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:RATIONS ANALYSIS TECHNICAL
MEMORANDUM NO. 3

JUNE 1963

DEPOT INVENTORY
ACCURACY GOALS

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DIRECTORATE OF OPERATIONS
HQ, AIR FORCE LOGISTICS COMMAND

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OPERATIONS ANALYSIS TECHNICAL MEMORANDUM NO. 3

DEPOT

INVENTORY

ACCURACY

GOALS

by

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and

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ABSTRACT

This paper discusses some basic concepts about accuracy and depot inventory accuracy goals. It also provides a survey of several possible methods of determining depot inventory accuracy goals and discusses the relative merits of each method. In the process it also discusses briefly some new approaches to economical inventorying.

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I. INTRODUCTION

In November 1962 the Vice Commander of the Air Force Logistics Command, Lt. Gen. K. B. Hobson, asked the Operations Analysis Office to look into the problem of setting depot inventory accuracy goals. Such goals had been included in the recently established Field Performance Reviews, conducted in the months when there is no Commanders' Conference. Several Inventory Control measures are presented to the Hq AFLC staff as part of the performance measurement of our Air Materiel Areas (AMAs). These measures of performance are also presented in the Executive Control Meeting portion of the Commanders' Conference. Concern was expressed as to whether the goals being used were right and if not, what should they be? It is very important to maintain high accuracy in inventory records because so much of our logistics management system depends upon them. Ideally, 100% inventory accuracy could be desired, out this is seldom, if ever, attained because of practical, economic considerations. There must, therefore, be some "best" value short of 100% which would represent a valid goal. This memorandum examines the problem of finding this "best" value.

II. DEFINITIONS AND BASIC CONCEPTS

In the process of preparing a briefing to present some ideas on how to set inventory accuracy goals, some basic definitions were introduced. These may appear to be too simple and too obvious to be needed, yet it has been observed that numerous misconceptions arise in connection with just such simple but fundamental ideas.

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Accuracy

Accuracy is defined as the degree of agreement between two number, where one of the numbers is considered to be "true" and the other an 'estimate."

If the true and the estimated values are equal, the accuracy is 100%. If the true and the estimated values are unequal, there is an error. The amount of error is simply the difference between the true and estimated values. The relative error is found by dividing this difference by the true value, thus indicating the amount of error in relation to true value units as a ratio or a percent. Accuracy is then determined by subtracting the relative error, in percent, from 100%. For example, if the true value is 500 and an estimate is 300 there is an error of 200 units. The relative error is 200 divided by 500 or 40%. The accuracy is then 100% minus 40% or 60%. Note that if the estimate had been 700 the error would still be 200 units, the relative error 40% and the accuracy 60%. In the computation of relative error, we are ignoring whether the estimated value was over or under the true value. In formula form this is:

(1) Relative error in % = $\dfrac{|true - estimate|}{true} \times 100\%$.

(2) Accuracy in % = 100% - relative error in %.

Thus, the computation of accuracy is done in two steps, computation of relative error and conversion to an accuracy statement. There is only one way that we can have 100% accuracy and that is when the true value is equal to the estimate. Imagine that we have an accuracy scale and a corresponding relative error scale (in reverse) as follows:

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```
                                                        Accuracy Scale
-50% - - - - -   0%            50%            100%

