THE CHALLENGES
OF
LOW-COST, AUTOMATED SATELLITE OPERATIONS

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ABSTRACT
Satellite operations have been inherently manpower intensive since they began over thirty years ago. Since manpower intensive equates to costs, this mode of operations cannot survive in light of government budget cuts and commercial profitability. Two factors are now key for both government and commercial satellite control centers: 1) systems must be highly automated to minimize the operations staff, and 2) these automated systems must be deployed and enhanced at a low cost. This paper describes the three principle challenges which arise in migrating from high-cost, manpower intensive satellite operations to low-cost, automated satellite operations and makes recommendations for solving them.

KEY WORDS
Satellite Operations, Automated Operations, Low-Cost, Telemetry Processing

INTRODUCTION
Military satellites have grown increasingly complex as the defense department has sought to take advantage of new technologies which could be deployed and used in space. The ground systems which have evolved to support them have grown more complex as well. The sophistication and high cost of most military satellites have caused the ground systems that support them to be staffed by highly-skilled personnel with specialized training who closely monitor all contacts on a contact by
contact basis. Military satellite control centers are now being driven to reduce both the number and skill levels of their satellite operations staff to meet the reduced funding requirements in coming fiscal years.

Commercial satellites have steadily increased in number and have entered into a period of rapid growth as the race to provide low-cost global telecommunications and positioning services intensifies. Several commercial ventures are planning to launch large constellations (e.g., Teledesic may have as many as 840 vehicles in orbit), and the Satellite Operation Centers to support these large constellations will have to make thousands of contacts with their spacecraft each day. Many control centers will likely support multiple constellations as well. In spite of this complexity, profitability considerations will mandate low cost systems which require a minimal support staff.

When combined, these four factors (reduced staffing, reduced skills, increased vehicles, increased number of constellations) would cause a compound growth in cost if traditional ground operations and traditional system development approaches are used. For the military to continue to support complex, costly vehicles and for commercial entities to profitably conduct thousands of daily contacts, satellite operations must be low-cost and highly automated.

The goal of low-cost, highly automated satellite operations presents three fundamental challenges:

- A single operator must be able to support multiple concurrent contacts.
- Anomalous conditions must be handled by automating system responses.
- The system itself must be implemented at a low cost and easily support enhancements.

MULTIPLE CONCURRENT CONTACTS

A highly automated satellite ground system should allow a single operator to conduct multiple contacts simultaneously. Doing so requires a fundamental shift in thinking about the level and type of data presented to the operator.
For a single user to support multiple, simultaneous contacts, the operator must be presented system level concepts, not vehicle specific details. The system performs the routine (and tedious) monitoring role and essentially focuses the operator’s attention to items requiring action. In many cases, a satellite contact should be initiated, performed, and closed-out with no active operator participation.

A display concept which supports this level of automation divides the screen into three areas or zones. System level status is displayed in the upper left area. This area provides the user with a synopsis of current contacts in process and some visibility into upcoming contacts. The upper right area is used to notify the operator of key events, and most importantly, directly prompts the operator for action. If all is benign, only these two screen areas are active.

The remaining real estate of the screen is used when the user is involved in carrying out a specific action. When the system is supporting an action that requires more operator involvement, the user interface must focus the operator’s attention on that one activity. The operator should not be required to “pick out” the important information among detailed data on the monitor.

For example, when the user selects and resolves an alert, the necessary windows are automatically displayed on the screen. Contact-specific information (such as detailed vehicle status) should be displayed only while the user is performing a specific action which requires the operator to have that particular data available to support making the decision(s) necessary to accomplish the action.

TELEMETRY MONITORING AND DISPLAY

Many of the systems in operation today present detailed, vehicle specific data to the user. These data intensive displays resemble what one might expect to find at the satellite manufacturer during vehicle testing: raw text telemetry, measurands plots, vehicle schematics. This is not surprising given that many of the commercial products used in today’s ground systems were originally designed for test activities. In many cases, the system used for vehicle testing and checkout at the factory migrates virtually unchanged to the operation center.
Certainly detailed vehicle status via its downlinked telemetry is essential to successful on-orbit operations, but systems that focus the operator’s attention on this data are inappropriate to automated contacts. To support normal operations of several contacts, telemetry monitoring must be carried out essentially without operator interaction. The system must perform the tedious task of meticulously monitoring vehicle measurands and assessing the state of the satellite and its subsystems.

