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Low-Earth-Orbiter Resource Allocation and Capacity Planning for the DSN Using LEO4CAST

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The Deep Space Network provides tracking and communication services for a number of U.S. and international low-Earth-orbiting (LEO) and near-Earth missions. This service is supplied by the 26-m subnet (located at each of the DSN complexes), the 9-m and the 34-m Antenna Research System antennas at Goldstone, and the 11-m antennas (following the orbital VLBI mission). An increasing number of LEO missions are planned for DSN support, which will result in increasingly complex ground resource allocation and mission support trades. To support TDA decision making on mission support and cost-effective ground system evolution for this 26-m subnet, LEO4CAST has been developed. LEO4CAST is a tool that uses statistical approaches to provide useful information for long-term ground system capacity planning and near-term resource allocation (prior to detailed time-of-day scheduling). LEO4CAST is currently beta-test software and is being exercised by both the Office of Telecommunications and Data Acquisition (TDA) and the JPL Systems Division.

I. Introduction

The DSN is responsible for planning, allocating, and operating the set of ground antennas that supports low-Earth-orbiting (LEO) and other near-Earth missions. Typically, the DSN accommodates user requirements through a combination of explicit resource allocation and negotiation of user requests. With the impending increase in mission requests for coverage on the near-Earth antenna set, negotiations become significantly more complex and costly.

Figure 1 provides an overall view of the LEO subnet capacity-planning and mission-support analysis process. LEO4CAST, a low-Earth-orbiter load-forecasting, resource-allocation, and capacity-planning simulation, is designed to support that analysis process. It is built on analysis capabilities already operational for the 34- and 70-m subnets, PC4CAST [1], which is used by TDA and the Multimission Operations Systems Office (MOSO) for resource allocation and capacity planning. Direct application of this tool, however, is inappropriate due to several complicating factors unique to low-Earth-orbiter missions and ground systems. Of primary importance is the uncertainty in low-Earth-orbiter mission trajectories (primarily due to atmospheric drag), which impacts mission view periods beyond several weeks. The new LEO4CAST software tool provides the capability to statistically determine antenna loading by missions with uncertain view periods. It uses the PC4CAST methodology to calculate deterministic mission loads, and when combined with the probabilistic mission loads, it generates mission accommodation, inter-mission conflict, and ground system loading statistics.

