MISSION ACTIVITIES PLANNING FOR A HERMES MISSION BY MEANS OF AI-TECHNOLOGY

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ABSTRACT

Mission Activities Planning is a complex task to be performed by mission control centers. AI technology can offer attractive solutions to the planning problem. This paper presents the use of a new AI-based Mission Planning System for crew activity planning which has been set up in the course of an ESA project in cooperation with an industrial consortium led by **ERNO Raumfahrttechnik**. Based on a HERMES servicing mission to the **COLUMBUS** Man Tended Free Flyer (MTFF) with complex time and resource constraints appr. 2000 activities with 50 different resources have been generated, processed and planned with parametric variation of operationally sensitive parameters. The architecture as well as the performance of the mission planning system is discussed. An outlook to future planning scenarios, the requirements and how a system like **MARS** can fulfill those requirements is given.

Key Words: crew activity planning, time- and resources constraints, distributed planning, rule based planning.

1. MISSION SCENARIO & OVERVIEW

The case study conducted is based on a HERMES servicing mission to the COLUMBUS Man Tended Free Flyer [ref 1]. The mission scenario includes a HERMES launch rate of 2 per year. The involved ground segment comprises a Hermes Flight Conrol Center (HFCC), an MTFF Control Center (MSCC), a coordinating Combined Mission Control Center (CMCC) as well as User and Engineering Support Centers.
Crew activity planning for such type of missions has to consider the following main aspects:

o the HERMES spaceplane system:
- launched by an ARIANE 5 launcher
- Mass of payload 3.0 metric tons
- nominal mission duration: 10 days (Free Flyer Servicing: 6 days)
- 3 crewmembers (commander, pilot, mission engineer)

o the Man Tended Free Flying Laboratory:
- 2 segment Pressurized Module (PM) for accomodation of 16 P/L racks (12 m^3)
- Resource Module (RM) docked to PM
- Propulsion subsystem for altitude and attitude control
- ARIANE 5 launch vehicle

o MTFF servicing concept:
- Corrective/Preventive Maintenance
- Replenishment of consumables
- Inspection and cleaning
- Implementation of growth features
- P/L Upgrading, repair, reconfiguration & replacement of payload facilities
- P/L Resupply and collection of samples & consumables
- P/L Checkout and set-up of P/L processes
- Servicing by IVA, EVA, Remote Manipulation and combined EVA and Remote Manipulation activities.

o Mission Cargo Sets includes all serviceable items for a single servicing mission, including:
- permanent travellers (to be flown each mission)
- life limited items (to be exchanged at end of life)
- stochastic items (corrective maintenance)
- consumables (e.g. gases & fluids)
- airborne support equipment (ASE) & tools

2. THE PLANNING APPROACH

Crew tasks like internal servicing of subsystems or payloads, external servicing of subsystems, crew sustaining operations, etc. can be broken down into subtasks and activities. The resulting

hierarchical structure of crew activities has to be converted into a planning database which can then be accessed by the planning system.
The nodes of the planning database contain all the relevant planning information, like: earliest and latest start time, permissible time window, used resources (power, crew member, sun / eclipse phases, communication channels, etc.), antecedent links to other activities etc.
Resources are specified by : name, type, availability and max capacity.
The idea is first to build a **generic** planning database which can serve as a library of generic tasks, subtasks and activities to be copied for reuse and customization for a **specific** mission, thus to reduce significantly the effort for the compilation of planning data. The contents of the specific database depends totally on the Mission Cargo Sets.
Consistency checks of the specific DB (e.g. missing or inconsistent antecedent links) are supported by the planning system itself.
Such a system can be easily used as a valuable tool for quick assessment of design changes by planning with parametric variation of operational sensitive parameters.

3. THE PLANNING SYSTEM

3.1 The MARS Scheduling System

The scheduling of the activities selected for a specific mission was performed by means of the AI based mission planning tool **MARS** (Mission Activities and Resource Scheduler [ref 2]) developed by ERNO Raumfahrtechnik GmbH. The design of MARS explicitly takes into account the complexity aspects of current and future space missions. It has been steadily evolved in tight cooperation with operational users. Within the ESTEC contract **NEPTUNE** (New Expert System for Users in a Network Environment [ref 3]) MARS was enhanced by more general resource handling capabilities, a rule system, configuration management features and distributed planning capabilities. It now includes all features necessary to successfully apply it not only to space missions planning but to any kind of large project scheduling.

