *et al.* (1994) formulated a model to assign Navy personnel to units to maximize the readiness of those units, using the pay scale to measure an individual's readiness. Ali *et al.* (1993) implemented an algorithm for the Navy to assign personnel to jobs, with the option of first sending individuals to technical school. Justice (1993) developed a model to reduce the idle time of students attending military classes. To schedule basic training in Germany, Drews (1995) developed a two-part heuristic of selection followed by an improvement phase.

In a spectacular effort, Oelschig & Wessels (1997) redesigned the force structure of the South African National Defense Force. They used an integer programming model that considered (among other things) the costs to change readiness states of various types of forces. They used rough estimates of these costs, measuring in years the time required to train military units, for example (Wessels (1996)). Their paper won the Franz Edelman prize, and their project resulted in a savings on the approved force design of more than 22%, with opportunities for more savings. (The Franz Edelman prize, sponsored by the Institute for Operations Research and Management Science, is awarded for outstanding operations research practice.) However, this successful force structure work still leaves readiness measurement undone.

Olvey *et al.* (1984) wrote a textbook with an economic analysis, illuminating national security with economic theory.

The best analysis of readiness seen to date is Betts (1995), an articulate and impressive book with historical and political insight. Betts says qualitatively what we wish to say quantitatively.

The measures of readiness used by the U.S. military need improvement

Moore *et al.* (1995) found that current measures of readiness are coarse, dissimilar and incomparable across the services. These measures survey inputs (such as material counts) rather than outputs (such as force capability). The measures provide useful but insufficient information, usually diluted and sometimes misleading. The measures give a general idea of readiness, but do not provide sufficient information to plan the operation for a mission. Army commanders report material counts, and also their estimates of train-up time (the days required to prepare if they were mobilized). Higher organizational levels aggregate this number-of-days information into two-week buckets called C-levels; a large organization, such as a division, is assessed to have the C-level of its least ready subunit. For example, a tank battalion with a train-up time of 14 days or less is C-1. A division with all battalions but one at C-1 is not C-1, but is assessed as ready as its least ready battalion. Not surprisingly, units have a tendency to report train-up times of exactly 14, 28, or 42 days (Hanser *et al.* (1996)). The Navy measures readiness as percent training completed. The Air Force measures percent air crews qualified. This mixture of measures also prevents readiness assessment for joint operations. For Desert Shield, Stucker & Kameny (1993) found that the military readiness database was inadequate to determine which units were most ready because the readiness data were not in units of time.

An overall review of military readiness typically consists of graphs of indicators, such as the C-levels or the percent of new recruits that have completed high school, for a set of years. Such information suggests trends that indicate generally whether the military is getting more or less ready over a long period of time. These indices are interesting and sometimes entertaining, but do not show whether a given division or battalion can fight a certain mission or how much readiness these units would gain if they were given more money. So whether the unit is a small battalion or a large task force, it is difficult to determine its readiness.

And there are still more problems. The best of these measures can mislead planners when prioritizing allocation of resources. If a division is C-3 because only one of its battalions is C-3, should that battalion receive priority for resources? An analyst following a systems approach should ask for more information first. (We provide a numerical example later.)

The existing readiness measures may be sufficient for holding commanders accountable, but they are subject to politicking and gaming, where officers send to their superiors readiness information clouded with indirect messages. For example, a readiness report that puts a unit slightly into the next less-ready C-level can be read as a demand for more resources rather than as an accurate indicator of readiness.

Perhaps readiness is not amenable to quantitative analysis. Are we left with simply trying to nail jello to a wall?

Four criteria for readiness measurement

The second aim of this paper is to provide criteria by which to judge a measure of readiness and to propose models to measure readiness rigorously.

What is readiness? It is easy to get tangled in philosophical and rhetorical arguments about definitions.

Ordinary dictionaries give definitions for binary readiness: Either you are ready or you are not. Such definitions prevent a continuous measure and thus are not very helpful. For our purposes, readiness is proximity to being ready. A substitute word that is more obviously a range, such as "strength" or "capacity", might deflate some of the noise about this subject.

A commander has the responsibility to make judgments about his unit. It is easy to invent scenarios or find anecdotes where several "measures of readiness" contradict the commander's judgment. Because the commander has the responsibility for the decision, we conclude that the only irrefutable definition of readiness is the commander's judgment.

However, the definition of readiness in the commander's head is not helpful to anyone else unless that definition has been concretely portrayed as a numerical measure (or a decision). So, even though it is the only one that matters, this definition is not very helpful either.

Since *definitions* of readiness are not helpful, we instead seek a *measure*, a numerical proxy for the commander's judgment, and we will pragmatically and unphilosophically call that readiness. We worry less about defining readiness and worry more about finding good measures that can be easily explained, easily stored in computers, provide operational guidance, and do not contradict good judgment. (Current measures fail primarily on the last two.) The focus is therefore on the quality of the measures and criteria for their use and existence.