                                                        Relative Error
150%            100%           50%            0% Scale (in reverse)
```
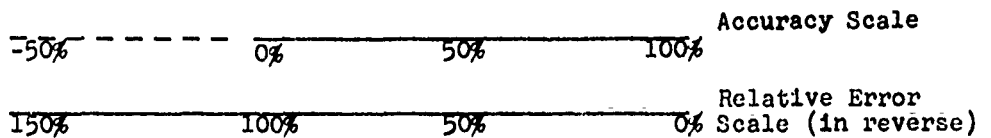
Here we can see that 100% accuracy is that condition where there
is zero error. As we depart from 100% accuracy toward 0% we move
to conditions where the differences between the true value and
the estimated value are increasing (the error is increasing).
When the difference is equal to the true value, we have 100%
relative error and we are at the 0% point on the accuracy scale.
If the difference is greater than the true value, then the relative
error is greater than 100%, and the corresponding accuracy state-
ment could be considered negative. Thus we see that the error
scale ranges from 0% to positive infinity while the accuracy
scale ranges from negative infinity to plus 100%.

If we wish to work only with positive numbers, then we
should work with relative error figures. However, there may
be psychological reasons why we may want to stress the goodness
of the situation rather than the badness. This seems to be the
situation in the inventory area, where we rate the goodness of
the AMA inventory management, not the badness, and so we use
the accuracy rates.

There is one step we took in the accuracy measurement which
needs a bit more dicussion. One must be careful always to use
the "true" value as the denominator (that is, the equivalent of
100%) in the computation of the relative error, otherwise there
will be distortion. For example, we saw above that the relative
error was 40% and the accuracy was 60% when the true value was

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500 and the estimate 300. Now if we had mistakenly used the "estimate" as the denominator in the computation of relative error, we would have had a 67% relative error rate (200 divided by 300), and 33% accuracy. Thus the correct accuracy value of 60% is distorted to 33% simply by using the wrong choice of a yardstick for the 100% value.

In summary, the accuracy relationship between two numbers is expressible as a relative error rate, in which the absolute difference between the two numbers is divided by the _true_ value. This can be converted to an accuracy statement by subtracting the relative error in percent from 100%. Special care must be taken to assure that the right yardstick is used as the 100% value.

Inventory Accuracy

So far we have looked at the idea of accuracy from an abstract viewpoint. Now let us try to adapt the definition to the measurement of inventory accuracy. Here we are concerned with comparing quantities counted during a physical inventory with quantities in record balances. The definition of inventory could be very broad so as to cover all USAF assets worldwide. However, we have narrowed the definition for the purposes of this paper to include only the depot inventories of supplies and their records. There are two levels of aggregation we might consider when calculating inventory accuracy. We will call these Case 1 when we are measuring the accuracy of a single line item and Case 2 when we are measuring the accuracy of a group of several line items (such as a lot for sampling purposes, a complete AMA's inventory, the total AFLC inventory, etc.).

Case 1 - Single Line Item

Here we are concerned with the degree of agreement between the record balance and the actual stock on hand for a single line item. The record balance should be considered as the estimated value and the physical count of the stock on hand should be considered the true value. Actually, the physical count is in itself an estimate of the true unknown quantity on hand since the count may also be inaccurate. However, whenever there is a difference between a verified count and the record balance, the balance is the figure which is usually changed, thus revealing that a verified count is taken to be the true value. Once these substitutions (count = true, record = estimate) have been made in equations (1) and (2) the accuracy formulae become:

(3) Relative error in % = $\dfrac{|\text{count}-\text{record}|}{\text{count}}$ x 100%.

(4) Accuracy in % = 100% - relative error in %.

Example: True value = count = 200 units.

Estimated value = record = 150 units.

Relative error in % = $\dfrac{50}{200}$ = 25%

Accuracy in % = 100% - 25% = 75%.

An important thing to note about the computation for a single line item is that the comparison is done in terms of number of units of the line item such as 200 and 150 units. Thus, we say that the computation of accuracy for a single line item is on a unit basis.

Another important point to notice is that the physical count

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is used in the denominator when computing the relative error
since it is considered to be the true value. Current Supply
procedures use the record balance as the denominator, which
causes some distortion in the resulting accuracy figures as
we saw in the section on accuracy above. We recommend that the
Supply procedures be changed to use the count as the denominator
so that the resulting measurements will have greater validity.

Table I furnishes some examples of how accuracy is com-
puted for each of 10 line items. Note the differences between
the error rates when the record is used as the denominator
instead of the count.

Case 2 - Group of Line Items

We have a different situation when we consider the accu-
racy of a group of line items since there are several possible
ways of calculating a single accuracy figure to represent the
whole group. Table II illustrates several ways in which an
average accuracy can be obtained for the whole group. The
figures in Table II are based on Table I. Table II entries
will be explained in the following paragraphs on methods of
computation.

TABLE I

EXAMPLES OF LINE ITEMS

Line Item	Count	Record	Difference	Relative Error in % (Count as Denominator)	Relative Error in % (Record as Denominator)
1	100	20	80	80%	400%
2	200	570	370	185%	65%
3	300	270	30	10% III	11%
4	400	150	250	63%	167%
5	500	600	100	20%	17%
6	500	490	10	2% II, III	2% II, III
7	1000	500	500	50%	100%
8	2000	1900	100	5% II, III	5% II, III
9	2000	1000	1000	50%	100%
10	3000	1500	1500	50%	100%

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TABLE II

SOME WAYS OF MEASURING INVENTORY ACCURACY FOR A GROUP OF LINE ITEMS

Method	Count as Base	Record as Base
1. Unweighted average error rate	$100 \times \dfrac{515}{10} = 52\%$	$100 \times \dfrac{967}{10} = 97\%$
Unweighted average accuracy	$100\% - 52\% = 48\%$	$100 - 97\% = 3\%$
2. Weighted av. error rate	$100 \times \dfrac{3940}{10,000} = 39\%$	$100 \times \dfrac{3940}{7000} = 56\%$
Weighted av. accuracy (Cost Cat I)	$100\% - 39\% = 61\%$	$100\% - 56\% = 44\%$
3. Unweighted accurate items (Cost Cat II)	$100 \times \dfrac{2}{10} = 20\%$	$100 \times \dfrac{2}{10} = 20\%$
4. Unweighted accurate items (Cost Cat III)	$100 \times \dfrac{3}{10} = 30\%$	$100 \times \dfrac{2}{10} = 20\%$
5. Weighted accurate items (Cost Cat II)	$100 \times \dfrac{2500}{10,000} = 25\%$	$100 \times \dfrac{2390}{7000} = 34\%$