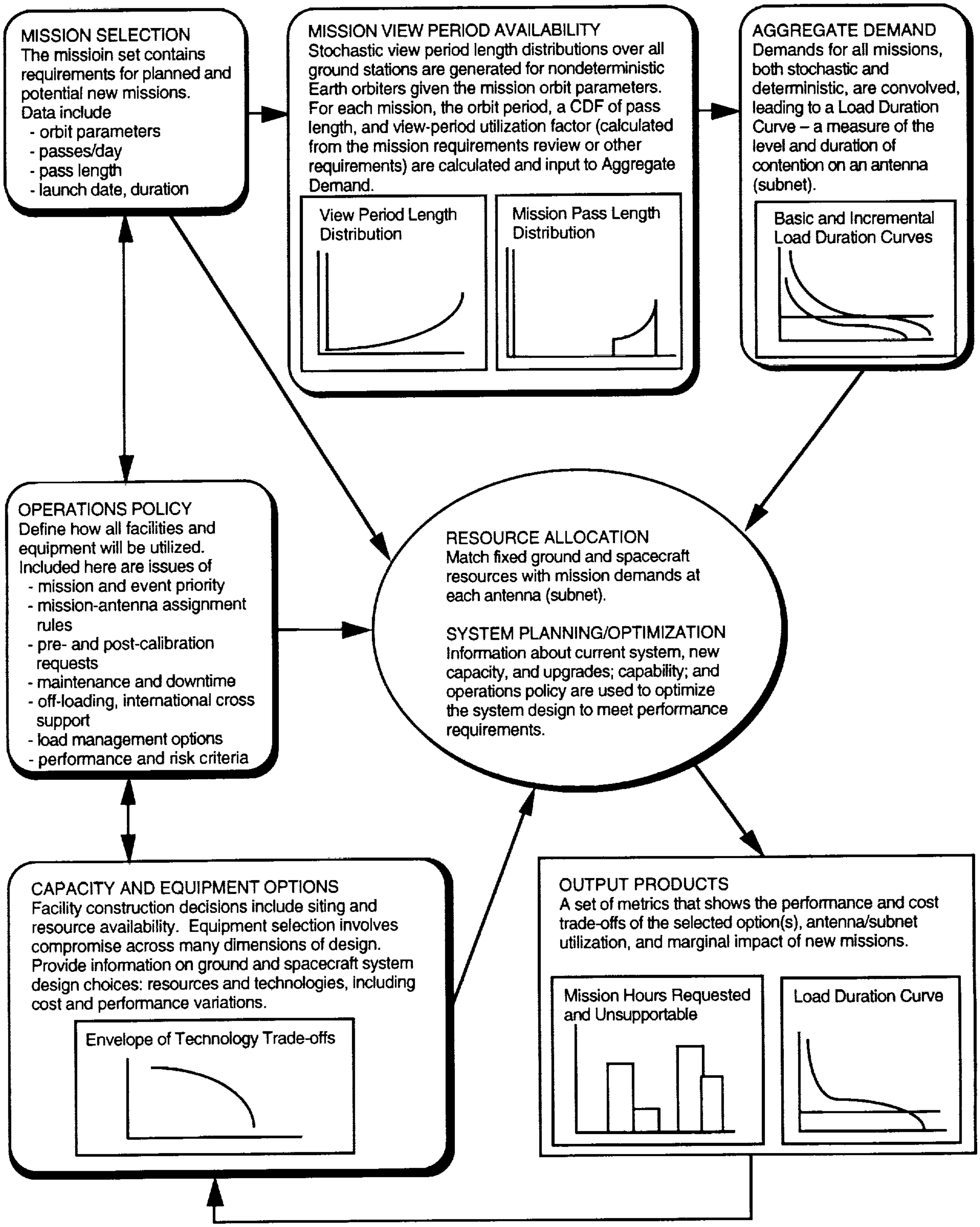

Fig. 1. LEO subnet capacity planning and mission support.

LEO4CAST provides the capability to assess numerous ground resource and flight system options using "what if" sensitivity analysis techniques. The scope of analysis spans mission parameter variation (e.g., mission sets, requests, and priorities) and ground system options (e.g., current and proposed antenna capacity, location, capability, and operations procedures). Analysis results reflect the uncertain nature of mission demands and provide an improved basis on which to base mission coverage commitments. Furthermore, impacts of improved operational processes (e.g., reduced pre- and post-calibration times), additional DSN or non-DSN antennas, or changes to mission priorities can be directly assessed.

In the following sections, LEO4CAST's capabilities are described and sample output metrics are displayed. Anticipated future developments to support TDA decision making are also discussed. LEO4CAST is currently in beta test and has a *Preliminary User's Guide.*[1] It is anticipated that additional system performance metrics to support TDA planning will be identified while undergoing beta test.

II. System Architecture

LEO4CAST is a Microsoft Windows application that has been developed for initial use on client–server architecture, Novell-networked IBM PCs. It consists of a set of relational databases, a probabilistic view period generator and load forecaster, and custom output forms (Fig. 2). For timely, cost-effective development, commercial off-the-shelf software and reusable software modules have been utilized wherever practical. This allows development activity to focus on design and implementation of algorithms specific to forecasting and capacity planning.

Operation of the tool requires network access to a Systems Division–maintained view period database for those missions having predictable known station rise and set times. Additional user inputs are entered and modified using Microsoft ACCESS, a standard relational database–interface tool, on Btrieve databases in the user's home directory. The analytical engine uses both new and reused (from PC4CAST) code written in Borland C++ (Version 4.0) utilizing object-oriented design principles. Where possible, the code is ANSI standard C++, thus facilitating evolution to a multiplatform environment. Tabular outputs provide input to Microsoft Excel for graphical display. In Excel, users can use the existing graphical outputs or design their own to suit the needs of any particular study.

III. Method

LEO4CAST computes loading statistics for a set of antennas and a set of missions that require telecommunications services during a fixed forecast interval. Each mission is characterized by either explicit view periods or by orbit parameters: semimajor axis, eccentricity, inclination, and argument of perigee. These parameters are used to generate view-period-length probability distributions for each antenna. Mission view periods generated internally are referred to as probabilistic (or stochastic). In creating these distributions a lack of information about orbit timing drives the use of uniform random distributions for the ascending node and the crossing time for each mission.

