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A Capabilities Based Measure of Readiness

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A Capabilities Based Readiness Metric

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Abstract

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Army Aviation Readiness, a New Metric for Reporting and an Inventory Replenishment Model

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Abstract

During periods of high operational tempo, many unbiased observers note Army Aviation readiness reports do not match the true state of readiness, where true readiness levels appear lower than those stated. A proposed new metric using a part set hierarchy linked to mission capability enables two distinct integer program decision models. This paper offers a solution to the first decision model and showcases the implications for unit readiness with regard to cannibalization. The first model assumes a set of aircraft down for maintenance where the defective parts are known as well as the parts available in inventory. Now we can maximize total utility of the entire fleet weapons systems subject to parts availability constraints. We also formulate an inventory replenishment model based on this metric, which ties replenishment to maximizing readiness if cost is an issue.

Keywords:
Part Set Hierarchy, Army Aviation Readiness, Mission Capability Level

1. INTRODUCTION

Recent transformations in the Army depict a need for more visibility on current readiness as well as efficient methods for ordering and assigning parts to equipment. "The demands of current operations/continuous, worldwide operations have accelerated the need to transform our armed forces and undertake an increasingly complex array of missions around the world. In response we are moving from a "threat-based" to a "capabilities-based" approach to defense planning. This means not just focusing on who might threaten the United States and where and when, but also how we might be threatened and what capabilities are needed to deter and defend against those threats" (Strategic Communications Current Themes/Messages and Talking Points 2004). Consistent with this quotation, the Army needs similar readiness metrics for materiel.

This paper focuses on a newly proposed metric possessing the capability to optimally assign parts to aircraft and provide commanders a clear concise reporting method ensuring an accurate "capabilities based" depiction of readiness. Traditional focus in Army Aviation centers around a measure known as Supply Material Availability (SMA), which is, simply put, a ratio of the number of parts requests filled divided by the total number of requests.

In August 2000 the Washington Times reported on an internal Army document revealing that 12 of 20 U.S. Army combat schools currently rank C-4, the lowest readiness level in basic skills. Specifically, the U.S. Army Aviation Center at Fort Rucker, Alabama ranks among the Army training sites with low basic readiness (Price 2000). The low readiness is attributed to defense budget cuts during the 90's, manifesting the long term shortage in spare parts and aging combat systems faced by the Army today. In trying to address the problems faced today the Army contracted RAND to investigate the requirements to sustain the transforming Army. In the RAND report, the author advocates more sophisticated measures displayed as a decision tree which indicates whether identified key performance parameters have been met, such as "broke to fix time" and failure rates (Peltz 2003). This still shows a focus on macro measures which can help in identifying causes but cannot give precise military assessment of strength to carry out a given mission.

The proposed metric and need is highlighted in a previous paper. In short, the metric centers itself around a part set hierarchy for Army Aviation airframe types. Levels of mission capability have a one-to-one correspondence with an associated parts set. The levels of mission capability are linked to a value function, with value achieved only if a parts set is complete, and each subordinate parts set is complete (Kaczynski et al 2004). The decision model and example solutions follow.

Readiness can be misleading in different ways. In November 2003, in a Senior Readiness Oversight Council (SROC) meeting chaired by the Deputy Secretary of Defense the Air Force reported low readiness rates prior to operations in Afghanistan and Iraq, yet the Air Force was able to perform the specific missions required (Junor 2004). Top Pentagon officials noted the disconnect between actual capabilities and the macro readiness metric. Noting this same disconnect more than a year earlier, the Defense Readiness Reporting System (DRRS) is pursuing a capabilities based readiness metric based on guidance from top Pentagon officials (Mayberry 2003).

2. INTEGER PROGRAM AND SOLUTIONS

2a. Decision Model

In this decision model we assume a set of aircraft are down for maintenance and all of the defective parts are known. The parts in inventory are also known, hence the decision is which parts to order, which defective parts are replaced from inventory, and where cannibalization should occur if necessary. The model is based on the following definitions.

