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Mathematical Analysis Techniques For Modeling The Space Network Activities

Abstract submitted to the Graduate Internship Program
NASA-Space Technology Development
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The NCC is the operational manager of the Space Network (a facility consisting of personnel, communication links and computing equipment providing user communication services). The NCC provides utilities for:

- the scheduling support activities for the user community
- disseminates schedule information to the user as well as the other Space Network elements
- controls the services provided by the other Space Network elements
- maintains SN status and configuration information
- assures service performance
- coordinates fault isolation activities
- generates performance reports

The increasing complexity of the Space Network (i.e., ATDRSS, STGT) has created a need to evaluate its impact on the performance of the NCC. Currently these utilities are not available. However, using mathematical modeling techniques, they can be realized.

Modeling provides assistance to managers in the decision making process. It can be used to assess the impact of changes in requirements and design, identify potential bottlenecks and illustrate current operations and the effects of future enhancements. The two former items fall in the category of performance prediction, while the latter enables a person to assimilate and understand the operation of the NCC.

There are two ways to model problems. One way, called simulation, uses a computer to evaluate the system numerically over time. Simulation is a good tool for modeling detailed dynamics. Another method, called mathematical analysis (i.e. linear programming, queuing theory, etc...), is a good tool for optimization.

The NCC/SNC Modeling project has two objectives. The first objective of this effort is to develop a model of the Network Control Center which can be used for performance analysis and future expansion feasibility studies. The second objective is to provide a way of evaluating candidate designs and architectures for the emerging Space Network Control (SNC). The purpose of my research was to identify mathematical techniques for modeling activities within Code 530 . More specifically I chose to investigate the use of linear programming in conjunction with probability theory for modeling activities within Code 530.

In order to find a correlation between linear programming and probability theory, I first had to define a smaller scale problem. Since linear programming is a great modeling tool for optimization, I decided to model the Space Network resource allocation. The objective of this model was to optimize the Space Network (SN) resource allocation under nominal conditions and to compare current resource utilization against optimum resource allocation strategy without time dependency.

I wanted to show, by properly identifying the variables, that if there exists an optimal solution, then no matter how the boundary conditions change, the system should still be able to achieve optimal usage. I also wanted to examine the flexibility of the boundary conditions (by boundary conditions, I mean scheduling constraints).

By letting X_1, X_2, X_3, X_4 equal my resources (i.e. the channels found in two TDRS), the equation of the problem becomes:

Optimize $Z = 4X_1 + 4X_2 + 2X_3 + 38X_4$

where X_1 = SSA or KSA Forward

X_2 = SSA or KSA Return

X_3 = MA Forward

X_4 = MA Return

After examining several booklets to find the Space Network agreements for the various spacecraft, I discovered that approximately twenty percent of the available resources are being utilized. Thus illustrating that, in theory, there exists a surplus of resources. However, the problem is too dynamic for the use of linear programming only. Therefore this particular model cannot be used to accurately describe the Space Network system. Even after comparing current resource allocation with the agreement, I still found that approximately twenty to thirty five percent of the resources were still being utilized.

In conclusion, I could not find a direct correlation between the use of linear programming and probability theory. However, I'm not totally convinced linear programming and probability theory would not work with modeling activities within Code 530. Therefore during the two week hiatus before school starts, I will continue to work on that correlation.

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Agenda

- Objective
- Background
- Approach
- Small Scale Model
- Conclusion

Objective

- To explore and identify mathematical analysis techniques applicable for modeling Code 530 activities
  - - In particular, the use of linear programming