Why have criteria for readiness measurement? The measure itself needs a yardstick. We wish to know what we get for the effort, what one measure offers that another is lacking. Informally, a measure of readiness is *perfect* if it has all the following attributes.

Completeness. Readiness depends on people, money (including equipment and resources), time, and the missions. A measure that ignores one or more of these factors misses part of the story about readiness. If one is left out, we get a snapshot or simplification at best. Without the context of all four factors, measures such as material counts are viewed blindly as "more is better." A complete measure utilizes all relevant information.

Simplicity. We would like simple measures, meaningful at all levels, from soldier to Congress and the public. A reasonable civilian layperson can interpret a simple measure with little or no assistance.

Additivity. An additive measure of readiness allows readiness from many units to be added together to get a total readiness over all units. It would be useful to add up the readiness of an air squadron, a tank battalion, a ship, and a hospital unit, in order to get the total readiness of these units. Although it would seem impossible across different types of units, we provide such a measure below.

Prescription. A prescriptive measure of readiness induces useful feedback to those who generate the source data, to the units (e.g., battalions) themselves. When the unit creates data on a prescriptive readiness measure, the unit receives complex and useful information as a direct or indirect result.

A *perfect* measure of readiness is complete, simple, additive and prescriptive. Let us look at a few examples of readiness measures.

The one-dimensional number of tanks in operating condition is an incomplete measure of readiness, though it is a simple and additive measure. The missions that a tank could successfully engage in may reasonably be known by the designers of the tank, but tanks require crew, so the measure ignores people. If the unit's readiness is measured by the number of operating tanks, then the commander can improve readiness on this dimension only by increasing the number of operating tanks, and he should be penalized for every tank that is not operating. More operating tanks is considered better than fewer operating tanks. The measure disregards the degree that crew is available and trained, the cost of maintaining the tanks, the length of the supply chain, and the timing in a mission when the tanks would be required. If compared to other units, the battalion can do little beyond celebrating or grieving, so the measure is not prescriptive. The feedback probably will not help them know how to adjust the number of operating tanks. Only that more is better.

Train-up time is a simple measure, and it can be a complete measure. It includes people. It may factor in money (we give models with and without a budget constraint). It can be measured for a specific mission's operation or set of operations. It is not additive – adding together the train-up times of two units is meaningless. Without other information (such as a feasible schedule), train-up time is not a prescriptive measure. Like the number of operating tanks, there is nothing to tell the unit that they do not already know. Since train-up time is not additive or prescriptive, then it is not perfect.

C-levels are not complete, since the calculation uses neither money nor a specific mission. Only the Army uses time in a C-level calculation. C-levels are certainly not additive or prescriptive. They provide no useful information to the unit providing the raw data, though lower-level commanders can attempt to pass extraneous signals to higher levels by manipulating C-levels. Mainly, they are fairly simple.

While the military needs measures that satisfy only some of these four criteria (somebody should be paying attention to the number of operating tanks), no currently available measure satisfies all of them. In order to provide such a measure, we need a new concept, a new paradigm, for measuring readiness.

Time should be the basis of readiness measurement

Betts (1995) defines readiness as capability in time. He points out that military experts discuss readiness in terms of technical indicators, such as fill rates of personnel and equipment, mean time between failure of equipment, days of peacetime stocks on hand, etc. Betts states that this "narrower definition, however, *provides no guidance for defense policy*, especially in a time when the danger of a major war seems remote." (Emphasis in the original.) He goes on to say:

> What percentage of any defense budget should be allocated to training, maintenance, or spare parts as opposed to larger numbers of weapons

> systems and troop formations? The experts' narrow notion of readiness offers no answers to that question. Understanding how to get military forces up and running and in razor sharp condition says nothing about exactly at what points, over long periods in peacetime, those qualities of readiness should be brought to a peak, or what other elements of capability (such as sheer size of the force structure) should be limited in order to maximize operational readiness. The emphasis on immediate operational availability as the measure of readiness is an artifact of the cold war.

He goes on to give a three-part definition of readiness: "Military readiness pertains to the relation between available time and needed capability...A country is militarily ready as long as the time needed to convert potential capability into the actual capability needed is not longer than the time between the decision to convert and the onset of war...A country proves not to be ready when a gap between its actual and potential capability causes a gap between the supply of capability and the demand for it."

Moore *et al.* (1995) made an outstanding case for defining and measuring readiness at unit level by the crucial attribute of *time*. They found that time unifies readiness measurement, and the time to prepare – train-up time – measures readiness more accurately than measures of inputs such as personnel and material. Train-up time reflects the changes in an organization's status over time, indicating whether that unit is becoming more trained or less trained overall. Train-up time allows the training status of related units to be compared. In short, time should be the basis for readiness measurement in the military.