6. Weighted accurate items (Cost Cat III)	$100 \times \dfrac{2800}{10,000} = 28\%$	$100 \times \dfrac{2390}{7000} = 34\%$

Unweighted Average Accuracy Method

The first method shown in Table II calculates the average error rate simply by adding the relative errors in Table I for all the line items, and dividing this sum by the number of line items. It is called "unweighted" because all the line items are given the same importance or weight. Following this process, we see that the accuracy turns out to be 48% when the count is used as the denominator and only 3% if the record balance is used. Notice how little increase in relative error would be needed before the accuracy based on the record balance would be negative.

Weighted Average Accuracy Method

If we decide that the line items are not of equal importance, then the unweighted method shown above should not be used. For instance, if the number of units per line item is important, then the weighted average accuracy method would be better. Under this method the error percentages for each line item in Table I are multiplied by the unit counts as weights for the line item, the products are added, the sum divided by the total weights, and the result converted to a percentage. This is the standard method for obtaining a weighted average. The same result can be obtained more easily by dividing the total of the "difference" column by the total of the "count" column and converting the result to a percentage.

When this procedure was followed in computing Table II, we saw that the accuracy turned out to be 61% when the count was

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used as the denominator or 44% when the record was used. Note the substantial increase in indicated accuracy over what was obtained for the unweighted case. This resulted from the fact that the line items in Table I which have the most units also tended to have the least errors. These lower error rates were given more weight causing the average accuracy for the whole group to increase.

This is the method that has been used to calculate AMA and AFLC inventory accuracies for Cost Category I (Hi-Valu) items.

Unweighted Accurate Items Method for Cost Categories II and III

Cost Category II and III items are currently inventoried by sampling methods in which an AMA's inventory is subdivided into several lots. Each lot is then "sampled" periodically by selecting line items at random from the lot. The selected line items are then counted and the relative error is computed for each as in the Case 1 - Single Line Item method. The relative errors for the line items in the sample are then reviewed to determine which line items are "in error." A line item is "in error" when the relative error exceeds 5% if it is a Category II item, or when the relative error exceeds 10% for a Category III item. Thus, a certain amount of relative error is tolerated in each line item sampled, but when the acceptable limit is exceeded the line item has unacceptable accuracy.

Now to calculate an estimate of the accuracy for the group of line items in the whole sample, the number of line items not "in error" is divided by the total number of line items in the

sample, and the result converted to a percent. The "sample
accuracy" thus found is an estimate of the accuracy for the
entire lot, which we call in Table II the "unweighted accurate
items," as it tends to describe how many items are accurate
rather than how accurate or inaccurate the items are.

For example, assume that the 10 line items in Table I
represent the sample of line items which were counted. The
relative errors were computed for each as listed. Now if the
10 items were all Cat. II, the good ones, those not "in error,"
are the ones where the relative error is 5% or less. The ones
which are good are items 6 and 8 as indicated by the Roman
Numeral IIs in Table I. The "unweighted accurate items" is
then 20% since 2 line items out of the total sample of 10 line
items were good. If the 10 items were Cat. III, the items
having 10% or less relative error are considered good. In addi-
tion to items 6 and 8 we also will count item 3 (when "count" is
the denominator) as good. Thus, in this case, the "unweighted
accurate items" will be 30%. These results are shown in Table
II under methods 3 and 4.

There have been some discussions recently about the possi-
bility of using a similar approach for Cost Category I (Hi-Valu),
except that here there will be no acceptable error rate greater
than 0%. If the line items in Table I were all Category I
items none would be good items since all of them have relative
errors greater than zero. Thus, the accuracy for the whole group
would be zero. This compares with the 61% (or 44% with "record"

as denominator) shown in method 2 of Table II as Hi-Valu is
now being computed. We see that the "accurate item" method
would give a higher measure of accuracy in relation to the
weighted average method whenever many relative errors fall
w'thin the "acceptable" range, and it would give a lower
measure of accuracy if the relative errors fall outside the
"acceptable" range as they would do in the Cat I case men-
tioned here (which we view unfavorably).

If an average accuracy for an entire AMA or for all of
AFLC is desired, the current procedures are similar to those
in Table II, except that the total items sampled and the
total number of good items are obtained from all the samples
of all the lots, and then the accuracy is computed by dividing
the total good items by the total items sampled, and converting
the result to a percent (lines 3 and 4, Table II).

This approach for computing the accuracy for a group of
line items is very different from the ones described in the
previous sections. In the first place, the concept of having
an acceptable error rate for each line item is used. Then each
line item is considered to be either good or bad, not 80% good,
or 20% bad, or some other percentage determined from the
relative error as before. Therefore, the computation proceeds on
an item basis, rather than a unit basis as before. Thus, here
we speak of the percentage of the line items which are good,
whereas before we spoke of how close the agreement was between
the count and the record balances for the group as a whole.
If one is concerned with how well a manager is doing across-
the-board, perhaps the computation on an item basis is useful,

while if impact of inventory error on the total logistics process is the major concern perhaps the computation on a unit basis is better.

Another thing to note about this method is that it gives equal weight to each line item in the computation. Thus, to use this method with validity, we must be prepared to say that any one line item is no more important than any other. If we cannot say this, then perhaps the following method, which is a modification of this one, can be used.

Weighted Accurate Items Method for Cost Categories II and III