Variables: $y_{jk} = \begin{cases} 1 \\ 0 \end{cases}$ if parts set j is feasible on aircraft k, 0 otherwise

$\Delta_j =$ value gained when parts set j is feasible on an aircraft

$x_{ijk} = \begin{cases} 1 \\ 0 \end{cases}$ if item i in parts set j is operable on aircraft k, 0 otherwise

n_i = number of items in parts set i

Q_i = on hand inventory for item i

Objective Function: Maximize $\sum_{j,k} y_{jk} \cdot \Delta_j$ (2)

Constraints: $x_{ijk} = 1$ if the part is operable, otherwise 0

$y_{jk} \leq \frac{\sum_i x_{ijk}}{n_i}$ all items in parts set must be operable to get the associated parts

set value for any given aircraft

$y_{jk} \geq y_{j+1,k}$ we must have value at parts set level j to get value at level $j + 1$

$\sum_k x_{ijk} \leq Q_i \quad \forall$ *j and k and for i,j,k such that* $x_{[illegible]} = 0$ cannot assign more items to aircraft than are

One issue arising early in development for the reporting model and for inventory assignments is concavity or convexity of the value curve. At issue was where the bulk of the value occurred. In looking at the mission breakdown for an AH-64 Apache, few would argue that its ability to conduct attacks and bring lethality to the battlefield is its most important mission in terms of a hierarchy. However, the aircraft is also often deployed in peacekeeping operations where the ability to conduct reconnaissance is deemed important.

In sorting out mission complexity, it is possible using our model to accomplish both objectives and measure correspondingly accurate readiness pictures. In the lethality mission (for example a night deep attack) where the primary focus is killing the enemy, the bulk of value lies with these top priority missions. Therefore in looking at the value curve, the shape lends itself to a convex shape. This is an absolute necessity in this environment, providing the force and leadership at every level the ability to plan for current and future operations as well as conduct crisis response.

The opposite may be true in peacekeeping operations. Surveillance and troop support dominate the area of operations during this difficult and critical mission. There is always the possibility that the attack mission might be conducted, however, the value of the attack mission in this environment may be decreased. By weighting the lower prioritized mission with a higher value, the value curve becomes more concave. If we look at the equation:

$$\sum_k y_{j,k} = Y_j$$

This represents the number of aircraft that have a part set j complete and hence can perform missions that only need parts sets up to and including level j. The Y_j then becomes an interpretable metric useful for commanders in assessing readiness to perform a required set of missions.

Given these differing value curves and associated environments, the intriguing question is the effect on the model. The linear program outlined in appendix A investigates this dilemma (that of different units placing different values on the same missions). The LP assumes two value curves, convex and concave. For a part set hierarchy consisting of four levels, each with two parts, respective costs, and a budget, we can generalize how the model orders parts. Since the lower parts sets involve those parts required for flight and safety of flight, they tend to be more expensive parts, like engines, transmissions, etc. We assume no inventory is carried, and orders cannot exceed a known budget constraint. In Appendix A, compare the y_i set for the budget of $105,000 to see the how the shape of the value curve affects the solution. With a convex value curve you get one more plane with the top parts set completed allowing more assets for a mission that needs full lethality.

2b. Examples

We apply the model for a set of three, $k = 3$ aircraft, each with five, $j = 5$ part sets. In the first example provided we remove the option of cannibalization. The model provides an initial readiness value, parts inoperable identified, a budget constraint for ordering, and two ordering schemes. See figure 1 for the initial conditions (note: there is also a part missing from part set 2 on aircraft 3).

