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SYSTEM TROUBLE-SHOOTING

As we all know, the concept of trouble-shooting has generally been used to summarize the process of isolating malfunctions in electronic equipment. I should like to explore its application to the diagnosis of performance of large operational systems, or the prototypes of such systems, and their parts. In this context, as with electronic equipment, the process is one of locating components whose malperformance is preventing the desired system output. The purpose is to determine remedial action. The method is to make measurements at various locations.

However, system trouble-shooting is also obviously different. It occurs on a grander scale. The system components may be subsystems; in command/control or information systems these may be the sensors, the data processing and utilization portions, or the effector parts of the system. Or one may trouble-shoot such systems to locate faults as resident in the hardware, in the computer programs, or in the human elements. The remedial action does not consist of replacing and repairing; within the human factors area it may take the form of training, of selection or manning, of procedural or organizational changes, or of equipment or computer program redesign. The methods are more complex than applying voltmeters to test points. Complex system and subsystem tests are necessary; determinations must be made about the selection of measures and the criteria against which to match them; and techniques must be developed and used for relating these measures to each other.

The measurement considerations in system trouble-shooting appear to have received relatively little investigation, and this is one reason why I have selected this as a topic. I shall discuss briefly a number of possible guidelines and draw on pertinent work which the System Development Corporation and other agencies have undertaken in connection with SAGE and other systems.

1. Measures used for diagnosis may differ from those appropriate for obtaining evaluations of system capability.

    Evaluation and diagnosis as differing goals in field testing have been examined by Meister[9] and Searle[15], and the latter has explored the difference with respect to the selection of performance measures. The engineer primarily concerned with improving a system, Searle says, "wants a system performance measure which can be used to determine the areas in which improvement should yield the highest payoff, and to demonstrate whether changes are effective," rather than some magnitude measure with extremely high validity. As an example, he takes measures of CEP for a bombing aircraft system based on distributions of error obtained through practice "bombing" of domestic targets. Such measures lack sufficient

validity for evaluation of system capability, since many relevant factors
were not present in their derivation, but they can be used for diagnosis
of relative contributions of various subsystems to the total system error.
Certain assumptions must be made about the general nature of the missing
factors, the direction of their influence, and the representativeness of
the factors which are present in the practice "bombing." Searle states:
"Hence, let us cease worrying for the moment whether the obtained CEP of
1000 yards, say, is 50 or even 2000 yards less than the real one. We
shall use the obtained CEP to study which system subfunctions and/or
components are most important, and then see whether this information is
helpful in identifying the directions and nature of most needed further
developmental work."

2. Component and subsystem measures become essential and must be related to
    end measures.

Wolin[17] has discussed some of the relationships between subsystem measures
and end-performance measures. He makes the point that Step II in a system
may operate with 100 per cent efficiency "in the sense that, for every
successful processing performed in Step I, Step II operates perfectly."
However, it is obvious that if Step I operates with only 50 per cent
efficiency, the system will operate at the same unsatisfactory level.
Now, as Wolin points out, making Step I 100 per cent efficient may by no
means bring the system to 100 per cent efficiency, because "the chances
are very great that compatibility between Steps I and II has been lost."
In such a case, Step II must be redesigned with Step I in mind.

Another problem in relating subsystem measures to each other is the
selection of a common denominator. Use of the same kind of criterion
measure facilitates determining such relationships. For example, as we
all know, cost figures are often used by operations analysts for this
purpose. Probability estimates constitute another common denominator
as illustrated in a description by Jones[6] of a model of effectiveness of
an Aircraft Carrier Attack Force in terms of the expected number of tar-
gets destroyed in a given period of time. Of course, various kinds of
measures are assembled to generate the probability figures in the model
and submodels, as is also the case with a cost criterion, and the problems
of manipulating these are not always easily resolved.