Tracking requirements for each mission are aggregated to forecast the demand on each antenna. All deterministic missions are first combined together into a load duration curve (LDC), as is done in PC4CAST. This involves collecting all the statistics on mission contention derived from the input station rise and set times for each mission, modified by requirements information. The independence of the deterministic and stochastic mission sets allows them to be combined to yield the total antenna LDC. The information contained in the LDC provides a complete set of loading and contention statistics. Outputs for each antenna, which include summary metrics for marginal mission impacts and pairwise mission contention,

[1] *LEO4CAST Preliminary User's Guide* (internal document), Jet Propulsion Laboratory, Pasadena, California, April 1994.

are generated and can be used in Excel to generate charts and tables. See Section V for a description of performance output metrics currently available.[2]

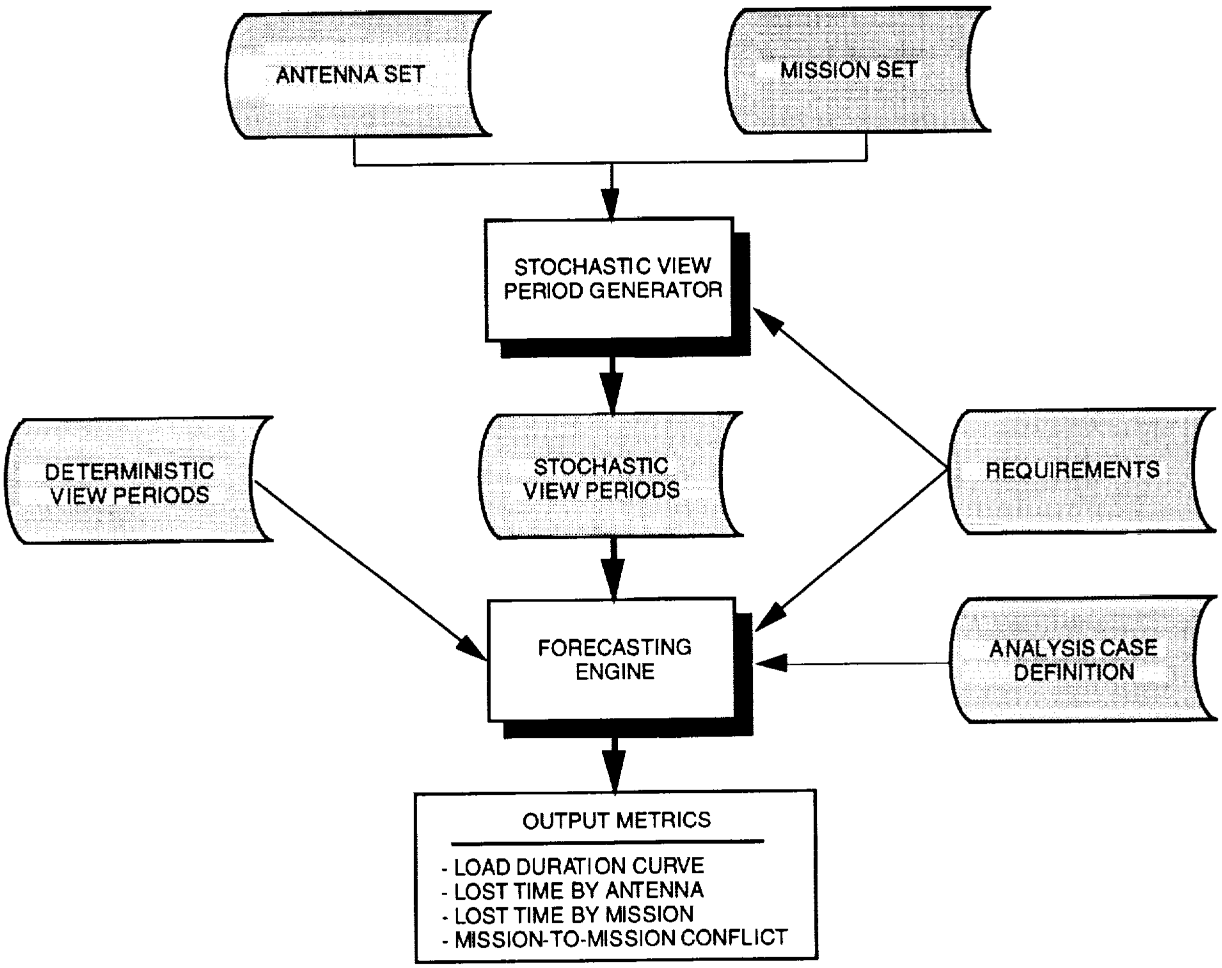

Fig. 2. LEO4CAST architecture.

IV. Inputs

User inputs to LEO4CAST are of four types: forecast interval, mission orbit parameters, antenna location, and mission-tracking requirements by antenna. For those missions with known view periods, view-period rise and set times are read directly from an external file. In addition, there is an initialization file (LEO4CAST.INI) for setting up run-time performance and accuracy parameters.