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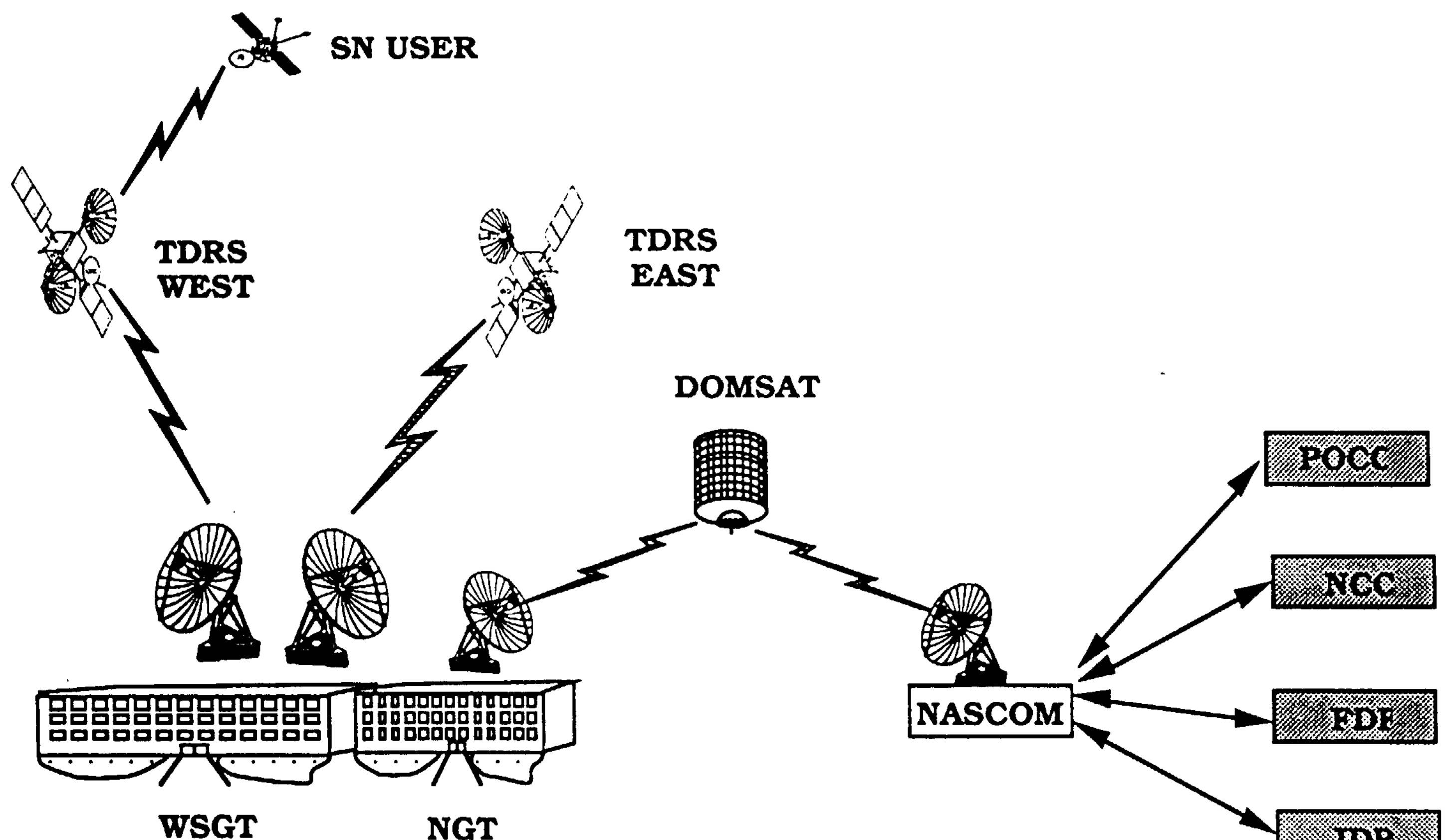
Background



Approach

- Read several documents on the Network Control Center (NCC) and Tracking and Data Relay Satellite System (TDRSS) in order to understand the Space Network
- Read several papers on combining linear programming with probability theory
- Modeled small scale version of the system
- Identified variables
- Gathered data
- Compared actual usage versus theoretical usage

Small Scale Model

- Optimize Space Network (SN) resource allocation under nominal conditions
- Compare current resource utilization against optimum resource allocation strategy without time dependency

Small Scale Model Continued

$$Z = 4\,X1 + 4\,X2 + 4\,X3 + 38\,X4$$

where

- X1 = SSA / KSA Forward
- X2 = SSA / KSA Return
- X3 = MA Forward
- X4 = MA Return

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Small Scale Model Continued...