Train-up time can be predicted approximately with linear regression, based on inputs such as people available or quantities in stock (Lippiatt *et al.* (1992a), Lippiatt *et al.* (1992b)). However, regression gives little indication as to why a change in inputs results in a change in readiness; it only suggests that some relationship exists. Although regression has the advantage of requiring no effort of the manager himself, it provides no schedule for the organization.

Yang & Ignizio (1987) and Yang (1982) describe scheduling models to minimize the time to conduct battalion training, though it is unclear whether their models are for peacetime or the emergency. (See also Ignizio *et al.* (1981); Ignizio (1980); Yang & Ignizio (1989); and Yang *et al.* (1989).) Their algorithm would provide a heuristic solution for the simplest problem described below (the train-up problem). Their invented data have fewer precedence constraints, but more complicated resource constraints than the data we observed for a tank battalion.

Measuring military readiness in units of time parallels measures of readiness in civilian applications. For example, Beltrami (1981) and Karkazis (1990) used response time as the measure in their studies of police and fire department readiness.

We endorse Betts (1995) and Moore *et al.* (1995) in using time as the basis of readiness measurement at the unit level, though we extend readiness measurement beyond units of time for higher organizational levels. (We shall see that train-up time is still an imperfect measure.) This paper uses the example of a tank battalion, but every unit and every service, including material and equipment readiness, may be evaluated in a similar fashion. Sometimes it takes a while to see, and the details would be different, but the overall approach must be the same. It is very important to see that this approach – measuring unit-level readiness in units of time with an operations research scheduling model – must apply to *all* services.

We next give a simple conceptual description of the new models of readiness. Solutions to three related unit readiness problems provide a way to measure readiness for a low-level unit, such as a tank battalion. (We studied a tank battalion rather than a smaller unit, such as a company or platoon, because, in the Army, the battalion is the smallest unit of organization for which readiness is measured and recorded.) Solutions to two organizational readiness problems provide a way to measure readiness for a higher-level unit, such as a division or an even larger unit.

The unit readiness problems

The train-up problem

The first unit readiness problem is to measure the readiness, in units of time, of a unit at a low organizational level, such as a tank battalion. In an emergency, the commander of a tank battalion may be ordered to immediately train his battalion fully for a specific mission. His soldiers are probably not fully trained (in his judgment), and therefore require some set of training exercises in order to be ready. The makespan of the schedule of these training events is the train-up time. The details of the scheduling problem for the tank battalion are messy, but **measuring readiness in units of time boils down to solving a scheduling problem over the required training activities**. Finding the minimum makespan schedule of training events is *the train-up problem*.

The tank battalion commander is required to estimate his unit's train-up time each month. To make this estimate, he has to guess the makespan of the train-up schedule, an exceedingly difficult task; the train-up problem (minimizing train-up time) for a tank battalion is NP-hard (Raffensperger 1997:37). At any point in time, every tank battalion has a train-up time. The problem is that no commander knows his unit's train-up time exactly because the scheduling problem is too hard.

We provided a method to find optimal solutions for the train-up problem for a tank battalion in Raffensperger & Schrage (1997), and tested the solution method with actual data. A different type of unit, such as a medical unit or a Navy air squadron, is likely to require a different type of solution method.

In the train-up problem, we ignore money, so train-up time (as calculated by solving the train-up problem) is an incomplete measure. If a commander receives orders to deploy, budget limitations are relaxed – purse strings open wide when the country prepares for war. Though train-up time is an incomplete measure, it gives an accurate snapshot of the readiness of one unit in isolation. How do we include the factor of money? The budget is constrained only in peacetime, so a model that includes a budget constraint must be part of a peacetime model.

The readiness budget problem

The second unit readiness problem is to find the readiness of a unit at a low organizational level, such as a tank battalion, given a fixed peacetime budget. Algebraically, this is a straightforward addition to the train-up problem – a train-up problem with a budget constraint.

The commander's planning horizon has two parts, peacetime and wartime. In peacetime, the budget limits training. Unfinished peacetime training must be completed in an emergency, and it lengthens train-up time. To minimize train-up time, the battalion commander must select which training exercises to schedule in peacetime and which to schedule in the emergency. Money spent on peacetime training is exchanged for a shorter response time in the emergency. The problem of scheduling training over both the peacetime and emergency planning horizons, subject to the peacetime budget, is *the readiness budget problem*.

We can think of the two planning horizons as two knapsacks, one for peacetime and one for the emergency. The capacity of the peacetime knapsack is mainly the budget constraint. The capacity of the emergency knapsack is the desired response time.