Typically the satellite’s health, as reported by its telemetry, is displayed to the operator in the form of color-coded tiered-up view of the vehicle and its major subsystems based on out of limit conditions. Since several measurands are likely out of limits simply due to the vehicle’s state (e.g. Side A is inactive, while Side B is active or the vehicle is in eclipse), one common result of is that a significant number of the subsystems show as yellow or red, and thus, the satellite itself is nearly always showing as degraded to the operator. Unfortunately, operators work around this condition by ignoring the summary data being presented to them and viewing the detailed telemetry.

To minimize operator involvement, the system must process the telemetry and report the vehicles condition using state-based limit checking. Much the way an expert operator does, the telemetry processing system must determine the state of the vehicle and make appropriate changes to the values it is using for measurand limit checking. This adaptive approach to telemetry processing can help alleviate the “somethings always red” phenomenon and provide the operator with valid high level vehicle status.

**ANOMALOUS CONDITIONS**

For highly automated operations, the system must prompt the user only when the system itself cannot carry out the required action or when operator confirmation is deemed necessary.

A recent study examined the potential application of decision support technology on anomaly resolution. This study examined satellite contacts conducted by one satellite control network between 1991 and 1994. This four year period included over 30,000 satellite vehicle contacts per year. Anomalies associated with both the ground system
and satellite vehicles were categorized in terms of how they should be handled by
decision support tool:

- A problem was classified as a candidate for automated operations decision
  support if a well-defined response could be determined and enacted with little or
  no operator intervention.
- A problem was classified as a candidate for semi-automated operations decision
  support if one of several pre-defined responses needed to be chosen, or if
  experienced personnel were needed in the decision making process.
- A problem was not considered to be a good candidate for decision support if no
  response to the problem was known or its resolution required detailed vehicle
  expertise.

The problems where further classified as to the affect on completing the satellite
support. Classifications used were:

- Supports were considered marginal if the operator was required to take an
  unplanned action to resolve a ground system problem.
- Supports were considered failed or lost if a ground system problem prevented
  completion of the support objectives.
- Supports where classified as having a satellite vehicle problem if an unplanned
  action was required due to a satellite vehicle problem.

The first key piece of information from the study is that over ninety percent of all
satellite contacts have no anomalies, and therefore, are efficiently and easily handled
by automated processing. When looking at the remaining ten percent, one somewhat
surprising fact is that a majority of the problems which lead to marginal or failed
contacts were problems with the ground system and not the result of vehicle
anomalies.

The study concluded that 90% of the Ground System Problems and 41% of the
Satellite Vehicle Anomalies are candidates for automated operations decision
support. These problems and anomalies were further analyzed as to the frequency of
occurrence. It is not cost effective to develop rules for problems or anomalies which
occur rarely.
The results of this analysis showed that 54% of the Ground System Problems occurred at least twice per year, while only 10% of the Satellite Vehicle Anomalies occurred twice per year. When combined, these two pieces of data indicate that while 49% - 63% of Ground System Anomalies are good candidates for decision support, only 4% - 8% of Satellite Vehicle Anomalies are good candidates for decision support.

Given that the majority of marginal or failed supports can be linked back to ground system problems, traditional use of expert systems in satellite ground systems may provide minimal benefit. Most applications of decision support technology have focused on anomaly prediction and resolution for the satellite. This application requires a high-performance inference engine and the tedious development of sophisticated rules. For resolution of ground system problems, the best candidate decision support systems are those that have a strong process control flavor since most ground activities relate to configuring equipment and establishing communications links.