Perhaps the most frequently used diagnostic procedure for system trouble-
shooting is the non-quantitative one of trying to trace back from result
to origin analytically. For example, in an air defense exercise one
might discover that several "targets" never were intercepted in Sector
A and that their tracks were never cross-told from Sector B. It may be
a reasonable deduction that proper cross-telling would have resulted in
their interception. However, such analyses do not provide information

as to the relative contribution of cross-telling, in comparison with other system functions, to the total system malperformance. It is rather rare that more quantitative, generalized relationships are ascertained in complex systems, as, for example, kill probability as a function of tracking "goodness" in SAGE. A study of SAGE end-measures, subsystem measures and their inter-relationships has recently been undertaken at SDC by J. T. Rowell, using data from training and tactical evaluation missions. In addition, an experimental study is being conducted to assess the effects of degradation in the surveillance subsystem on the actions of the weapons team, where system measures and subsystem measures are the same (e.g., "kills"). Weapons teams alternately receive inputs actually processed by the surveillance subsystem operators in one session and processed by pre-programmed "correct" surveillance actions (i.e., untouched by human surveillance hands) in another session.

An even more difficult problem is to distinguish between the error contributions from hardware, from computer programs and from personnel. Here one must obtain performance data emanating exclusively from one or two of these classes of potential sources. Shapero and Erickson[16] have the following to say in regard to isolating human-initiated malfunctions in weapons systems:

"The primary inadequacy of the data as presently collected in regard to human-initiated malfunctions is that it is difficult, if not impossible, to refer the failure event to any model that describes the dynamic interactions of the failed item with the human components of the system. It is, consequently, difficult to identify those human components or characteristics of the system that might be modified in order to prevent recurrence of the failure. It is proposed here that this inadequacy can be overcome by modifying present failure reporting forms and procedures to require an explicit identification of the specific operation during which a failure is recognized as such."

3. End measures may be of limited value in assessing the performance of subsystems or elements functioning earlier in the data flow.

This is the case where one is testing an operational or prototype system and cannot manipulate subsystem features experimentally. It should be apparent that without such variation in independent variables, the end measure will not point to the source of variance among the subsystems, or among the hardware, program and human components. Even in experimental situations it may be preferable to seek interim rather than end measures.

For example, in testing a ground-based computing and tracking system for
control of interceptor aircraft, one may prefer to obtain measures of
interceptor position at the point of presumed handover to the aircraft's
fire control system, as Parsons[12], [13] did in field testing and laboratory
testing of the AN/GPA-23. This procedure enables one to hold constant any
effects on total system performance coming from the last subsystem (when
total system is defined as including the autonomous functioning of the
interceptor).

On the other hand, a case for using end measures is made by Hitt and Ray[5]
in their report on the Battelle Memorial Institute laboratory studies of
effectiveness of electronic countermeasures. Although they manipulated
ECM parameters whose immediate impacts occur among surveillance operators,
their dependent variable was kill probability. They state:

"One of the most important conclusions to be derived from the present re-
search program is that it seems imperative that the evaluation of ECM
effectiveness be done within a systems framework. If this research pro-
gram had been designed to ascertain the effects of ECM on radar-operator
performance, several measures of operator performance would have been
available. In turn, the selected ECM displays could have been rank
ordered on a degree-of-effectiveness continuum, according to the mean
operator performance scores achieved under the various displays. Based
upon previous work at Battelle, it is certain that the results obtained
from such an approach would have been misleading. (Mean range errors
and mean azimuth errors made by the operator, for example, appear to be
unrelated to P_k.)"

In another report by Gordon, Hitt, Ray and Wetherbee[4], the Battelle in-
vestigators found that surveillance-type criteria of ECM effectiveness
such as probability of establishing a track and blip/scan ratio were
highly related to kill probability (P_k). They conclude:

"Although definite correlations have been noted among the various criteria
which might be used to assess ECM effectiveness, it is apparent that they
are not equally good measures. Only a true systems measure such as
probability of kill can provide a meaningful measure of ECM effectiveness
against the defensive system it is intended to combat. The other measures
discussed can be used to obtain a comparison between two types of counter-
measures used against a given system, but they cannot be used to make com-
parisons between systems. An absolute measure of effectiveness, such as
P_k, can be obtained from the other criteria only if the relationship
between the criteria is known for the particular system under study. In
the final analysis only a true system measure can establish an absolute,
meaningful, and generally applicable measure of ECM effectiveness."