For example, suppose the tank battalion commander is planning training for February and March. He should minimize the train-up time that he reports to his commander on April 15. This is shown graphically in Figure 1. The commander will try to schedule as much training as possible in peacetime, subject to the budget. He will try to put long, cheap exercises in peacetime, and short, expensive ones in the go-to-war schedule.

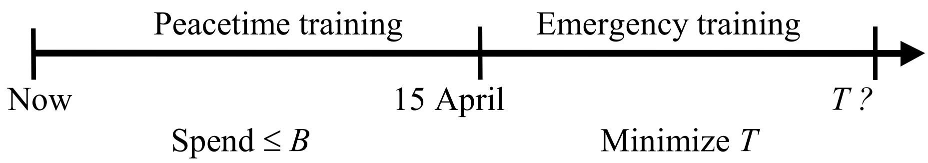

Figure 1 Minimizing train-up time T subject to a peacetime budget B

The readiness budget problem captures virtually all readiness information with respect to training for a tank battalion. The model improves readiness since we find an optimal training schedule given the current budget. The model becomes even richer when we solve it several times, changing the budget parametrically. We find the "Holy Grail" of readiness: the amount of readiness, as measured by train-up time, that we get for an additional peacetime dollar.

Figure 2 is a graph of train-up time versus peacetime budget for a tank battalion, based on actual data. The stepwise shape suggests that money should be allocated in bundles. The bundles should be adjusted to the steps. Between steps, train-up time changes disproportionately for a slight change in money.

Train-up time for a given peacetime budget, when calculated with this model, is a complete, simple, and prescriptive measure, providing rich feedback to the unit ("Here is your training schedule for the next three months, and here is the train-up time we expect if we give you *X* more dollars"). Train-up time is not additive across units. Also, train-up time is appropriate only for a low-level unit.

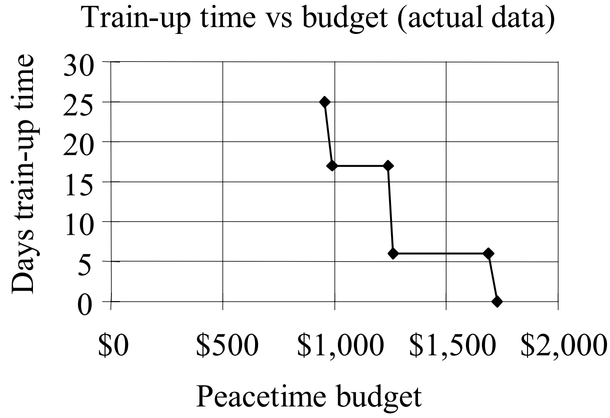

Figure 2 Change in train-up time versus peacetime budget (actual data for a tank battalion)

The marginal cost of readiness is the change in budget with respect to train-up time. One way to improve this curve is by purchasing capacity.

The readiness capacity problem

Training requires resources, such as simulation devices or ranges for tank gunnery exercises. Different resources may be partial substitutes with varying training effectiveness. Sometimes, money is provided to purchase additional resources in order to reduce train-up time. The problem of choosing additional training resources with a limited budget to minimize train-up time, is the readiness capacity problem.

Murty *et al.* (1995) describe a model for an Army battalion that helps choose a mix of training devices, the best training method, and the frequency with which the devices should be used. They take into account a learning curve to help decide the frequency and consider many more skills than we model. Our model of a tank battalion (Raffensperger & Schrage (1997)) does not take into account a learning curve; the effectiveness of each device must be determined in advance. However, our model selects resources and produces a feasible schedule.

The three unit readiness problems are to minimize the train-up time of a unit, to minimize the train-up time of a unit subject to a peacetime budget constraint, and to minimize train-up time subject to a budget constraint on the purchase of additional capacity. Together, these problems model readiness measurement at the unit level.

The organizational readiness problems

How can we scale up readiness to higher organization levels, such as a division? First, we give a model of aggregate readiness to calculate the readiness of many units, even if the units are heterogeneous (e.g., made up of a tank battalion, a medical unit, and an air wing). Second, we give a model of cyclic readiness to specify the optimal states of readiness. We have not yet solved these two models because their solution requires results for the readiness budget problem from many units. Our immediate contribution is a rigorous definition of readiness.

The aggregate readiness problem

Promised earlier was a numerical example of how readiness information, even accurate readiness information, can be misleading. Suppose two tank battalions, *A* and *B*, implement a system to solve the readiness budget problem and find they have train-up times of 11 days and 29 days, respectively. What is the overall readiness of these two units?

Following the usual notion of readiness used to assess C-levels, the division is only as ready as its least ready battalion. Since unit *B* is least ready, current methods would assess the combined readiness of units *A* and *B* at 29 days, which would be C-3.