Commercially available decision support products were also categorized in terms of their ability to support automated and semi-automated operations. This study found that appropriate decision support tools for either application are readily available. A hypothetical decision support tool was applied to the anomalies which were deemed good candidates for automated operations to determine the impact on the contact success rate and operator workload. Results indicated that the application of decision support technology would decrease the number of contacts with unplanned actions by over 36%. (See Figure 1).

One factor which limits the ability of an operator to run simultaneous contacts is the need for the operator to respond to unplanned events. The application of a process control decision support system assists in allowing a single operator to run multiple simultaneous contacts. For an operator running five simultaneous contacts, the application of decision support will reduce the probability that the operator will have to respond to an unplanned event from 23% to 16%.
Figure 1, Affect of DSS on Supports with Unplanned Events

Even with the use of decision support systems, the operators will need to respond to anomalous conditions. In a system where operators are running multiple simultaneous supports this raises the question of how an operator deals with a condition which requires his full attention. Three different concepts for handling this situation are:

- The operator hands-off the supports that are not affected by the anomaly. This is similar to the way air traffic controllers handle problems. This concept requires enough operators to ensure one is available to receive the hand-off.
- The operator keeps all supports and assumes that the system will successfully complete the remaining supports without requiring his attention.
- The operator hands-off the problem support. This requires enough operators to ensure one is available to receive the hand-off.

SYSTEM IMPLEMENTATION

Not only must future systems support multiple concurrent contacts and provide decision support, they must also be implemented in a manner that preserves profit and survives military budget cuts. This cannot be achieved using traditional systems development. The new system must integrate modern commercial products using open system standards. The design approach must make use of modern design
technology including: client/server distributed processing, object-oriented methodologies, and message passing (see Figure 2).

Figure 2, System Implementation

Client/Server Architecture: The system should be based on a client/server architecture to allow the effective distribution of processes across the system. The flexibility of this architecture allows the system to dynamically allocate processes across the system to meet variable processing requirements.

Taking traditional client/server one step further by using the object-oriented principle of inheritance can dramatically reduce system complexity. All of the servers can be derived from a common base class to allow the inheritance of a common interface. This common interface means that the client application is effectively isolated from the specifics of the individual servers and can use common methods to access all servers. This also allows the creation of new servers to meet future needs without affecting existing client applications.
Object-Oriented Methodologies:  Object-oriented methodologies can also be used in the design and development to maximize the reuse of common behavior and encapsulate applications to increase system modularity. Throughout the system a set of generic base capabilities can be defined and specializations derived to meet particular needs of the customer. This capability will allow the addition of similar processes with minimal code development.

Another technique is the encapsulation of applications, including Commercial Off The Self products and their data, within system objects. This encapsulation will provide a consistent external view of the object regardless of the specific implementation of the application. This capability greatly enhances the integration of new applications. A second benefit is to allow applications to change, in response to future needs, without disrupting the entire system. The alternative is to develop unique “bridges” or “glue-code” between each application. The major drawback of this approach is each application has many unique interfaces, each one affecting another application; a change to an application is rippled through each interface to the adjoining applications.

Message Passing: Use of a messaging system that provides a communication service to deliver messages created by one application to others provides another layer of isolation between applications. It enables independent applications to communicate without explicit knowledge of each other. The use of messaging allows the allocation of applications independently of each other. This independence not only allows the applications to be allocated across various workstations, but when coupled with modern network technology allows functions to be transparently allocated across nodes. This not only provides flexibility in allocation, but also allows functions which are currently assigned to a given node to be accomplished at any node.

CONCLUSION

Low-cost systems which support highly automated satellite contacts are key to solving the challenges facing satellite control centers. Whether military or commercial, the systems within successful control centers must allow a single operator to simultaneously support multiple contacts, utilize decision support systems appropriately, and be easily established and enhanced.
Only through automation can an operation that has traditionally been very manpower intensive for a few contacts be scaled down in staffing requirements and up in contacts/day. And only through modern design approaches and incorporation of computer/networking technologies can these highly-automated systems be implemented, operated, enhanced, and maintained at low cost.