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LRS-II: A Specialized Knowledge System For Launch Resource Scheduling

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ABSTRACT

This research used the Level 5 expert system software to develop a specialized knowledge system called the Launch Resource Scheduling system (LRS-II). LRS-II will be used as a decision aid by USSPACECOM to determine if there is sufficient launch capability to meet future satellite requirements and to quickly assess the impact of contingencies such as launch or on-orbit failures. LRS-II uses multiple knowledge bases to match satellite launch requirements to available launch vehicles, launch pads, and upper stages. Specialized knowledge about satellite requirements and launch resources are stored in dBase III files. Level 5 knowledge base rules match specific fields of the satellite record against fields in the resource records to schedule the earliest launch resources that meet the satellite requirement. During manifesting, the constraints of satellite and resource availability, site processing time, shuttle mission duration, and satellite on-orbit checkout time are used to insure the selected launch date is accurate.

BACKGROUND

The United States Space Command's (USSPACECOM) Deputy Director for Space Operations (J3O) identifies operational needs for current and future space systems. In the spring of 1986, J3O requested a computer program be developed to provide an estimate of the launch support required to maintain any number of satellite constellations at a given level of performance. The research of Koch (Koch, 1986:2) developed a prototype tool which an operator at J3O could use to match satellite requirements against available launch resources.

J3O was very pleased with the LRS prototype. LRS demonstrated that a knowledge based approach was applicable to the launch manifesting problem. However, the prototype system was limited because it only contained procedural knowledge and lacked specialized knowledge about the satellite constellations under USSPACECOM's operational responsibility. This research addresses this major limitation.

PROBLEM

U.S. Space Command staff need a computer program which allows them to do long-range scheduling of launch resources for the satellite constellations under their operational responsibility. These constellations include the Global Positioning System (GPS), the Defense Meteorological Satellite Program (DMSP), the Fleet Satellite Communication System (FLTSAT), the TRANSIT System, and other classified constellations. Also, the program should allow operators to quickly assess the impact of contingencies such as launch or on-orbit failures (Thompson, 1987:2).

LAUNCH MANIFESTING PROCESS

The launch manifest process is shown in Figure 1 (Dutry, 1987). Air Force Space Division prepares a draft DOD mission model based on System Program Office (SPO) launch requirements, available ELVs, and the NASA space shuttle manifest. The Space Division mission model goes to Air Force Systems Command for approval. Then, HQ USAF chairs the DOD Space Launch Users Committee to confirm service support for budget requirements to pay for the DOD missions. The DOD mission model is then reconciled against the available ELV assets and the required STS launch capability is negotiated with NASA.

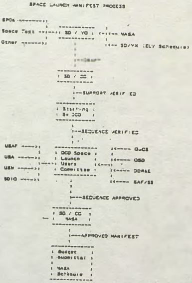

Figure 1. Launch Manifest Process

In 1988 USSPACECOM becomes a voting member of the DOD Space Launch Users Committee and will directly advocate the requirements of its component commands and the other unified and specified commands. The proliferation of launch vehicles and increasing satellite requirements led J3O to request a computer program to assist them in matching satellite requirements against launch resources. Boller explained that they need a computer program which allows them to build an eight year launch manifest and also allows them to ask "what-if" questions. "The program should serve as a long range scheduler and it should also allow us to assess day to day impacts such as the loss of a satellite" (Boller, 1987). USSPACECOM plans to use LRS-II to build launch manifests for the satellite constellations for which they have operational responsibility.

MANIFESTING HEURISTICS

The heuristics of matching specific satellites to specific launch resources requires specialized knowledge for each satellite constellation. This insures the correct matching and allows for ease of maintenance of the knowledge base when constellations are added or deleted. For example, in the operational world, a GPS satellite scheduled on a Delta flies alone, but GPS satellites scheduled for the shuttle launch in pairs. Or, a Nova satellite flies alone on a Scout while Oscar satellites fly in pairs on a Scout. The heuristics for manifesting satellites USSPACECOM has operational responsibility for were obtained by interviewing J3O operators (Thompson, 1987). These heuristics form the basis of LRS-II.