The main modules of **MARS** comprise the **Database Editor** and the **Scheduler** each of which will be briefly described in the following.
The **Database Editor** is a graphical interactive tool to allow the efficient creation and modification of activity and resource descriptions, rules to direct the scheduling process and constraints. Activities are hierarchically structured as explained in chapter 2 and handled by the Activity Editor [Fig. 1].

Activities are described by the following major attributes:

- o Full activity name and abbreviation, position in the activity hierarchy.
- o Earliest and latest possible start time and due date (if fixed by problem at hand).
- o Minimum and maximum duration.
- o Any number of antecedent activities and min/-max delay times to them (logical dependencies).
- o Priority, keywords and comments by the user.
- o Interdependencies to other activities (mutually exclusive set of activities).
- o Any number of resource requests in the form of: resource-name and resource request profiles.

The **Resource Editor** allows the specification of resources as well as the generation of resource availability profiles. Any number of different resources can be introduced by the user. Each resource can be of one of the following types:

- o **Sharable** resources represent system states. E.g. the execution of several activities can be restricted to happen during certain day or night periods (SUN-ECLIPSE Phases).
- o **Depletable** resources can be used to describe incremental consumption of a given capacity, e.g. Battery or Storage Place.
- o **Reusable** resources can only be used by one user at a time but are available afterwards, e.g. Tools and Energy. Conventional project planning tools only provide this single type of resource.
- o **Tri-state** resources allow to specify mutually exclusive sets of activities (e.g. activities of one set cannot run in parallel with activities of another set). It is a combination of sharable and reusable.

Optionally resource requests can be defined that are used permanently even after termination of the given activity. Resources can also be generated by activities. Additionally a calendar defining the general working hours and off days can be defined as in any conventional project planning system.

For the generation of schedules and timelines adhering to all given constraints a set of rules (heuristics) can be specified using the **Rule Editor**. Those rules influence or direct the scheduling process. E.g. it is possible to schedule in