Figure 1: Initial Conditions

OBJECTIVE 1.3

Initial readiness

PART SETS		INV (Q)	PART ON AIRCRAFT AIRCRAFT1	AIRCRAFT2	AIRCRAFT3
1	Engine	0	1	1	1
	Flight Controls	0	1	1	1
	Main Rotor System	0	1	1	1
	Tail Rotor System	1	[illegible]	[illegible]	0
	Gearbox	1	[illegible]	[illegible]	0
	Fuel System	1	[illegible]	[illegible]	0
	Unsecure Radio	1	1	1	0
	Heading Indicator	1	1	1	0
2	Direct View Optics	0	1	1	0
	Day TV	0	1	1	1
	GPS	0	1	1	1
3	Aircraft Surv Equip (ASE)	0	1	1	1
	Secure Commo	0	1	1	1
	30MM GUN	0	1	[illegible]	[illegible]
4	Area Wpn Sys (RKTs)	0	0	[illegible]	[illegible]
	Point TGT Sys (Hellfire)	0	[illegible]	1	1
5	Forward Looking Infared (FLIR)	0	1	1	1

Assume each part costs

Assume part cost is

Assume that along with the initial conditions provided above, we introduce a budget constraint on parts we can order. Here the constraint is $5,000 and the circled parts for aircraft 3 are $1,000 each. Additionally the missing part from aircraft 1 costs $5,000. If we order the parts circled for aircraft 3, the integer program returns the results listed in figure 2. The readiness objective increased by 0.05, and the resulting SMA is 5/7. While SMA is high, readiness only increased by a small amount. Using the same initial conditions, we can also choose to order the part for aircraft 1. In doing so, we achieve the results depicted in

Figure 2: Feasible Solution

OBJECTIVE 1.35

PART SETS		INV (Q)	PART ON AIRCRAFT AIRCRAFT 1	AIRCRAFT 2	AIRCRAFT 3
1	[illegible]	0	1	1	1
	Flight Controls	0	1	1	1
	Main Rotor System	0	1	1	1
	Tail Rotor System	0	1	1	1
	Gearbox	0	[illegible]	[illegible]	1
	Fuel System	0	[illegible]	[illegible]	1
	Unsecure Radio	0	[illegible]	[illegible]	1
	Heading Indicator	0	[illegible]	[illegible]	1
2	Direct View Optics	0	[illegible]	[illegible]	0
	Day TV	0	1	1	1
	GPS	0	1	1	1
3	Aircraft Surv Equip (ASE)	0	1	1	1
	Secure Commo	0	1	1	1
	30MM GUN	0	1	[illegible]	[illegible]
4	Area Wpn Sys (RKTs)	0	0	[illegible]	[illegible]
	Point TGT Sys (Hellfire)	0	[illegible]	1	1
5	Forward Looking Infared (FLIR)	0	1	1	1

Positive delta, 0.05, achieved in ordering 5 parts. Total cost

Parts ordered are filled. SMA for ordering period is

No improvement for

Figure 3: After Optimization

OBJECTIVE 2.00

PART SETS		INV (Q)	PART ON AIRCRAFT AIRCRAFT 1	AIRCRAFT 2	AIRCRAFT 3
1	[illegible]	0	1	1	1
	Flight Controls	0	1	1	1
	Main Rotor System	0	1	1	1
	Tail Rotor System	0	1	1	0
	Gearbox	0	[illegible]	[illegible]	0
	Fuel System	0	[illegible]	[illegible]	0
	Unsecure Radio	0	[illegible]	[illegible]	0
	Heading Indicator	0	1	1	0
2	Direct View Optics	0	1	1	0
	Day TV	0	1	1	1
	GPS	0	1	1	1
3	Aircraft Surv Equip (ASE)	0	1	1	1
	Secure Commo	0	1	[illegible]	[illegible]
	30MM GUN	0	1	[illegible]	[illegible]
4	Area Wpn Sys (RKTs)	0	1	[illegible]	[illegible]
	Point TGT Sys (Hellfire)	0	[illegible]	[illegible]	[illegible]
5	Forward Looking Infared (FLIR)	0	1	1	1

Positive delta, 0.70, achieved in ordering only 1 part. Total

No improvement for aircraft 3.