The main difference between this method and the Unweighted Accurate Items Method is that the line items are weighted by the number of units contained in each. The use of an acceptable error rate permits us to decide whether any particular line item is good or bad as before. Let us assign a value of "1" if the item is good and a "0" if the item is bad. Therefore, ones will be assigned wherever there is a II or a III on Table I depending upon whether we assume Category II or Category III. We see that items 6 and 8 of Table I are good Cat II items when the count is the denominator. To obtain a weighted average, we multiply the zeros or ones by the count for each line item and add the products. This gives a total of 2500 (500 from item 6 and 2000 from item 8 and zeros elsewhere). We then divide by the total count and convert the result to a percentage, getting 25% $\left(\frac{2500}{10,000} \times 100 \right)$. We obtain the other entries in Methods 5 and 6 of Table II in a similar fashion. The figures

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differ from those in lines 3 and 4, and we may prefer them if we do not wish to consider all line items of equal importance.

Inventory Accuracy Summary

We see from Table II that there are a number of possible ways of determining an accuracy figure from the data in Table I. Undoubtedly there are many other ways as well. Looking over the results we see that the accuracy figures range from 3% to 61%! One naturally wonders which is right, or even whether any is right. The set of methods used today by APLC are methods 2, 3, and 4 using record figures as the base. One can best determine which method to use by considering the assumptions upon which each method is based, as discussed in the above paragraphs. We have already noted that the record balances should not be used as bases or denominators in accuracy computations, so that cuts the choices down by one half, leaving only the choices in the "Count as Base" column. The main differences between the methods revolve around two ideas: whether to allow small errors to count as though they are not errors at all, and whether to treat all line items or all units as having approximately equal importance. It may help to have a table to indicate which method to use once decisions are made as to which ideas are important (see Table III).

TABLE III

INVENTORY ACCURACY METHOD TO USE

	Weighted Average	Unweighted Average
Units are basis	2	1
Items are basis (small errors negligible)	5, 6	3, 4

KEY

Method	Title
1	Unweighted average accuracy
2	Weighted average accuracy
3, 4	Unweighted accurate items (Cat II or III)
5, 6	Weighted accurate items (Cat II or III)

The decision between units and items will hinge upon whether one is primarily concerned with how well an item manager is doing his job over the full range of his items, or what the impact is likely to be or AF logistics. If supervision aspects are uppermost then "items are basis" will be chosen; if impact is uppermost then "units are basis" will be chosen. This could be further refined, of course, by distinguishing between items in terms of their relative essentiality or mission impact; further discussion along these lines is not being attempted in this paper.

The decision about the use of weights when computing the accuracy depends upon how alike the line items are. If quantities of units per line item are either roughly equal over all the line items being measured, or are not considered of importance, then no weights should be used. If the quantity

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of units per line item varies considerably from line item to line item and if this is thought to be significant, then weighting the average by the unit count per line item is desirable. The authors of this paper believe that reflection of probable logistic impact is best accomplished by use of Method 2, with Methods 5 and 6 as the next preferred.

Goals

Having examined some definitions of accuracy and inventory accuracy, we now proceed to discuss some ideas about goals. First the purpose: a goal may be a target to shoot at (if not necessarily to reach), or it may be a planning factor or standard which is normally achieved. The policy chosen will have a great impact on the inventory accuracy goal chosen.

A goal may be used to promote such things as best efficiency, or competition between activities, or emphasis for certain items or categories of items. Measurements of achievement of the designated goals may also provide the basis for comparing one activity with another or for making decisions about changes in procedures. Chart 1 illustrates how the procedure used as well as AMA effort may affect achieved inventory accuracy.

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CHART I

Procedures, AMA Effort, and Inventory Accuracy
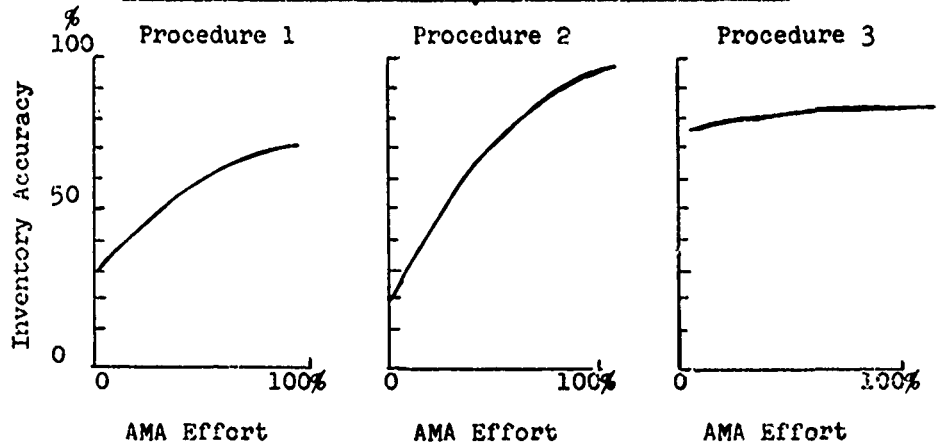
Three procedures are illustrated. In the first, inventory accuracy might range from 30% to 70% depending upon the AMA effort. The potential of the method is limited, for some reason, so that greater than 70% accuracy could not be achieved even with great AMA effort. Procedure 2 ranges from 20% to nearly 100%, depending upon AMA effort. Here increased pressure on the AMA to apply the procedure would pay off with increased inventory accuracy. If Procedure 3 were used no amount of pressure on the AMA to apply the procedures would pay off since inventory accuracy is nearly independent of AMA effort. Procedure 3 is a desirable management procedure in the sense that uniform results could be expected from all AMAs. Thus we see that a Headquarters or other activity which measures performance of a subordinate should recognize the effect that the prescribed procedures have on the factor measured. If Procedure 2 happens to be in use, then very high accuracy can

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be expected, and obtained, with adequate supervision. If
Procedure 1 or 3 happens to be in use, then no amount of super-
vision, assistance or pressure can increase the inventory
accuracy to levels higher than about 80%. Emphasis on motivation
should be applied only if there is reason to believe that the
existing procedures will permit highly desirable consequences
to flow from greater efforts. In other cases it may be neces-
sary to make some procedural changes as well as to emphasize
AMS action.

In addition to the above considerations, decisions must
be made about some other factors when establishing goals:

Basis: Should the goal be based on ideals, or on past
performance, or should costs be considered to obtain an optimal
solution?

Term: Should a goal be for a short term or a long one,
that is, should it be revised frequently or infrequently?

Flexibility: Should a goal be the same for all activ-
ities, or should it be tailored to the characteristics of each
activity?

III. METHODS OF SETTING INVENTORY ACCURACY GOALS

There are several possible ways to set inventory accuracy goals. We will discuss 4 general methods and some related sub-methods in this paper. They are:

1. Management Decision Method
2. Average Accuracy Method
3. Significant Variable Method
4. Inventory Interval Methods
   a. Preselected Method
   b. Minimum Cost Methods
      (1) Without Sampling
      (2) With Sampling
   c. Low Point Method

Management Decision Method