Now suppose some additional money becomes available for training. Which is better – to reduce the train-up time of *A* or to reduce the train-up time of *B*? Again following the usual logic, improving the readiness of the "less ready" unit will improve the readiness of the larger organization, and improving the readiness of unit *B* would change the whole division from C-3 to C-2. Besides, we may reasonably assume decreasing return on readiness to dollars, so it would be cheaper to reduce train-up days from 29 to 28 than from 11 to 10. Therefore, spend money on unit *B* to reduce its train-up time to 28 days. Note that we have no operational guidance whatsoever beyond "Improve C-levels."

However, suppose we ask the intelligence service which is the mission *du jour*. Say it is Grenada. Further, suppose we ask the operational planner when tank battalions must arrive, and we ask the logistician how long it will take to move them to the scene of action. For instance, suppose tank units would be required on days 10 and 31. The solution is obvious. To be ready for Grenada, unit *A* would have to improve its train-up time by one day, and unit *B* is just fine. Units *A* and *B* together are unready with respect to the Grenada mission by the cost of reducing the train-up time of unit *A* by one day. The cost to adjust the train-up time of both units in order to satisfy the mission is a complete measure of readiness – it includes people (in the training required), money, time, and the mission. More is *not* better. There are optimal levels of readiness. The solution described in the previous paragraph would be an egregious error. Spending additional money on unit *B* would be a waste, and would still leave the division unprepared for the mission.

Military logistics personnel plan for operations by writing schedules for deployment to the mission theater. The schedules show the type of unit required, the mode of transportation, and the destination, by time period. These timelines are called *time phased force deployment lists* (TPFDLs). (There is controversy over the accuracy of these TPFDLs (Yost 1995), but TPFDL improvement is a separate problem.)

To optimize these timelines, Jarvis & Ratliff (1983) implemented the SCOPE system for the military. They minimized the dollar cost of transportation. SCOPE assumed that all units are ready at day zero. Of course, not all units are ready at day zero because the peacetime budget is limited. More recently, Rosenthal *et al.* (1997) solved a difficult linear programming model called NRMO for the U.S. Air Force Studies and Analyses Agency. NRMO schedules actual transportation as closely as possible to a desired TPFDL, taking into account physical and policy constraints. NRMO assumes units are ready at some known availability date.

For the organizational readiness problems, we define a mission simply as a TPFDL: a schedule that requires certain types of units and equipment to arrive in the mission theater at specific times. The TPFDL is independent of the state of training or the state of the equipment. (Actually, a mission is a stated purpose and a reason for it, and an operation carries out the mission. We will use the term mission to mean both, and a mission is specified by a TPFDL.) A TPFDL simply specifies a demand at a point in time for an asset, if the mission were begun immediately.

Suppose that every unit implemented a scheduling system to solve the readiness budget problem. By changing the peacetime budget parametrically for each unit, we can get the cost to change states of readiness, as shown in Figure 2. For example, if we wish to change unit *A*'s train-up time from 14 days to 13 days, given the current state of the unit, the readiness budget problem helps us determine the amount of money required over the next three months to adjust the unit's train-up time. It seems reasonable that we can make the unit's train-up time longer for free. So the costs of changing readiness are found by solving the readiness budget problem several times for each unit.

This suggests a new model of readiness for large organizations: assign units to transportation schedules, minimizing the total cost to change unit train-up times to satisfy the mission. The coefficients in the objective function are the costs of changing train-up times, as found by each unit's solution to its readiness budget problem. The total unreadiness over all units is the additional peacetime money required to adjust current readiness levels so that the mission transportation plan could be satisfied.

Now, here is the really beautiful part of this model: If we can solve the unit readiness budget problem, then we can calculate a measure of readiness for a large heterogeneous organization in dollars. Finally, we have a **perfect** measure of readiness.

The paradigm generalizes to assets besides people, such as equipment. For example, the number of operating tanks is useful information, but more useful is the time required to make operational the full battalion's complement of tanks. More useful still is the total cost to provide enough operating tanks to satisfy a timeline for a mission (or stochastic set of missions). Making these measurements requires information about the supply chain for the parts required to repair equipment. We need to measure the time required to repair a set of tanks, determine the marginal cost to improve that time, and then assign tanks to TPFDLs at minimum cost. The models that must be solved are suggested by the paradigm. They may not be easy to solve, but the problem is much better specified than if the definition of readiness were simply a C-level, a material count, or days to train the least ready unit.

For a large organization, we define readiness for a mission as the additional peacetime money required for all assets (units and equipment) to change readiness states in order to satisfy the TPFDL. (For simplicity, the minimum time required to prepare equipment will also be called train-up time.) This may be calculated with the following assignment problem.