Part is ordered and filled. SMA for ordering period is

figure 3. The readiness objective is noticeably better, increasing by 0.70, though SMA is only 1/7. While this example is very simple, it does showcase the weakness of using SMA as a metric for readiness. By maximizing SMA with respect to a budget, the model returns a readiness objective value 67.5% lower than can be achieved utilizing optimization.

For a second example consider the following, we utilize a set of initial conditions and the ability to cannibalize parts from one aircraft to another. A budget constraint of $5,000 exists, aircraft 3 needs five parts at a cost of $1,000 each. Aircrafts one and two are each missing one part at a cost of $6,000 each. Clearly we cannot satisfy an order for aircrafts 1 and 2. However, we can order the parts for aircraft 3 and stay within the limits of the budget constraint. Normally, this would represent an optimal solution for this ordering cycle. See figure 4 for the initial conditions and figure 5 for the parts replacement on aircraft 3 without cannibalization. This offers an increase in readiness, though no improvement occurs for aircrafts 1 and 2, however, SMA is maximized.

Figure 4: Initial Conditions

OBJECTIVE 0.6

Initial readiness

Assume each part costs $1,000.

Assume part cost is $6,000.

PART SETS		INV (Q)	PART ON AIRCRAFT AIRCRAFT 1	AIRCRAFT 2	AIRCRAFT 3
1	Engine	0	1	1	1
	Flight Controls	0	1	1	1
	Main Rotor System	0	1	1	1
	Tail Rotor System	0	[illegible]	[illegible]	0
	Gearbox	0	[illegible]	[illegible]	0
	Fuel System	0	[illegible]	[illegible]	0
	Unsecure Radio	0	1	1	0
	Heading Indicator	0	1	1	0
2	Direct View Optics	0	1	1	1
	Day TV	0	1	1	1
	GPS	0	1	1	1
3	Aircraft Surv Equip (ASE)	0	1	1	1
	Secure Commo	[illegible]	[illegible]	1	1
	30MM GUN	[illegible]	[illegible]	0	1
4	Area Wpn Sys (RKTs)	0	0	1	1
	Point TGT Sys (Hellfire)	0	1	1	1
5	Forward Looking Infared (FLIR)	0	1	1	1

Allowing cannibalization to occur shows added value for the readiness objective (see figure 6). Notice that the part missing on aircraft 2 is filled from the working part on aircraft 1. The added value is now 0.70 more than if cannibalization had not occurred. Realizing there is a cost involved in cannibalization with regard to extra work performed, the risk of damaging additional parts due to the extra work, and possibly reduced morale among mechanics, precautions must exist prior to any cannibalization action and all actions must be supported by the command. The model does allow the addition of manpower and time constraints, so if given appropriate costs, we can include these considerations. As of March 2002, cannibalization rates for Air Force and Navy helicopters were more than double those of the Army [3]. While this doesn't necessarily imply that the Army has it wrong, it leads to a logical question, being whether the cannibalization (if conducted optimally) is resulting in higher readiness rates in one of the services.