RESOURCES (2 TDRS)		AVAILABILITY	ACTUAL USAGE	AGREED UPON USAGE
SSA / KSA	FWD	2,880	971.57	1,061.16
	RTN	2,880	637.04	877.75
MA	FWD	2,880	380.22	465.24
	RTN	54,720	1,384.52	388.00
TOTAL	FWD	5,760	1,351.79	1,526.40
	RTN	57,600	2,021.56	1,265.75

C.3

Conclusion

- **Could not find correlation between the problem and the use of linear programming in conjunction with probability theory**
  However, not totally convinced linear programming with probability theory would not work. Will continue to work on correlation

- **In theory, enough resources exist to support the various spacecraft**
  That is not to say there exists no problem with the scheduling of the resources
  Need to look into the scheduling process as well as other constraints for scheduling

Summer Projects

1) Analysis of Proposed Cost Estimating Course
   - memo to B. Dixon

2) Writing and Editing "Introduction to Goddard Spacecraft Subsystem Cost Model"
   - to be published as an RAO Research Note

3) Writing and Updating "Cost Profiles for GSFC Satellite Projects"
   - to be published as an RAO Research Note

4) Analysis of ATDRSS Cost Estimates
   -memo to P. Villone

Conclusions continued

- initial estimate seems to include savings from a learning curve effect which may not ever be realized
- if valid, learning curve saves 26 months off schedule
- if invalid, learning curve yields an 18% overrun

As currently stated this project seems to be a risky propositions, at best

- Shape and smooth data by a Gauss-Newton non linear least squares fit and compare to average profile
    - Figure 3
    - problems
        - yearly peak to soon
            - either

              initial years is too much and the rest is ok
            - or

              initial years are ok and learning curve has shrunk rest of data points

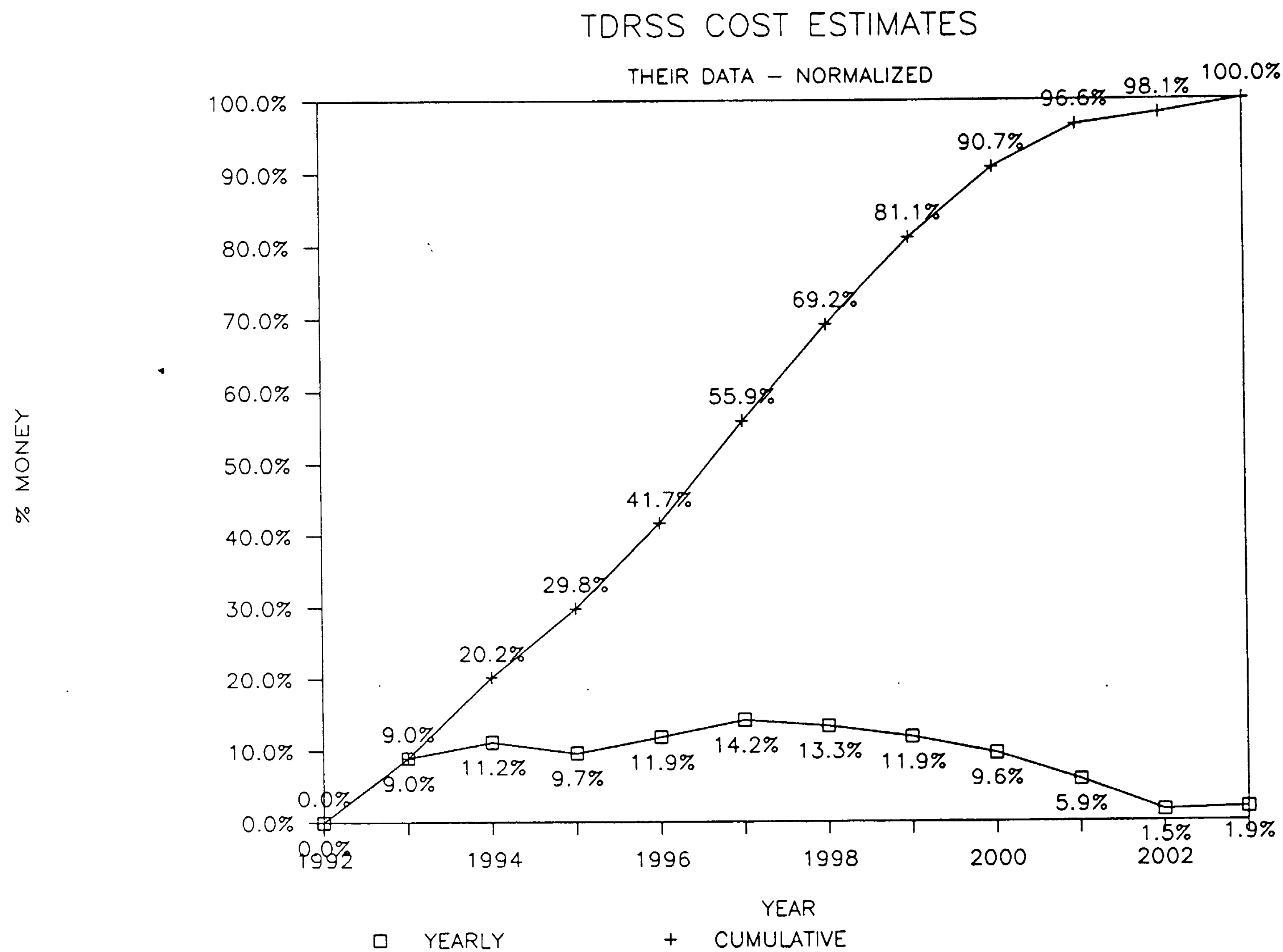
        - delta between the 2 cumulative curves is uniform with a peak of 18% = overrun if learning curve is wrong