LRS-II MANIFESTING PROCESS

LRS-II uses four knowledge bases to allow complete manifesting of 13 satellite constellations. This manifesting process is shown in Figure 2. Processing begins with LRS-II selecting the satellite requirement with the earliest Desired Launch Date from the satellite database (the database must be ordered by earliest launch date). If the satellite is marked as Launched, LRS-II selects the next satellite until it finds an unsatisfied satellite requirement.

The next step is to match the earliest available launch vehicle to the satellite. This is done by matching the Launch Vehicle 1 field of the satellite record (Figure 3) against the Vehicle Type field of each launch vehicle record (Figure 4) until the earliest available Type 1 launch vehicle is found. The Upper Stage fields of the satellite and launch vehicle are also matched to insure the selected vehicle can accommodate the required upper stage.

Next, the earliest available launch pad is matched to the selected Type 1 launch vehicle. This is done by matching the Pad fields of the launch vehicle record against the Pad Type field of each launch pad record until the earliest available launch pad is found. The Coast field of the satellite record and the pad record are also matched to insure a pad on the correct coast is selected.

If the satellite requires an upper stage, then the Upper Stage fields of the satellite, launch vehicle, and launch pad records are matched against the Stage Type field of each upper stage record until the earliest available upper stage is found. This insures the upper stage can boost the satellite, the launch vehicle can accommodate the upper stage, and the launch pad can process the upper stage.

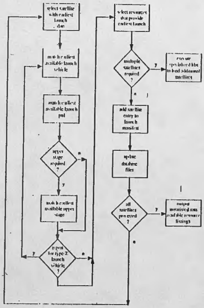

Figure 2. LRS-II Manifesting Process

To determine the earliest day the satellite could be launched, the following calculation occurs. The pad Next Available day is the earliest day site processing can begin. If the launch vehicle is available before this day, then the launch vehicle Site Processing Time is added to the pad Next Available day to determine when upper stage processing can begin. If the launch vehicle is available after this earliest day, then the earliest day is

Information for Satellite Record Number 4

Satellite Name	GPS-4
Constellation	GPS
Launch Vehicle 1	SHUTTLE
Launch Vehicle 2	DELTA
Upper Stage 1	SGS
Upper Stage 2	NONE
Coast	EAST
Available	4
Site Processing Time	14
Desired Launch Date	4
Not Later Than Launch Date	999999
On-Orbit Checkout Time	30
Launched	L
Earliest Launch Date	132
Launch Date	132
Initial Operational Capability .	162
Vehicle Used	OV-1
Pad Used	SLC-39A
Stage Used	SGS-4
Vehicle Delay	Y
Pad Delay	Y
Stage Delay	Y
Reason Satellite Not Launched1 ..	NONE
Reason Satellite Not Launched2 .	NONE

Figure 3. Satellite Record

Information for Vehicle Record Number 3

Vehicle Name	OV-1
Vehicle Type	SHUTTLE
East Pad 1	SLC-39A
East Pad 2	SLC-39B
West Pad 1	NONE1
West Pad 2	NONE1
Upper Stage 1	SGS
Upper Stage 2	IUS
First Available	30
Site Processing Time	60
Mission Duration	14
Turn Time	90
Launch Date	132
First Satellite	GPS-3
Second Satellite	GPS-4
Next Available	236

Figure 4.. Launch Vehicle Record

advanced to the day the launch vehicle is available and launch vehicle Site Processing Time is added to determine when upper stage processing can begin. The same calculation occurs for the upper stage and the satellite until the earliest day all resources are available and processed for launch is determined.

Once a Type 1 launch vehicle, launch pad, and upper stage are matched to the satellite, there is a potential entry for the manifest. However, to insure the satellite requirement is met by the earliest available resources, a Type 2 launch vehicle, if any, is also matched against the satellite requirement. Launch pad and upper stage are again matched, and then LRS-II selects the launch vehicle, launch pad, and upper stage combination that meets the satellite requirement earliest.

After the satellite requirement is met, LRS-II checks whether the satellite constellation and selected launch vehicle allow multiple satellites. If multiple satellites are allowed, LRS-II passes control to specialized knowledge bases to match additional satellites and upper stages. These specialized knowledge bases search the satellite database for the next unlaunched satellite (must be same constellation) and load the second satellite on the selected launch vehicle. If a second satellite or required upper stage are not available, the first satellite is launched by itself. The combined site processing time to process the first satellite and second satellite (if loaded) determine the earliest day the satellite requirement can be met. Per USSPACECOM direction, if the Earliest Launch Date is earlier than the satellite Desired Launch Date, then the satellite is launched on the Desired Launch Date (Thompson, 1987:3).