Nonspacecraft users of antenna time (e.g., such DSN services as antenna calibration and maintenance) should be included as "Missions," in addition to the set of spacecraft missions. LEO missions are modeled probabilistically and require mission orbit parameters be specified. Deterministic missions must have their view periods entered into the "View Period" database on the server. The "Antenna" database contains information describing the antenna location (latitude and longitude). The "Requirements" database is

[2] For more information on the LEO4CAST analysis procedures and a real application of the methodology, see G. Fox, C. Borden, and S. Matousek, *Future DSN Support of Small Earth Orbiters*, Section 7, "Ground System Load Forecasting and Capacity Planning Analysis," JPL D-10099 (internal document), Jet Propulsion Laboratory, Pasadena, California, October 14, 1993. A future paper will discuss the analytical approaches used.

where tracking requirements for missions are identified and assigned to the ground system resources (antennas). Mission requests for each antenna include tracks per day, minutes per track, and minimum acceptable view-period length. Requirements also include antenna pre- and post-calibration times.

V. Outputs and Graphics

LEO4CAST provides a number of output metrics useful for ground system planning and mission design analysis. The primary output is a load-duration curve (LDC) table that displays the combined demands of all missions on each antenna and subnet. Mission view periods, tracking requests, and ground-system operations requirements are included in the LDC. Figure 3 displays a sample LEO4CAST load-duration curve for the fourth quarter of 1995.[3] The duration is the fraction of time at which load is greater than or equal to the selected load level. The area under the curve above 1.0 (subnets) reflects the amount of time that missions are unable to be supported by the subnet due to simultaneous contention (i.e., lost time). Figure 4 provides the mission data used in the study.

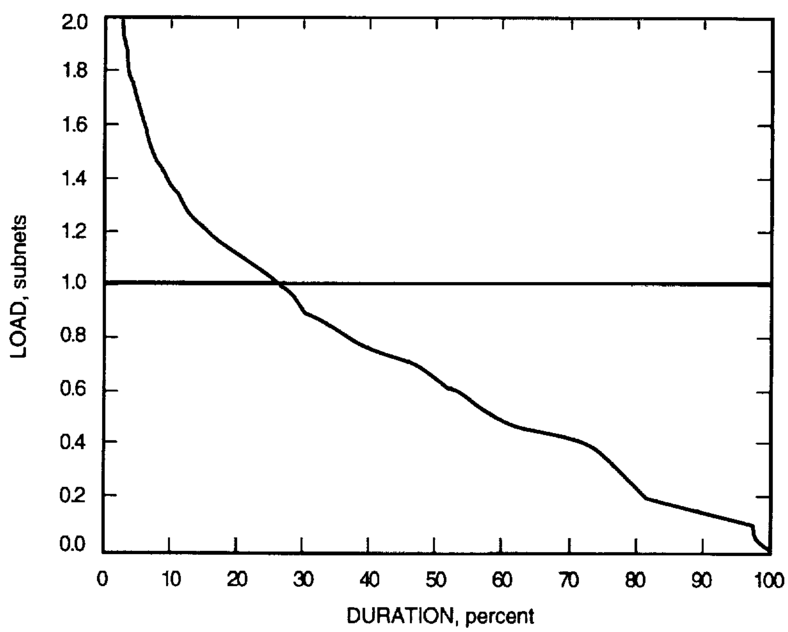

Fig. 3. Fourth quarter 1995 baseline 26-m subnet loading. Lost time = 14.75 percent.

For forecasting studies, mission lost time provides a view to the amount of mission conflict on the designated antenna set. Ground system and mission planners can use these lost time outputs for long-term "what if" studies of changes in ground system capacity, capability, or operations procedures, and for mission sensitivity studies. Figure 5 presents a 5-year display of lost time for 1995–1999.[4] The multiyear aspect of the figure provides insight into the long-term nature of demand on the system. Of particular note is the reduction in lost time (as a percent of requested time) after the second quarter of 1995 due to reducing pre- and post-calibration time requirements from 25 to 12 min. Furthermore, the overall level of mission requests unsupportable over the 5-year time horizon is significant. LEO4CAST provides a quantitative basis for evaluating lost time and the consequences of changes in mission requests and/or ground system capability.

[3] Ibid.

[4] Ibid.