Data:
a_{ut} = the number of assets of type u that are required to be transported out to do the mission (and are therefore done with training) on day t.
c_{vut} = the cost for asset v of type u to be ready to go at day t. This is the cost required to change the train-up time of asset v from its current train-up time to a train-up time of t days (calculated by solution of the readiness budget problem). If the train-up time for the asset is already smaller than t, then we assume this to be zero or close to zero. Transportation costs may also be included.

Decision variable:
x_{vut} = 1 if we assign asset v of type u to transport out on day t, else 0.

(1) $\text{Min} \sum_{v,u,t} c_{vut} x_{vut}$

(2) $\sum_{v} x_{vut} = a_{ut}$ for all u, t.

(3) $\sum_{t} x_{vut} \leq 1$ for all v, u.

(4) $x_{vut} \in \{0,1\}$ for all v, u, t.

As formulated above, the model decomposes over the type of asset u, so we can calculate readiness by type of asset, and we can implement or test this by starting small. The model is a transportation model that can be solved quickly with standard techniques.

The optimal objective function values for a mission may be zero, implying that all needed assets could be transported out at times on or beyond their current train-up times. This model will show which units can reduce training levels. The model may be used to determine the mix of active and reserve forces, by observing the mix assigned to each type of mission. With the addition of a subscript for missions, the model may include multiple missions at once (possibly stochastically), though timing of the missions complicates the problem, and additional constraints must be added to prevent assignment of too many missions to a single unit. The model may include the peacetime costs of maintaining the units.

This simple formulation leaves out important complexities regarding the ability to mobilize units over time. A better formulation would consider the types of lift available, capacity at transportation hubs, penalties for delays, etc. The SCOPE and the NRMO mobility systems could be modified to solve this problem as part of optimizing the TPFDL. To include readiness information, the cost of moving one unit at a particular time must include the cost of changing the train-up time in order to satisfy the TPFDL at a certain time period. The point is that measuring aggregate readiness is a mobility problem.

So the aggregate readiness problem helps us determine readiness for a large heterogeneous organization by assigning assets to a certain level of readiness at minimum cost. However, the aggregate readiness problem and the unit readiness problems do not tell us which state of readiness a unit should have next year. The models only react to a battalion's existing level of readiness: each unit should move to a specific level of readiness and stay there. This would hardly be fair to the soldiers required to be at high readiness on a permanent basis (or to their families). How do we prescribe and direct the optimal levels of readiness for many units over a long period?

The cyclic readiness problem

The cyclic readiness problem addresses the following question: For each month over a long peacetime horizon (such as ten years), for a list of units (actually any asset), should each unit raise, maintain, or lower its readiness, and should the unit stay in one location or move to another location? Each location has a capacity on the number of units it can support. In every peacetime month, a sufficient number of units must be sufficiently ready to satisfy a set of mission TPFDLs. The objective is to minimize total cost.

The cyclic readiness problem is a generalization of the aggregate readiness problem, and it can be confusing. As with the aggregate readiness problem above, solution information from the readiness budget problem must be available.

To model this problem, we assume a cycle of readiness of, say, T_C=24 months. In every cycle, each unit must maintain the highest level of readiness for a minimum number of periods, say T_R=6 months. We expect that over the cycle of 24 months, the unit would gradually move up to its highest readiness level; at the end of the six months of high readiness, the unit would move down to a lower readiness level. This cyclic approach fits well with current readiness planning. The Navy tends to operate cyclically, with ships on 18-month cycles, taking turns at high and low readiness. The Army does not operate cyclically in the same way; divisions are generally assigned rough levels of readiness on a permanent basis. But even though the Army assigns approximate readiness priorities to units, all tank battalions must periodically reach a high level of readiness to requalify on various skills.