After the satellite is added to the launch manifest, the satellite and launch resource records are updated. The Earliest Launch Date, scheduled Launch Date, Initial Operational Capability, resources used, and resource delay fields of the manifested satellite are updated. Each resource record is updated to show how the resource was used and when it is available again, if reusable.

The above steps are repeated until all satellite requirements are processed. If, during processing, launch resources for a Type 1 launch vehicle are unavailable to meet the satellite requirement, LRS-II enters the reason in the Reason Satellite Not Launched 1 field of the satellite record and attempts to match a Type 2 launch vehicle. If a Type 2 launch vehicle is matched, LRS-II continues matching other resources. Again, if a resource is unavailable, the reason is listed in the Reason Satellite Not Launched 2 field of the satellite record and LRS-II attempts to process the next satellite requirement. LRS-II attempts to match launch resources to satellite requirements until all satellites are processed or a satellite Desired Launch Date exceeds the Ending Day of the schedule.

OUTPUT

The three outputs generated by LRS-II are the launch manifest, the list of unsatisfied satellite requirements, and the list of available launch resources at the end of the schedule.

An example of a launch manifest is shown in Figure 5. The top of the manifest shows who created it, when they created it, and any additional comments. The program header is followed by the starting and ending day of the schedule, and any special information about how to schedule particular satellite constellations. The rest of the manifest lists individual entries for each satellite scheduled. Each entry lists the satellite scheduled, satellite scheduling dates, launch resources used, and the reason the satellite missed launch, if required.

The list of unsatisfied satellite requirements is the second LRS-II output. Each entry in this list includes the satellite missing launch, the satellite desired launch date, and the reason the satellite missed launch.

The final output of LRS-II is a list of available launch resources at the end of the schedule. This output includes separate lists of available launch vehicles, launch pads, and upper stages and when they are available.

The Starting Day of the Schedule is 1.

The Ending Day of the Schedule is 999999.

Schedule GPS Singly

SATELLITE SCHEDULED	DESIRED DATE	LAUNCH DATE	IOC DATE	LAUNCH VEHICLE	LAUNCH PAD	UPPER STAGE	REASON MISSED
SANMARCO-D	334	334	364	SCOUT-1	KENYA		
NOAA H	414	414	444	A-63E	SLC-3W		
DMSP F-9	425	504	534	A-59E	SLC-3W		
TDRS-C	488	488	518	DISCOVERY	SLC-39A	IUS-1	
SOOS-3	516	516	546	SCOUT-2	SLC-5		
GPS-1	608	608	638	DELTA-1	SLC-17A	PAM-1	
COBE	700	700	730	DELTA-2	SLC-2		
TDRS-D	850	850	880	DISCOVERY	SLC-39A	IUS-2	
HUB TELE	942	942	972	ATLANTIS	SLC-39A		
ITV-2	1000	1000	1000	SCOUT-3	WALLOPS		

Figure 5. Launch Manifest

TESTING

To verify and validate LRS-II's correct operation, three levels of testing were used. The first level of testing verified the correct operation of each individual module. The second level of testing validated the integrated LRS-II system manifested each satellite constellation correctly. The third level of testing was an actual field test of the prototype LRS-II system.

To accomplish module testing, a series of test cases was used to iteratively refine the design of LRS-II. Each test case was designed to exercise a specific function of each module. An individual test consisted of entering the satellite requirement and launch resource information into each database. Next, LRS-II operation was started and specific module functions were executed. The Level 5 reports system was used to verify that each rule of a function executed correctly. As errors were discovered, the Level 5 editor allowed easy modification of the rule and the test case was reaccomplished.

System level testing validated that the integrated LRS-II system manifested each satellite constellation correctly. Correctly means the proper launch vehicles, launch pads, and upper stages were matched against satellite requirements as specified by USSPACECOM. To accomplish system level testing, a 23 satellite test case was used to match each satellite constellation to every possible configuration of launch resources for that constellation. The results of this test validated LRS-II as ready for field testing at USSPACECOM.