Project	Launch Date	End Primary Mission	End Extended Mission	Requirements, passes/day	Perigree, km	Apogee, km	Inclination, deg	
NIMBUS-7	24-Oct-78	4-Jan-90	31-Dec-99	6 15min/pass)	944	968	99	
ROSAT	1-Jun-90	31-Dec-95	31-Dec-95	2 (10min/pass)	580	580	53	No views at Canberra, Fairbanks, McMurdo
SAMPEX	12-Jun-92	30-Jul-95	31-Dec-99	3 (8min/pass)	514	692	82	
TOPEX/POSEIDON	10-Aug-92	10-Aug-95	10-Aug-97	6 (10min/pass)	1336	1336	66	
YOHKOH	26-Aug-91	25-Aug-94	26-Aug-99	4 (9min/pass) &2 (9.5min/pass)*	515	770	31.1	No views at Fairbanks, McMurdo
ASTRO-D	20-Feb-93	10-Mar-96	1-Jan-00	4 (10min/pass)	536	642	31.1	No views at Canberra, Fairbanks, McMurdo
FAST	23-Aug-94	30-Sep-95	31-Dec-99	4 (30min/pass)	350	4200	83	No views at Canberra, McMurdo
IRTS	1-Jan-95	2-Jul-95	2-Jul-95	4 (5min/pass)*	400	500	97*	
NOAA-K	1-Mar-95	30-Apr-95	28-Feb-97	6 (16min/pass)	833	833	99	
NOAA-L	1-Jul-96	30-Aug-96	1-Jul-98	6 (16min/pass)	870	870	99	
NOAA-M	1-Jan-97	2-Mar-97	1-Jan-99	6 (16min/pass)	833	833	99	
RADARSAT	1-Feb-95	2-May-95	1-Feb-00	3 (10min/pass)	792	792	98.5	Requirements at Canberra only
SWAS	1-Jun-95	30-Jun-98	31-Dec-99	3 (8min/pass)	600	600	65	
TOMS-EP	1-Jul-94	31-Jul-96	31-Jul-00	4 (15min/pass)	955	955	99.3	
GAMES	1-Jun-98	15-Dec-98	15-Jun-01	3 (10min/pass)*	480	480	86	
LTP5-1	1-Jun-99	31-Jul-99	30-Aug-99	6 (5min/pass)*	350	350	28.5	No views at Madrid, Fairbanks, McMurdo
STEP	1-Sep-99	13-May-00	13-May-00	1.875 (8min/pass)	550	550	97.84	
TIMED L	1-Dec-99	30-Nov-01	30-Nov-01	2.1425 (7min/pass)	400	400	49	No views at Fairbanks, McMurdo
GEOTAIL	24-Jul-92	2-Jul-95	31-Dec-99	24/week(1hr/pass)	512,000	1,400,000	5	Double lunar swingbys, night view
ACE	1-Aug-97	31-Dec-99	31-Dec-02	1/day (3hr/pass)	L1 Halo	L1 Halo	28.8	
AXAF I	1-Sep-98	9-Sep-03	9-Sep-03	1/day (8hr/pass)*	10,000	100,000	28.5	
Cluster	1-Dec-95	1-Mar-98	31-Dec-99	10/month (2hr/pass)	25,512	140,316	90	
ISO	10-Sep-95	1-Apr-97	30-Jun-97	1/day (8hr/pass)	1,000	70,000	5.2	
POLAR	1-May-94	2-Dec-95	31-Dec-99	4/day (45min/pass) & 1/day (216min/pass)	12,756	57,403	90	
SOHO	1-Jul-95	29-Nov-97	21-Jan-00	3/day (1.6hr/pass) & 1/day (8hr/pass)	6,554	1,213,350	28.8	Maintains 4-deg sun angle at L1 point (1,700,000 km)
STRV 1	12-Feb-94	12-Feb-95	12-Feb-95	1/day (2hr/pass)*	200	35,977	7	
WIND	12-Dec-93	12-Dec-95	12-Dec-96	1/day (2hr/pass)	510,215	1,594,535	5	Double lunar swingbys, day view

The first 18 missions are modeled as stochastic, the last 9 as deterministic.
Assumes 6-deg horizon mask.
Launch support, NSTS requirements, and backup support for other subnets/systems are not included.
***Best estimate.**

Fig. 4. Mission set for 26-m subnet loading.