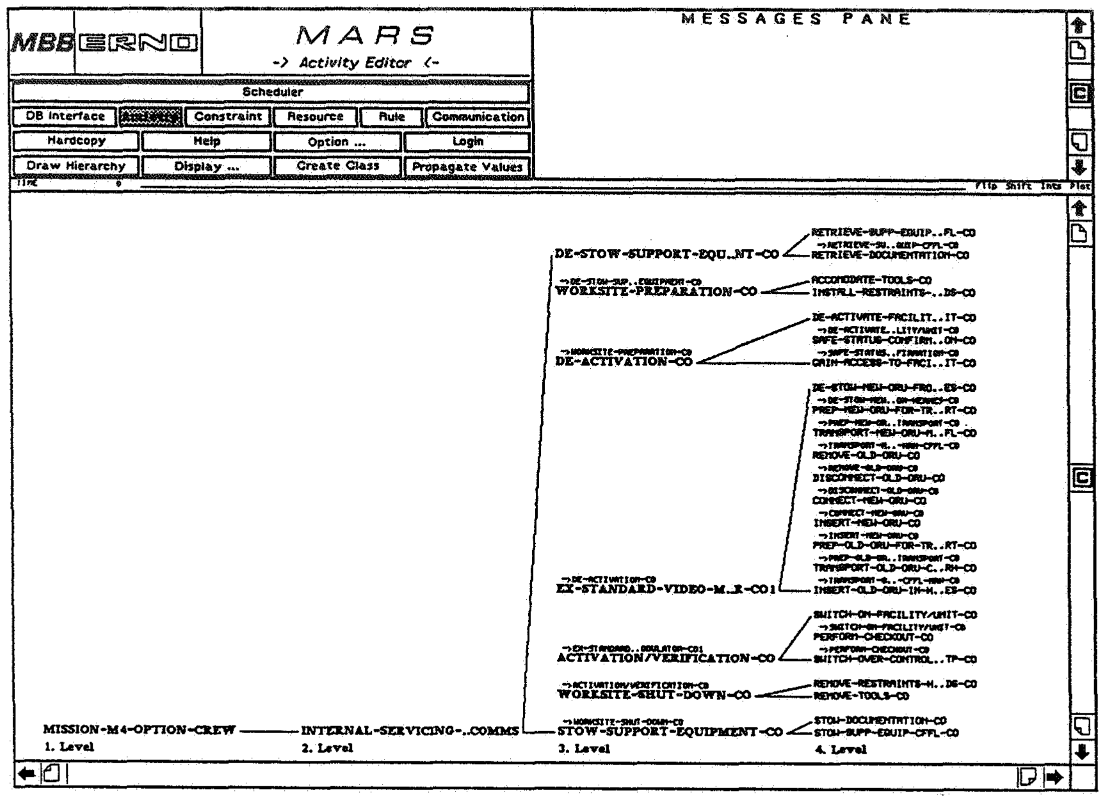

Fig. 1 The Activity Editor

priority a selected set of activities or to schedule in priority the most resource consuming activities. Using this feature of **MARS** the user is very flexible in defining his/her own preferences or goals to be achieved by the scheduling process.

Four different rule types exist:

- o **Scheduling Rules**, which select the set of activities for the next pass of the scheduling process.
- o **Activity Selection Rules**, which influence the selection of the next to be scheduled activities.
- o **Rescheduling Rules**, which influence the rescheduling process and
- o **Backtracking Rules**, which direct the scheduling process during backtracking situations.

Scheduler

The basic problem in any scheduling process involving (limited) resources is defined by the requirement to satisfy both temporal and resource constraints simultaneously.

For **MARS** therefore a new method has been developed, called **Time Constraints Propagation Mechanism** (TCPM), that transforms all symbolic time constraints on and between activities into a computationally much more efficient algebraic representation covering all time relations defined between activities. At first "time constraint windows" are computed for each activity with respect to the totality of all temporal constraints imposed on the plan. Scheduling of activities only within these time windows guarantees that no temporal constraint conflicts will occur at any point in the scheduling process. Thus futile attempts to schedule activities outside these windows are avoided, thereby speeding up the scheduling process considerably and increasing the chance of generating a conflict-free schedule. It is the task of the TCPM to compute and dynamically update these permissible time windows after each scheduling step.

This separation between handling time and resource constraints leads to a scheduling strategy whereby at each point in time, starting from left to right on the time axis, only those activities which lie within their permissible time windows and whose resource and target requests are satisfied by the resource and target availability profiles for the total duration of the activity are identified. Obviously each of these activities individually represents a candidate for scheduling. However, usually not all candidates can be scheduled simultaneously, but only candidate subsets. To influence which subset is assigned the highest priority for being scheduled the user can tailor the involved heuristics with the help of the rule system mentioned above. Activities whose resource requests cannot be met at that particular scheduling step are shifted in time to the beginning of their next "resource window", where their resource request can be fulfilled, but staying within their computed time window.

In this way generating timelines and schedules with MARS can proceed fully automatically, fully interactively where the operator selects each activity to be scheduled, or in a "mixed mode". In all modes the user can follow the dynamically unfolding scheduling process graphically on the "temporal level". At any point in the scheduling process one is able to re-edit activities or resource availability profiles, perform backtrack operations and call up conflict inspection displays, such as:

- o Display of the schedule and composite timelines in the form barcharts and Gantt diagrams.
- o Resource Usage, giving the percentage resource exploitation over the total mission time (as an indication of the schedule quality).
- o Any type and duration of resource violations and involved activities are graphically displayed.
- o The user can graphically shift an activity forward or backward in time and view the induced conflicts (or conflict-free areas for scheduling) dynamically displayed by the "co-moving" scheduler (on forward shift) or Backtrack Module (on backward shift).

A typical example of a schedule generated by MARS is depicted in Fig. 2.