Field testing demonstrated the actual operation of the LRS-II prototype to its intended user, USSPACECOM. The primary purpose of field testing was to allow the user to see the operation of the prototype system and to propose extensions that would make LRS-II more useful in its operational environment. A secondary purpose of field testing was to use actual launch system data to test LRS-II. Field testing of the operational LRS-II system will be completed in 1988.

STOPLIGHT

USSPACECOM uses the STOPLIGHT computer program to determine the status of their on-orbit satellite constellations and to predict when satellites must be launched to keep the constellations operational. STOPLIGHT is a microcomputer based computer program developed by AFSPACECOM. STOPLIGHT provides decision-makers with the ability to quickly review current and predicted on-orbit satellite capability and to evaluate proposed launch manifests (Williams, T., 1987).

The STOPLIGHT output gives the predicted status of the satellite constellation for the next eight years. Figure 6 is the output of STOPLIGHT for the GPS satellite constellation. STOPLIGHT uses the projected end of life of each satellite to predict the system status. A ratio, of the number of predicted healthy satellites to the number of required operational satellites, determines the predicted system status. If the ratio is 90% or more, the status is green. If the ratio is between 67% and 89% (more than 2/3), the status is yellow. If the ratio is less than 67% (less than 2/3), the status is red; hence the name STOPLIGHT.

User requirements, as reflected in STOPLIGHT need dates, determine when a launch is required to keep the satellite constellation at its full on-orbit requirement. However, USSPACECOM does not have any program which matches satellite requirements to available launch resources. LRS-II will perform this scheduling.

04-23-1987 Classification: UNCLASSIFIED

DETAIL SYSTEM STATUS

MISSION: Navigation PROGRAM: NAVSTAR OPSCAP: N/A (R&D)

Constellation: Required: 18 / 3 On-Orbit: 6 / 0 Checkout 1 Months

Booster/Launch Complex: Atlas/WSMC SLC-3 (STS and Delta/ESMC)

SPACECRAFT	GPS-3	GPS-4	[illegible]	GPS-9	GPS-10	GPS-11
Launch Date	10 / 78	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Proj EOL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

EOL Source: [illegible]

CY	1987	1988	1989	1990	1991	1992	1993	1994
Need Dates	1	1						
Boat Available	[illegible]	[illegible]	[illegible]	[illegible]				
Ground System				User Set Prediction				
Launch Schedule		[illegible]	[illegible]	[illegible]	[illegible]			
Predicted System Status	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Comments: Deltas available Oct 89. Although R&D, NAVSTAR Block 1 supports Trident testing and other users

Classification: UNCLASSIFIED AFSPACECOM/DOS

Figure 6. Stoplight Output

OPERATOR USE OF LRS-II

A USSPACECOM operator will take the latest STOPLIGHT output and determine which satellites require launch. The operator will then prioritize the satellite requirements by earliest desired launch date. The operator then determines which launch resources (upperstages, launch vehicles, pads) are available in the database and LRS-II will match the satellite requirements against the available launch resources to build a launch manifest.

The manifest generated by LRS-II will be used as input to STOPLIGHT to determine the new predicted status of each constellation. The USSPACECOM operator can iteratively change the numbers and types of launch resources available and use the manifests generated by LRS-II as inputs to STOPLIGHT. This provides the USSPACECOM operator with the capability to assess the impact of using different launch resource configurations to meet satellite requirements. In addition, if resource capability changes for a particular satellite constellation, the operator can easily modify the appropriate knowledge base without affecting the rest of the system. This allows USSPACECOM operators to assess the impact of future launch systems and to plan for the right mix of launch resources.

SUMMARY

LRS-II is a specialized knowledge system which will be used by USSPACECOM as a decision aid to determine if their is sufficient launch capability to meet future satellite requirements and to quickly assess the impact of contingencies such as launch or on-orbit failure. LRS-II uses multiple knowledge bases to match satellite launch requirements to available launch resources. Specialized knowledge about satellite requirements and launch resources are stored in dBase III database files. Level 5 knowledge base rules match specific fields of the satellite record against fields in the resource records to schedule the earliest launch resources which meet the satellite requirement. Field testing of LRS-II should be completed in 1988.

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