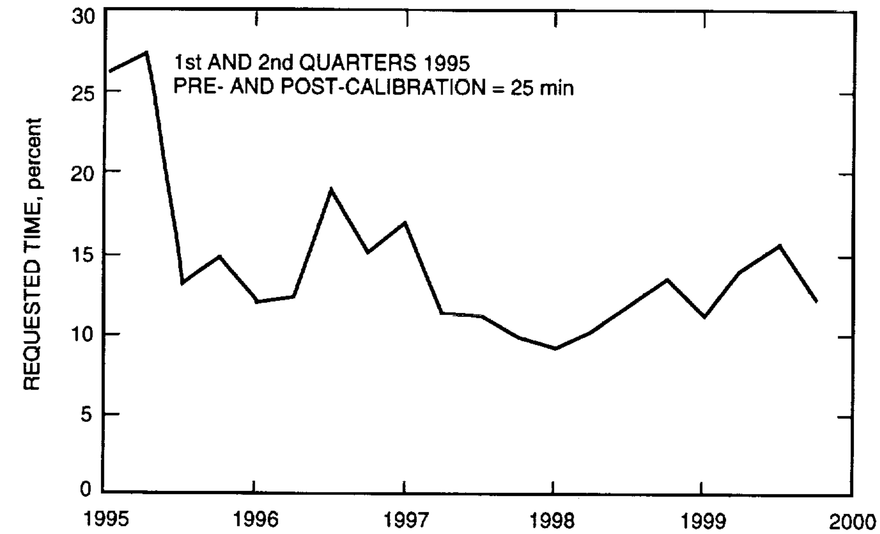

Fig. 5. Percent of lost time for the 26-m network for 1995–1999. Pre- and post-calibration = 12 min for all missions.

A sensitivity analysis on reduction of pre- and post-calibration time from 25 to 12 min is shown in Fig. 6. The percentage of mission lost time is shown to increase significantly (e.g., in the second quarter of 1996 there is a 56-percent increase in lost time, from 12.2 to 19.1 percent, due to an increase in pre- and post-calibration time from 12 to 25 min). To illustrate the importance of operations time dedicated to pre- and post-calibration, a second curve is added to the figure indicating the benefit of a second low-Earth-orbiter antenna added at Goldstone. To first order, the additional antenna provides only a small improvement over reduced pre- and post-calibration time reduction. Long-term planning of mission, antenna capacity, and operations policies are facilitated by these types of LEO4CAST "what if" analysis capabilities. Future capabilities will also include life-cycle cost-effectiveness measures.

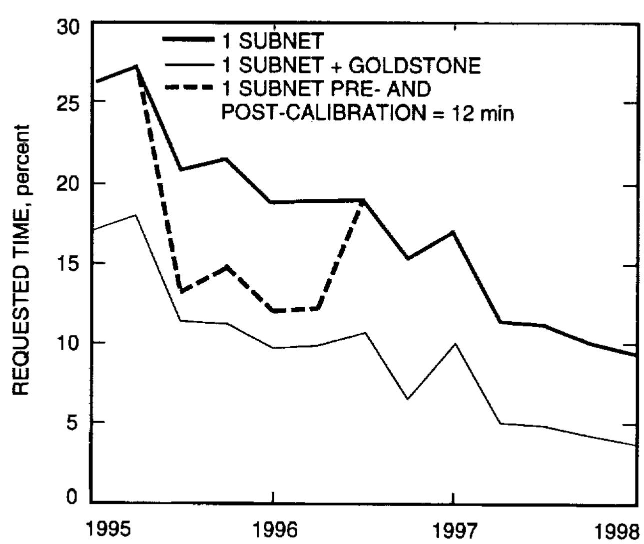

Fig. 6. Percent of lost time for the 26-m subnet for 1995–1997. Reduction of pre- and post-calibration from 25 to 12 min delayed from mid-1995 to mid-1996.

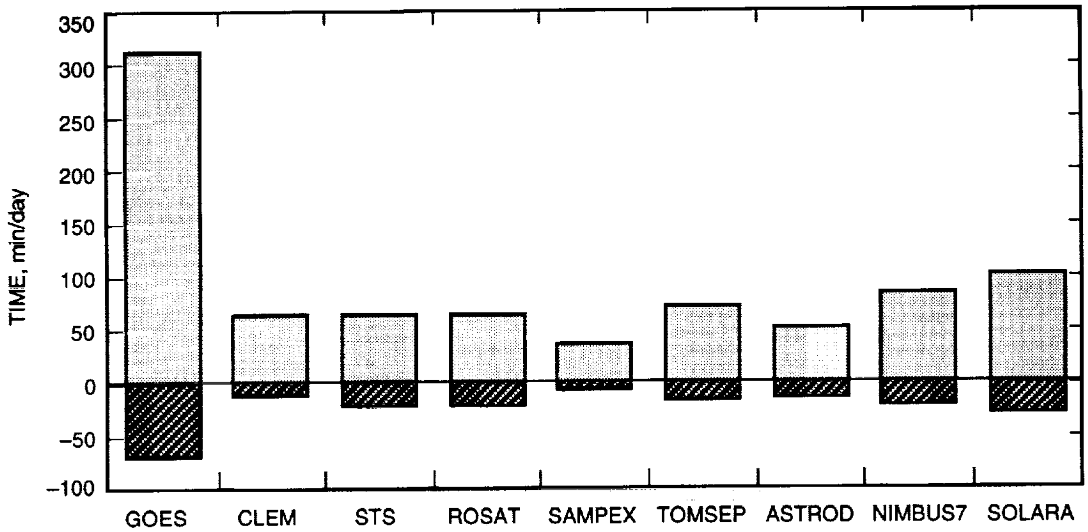

Fig. 7. Mission requirements at Goldstone. Marginal unscheduled time, including pre- and post-calibration.