Figure 5: Feasible Solution

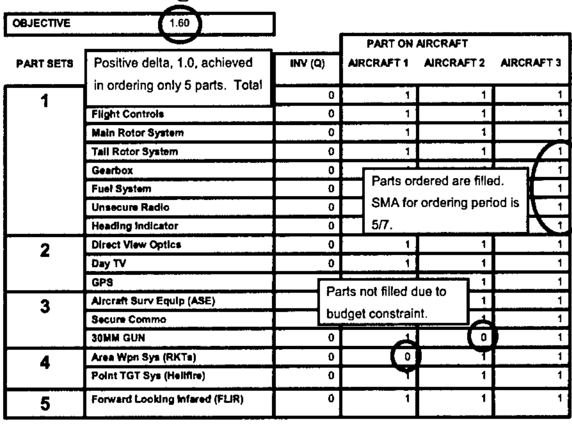
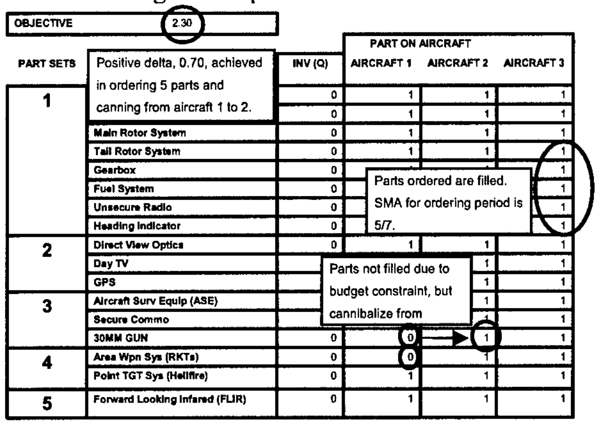


Figure 6: Optimal Solution



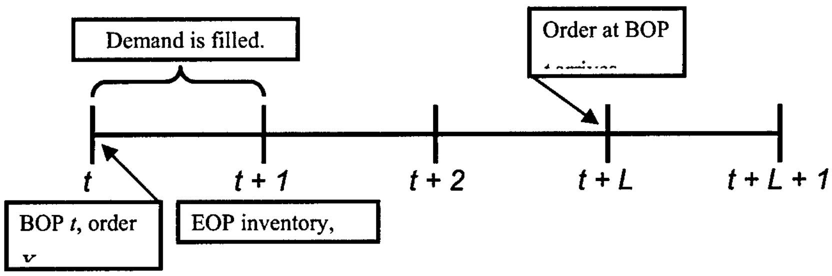
In contrast to the examples provided above, current procedures lack the insight to optimize readiness. Current practice in logistical decisions involves simple considerations such as first to request a part receives the part, or possibly the aircraft with the most time in a non-mission capable status for a particular part will receive the next part eligible. Though these examples are simple for decisions with only three aircraft, technology exists to extend this model for larger units and even to the fleet level. This becomes particularly valuable in assigning high dollar/priority parts like engines, transmissions, etc. With traditionally long lead times and demand that exceeds supply, their placement is of principal concern.

3. INVENTORY ORDERING MODEL

In a previously conducted study, high SMA measures resulted from not only ordering inexpensive parts, but also those parts that were fast moving instead of the higher cost, slow moving parts. These higher cost parts were associated with longer lead times resulting in aircraft being down for significant periods of time. Current procedures order these parts on an as-needed basis. In other words, the part is ordered only after it is identified as inoperable on an aircraft. Significant data exists for high dollar, significant lead time parts to forecast demand and make reasonable estimates on future requirements. This ordering practice requires readiness be entirely dependent on lead times and part availability in most instances. The current lack of spare Army aviation parts compounds this issue.

The part set hierarchy linked to levels of mission capability facilitates a model that can include inventory and lead times. The model's goal is to order only the amounts required to achieve the maximum readiness value possible. The part set dependency forces an important aspect of this model. That is, if a part set cannot be filled there is no need to order a subset of the parts, the budget is better allocated somewhere else. Since the model includes time periods, an explanation is best suited by looking at a timeline (see figure 7). Lead time for a part is defined as L and the current time period is t. Assume orders are cut at the beginning of the period (BOP), inventory balance is at the end of the period (EOP), and past orders are known in terms of when they arrive. Also assume that shortages can be backlogged, meaning the amount short for a particular part can increase the demand for the next period.

Figure 7. Timeline for inventory ordering model



3a. Model Defined

The inventory ordering model follows.