This is probably the simplest of all possible methods. Here someone with authority and a good background sets the goal by subjective means. Because no particular formula or data manipulation is involved, the decision may be hard to defend, particularly if someone else with equal background and experience believes some other goal is better. The method has the advantages that it is easy to establish and that depending on the skill of the decision maker, more variables can be considered than might be possible with more complex analytic methods. This method probably would not provide the best goal, however, and may produce poor goals if the decision maker uses poor judgment or has inadequate background and experience.

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Average Accuracy Method

This method works something like this: Each time that
the AMAs report their accuracy to the Headquarters, an AFLC-
wide average accuracy is computed. This average accuracy
figure is then used as the goal for the next period. There
are several advantages in using a method of this type. It
is easy to understand and to apply. The AMAs which are
worse than average are readily spotted. The goal is always
attainable since about half the AMAs are already at it or ·
have exceeded it. It also has some disadvantages, such as:
it may not give a real challenge or incentive to the AMAs
already above average; one or two AMAs having very low or very
high accuracies could greatly influence the average and thus
the accuracy goal; all AMAs have the same goal, even though
certain AMAs may have items whose characteristics would tend
to lower the expected accuracy for these AMAs,

This method also has another feature: the goal may have
an upward trend over time since each report period each AMA
will strive to increase its accuracy over the last time.
Eventually a limit will be reached beyond which very little
improvement will be found possible, and this will be the
practical goal for the procedures in effect. It may be fairly
easy to determine the trend by plotting 3 or 4 report periods
in succession and then to predict future goals based on this
trend. Although predicting trends and identifying plateaus
may be feasible, the method furnishes little guidance in
setting inventory or sampling periods or in deciding whether

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alternative procedures should be used.

This technique has an advantage over the Management De-
cision Method described earlier in that it is based on reported
data and is therefore more objective. Variations of it may
also be found to be interesting, such as use of an upper
quartile instead of an average.

However, even greater advantages may be achieved by
looking a little more deeply into the "why" of the inventory
inaccuracy. This process leads to the next way of setting
accuracy goals.

Significant Variable Method

It seems reasonable that the error rate might be related
to some measurable characteristic of the item of inventory
under consideration. Some of these characteristics might be
the amount of issues and receipts occurring during a speci-
fied period of time, which we will call "activity rate", or
the unit price, or the number of units in the stock level of
an item, or the importance or mission essentiality of the
item, etc. In addition, such things as number of items
managed by the AMA and the number of storage locations per
item may have an impact on the expected accuracy rate.

Now if data are available it may be possible to determine
which characteristics affect inventory accuracy. One way to
see whether or not a general relationship exists between
inventory accuracy and any given characteristic is to make a
scatter diagram, as in Chart 2. Here we took the sample
inventory accuracies reported by the AMAs as of September 1962

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for Category II and III items, and plotted these against the
amount of activity per AMA for September. Here "Activity" is
in terms of thousands of line item transactions per month, and
line item transactions mean off-shelf shipments plus back
orders shipped plus receipts for the AMA.

CHART 2

AMA Inventory Accuracy vs. Cross AMA Activity
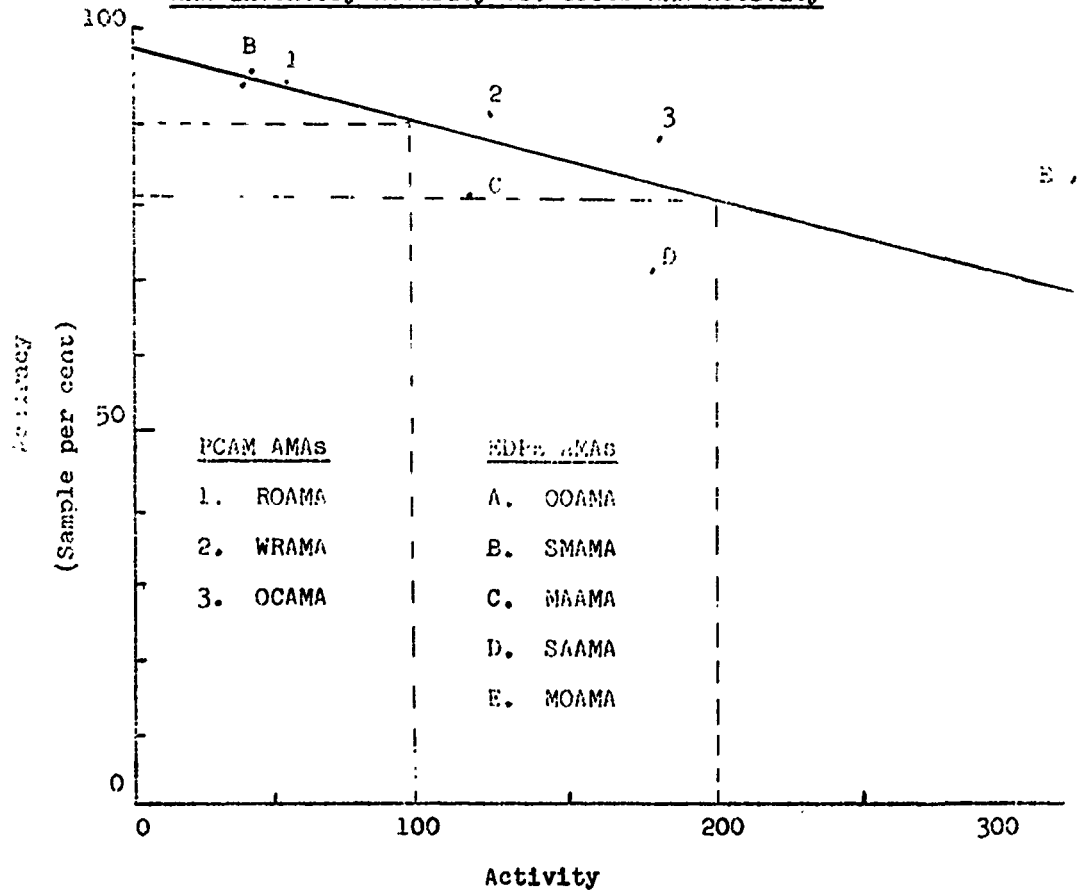
Activity

(Thousands of Line Item Transactions per Month as of Sep 62)

We see from Chart 2 that there appears to be a strong
tendency for the AMAs which have higher activity to have corres-
pondingly lower accuracy. Thus, we could say that it looks
as though activity is a significant variable in that AMA accuracy
tends to vary inversely with activity rate. In assessing this,
one can reason that each unit of activity is a chance for an
error to be made. If no activities occur, then no change should
be made to the records and there should be zero error. As more
activities occur, there are more chances for error and therefore
less accuracy is expected. Similar charts can be constructed
for any other characteristics thought to be important.

The example shown here, although based on actual data, is
primarily for illustrative purposes since it is based on a very
small amount of experience. With more months of data, and more
points plotted, more confidence could be placed in a graph of
accuracy vs. activity, with trend lines drawn through the points
using statistical techniques such as least squares. One line
is shown in Chart 2. However, when looking at the points by AMA
it also looks as though the type of statistical equipment used
to maintain the records may have influenced the inventory accuracy.
Note that the AMAs having electronic data processing equipment
(EDPE) tend to have lower accuracies than the AMAs having punched
card accounting machines (PCAM), except for MOAMA. If later
studies with more data indicate similar relationships, it may be
possible to construct two curves instead of one, so as to have
a curve for the EDPE AMAs and another for the PCAM AMAs. Later

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studies should also determine why MOAMA doesn't seem to behave
like the other EDPE AMAs; for example, those familiar with the
existing conditions may offer hypotheses about the effects of
specific key personnel at certain AMAs.

When a chart, such as Chart 2, is constructed for sig-
nificant variables, and enough data have been used to provide
confidence in the results, it is easy to set accuracy goals
which are more equitable than overall averages. For example,
if an AMA is expected to have 200 thousand transactions per
month, then Chart 2 will indicate 82% as the goal. If 100
thousand is expected, then the goal would be 90%. This is the
first method we have considered so far which does not assume that
all AMAs will use the same goal, as each goal will reflect the
value of the significant variable separately for each AMA.

This method has several advantages. In the first place,
it is objective since it is firmly based on actual data. The
method also permits the forecasting of goals for future time
periods, provided the significant variable can be forecast.
The method is simple to apply once the chart has been constructed
and, as we mentioned earlier, the goals are tailored for each AMA.