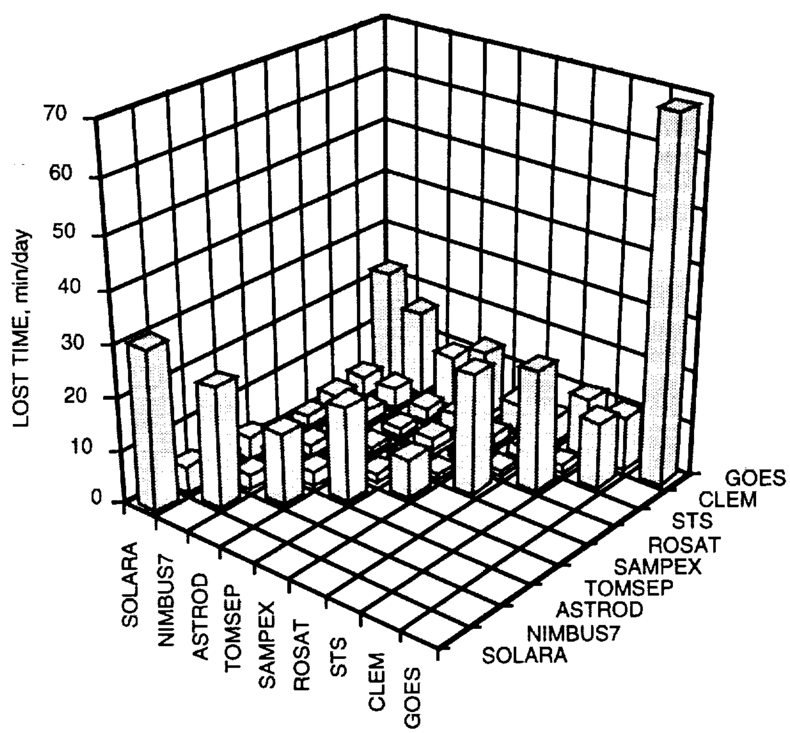

Fig. 8. Tall tent poles: mission bumps mission.

LEO4CAST also provides performance metrics to evaluate near-term resource allocation and mission request and/or priority options. To illustrate, mission-specific coverage and lost time on the 26-m subnet is shown in Fig. 7 for a recent analysis. The area above zero for each mission represents the expected mission coverage. Below zero indicates expected unsupportable requests (i.e., lost time due to contention with other missions).

A more detailed view as to which missions are simultaneously competing for antenna time is displayed in Figs. 8 and 9. Each mission's lost time matches the lost time shown in Fig. 7. Inter-mission conflicts

a-3.

are shown with the assumption that each conflicting mission's lost-time contribution reflects that it is the marginal mission (i.e., the last one to be loaded). When mission priorities for the low-Earth-orbiter and near-Earth missions are implemented in LEO4CAST, prioritized lost time will be displayed. As LEO4CAST gets additional use, it is anticipated that new long-range planning and near-term resource allocation metrics will be provided to support management decision making.

