E-Scheduling the Deep Space Network[1]

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Abstract— Anticipated growth in demand for NASA's Deep Space Network (DSN) and its services has created a need to streamline the delivery of telecommunications services. The process for scheduling services is a key component of the interface between mission customers requesting telecommunication support for their spacecraft and DSN providers managing the ground system (antennas). The scheduling process can be viewed as a reservation system for reserving tracking time (known as "tracks") for space missions.

The current scheduling process has evolved into a complex, assembly line operation in which different paper-based, file based, and manual systems are used to pass the schedule between different organizations. A variety of different and often arcane formats of the schedule are maintained in accordance with each organization's needs. As a result, mission customers are confronted with a complicated process requiring high levels of direct communication (phone, facsimile, email) and extensive conflict resolution meetings. As tracking reservations approach real-time operation, it is common for last minute schedule changes to require significant rework and new data support products while remote DSN Complexes must adapt to the changes.

This paper describes an operations concept for electronic scheduling and software interface for organizations to extract required views of the schedule. Advantages include widespread accessibility to a common schedule document, virtually instantaneous distribution of new schedule releases, and the ability of missions to perform conflict resolution off-line without time-consuming meetings.

The operations concept and e-scheduling tool are under development and testing for three scheduling organizations within the Telecommunications and Mission Operations Directorate at JPL. Observations relevant to the deployment of an e-scheduling operations concept are described.

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1. INTRODUCTION

A steady increase in the number of planetary missions over the next decade has created increased demand for the Deep Space Network (DSN) telecommunication system. One byproduct of this demand is an increasing number of schedule conflicts for DSN tracking time. Each mission reserves periods of time in the future to communicate with their spacecraft—these reservations are called "tracks." As the number of missions grows, competition for the same or overlapping track reservations creates conflicts that must be negotiated, mediated, and ultimately resolved. The process for scheduling DSN resources for each track was developed for much lower mission set numbers than those anticipated during the next 10 years. As a result, processes for scheduling and conflict resolution required modernization to address the additional demand in an efficient and effective manner.

In general, the current scheduling process spans 3 different organizations over three time phases [1]. Figure 1 highlights these elements which involve different teams, different data support products, different schedules, different authorizations, and different responsibilities at each phase. Within each phase, data support products required to execute a track are prepared based on the status of mission inputs. As the schedule progresses over time, changes are made based on conflict negotiations with other projects, changes initiated by the mission, and changes stemming from the ground system (e.g., failures or maintenance of planned equipment configurations). When these changes occur, regeneration of related data support items must be performed to maintain the latest versions.

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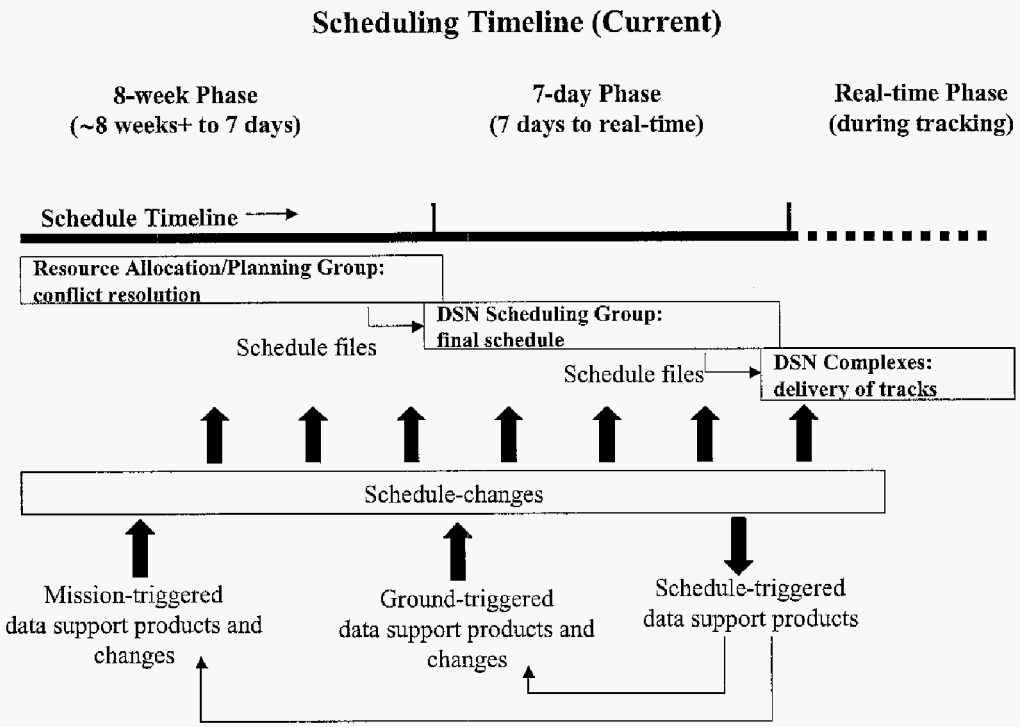