Variables: $X_{i,j,t}$ = an order for part i in part set j at the beginning of period t, it will arrive at the BOP, $t + L$

$n_{i,t}$ = number of aircraft capable of mission level i at time t added to the fleet

$I_{i,j,t}$ = inventory of parts i in part set j at time EOP t

v_i = incremental value of feasible part set i

$S_{i,j,t}$ = the shortage for item i, part set j, at the EOP t

$D_{i,j,t}$ = projected demand for item i, part set j, at the BOP t

MAX $\sum_{i,t} n_{i,t} \cdot v_i$

subject to $n_{j,t} \le I_{i,j,t-1} + X_{i,j,t-L} \ : \forall\ i,$ precludes full parts sets from exceeding inventory and limits $n_{j,t}$ to the minimum of the available item quantities

$n_{i,t} \le n_{j,t} \quad i = j+1, j = 1, 2, \ldots,$ number parts sets -1, mission dependency constraint

$n_{j,t} \le$ # of planes with non-functional part set j's at BOP t. Here more part sets can't be repaired than are listed "need repair".

Materiel balance equations:

for period t: $S_{i,j,t} - I_{i,j,t} = D_{i,j,t} - I_{i,j,t-1} + S_{i,j,t-1} -$ known order to arrive $t = 1, 2, \ldots, L-1$

for period $t+L$: $S_{i,j,t+L} - I_{i,j,t+L} = D_{i,j,t+L} - I_{i,j,t+L-1} - X_{i,j,t} + S_{i,j,t-1+L}$ for all $t \ge t+L$

Note that shortages are not penalized specifically but they do lower feasibility of parts sets since a shortage means no inventory for the next period exists, hence a lower availability. In this problem all values are integer, but no integer restriction is necessary because all coefficients in the constraint set are one. These constraints are a combination of i, j, and t, so there can be a large total number of constraints. For example, assuming a 12 week time horizon and 5 parts sets with 5 items in each parts set we have 300 constraints plus the nonnegativity conditions. For software currently available this is not a hard problem to solve optimally. The significant element in this model involves inventory ordering being driven by the readiness function whereas traditional models minimize cost. Cost is not minimized in this case but could still be included as a constraint.

Another possible problem is the number of periods modeled. A linear programming model solves the problem as if future demands are zero, i.e., inventory leaving the last period will be set to zero if possible. Hence it is a modeling problem to determine how far into the future to model. A normal planning horizon is L^2. You then reforecast and remodel after L periods of demands have been observed.

3b. Extending the Model

The presented model deserves consideration in arenas other than aviation. It is worthwhile to apply the model to other Army equipment lending support to optimizing readiness with respect to the constraints above. Provided that the same complexities and hierarchies exist between parts sets and missions, the model can be immediately extended. The next step in modeling is to write this as a stochastic linear program with recourse with a solution using a modeling approach involving Monte Carlo Simulation where the lead times and demand for parts are random variables.

4. CONCLUSION

Aviation units, brigade size and lower, have already discovered the merit of reporting readiness according to individual aircraft capability. A recent interview with an aviation brigade commander returning from OIF, revealed this finding. A standard operating procedure in the unit routinely updates individual aircraft capability. Since commanders already know this provides valuable insight for crisis reaction as well as long term planning, it naturally lends itself to formal reporting procedures. By implementing reporting of the measure outlined above, in addition to the value achieved by displaying an accurate measure of readiness useful to every level of command, the Army also receives the added benefit of optimal ordering and assignment of parts to aircraft models. We believe this metric and models based on it satisfy the intent of senior readiness officials.

Bibliography:

1. Department of Defense, "Quarterly Readiness Report to the Congress," Unclassified Annex H, January - March 2002.

References:

2. Junor, Laura, Personal Communication, 12 August 2004.

3. Kaczynski, William H., Bobbie L. Foote, Edward A. Pohl, "A Utility Based Optimal Metric Coordinating Mission Capability and Supply Level," Proceedings of the Institute of Industrial Engineers Annual Research Conference, Houston, Texas, 16 May 2004.