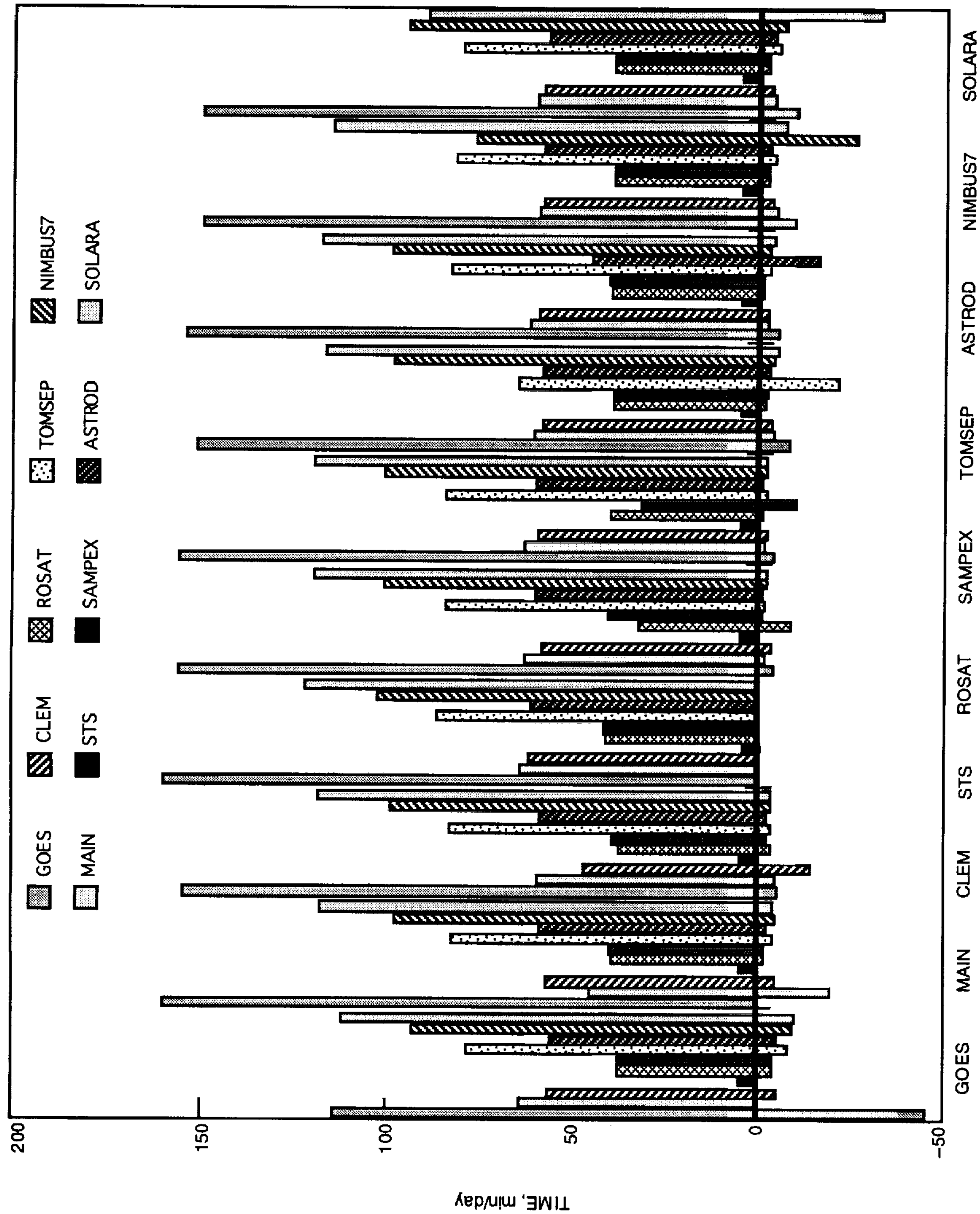

Fig. 9. Mission-on-mission lost time impact.

VI. Future Directions

LEO4CAST has been initially exercised on long-term mission and capacity planning studies and near-term resource allocation studies. As a result of these initial applications, recommendations for extensions and improvements in analysis capability, display of system performance metrics, and multiplatform access have been provided. It should be noted that extension of certain LEO4CAST capabilities will be closely coupled with PC4CAST developments.

In order to more realistically represent mission view periods and requirements, and to link missions whose orbits are serially correlated, a simulation capability is being investigated. Simulation would further enable more realistic assignment of missions to ground antennas, allow the determination of confidence levels in loading results, and provide a basis for the validation of the analytical model. It is anticipated that the simulation would supplement the analytical approach when more fidelity is desired.

Additional analysis extensions include automation of improved procedures for antenna allocation to missions. The current manual process is cumbersome and does not guarantee selection of a superior allocation. Specifically, realistic TDA rules and constraints must be incorporated within the optimization framework. Additional long-term analysis developments include capacity, capability, and siting evolution across subnets and a comprehensive end-to-end design trade-off analysis capability for ground and flight systems and processes. Trade-off studies between subsystems should consider not only performance variation but also system life-cycle cost minimization.

System performance metrics currently available, such as the LDC and the contention matrix, have been described above. Continuing application of LEO4CAST will result in the need for additional metrics to support mission and ground-system decision making. One potential area for further development is in support of a resource allocation process yet to be defined for the 26-m subnet. Such metrics are needed to provide timely insight into mission and antenna conflicts, which should assist in the resolution of contention and aid in providing a more efficient scheduling process.

The ability to access multiple databases and deploy cross-platform applications is becoming increasingly important. In the near term, MOSAIC is being evaluated for cost-effective, multiplatform data browsing. MOSAIC, or a future commercial follow-on, will be considered for multiplatform tool deployment in the future.

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Reference

[1] S. J. Loyola, "PC4CAST–A Tool for DSN Load Forecasting and Capacity Planning," *The Telecommunications and Data Acquisition Progress Report 42-114, vol. April–June 1993*, Jet Propulsion Laboratory, Pasadena, California, pp. 170–184, August 15, 1993.

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