Figure 1. Current Schedule Timeline Showing Organizations and Schedule-Change Interfaces

The first phase is called the planning phase where missions submit general track reservations to a Resource Allocation and Planning Group from about 8 weeks to years from the time actually needed. Such reservations are often estimates and placeholders for more specific requests determined as the mission evolves. Missions refine these requests into track reservations for operations. Conflicts are resolved manually as the schedule approaches 8-weeks to ensure that the schedule is conflict-free (to the extent possible). As the schedule progresses from 8 weeks to 7-days, changes are allowed which require weekly conflict-resolution meetings to maintain conflict-free status. Again, if tracks are moved around or equipment configurations are changed, large numbers of data support products must be regenerated and rechecked.

In the second phase, a conflict-free 8-week schedule is transmitted to a different organization called DSN Scheduling. During this phase, different versions of the schedule are prepared while integrating a separate scheduling process for near-Earth orbiter tracks using 26-meter antennas. Separate conflict checking and conflict-resolution processes are maintained for these changes to produce a 7-days schedule prior to tracking. Again, if changes are made to the 7-day schedule affecting data support products, the affected products and their dependencies must be regenerated. If conflicts cannot be resolved, the changes are referred to the manual conflict resolution process for the 8-week schedule (first phase).

During the third phase, DSN operators use the schedule to plan each 8-hour shift and monitor activity during the shift. If changes are required due to flight project requests, emergencies or random ground equipment failures, telephone communications are used between the mission, operator, scheduler, and the central operations chief to resolve the problem. Due to time urgency, documentation of changes is generally performed after the track.

Many of these processes involve manual elements requiring significant rework as changes are made. Overlaps between different organizations requiring multiple file transfers of data products between responsible functions creates configuration control problems and hampers response time. These problems compound as the schedule approaches real-time operations and the impacts of last-minute changes create problems for other missions because their ability to update the large quantity of data support products is limited.

2. E-SCHEDULING OPERATIONS CONCEPT

A key objective to enable more efficient and effective scheduling operations was consolidation of redundant functionality and reduction of manual data file handling [2]. The transfer of information between different schedule users necessitated numerous formats based on the same fundamental information. The proliferation of this wide variety of formats propagates into associated problems of versioning and connectivity for related data support products. As a result, if highly dependent input quantities changed, not only did a series of files need to be regenerated, but measures (usually manual) had to be taken to assure that proper versions of each file in the chain of data support products was correct. The Operations Concept (Figure 2) for electronic scheduling seeks to provide accessible and timely information about a variety of schedule products to its users via an end-to-end schedule database.

The aim of the operations concept was to maintain all schedule information in a version-controlled schedule database. Since different user organizations require different views of the same basic data for different phases of the schedule, access to the phase of interest would be controlled through selections in the user interface. Keeping the master schedule in a database provides improved response to changes, wider access, improved versioning, and the ability to publish updates quickly. An additional benefit is the removal of overlaps between organizations that created artificial "drop points" for the handoff of schedule products. Under the new operations concept, all three organizations place and remove data to and from the database reducing the need to wait for file transmissions and approvals that can be prompted by automatically generated electronic messages. When new versions of their respective products (8-week or 7-day schedule) are published. Notification to all interest parties is triggered automatically.