4. It can be difficult to obtain useful measures of data utilization or effector performance in information systems if the inputs from the sensors or data processing portions are uncontrolled or have been degraded.

   The purpose of this guideline for system trouble-shooting is to indicate the value of trying to control, during a test exercise, the inputs into the subsystem being tested and measured from another subsystem located earlier in the data flow. For example, in SAGE the inputs into the weapons subsystem will vary according to the processing by the surveillance subsystem, and naturally the outputs of the weapons subsystem will then also vary. In developing a weapons subsystem testing and training program for Air Defense Command, described by Cockrell and Murphy[3], we at SDC wanted to standardize the simulation inputs. The solution was to pre-program the switch actions which the surveillance operators should have taken and leave these operators entirely out of the exercise. Although this technique was evolved for proficiency testing and training purposes, it is applicable to system and subsystem diagnosis, as we have already noted in the case of Rowell's surveillance degradation study.

   There is another problem occasioned by "serial contamination." It is possible that if certain types of inputs are introduced into the surveillance portion of an information system in sufficient quantity, this subsystem may not process enough data to provide useful inputs to the subsequent parts of the system for either training or testing. The performance measures for these other subsystems would be meaningless for trouble-shooting within them.

5. Some measures have to be focussed explicitly on the interfaces between subsystems.

   The difficulty in attempting to derive system performance data by combining subsystem data has been alluded to by Christensen[2], who commented that "systems investigators experience understandable anguish when they attempt to define those segments of the system that can be extracted and abstracted for consideration without vitiation of over-all results upon reassembling the entire system (the 'partitioning' problem)."

   I suspect that behind this problem sometimes lies a neglect to obtain interface measures. Such measures include those of communication between subsystems, a class of measures emphasized by Kidd[7]. These measures help determine the fidelity with which the output from one subsystem was actually input into the other subsystem(s). Without fidelity, assumptions of equivalence between outputs from one and inputs into another may be made improperly and may be responsible for the reassembly problem. More than inter-person communications can be involved. In computer-based systems, the process of digitizing data for transmission from a sensor into a computer may bring about inequivalence (see Parsons[14]).

6. Inputs can profitably include "stressor" events, and in military systems
    consideration should be given to introducing the effects of hostile
    action.

    How does one obtain measures of how a system or its subsystems react to
    rare events? One technique is to force the event and increase its
    frequency. This has been done for SAGE surveillance training, as des-
    cribed by Okanes[11] and Arnold[1], by introducing simulated inputs which
    make the computer "track off" and consequently require manual interven-
    tion. To design such inputs, one must test the automatic tracking
    system to find out the circumstances under which the hardware and the
    computer program cannot maintain the track. It should be noted that
    this is also a technique for trouble-shooting the system to determine
    to which kinds of components (hardware, program or human) malfunctions
    should be attributed. Naturally, one must be certain that the measure-
    ment data obtained with this forcing technique are produced by identi-
    fiable stressors. Special programs linking inputs, data reduction and
    evaluation have been developed for this prupose (see Newlands, Ribler,
    Hanson, Irons, Katter and Levine[10]).

    As a final proposed guideline, let me add a favorite point of emphasis.
    It is sometimes preferred to measure system and subsystem performance at
    first under unrealistically simple conditions. In modern military systems
    this may mean omission of nuclear effects and electronic countermeasures.
    Not only can this approach lead to delusions of system grandeur and a
    protracted avoidance of realistic evaluation, but it may forestall just
    the kind of system trouble-shooting which is needed the most (and there-
    fore the soonest). Linville[8] has stressed that evaluation "would
    certainly have to involve....a range of enemy attack tactics and counter-
    measures as well as a range of defense weapons." In military systems,
    measurement of system performance must be based on the effects of what
    J. Mencher has called the "anti-system." One might suggest that the
    system and its anti-system constitute the total system to which measure-
    ment for trouble-shooting purposes should be applied.

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