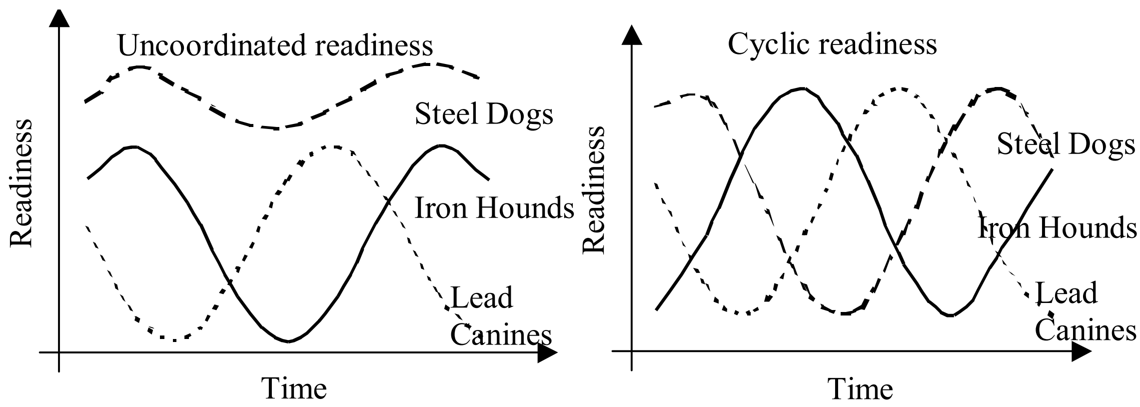

Figure *3* shows how readiness might change over time for three different Army tank battalions, with two different types of readiness cycles. In the left figure, one unit is required to be in the exhausting state of continual high readiness. Other units tend to be in the demoralizing state of continual low readiness. By contrast, the right figure shows how the three battalions could cycle through their respective levels of readiness, more like the Navy does already. At every point in time, at least one unit is ready for the mission. Later, the unit trades its assignment with another unit.

This figure somewhat oversimplifies the problem because each mission TPFDL, in fact, has a list of required readiness dates. In the first month of the peacetime plan, the Steel Dogs would be assigned to arrive at the mission theater early, if that mission were to occur. Also in the first month, the Iron Hounds would be assigned to arrive late, and the Lead Canines perhaps would not be assigned to the mission at all. In the second month, the Steel Dogs would trade assignments with the Iron Hounds. Units are reassigned as the readiness of each unit changes over time.

If the mission *did* arise, the unit assigned would already know when and where it was required. The unit can adjust its training and its train-up time more closely to the mission. Thus, solution of the cyclic readiness problem provides a measure of readiness that is highly prescriptive.

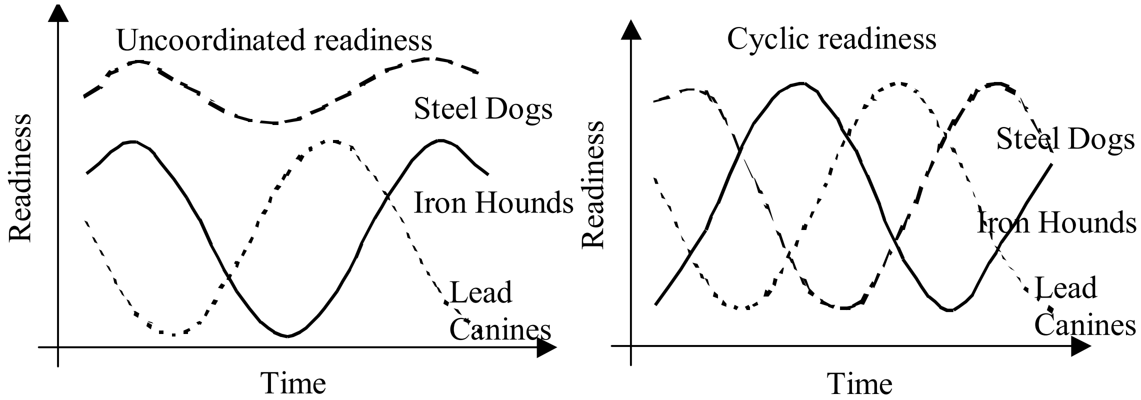

Figure 3 Unit readiness over time may follow different types of cycles

Some of these assignments may require positioning at particular locations. If a unit were required to have full readiness for a mission in Europe, the unit should most likely be located there in peacetime. (We can add transportation time to train-up time to obtain a "be there by then" time.) Similarly, if a unit were assigned a train-up time of 60 days, it may as well be located at an inexpensive location that does not require high readiness. So this model must also include information about the location of the units.

For each deployment date on each TPFDL, associate a forward or rear location. Each forward location is associated with a TPFDL deployment date that requires fast train-up time. Each rear location is associated with a TPFDL deployment date that allows a longer unit train-up time. We call one deployment date for one specific location of one TPFDL a slot.

The cyclic readiness problem is to assign slots – locations, missions, and levels of readiness – to units at minimum cost over time. For each period over a long peacetime horizon (such as 10 years), for a list of units, how should each unit raise, maintain, or lower its readiness, and should the unit stay in one location or move to another location? Each location has a capacity on the number of units it can support. The assignments of units to readiness states and locations must satisfy a set of TPFDLs in every time period. The objective is to minimize total cost.

The cyclic readiness problem is to assign units to slots at minimum cost over time. For simplicity of presentation, we assume a single TPFDL.

Indices:
h, i, j, state of readiness;
k, l, m, location;
p, a slot on the TPFDL (a deployment data for a specific location for the mission);
r, the unit;
t, $u = 1,\ldots,T$, time period.