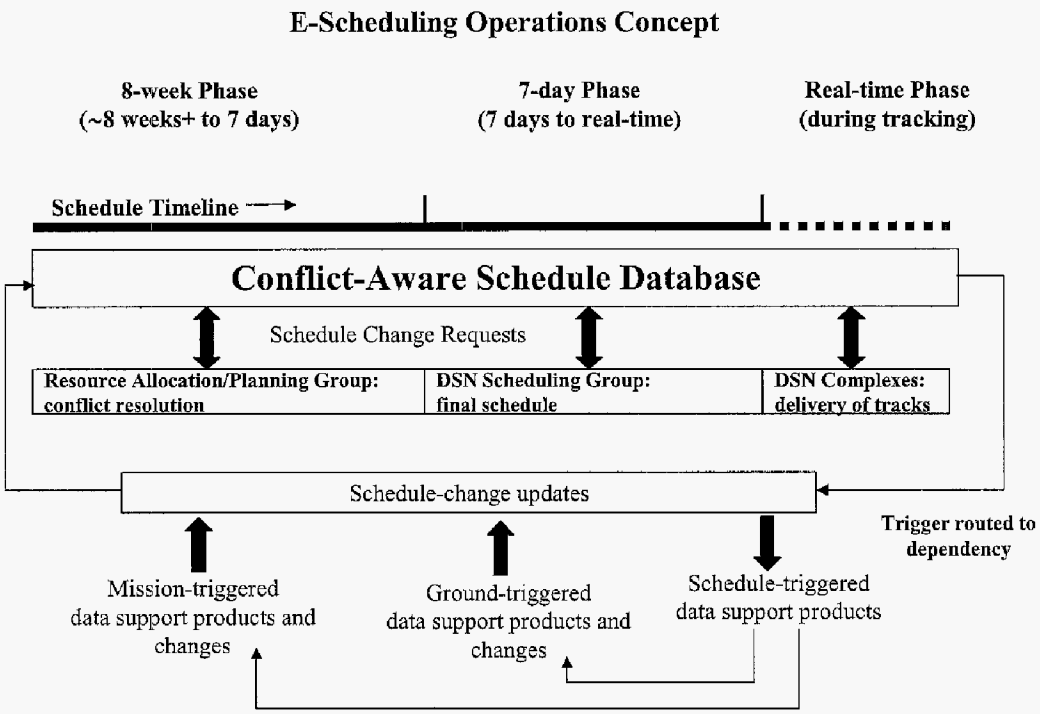

Figure 2. Electronic Scheduling Operations Concept Showing Streamlined Interfaces

3. E–SCHEDULING ARCHITECTURE

Implementing the E-Scheduling Operations Concept requires infrastructure modifications to provide the required capacity and security of data coupled with controlled levels of user access to appropriate phases of the schedule. Client-server architecture was used with an internal server to protect master schedule data and provide copies of required information to an external web server (Figure 3). The planning data at the 8-week point is published to the master database for use in operations. The component files (8-week, 7-day, and other schedule types are then published to an external web server for use by the client user interface. Changes are made via the client to files on the web server, which update the master database. This architecture insulates and protects the master database from direct access by users.

Additionally, centralization of schedules enables significant improvement to the speed of schedule changes at a number of levels. Because all users can view the current schedule release, in many cases it is not necessary to wait for weekly conflict resolution meetings since the scheduling interface identifies the conflicts among missions both graphically and through automatic notification to the conflicting mission representatives. Thus, each mission can view and identify competing missions for the tracks in conflict. With this information, missions can contact and negotiate with each other to remove the conflict, trade, negotiate other tracks, or choose to modify both tracks if minor overlaps can be eliminated.

When agreement is reached one or more parties submit an electronic schedule change request to remove the conflict. Similarly, if a mission observes a schedule opening, they can submit a schedule change request electronically to the schedule rather than to the manual process. If the change resolves the conflict, the responsible scheduling organization concurs electronically and the new schedule is published.

If the conflict is not resolved, the alternative manual process with its costly, time-consuming, labor-intensive meetings provides ample incentive for off-line cooperative bargaining using the electronic schedule. However, if the missions cannot settle the conflict using the e-schedule in a satisfactory manner to all party's, the manual process of mission prioritization and tradeoff analysis is then followed. In the future, support tools such as schedule-gap finders and prioritization schemes will be implemented to facilitate the negotiation process.

Because the old architecture involved multiple schedule files, significant overhead was incurred managing the items rather than their content. With the new architecture, schedule change approvals and adjustments replace the time spent managing and reviewing schedule formats and files under the old system. The e-scheduling architecture frees schedulers' to focus attention on scheduling activities rather than data management activities.