TABLE 1

TDRSS PROJECT

FY	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	TOTAL
LAUNCH NUMBER						LAUNCH1	L2	L3		L4	L5		L6	L7		L8	L9		L10	
STARTUP A1-A5	0	30.0	30.0	10.0																70.0
STARTUP A6-A10	0							30.0	30.0	10.0										70.0
REC S/C CON A-1	0	19.0	47.0	29.0	24.0	16.0														135.0
REC S/C CON A-2	0			42.0	36.0	32.3	11.2													121.5
REC S/C CON A-3	0				38.0	33.0	26.6	10.4												108.0
REC S/C CON A-4	0					22.0	36.0	27.0	16.3											101.3
REC S/C CON A-5	0						22.0	36.0	27.0	16.3										101.3
NONREC DESIGN A1-A5	0	38.0	24.0																	62.0
REC S/C CMPLX FC A1	0	6.3	15.5	9.6	7.9	5.3														44.6
REC S/C CMPLX FC A2	0			13.9	11.9	10.7	3.7													40.2
REC S/C CMPLX FC A3	0				12.5	10.9	8.8	3.4												35.6
REC S/C CMPLX FC A4	0					7.3	11.9	8.9	5.4											33.5
REC S/C CMPLX FC A5	0						7.3	11.9	8.9	5.4										33.5
SUSTAINING ENGINEER	0					20.0	20.0		15.8	25.0		10.0								90.8
IUS-NONREC	0	12.0	12.0																	24.0
IUS-REC	0		3.0	9.0	9.0	6.0	9.0	9.0	6.0	9.0	12.0	9.0								81.0
LAUNCH SUPPORT	0					3.0		3.0	3.0	3.0		3.0								15.0
STORAGE	0						0.1	0.1	0.1	0.1	0.1	0.1								0.6
POST STORAGE IST	0										6.0									6.0
TOTAL	0.0	105.3	131.5	113.5	139.3	166.5	156.6	139.7	112.5	68.8	18.1	22.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1173.9
CUMULATIVE TOTAL	0.0	105.3	236.8	350.3	489.6	656.1	812.7	952.4	1064.9	1133.7	1151.8	1173.9	1173.9	1173.9	1173.9	1173.9	1173.9	1173.9	1173.9	

FIGURE 2



TDRSS COST ESTIMATES
THEIR DATA – NORMALIZED
% MONEY
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
1992
1994
1996
1998
2000
2002
YEAR
0.0%
9.0%
20.2%
29.8%
41.7%
55.9%
69.2%
81.1%
90.7%
96.6%
98.1%
100.0%
0.0%
9.0%
11.2%
9.7%
11.9%
14.2%
13.3%
11.9%
9.6%
5.9%
1.5%
1.9%
YEARLY
CUMULATIVE

FIGURE 4

TDRSS/MODEL COMPARISONS