There are also some disadvantages. Data have to be collected
and analyzed to identify the significant variables and to de-
termine the relationships between these variables and inventory
accuracy. Charts which have already been made must be reviewed
and updated periodically to reflect possible shifts in the curve
caused by changes in the measured relationships.

Although this method is objective and has several advantages it has one shortcoming in common with all the methods discussed so far, and that is that no direct attempt has been made to influence inventorying policy while setting the goal. The following methods will show some ways to do this.

Inventory Interval Methods

The inventory accuracy at any given time can be shown to be dependent upon how long it has been since the last inventory count was made. Chart 3 illustrates this.

CHART 3

Inventory Accuracy vs. Time Since Last Count

Time Since Last Count
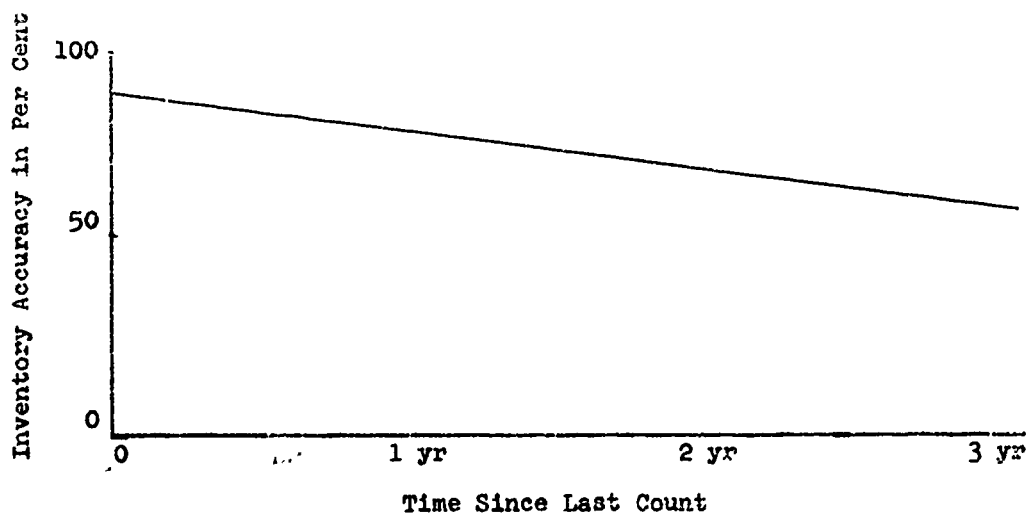
In this chart we see that at time zero, or immediately after an inventory count has been made and the records adjusted, the inventory accuracy may still be only 90%, due to errors in counting, records "in float" and not included in the reconciliation process, etc. As time goes on and activities (or other significant

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variable values) accumulate, the error rate grows and the inventory accuracy decreases. Although this chart is for illustrative purposes only, similar charts can be made for each AMA or subgroup within an AMA after an analysis of historical data has been accomplished. It may be that such graphs will not be linear, or that there will be more or less accuracy at time zero than shown above.

Using this type of chart we see that a goal can be determined once a time interval between the full counts is decided upon. There are many ways for making this type of decision and there are, therefore, a family of Inventory Interval Methods. The methods that will be discussed in this report are:

> Preselected Method
> Minimum Cost Methods
> Low Point Methods.

Preselected Method

Here management makes a decision as to how often to take an inventory. This decision then determines the Inventory Interval and Chart 3 provides the inventory accuracy goal. For example, if management decides that inventories are to be taken annually the goal may be 80%, as read from a chart like Chart 3. This method has the same general advantages and disadvantages as the Management Decision Method discussed earlier.

Minimum Cost Inventory Method, Non-Sampling Case

This method seeks optimal conditions by looking for the inventory count interval that will have minimum total costs. Now total costs can be thought of as the costs associated with operating with undetected inventory errors (error costs) and those associated with detecting and correcting errors (counting costs). Thus,

Total Cost = error costs + counting costs.

Some examples of error costs follow: If the inventory records are not accurate and reflect more assets than there really are, then there are likely to be backorders, NORS conditions which in turn can cause emergency actions such as expedited procurement actions, inter-base shipments, as well as excessive downtime, etc. In addition, disposal actions may be taken to get rid of spurious "excess" assets. All of these actions cost money, which is the error cost. Now if the inventory records are erroneous and reflect fewer assets than there really are available, then other error costs arise, such as making excessive purchases, thus creating long supply and incurring extra storage costs.

Counting costs include such things as manpower costs, computer costs, and delays in filling requisitions caused by closing the warehouse during the inventory operation.

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Chart 4 illustrates how the error and counting costs
vary with time since last count. If the count interval is
small, such as 3 months, then the error rate probably has not
grown much and annual error costs are low. At the same time,
annual counting costs are high because of the frequent counting.
As the count interval is lengthened, the annual error costs
rise and the annual counting costs decline. The sum of these
costs, total costs, may have a minimum, as it does in Chart 4.
If it does, the count interval where the total cost is least
is the optimal count interval. This occurs at $1\frac{1}{2}$ years in our
example. Then using Chart 3 and the optimal count interval
from Chart 4, the optimal inventory accuracy goal is determined.
This is about 75% for our illustration. Note that this is the
first method discussed that provides both the accuracy goal
and the management policy to achieve it.

This type of method has many advantages. As we have
seen, it provides an optimal goal and helps set policy. It is
also objective, and is tailored to individual AMA conditions.
Provided good factors are available, it is probably the best
type of method for determining inventory accuracy goals since
there is a sound management reason for the choices made -
minimum total operating costs (or, more accurately, optimum cost-
effectiveness).

One must pay for what he gets and this method is not with-
out its problems. The major one is estimating costs. The
counting costs are relatively easy to estimate since manpower
and machine cost factors are readily available. The error

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CHART 4

Minimum Cost Inventory Interval Model

Time Since Last Count (Count Interval)
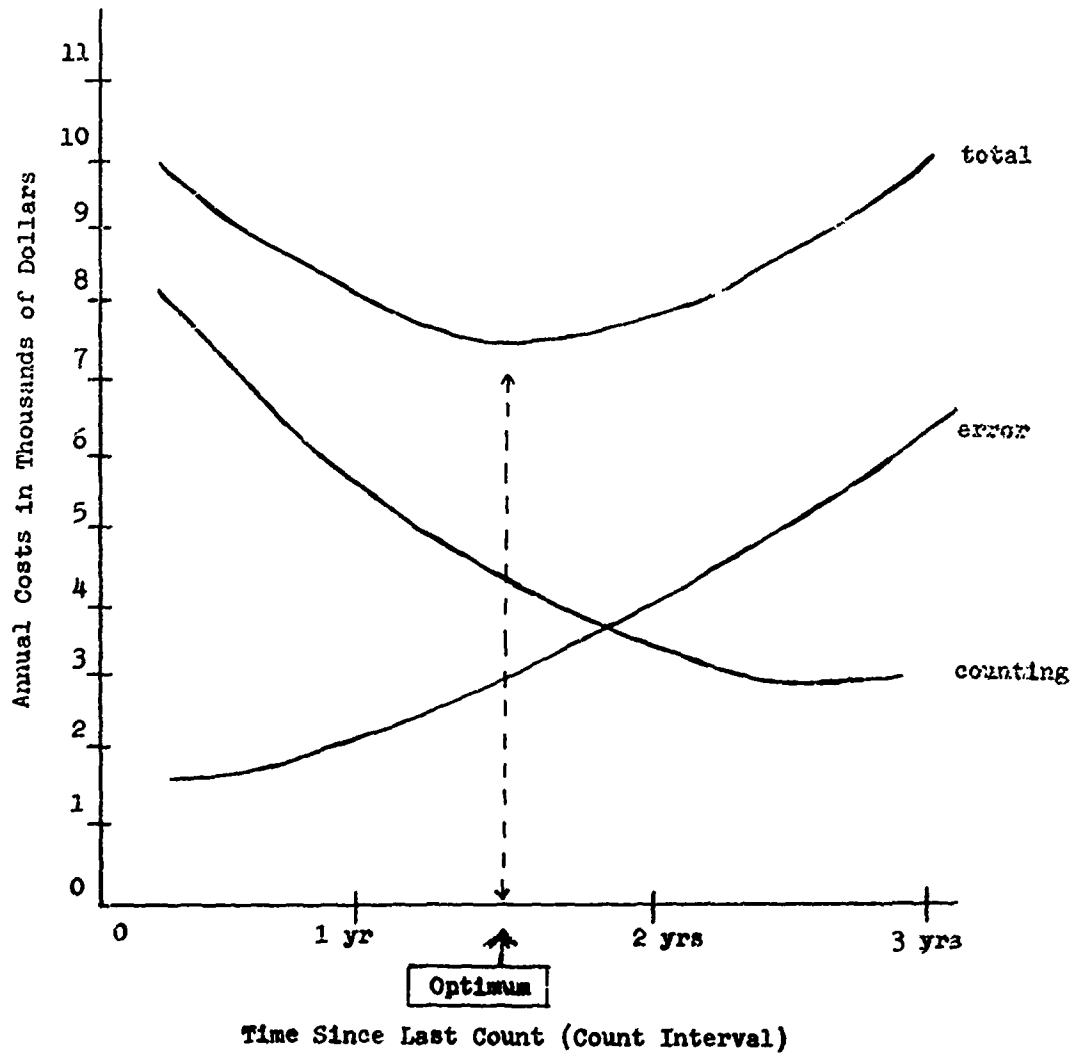
costs are more nebulous. It is much more difficult to measure the impact of increases in the NORS rate, backorders, etc., caused by inventory error. There are many who say that this cannot be done. However, there are other supply systems now in use that rely upon cost figures that are just as hard to come by. For example, the Economic Order Quantity methods now in use require estimates of costs to administer an order and of holding material in storage. Also, at the point where EOQ methods involve setting of a Safety Level they are involved in the same stockout values we are facing here. Furthermore, it is probably true that policies which do not overtly reflect these costs are actually implying such costs, and very possibly implying wholly unrealistic values. Finally, it may also be that our model is not affected too much by errors in certain cost estimates, and as long as costs are within reasonable limits the results obtained will be satisfactory. If this is the case, the method may very well be feasible.

Minimum Cost Inventory Method, for Sampling

This method is similar to the one just discussed in that the combined costs of errors and of checking inventory accuracy are to be minimized. In the method just discussed every inventory operation involved a complete counting of assets. Under the sampling method the assets are divided into subgroups known as lots. A random sample of line items is then selected from each lot, counted and compared with the record balances. If the accuracy of the sample is within acceptable quality control limits the entire lot is considered to be sufficiently accurate,