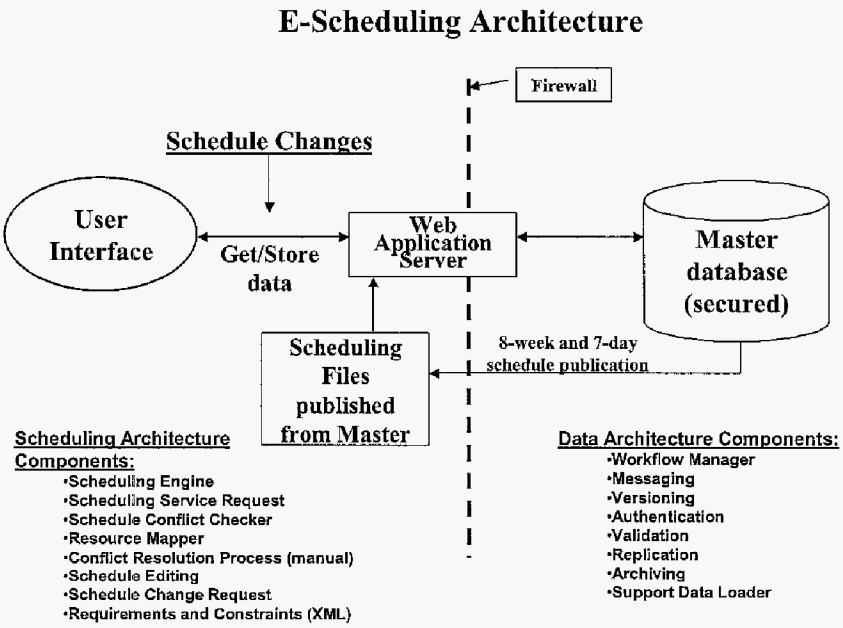

Figure 3. E-Scheduling Architecture for Schedule Changes and Publishing

Because many of the existing schedule products are used by legacy applications dependent on those products, the decision was made to continue providing these data in legacy form. As a result, legacy data products are passed through the system in the same formats. The approach for providing electronic viewing of schedules and the variety of formats was to use a user interface to display data from the master schedule via files published to a web server. The user interface provides schedule viewing for new and legacy formats during transition to the new operations concept.

4. E–SCHEDULING CLIENT APPLICATION

An electronic scheduling tool was developed to provide an interface between the various users and the schedule database [3]. The TIGRAS (Telecommunications and Operations Directorate Integrated Ground Resource Allocation System) user interface provides multiple views of the schedule in graphical and tabular form (Figure 4).

When the tool is started, schedule-related files are downloaded from the web-server and each track is displayed on a graphical timeline. The user can drag-and-drop selected tracks to make changes or conduct what-if analyses. The view periods (solid bars on each axis) show the feasible views of each spacecraft-ground antenna combination to guide the user in moving tracks. The lower portion of the display contains a scrolling list of tracks users can select to highlight missions in the graphic display. The left-hand side of the screen contains an assortment of options for the display. The user can sort by missions or antenna, specific dates of interest, or other criteria while computing statistics for utilization and support.

While a detailed description of the user interface is beyond the scope of this paper, this tool represents an advance in the capability to view e-schedules and the ability to provide legacy data items in a variety of formats via an exporting function [4].