4. Mayberry, Paul W., "Department of Defense: Presentation to the Subcommittee on Readiness and Management Support Committee on Armed Services United States Senate, Readiness of Our Armed Forces," Deputy Undersecretary of Defense (Readiness), April 9, 2003.

5. Peltz, Eric, "Equipment Sustainment Requirements for the Transforming Army," RAND report, RAND, 1700 Main ST, Santa Monica, Ca, 90407-2138, 2003.

6. Price, Deborah (Chairman, Republican Conference, U.S. House of Representatives), "Congressman Terry Everett Reacts to Army Training Readiness Report," August 31, 2000, http://www.gop.gov/item-news.asp?docId=38361, April 21, 2004.

7. Strategic Communications Current Themes/Messages and Talking Points, Army Strategic Theme: *Our Army at War...Relevant and Ready – Today and Tomorrow.* In coordination with: OCPA; OCLL; ASA(I&E); G1; G2; G3/5/7; G4; G8-PAE; ASA-MRA; SAALT; NGB; OCAR; TRADOC; HRC (DAPE-HR-P), November 5, 2004.

Appendix A

The following linear program investigates this dilemma (that of different units placing different values on the same missions). The LP assumes two value curves, convex and concave. Given a parts set hierarchy consisting of four levels, each level containing two parts, associated parts costs, and a budget, the model provides insight on order policy. Since the lower parts sets involve those parts required for flight and safety of flight, they tend to be more expensive parts, like engines, transmissions, etc. The model assumes no inventory is carried, and orders cannot exceed a known budget constraint.

$x_{i,j}$ = number of part j's ordered in part set i

$d_{i,j}$ = demand for part j in part set i

$c_{i,j}$ = cost of part j in part set i

b = budget for a given ordering period

y_i = number of aircraft with part set i complete/capable of conducting mission i

v_i = value of part set i as determined by the value curve

MAX $\quad \sum_i y_i \cdot v_i$

Subject to:

$x_{i,j} \geq 0$, integer

$y_i \geq 0$, integer

$y_i \leq \min_j \{x_{i,j}\}$, for all i

$\sum_{i,j} c_{i,j} \cdot x_{i,j} \leq b$, for all i,j

$y_i \leq y_{i-1}$, for $i = 2$ to n

$x_{i,j} \leq d_{i,j}$, for all i,j

LP Application: In looking at the results, the hierarchy constraints dominate ordering policy. Note that order policy is predictable based on shape of the value curve, that is, lower part sets with higher value forces the focus on lower parts and vice versa (while still meeting hierarchy constraints).

Given the following:

Part Set	$c_{i,1}$	$c_{i,2}$	v_i (concave)	v_i (convex)
PS 1	7500	6600	.4	.1
PS 2	3500	3500	.3	.2
PS 3	2000	2000	.2	.3
PS 4	1000	800	.1	.4

Results:

Convex													
Budget	Objective	$x_{1,1}$	$x_{1,2}$	$x_{2,1}$	$x_{2,2}$	$x_{3,1}$	$x_{3,2}$	$x_{4,1}$	$x_{4,2}$	y_1	y_2	y_3	y_4
\$15,000	0.1	1	1	0	0	0	0	0	1	1	0	0	0
\$30,000	1	1	1	1	1	1	1	1	1	1	1	1	1
\$45,000	1.1	2	2	1	1	2	2	1	1	2	1	1	1
\$60,000	2	2	2	2	2	2	2	2	2	2	2	2	2
\$62,000	2	3	2	2	2	2	2	2	2	2	2	2	2
\$75,000	2.3	3	3	3	3	2	2	2	2	3	3	2	2
\$90,000	3	4	3	3	3	3	3	3	3	3	3	3	3
\$105,000	3.3	4	4	4	4	4	3	3	3	4	4	3	3
\$107,600	4	4	4	4	4	4	4	4	4	4	4	4	4
Concave													
Budget	Objective	$x_{1,1}$	$x_{1,2}$	$x_{2,1}$	$x_{2,2}$	$x_{3,1}$	$x_{3,2}$	$x_{4,1}$	$x_{4,2}$	y_1	y_2	y_3	y_4
\$15,000	0.4	1	1	0	0	0	0	0	0	1	0	0	0