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and no further counting is done for that lot until the next time period. If the accuracy of the sample is not within the acceptable limits then the whole lot is deemed to be inaccurate and it is rejected. In this case the whole lot is recounted. Under conditions where the lot accuracy remains high over extended periods of time, such as when the activity rate is low, the sampling method saves manpower and time while giving information about how accurate the lot is.

In addition to these differences, a different approach is taken for determining the optimal inventory accuracy goal. Before, with the non-sampling model, the variable was the inventory interval. This variable was manipulated until that interval was found which minimized the total cost. Then the optimal accuracy goal was found from a graph of accuracy vs. time since last count. In the sampling model the inventory interval is fixed beforehand, based on other considerations. Then, based on a table of accuracy vs. time since last <u>full</u> count, as before, a table of "sampling & counting" costs is derived for various steps of the accuracy goal. A table of error costs per inventory accuracy step is also derived. Then a table of Total costs per inventory accuracy step is computed by adding the error costs and the "sampling & counting" costs. The step having the lowest cost determines the optimal inventory accuracy goal.

This procedure is simplified for illustrative purposes and can be modified to cover multiple sampling plans, statistical variation, and other appropriate changes. Our purpose here is to outline the basic method.

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The following example will illustrate the basic method. Assume that we have a single sampling plan that involves taking a sample of each lot each 6 months. If the accuracy for the group of line items in the sample is greater than the accuracy goal the lot will be accepted and no further action is taken for 6 months. Thus, the only cost incurred would be that associated with taking and counting the sample.

If, however, the sample accuracy is less than the accuracy goal, the additional cost of counting the whole lot is incurred.

Table IV will illustrate this process. Across the top of the left-hand half of the table we show the expected accuracy at the end of six month periods. This table would be derived from past experience data for a particular AMA or lot within an AMA and would be considered to be representative of future time periods under similar conditions. Beneath this table, the expected actions to be taken each time period are recorded for each step of the accuracy goal as given along the left hand column. For instance, reading across the 85% goal row we find a succession of "s, sc" actions. The "s" means that only the sample action was necessary since the 89% accuracy from the table at the top of the first column is greater than the 85% goal. The "sc" action in the next column means that when the sampling action, s, is taken the second six months, the 83% accuracy will cause the lot to be rejected and the additional action, counting (c), is taken. Following this the accuracy is assumed to return to the zero time accuracy of 95%. The next column has only an "s" because the accuracy will be 89%, etc. The rest of the table was derived in a similar fashion.

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TABLE IV

TABLE OF SAMPLING & COUNTING COSTS

Sampling Plan Actions (per lot)

Months since Count	0	6	12	18	24	30	36		Costs			
									Per Cycle *			Average
Accuracy in %	95	89	83	77	71	65	59		Total [s]	Total [c]	Grand [Total]	Annual
Goal												
100%	[sc	sc]	sc	sc	sc	sc	sc		$200	$2200	$2400	$2400
95	[sc	sc]	sc	sc	sc	sc	sc		200	2200	2400	2400
90	[sc	sc]	sc	sc	8c	sc	sc		200	2200	2400	2400
85	[s	sc]	sc	s	sc	s	s		200	1100	1300	1300
80	[s	s	sc]	s	s	s	sc		300	1100	1400	933
75	[s	s	s	s	8c]	s	s		400	1100	1500	750
70	[s	s	s	s	s	sc]	s		500	1100	1600	640
65	[s	s	s	s	s	sc]	s		500	1100	1600	640

s = cost to check accuracy by sampling = $100

c = costs to count lots = $1,100

* But no less than one year

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Now if we assume that the cost of a sampling action alone
is $100 and the cost of a counting action (c), s $1100, a
table of average annual costs of "sampling & counting" is com-
puted. This is shown on the right hand side of Table IV. The
entries in the table are computed from the entries on the left
hand side of the table which are within square brackets. The
brackets have been placed around one year's worth of actions
unless some other grouping is required for a complete cycle.
For instance, 18-month cycles occur for a goal of 80%, and
30 month cycles occur for a goal of 70%, etc. The figures
under the "Total [s]" column on the cost side of the table
were derived by counting the number of "s's" between the
brackets on the left-hand side of the table, and multiplying
this number by $100, the cost of each sampling action. The
figures under the "Total [c]" column were computed in a
similar fashion by counting the number of "c" actions between
brackets and multiplying by $1100, the cost of each "c" action.
The "Grand [Total]" figures were calculated by adding the
entries from the preceding two columns. These figures are
then converted to average annual figures for the last column
by multiplying by the fraction 2 divided by the number of
columns between the brackets on the left-hand side of the table.

Table V then lists for each inventory accuracy "trial goal"
the annual error costs as they might have been derived from
special studies or estimates and the annual sample-plan costs
as derived in Table IV, and the total annual costs. The optimal
goal for the sampling procedure is then found by selecting the

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row having the least total annual costs, which in our example occurs when the trial goal is 80%.

TABLE V

COMPUTATION OF OPTIMAL INVENTORY ACCURACY

GOAL FOR THE SAMPLING CASE

Trial Goals	Annual Error Costs	Annual Sample-Plan Costs	Total Annual Costs
100%	$ 0	$2400	$2400
95	50	2400	2450
90	100	2400	2500
85	200	1300	1500
80	400	933	1333
75	800	750	1550
70	1600	640	2240
65	3200	640	3840

This method, like the non-sampling minimum cost method, has many advantages. It makes full use of relationships which are presumed to exist between costs and error rates for each AMA, or lot within an AMA, in determining an objective, optimal inventory accuracy goal. If the goal is adopted and incorporated into the sampling procedures, and if the conditions under which the inventories are managed remain substantially as they had been otherwise, the total costs to the Air Force of inventory inaccuracy can be expected to be minimized. Thus, the method furnishes intrinsic benefits as well as an operating goal.