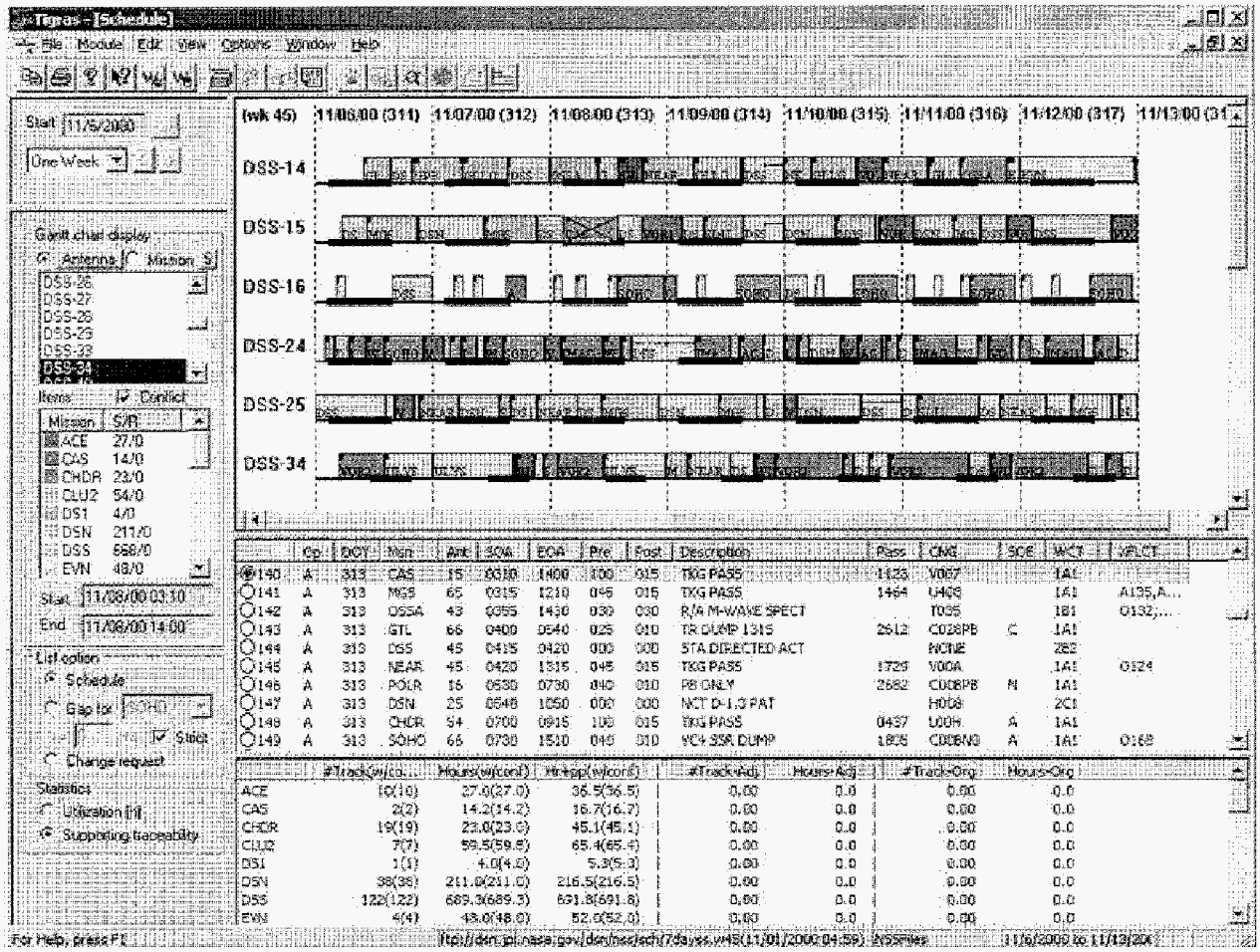

Figure 4. TIGRAS Client Application Showing Graphic Display (Upper Right), List View Table (Lower Right), and Options (Left Side)

5. DISCUSSION AND CONCLUSIONS

The development of an e-scheduling paradigm for DSN Operations faces a number of limitations and challenges. While the near-term system is capable of displaying schedules and handling changes, the long-term goal of an integrated system where the conflict checking process includes real-time status of DSN equipment has not been achieved. An integrated system should identify equipment unavailable due to maintenance or failures and prevent the scheduling of that equipment. However, in order to establish the critical link between the scheduling system and equipment status, an on-line capability for all schedulable equipment inventory is required. Such an effort would involve moving the information currently maintained manually at each complex to electronic form via an entry at the operator's console.

An additional challenge involves the transition between the three overlapping organizations operating on the schedule. While the number of data products to be mailed or transmitted among the organizations is to be simplified, the coordination and timing of actions by each organization must be well specified so the schedule moves smoothly through the system. This process is being defined between each of the three organizations.

During the course of developing the operations concept and implementation architecture for e-scheduling of DSN resources, a number of conclusions were drawn.

The first conclusion was that e-scheduling provides a more efficient process than the previous manual file-based system through:

- Faster turnaround of schedule changes through web-based publication of updated schedules
- Fewer weekly meetings of conflict resolution personnel to resolve minor conflicts better left between missions to solve off-line.
- Conflict resolution activities shifted from central meetings to missions in conflict. If missions can't resolve conflicts electronically, resolution is elevated to the established manual conflict resolution process.
- Common schedule data with custom interfaces and export formats for different users reduce duplication, reformatting, and management of redundant data product files.

The second conclusion was that e-scheduling would be more effective through:

- Shared knowledge of schedule information through open publication of schedules on the network.
- Focusing personnel on scheduling and conflict resolution activities rather than data/file management.
- Automation of accountability for schedule changes through versioning of the schedule database.
- Expanded capabilities and tool developments via common application programming interfaces to schedule data
- Reduced cost for scheduling activities by automating large components of the scheduling process, shifting conflict resolution to mission users, and reduction of manual and paper-based processes.

In addition, the e-scheduling operations concept sustains legacy requirements by maintaining legacy formats for users until they transition to the new system.

ACKNOWLEDGEMENTS

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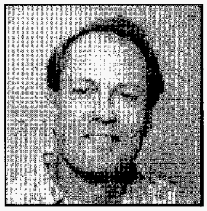

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