Data:
$e_{ikp} = 1$, if readiness state i at location k satisfies the TPFDL at slot p, zero otherwise.
a_{kp} = the number of units required on the TPFDL at location k and slot p.
$b_{ik} = 1$ if readiness state i at location k is considered high readiness, zero otherwise.

c_{ijklrt} = the cost (present value) to move unit r from readiness state i, location k, to readiness state j, location l, at time period t. These data are obtained from the solution to the readiness budget problem or a model like it.
f_{ir} = the space used by unit r at readiness state i.
F_k = total space available at location k.
T_C = total cycle length.
T_R= the number of periods in the cycle that a unit must be at the highest state of readiness. If T_R= 0, then no particular unit is required to be at high readiness, though each TPFDL must still be satisfied. If T_R=T_C, then all units must maintain high readiness at all times.
T = the number of periods in the planning horizon. A desirable horizon would be ten years, with a month for each period.

Decision variables:
$x_{ijklprt}$ = 1 if unit r moves from readiness state i and location k to readiness state j and location l at time period t, and is assigned slot p on the TPFDL. Zero otherwise.

Formulation:

(5) Min $\sum_{i,j,k,l,p,r,t} c_{ijklrt} x_{ijklprt}$

(6) $\sum_{i,j,l,r} e_{ikp} x_{ijklprt} = a_{kp}$ for all k, p, t.

(7) $\sum_{h,k,p} x_{hiklprt} = \sum_{j,m,p} x_{ijlmpr,t+1}$ for all i, l, r, t.

(8) $\sum_{i,j,l,p,r} f_{ir} x_{ijklprt} \le F_k$ for all k, t.

(9) $\sum_{i,j,k,l,p} \sum_{u=t}^{t+T_C-1} b_{ikp} x_{ijklpru} \ge T_R$ for all r, t.

(10) $x_{ijklprt} \in \{0,1\}$ for all i, j, k, l, p, r, t.

The number of subscripts suggests many variables, but they are related since readiness states are associated with slots and locations. For example, we can fix $x_{ijklprt}$ for t=0 to require an initial readiness state i at location k. The model may be defined over more than one TPFDL and over more than one type of unit. This was not shown here to simplify the presentation, and this would complicate solution if different types of units share capacity.

The model may be run with different base configurations or dynamic base configurations over time. A high-readiness unit may be required at a rear base to train other units. Different cycle times may occur at different locations, depending on whether or not a location has family support space. We may try to loosen the TPFDL constraint flexibly to save money.

With multiple TPFDLs in the model, missions may be assigned probabilities. This requires a definition of risk (preferably downside risk; see Eppen *et al.* (1989)). Possible definitions include the days error in satisfying a TPFDL, the cost to change readiness states to satisfy in wartime a TPFDL that was unsatisfied in peacetime, or damage to early-arriving units due to delayed deployment of later-arriving units. Theoretically, we could determine the distribution over a set of missions of peacetime costs versus risk.

A mindless push for "higher readiness" can be counterproductive. The cyclic readiness problem prescribes high readiness when and where it is needed at minimum peacetime cost.

Conclusion

For low-level units, readiness should be measured in units of time. Measuring readiness at unit level is inherently a scheduling problem.

To commanders of tank battalions, to commanders of air squadrons, to captains of ships, to all unit commanders, we recommend that you develop spreadsheets, PERT charts, or (ideally) integer programming models, to help you schedule training. Schedule peacetime training and go-to-war training in one model, and minimize the time required to complete the go-to-war training. (If you are already scheduled for deployment, then you can use a single planning horizon to see if you can deploy on time with the given budget.) Quantify the reduction in train-up time for additional money, and you will have an easier time justifying requests for additional funds, and an easier time justifying your current readiness status.

To logistics experts and operations planners, we recommend that you request readiness information – for training, for equipment, for all aspects of readiness – in units of time. The answer to "When can this unit and its equipment be ready?" is far more useful than the answer to "At what C-level is this unit?" Rather than finding out the number of crews trained, or the percent training complete, or the percent of operating equipment, find out when a unit can be ready.

For higher-level units, readiness can and should be measured in the complete and perfect measure of dollars. This calculation is inherently a mobility problem, and demands additional research.

To higher-level commanders, we recommend that you ask for readiness information that includes two numbers for each unit: the train-up time for the unit (for all assets, not just training), and the additional peacetime funds required over the next three months in order to improve that train-up time by one week. Improving readiness subject to your budget will get a lot easier.

To the policy-makers: Let's change the system.

To operations researchers: There is lots of work to do. We have scheduling systems to write for every single type of military unit. The problem of inaccurate TPFDLs must get fixed. Supply chain studies must be done to measure the cost of improving equipment readiness. Readiness can be measured rigorously, but we have our work cut out for us.

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