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The main disadvantages have to do with data. The method requires cost data for several error condition effects as well as for support of the inventory-counting effects. In addition, the AMA or lot accuracies must be analyzed in relation to the error growth over the time since the last full count was taken. However, the improvement in inventory management and total AF costs and effectiveness might far outweigh the additional costs and effort involved in obtaining satisfactory data for such an analysis.

Low Point Method

This method is based on the idea that the best time to take an inventory is when the stock level is at a low point so that the counting costs are small and the chances of making an accurate count are good. This idea has already been used in inventory procedures, particularly with respect to warehouse refusals. Whenever a warehouse refusal occurs a special inventory is taken. This event, low point, is often unpredictable. To be most effective, the low points should be predictable, either by item, or at least statistically for large numbers of items. In addition to being predictable the inventories should be planned to occur in advance of a requirements computation so that the best available information can be used. Therefore, it would be advantageous to plan inventories to be taken whenever a reorder point (or slightly higher point) is reached. Then we would reap the benefits of counting fewer items, consuming fewer manhours and time in the process, obtaining a more accurate result, and providing good support to requirements computations. Furthermore,

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we would avoid the heavy workloads of counting the items in long supply; such counts are probably the largest workloads and also the least useful ones.

Inventory accuracy goals can be established using the low point method by predicting the expected frequency of the occurrence of the low points, and then determining the accuracy from a graph of accuracy vs. time since last count, as in the other inventory interval methods. Although the method does not stress optimality in an overt way, it may nonetheless prove optimum by virtue of its expected economies and its concentration of effort where most beneficial.

IV. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, let us summarize what we have discussed so far. We have attempted to look at the whole area of inventory accuracy goals in a general way. We have examined the concepts of accuracy, of goals, and of what inventory accuracy goals are. We have recommended that AFLC use the actual count as the basis for computing inventory accuracy, rather than the record balance now being used. We have also observed that at the present time inventory accuracy measurements and goals are stated in two different ways: in terms of unit accuracy for Hi-Valu items and in terms of line item accuracy for the items under the sampling method, and we have indicated a preference for the "unit accuracy" method as used for Hi-Valu. We have also examined a number of methods of determining depot inventory accuracy goals and have discussed the relative merits of each. The "minimum cost" methods seem to be potentially valuable, not so much because of the goals they establish as for the management policies they recommend and the costs they save. The low point method also appears to have promise for providing management improvement at low cost.

We feel after studying the alternatives that the Command should move towards the use of the minimum cost method of setting goals and of managing the inventory. In a way, similar steps have already been taken in this direction in the requirements area in the Economic Order Quantity procedures. This is also in line with current DOD thinking on cost-effectiveness ratios. We should become more scientific in our approaches to

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getting more effectiveness from our money spent. The minimum cost approach is one way of accomplishing this in the inventory accuracy area through balancing mission costs and management costs.

When we concentrate more fully on the objective of filling other Commands' requirements we gradually see that really, from the standpoint of ready rates, NORS rates, etc., it is the number of units of shortage which is important about inventories and not so much the number of line items in which shortages exist. For example, if a line item has a shortage which causes downtime or a reduction in ready rates we know that at least one unit is short, or in other words, that we do not have all the units we need. If only one unit is short, then only one weapon can be down because of it. If 10 are short, then 10 weapons may be down because of this shortage. In either case, only one line item has the shortage. Of course there can be cases where two or more units overlap in their shortage effects, causing only one weapon to be NORS. On a probability basis, however, the NORS rate and other similar shortage measures, are more likely to vary in close relation to units short than line items short. Thus, to really study the problem and to really measure the impact of inventory inaccuracy we must work in terms of units of inventory and not restrict ourselves to line item thinking only.

Another very important point should be considered before we leave the discussion of mission support, and that is the relative importance of inventory items for mission accomplishment,

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or "mission essentiality" for short. The cost of a stock out
or shortage really is the loss of mission effectiveness that
results because of the absence of the unit. A shortage of some
units, such as ash trays, will have no effect on a mission by
an operating command, whereas the absence of a bearing or an
actuator or a piece of electronic equipment, or even a washer
or seal, might have serious effects. It seems reasonable that
the line items in our inventory could, in some way, be classified
and coded as essential or non-essential. This would not only
assist in determining the cost of an inventory shortage for use
in the minimum cost models, but it would also help the Inventory
Managers know where to place their management efforts. Perhaps
goals and inventory procedures should be established differently
for items with high mission essentiality than for those with
little or no mission essentiality. This would help emphasize
the more important items.

Although we feel strongly that the minimum cost approach
is the way to go, we also realize that sometimes we must crawl
before we walk. We think, that as a minimum, the first steps
to be taken would be to investigate the inventory error rate
growth in terms of its causes and to determine the significant
variables and their relationship to the error rate. This should
be done at least by AMA and in some cases by FSG or even FSC.
Goals could then be established by the Significant Variable
Method on a more equitable basis than current methods provide.
Later, after this has been done, this information on error growth
can be combined with cost impact data and mission essentiality

data to establish goals and management policies by the Minimum
Cost Methods.

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