$30,000	1	1	1	1	1	1	1	1	1	1	1	1	1
$45,000	1.4	2	2	2	1	1	1	1	1	2	1	1	1
$60,000	2	2	2	2	2	2	2	2	2	2	2	2	2
$62,000	2	3	3	2	2	1	1	0	0	3	2	1	0
$75,000	2.7	3	3	3	3	2	2	2	2	3	3	2	2
$90,000	3.1	4	4	3	3	3	3	0	0	4	3	3	0
$105,000	3.8	4	4	4	4	4	4	2	2	4	4	4	2
$107,600	4	4	4	4	4	4	4	4	4	4	4	4	4

Appendix B: Letter from Undersecretary Paul Mayberry

OFFICE OF THE UNDER SECRETARY OF DEFENSE
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WASHINGTON, D.C. 20301-4000

PERSONNEL AND
READINESS

MEMORANDUM FOR 72ND MORSS BARCHI PRIZE COMMITTEE

SUBJECT: 72nd MORRS Barchi Prize Nomination for Paper Titled, "Army Aviation Readiness, a New Metric for Reporting and an Inventory Replenishment Model", authored by, Bobbie L. Foote, CPT Steve Henderson, MAJ William H. Kaczynski, Edward A. Pohl

Capabilities or mission-based measures of materiel readiness are a natural extension of the Department's move toward a capabilities based readiness and planning system. Combatant Commanders need direct information on what their forces can do. Recent observations of military planning in OEF and OIF suggest that current measures of equipment condition (partially mission capable rates) do not depict the true capabilities of the Department's weapon systems.

Equipment readiness metrics should reflect capability of specific systems. The research work in progress by the analysts indicated above has tremendous potential in tackling the current problem. By linking specific missions to equipment capabilities, readiness can be truly maximized relative to the current objective. Their literature review and personal interviews indicate the importance of the problem, as well as the negative impact on the Force.

I believe the significance and originality of the concepts are worthy of the Barchi Prize. Commanders deserve a solution to the readiness reporting dilemma, this work may very well lead to that solution.

Paul W. Mayberry

Paul W. Mayberry
Deputy Under Secretary
Readiness

Appendix C: List of Abbreviations

A	
ARL	Army Research Lab
B	
BLOS	Beyond Line of Sight
C	
COP	Common Operating Picture
D	
DTIC	Defense Technical Information Center
L	
LOS	Line of Sight
M	
MOUT	Military Operations in Urban Terrain
N	
NLOS	Non-line of Sight
NVESD	Night Vision and Electronic Sensors Directorate
O	
ORCEN	Operations Research Center
S	
SA	Situation Awareness
SE	Systems Engineering
SEDD	Sensor and Electron Devices Directorate
SEDP	Systems Engineering Design Process
U	
UAV	Unmanned Aerial Vehicle
UGS	Unattended Ground Sensor
UGV	Unattended Ground Vehicle
USMA	United States Military Academy

*This table is sorted alphabetically

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14. ABSTRACT
In this paper written to satisfy the requirements of the Barchii prize nomination, problems with the readiness metric of The United States Army are explored and a solution devised. This metric allows a clearer picture of the current mission capability of a unit and provides guidelines for ordering parts and sub-systems. Field interviews with helicopter pilots, mechanics, and leaders documented the problem in the field. Congressional testimony was used to show that new metrics are needed and should be based on a definition of capability. This metric is general and can apply at the micro level (tank, helicopter, etc) or macro level (brigade, division an up)

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