3.2 The Mission Database

To demonstrate the ability of MARS to interact with different types of already existing or future mission specific data (e.g. configuration and planning data) and to support the concept of a **generic planning database** the mission planning data for this project has been stored in an external database whose structure reflects the foreseen COLUMBUS Mission Database Application (MDA). For this purpose the **Mission Database Application Software** (MIDAS) was developed based on the commercial ORACLE DBMS to provide MARS with the required data. The information maintained by MIDAS consists of:

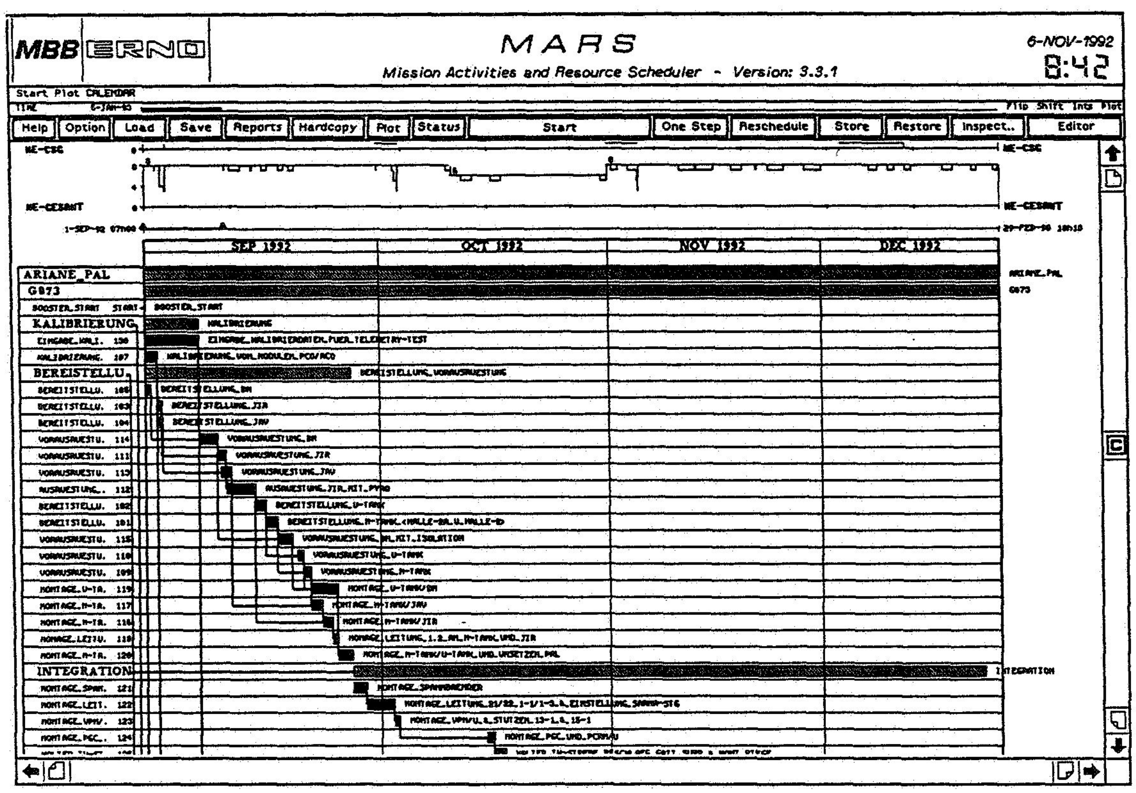

Fig. 2 MARS Scheduler

- o all scheduling relevant data, such as activity and resource definitions, resource availabilities, generic library of tasks and subtasks and Master Timelines (MTLs) as the result of the scheduling process,
- o and support data, such as the description of the Mission Cargo Sets (MCS) and ORACLE relevant data (database dictionary).

MIDAS allows the interactive data entry and maintenance. It supports the hierarchical name tree concept which provides for expressing the relation of objects in a tree like structure. Planning data for a specific mission can be generated by instantiating the generic activity descriptions depending on the selected mission cargo set. A version concept was implemented to allow tracking of data changes over time and provide access to actual or older versions of database item descriptions. Database access control features provide limited data manipulation privileges for certain data to certain user groups. Finally report generation, database recovery and consistency check functions have been implemented.

3.3 The Toolset Architecture

Since the MARS system and the MIDAS application were intended to be used in a distributed environment running on different physical machines (for this project MARS ran on a Symbolics Ivory LISP coprocessor board residing in a SUN 4/330 with the Genera 8.0 operating system whereas MIDAS was running on a SUN 3 with SunOS 4.0.3) interface S/W was developed to allow communication between MARS and MIDAS in a client - server architecture.

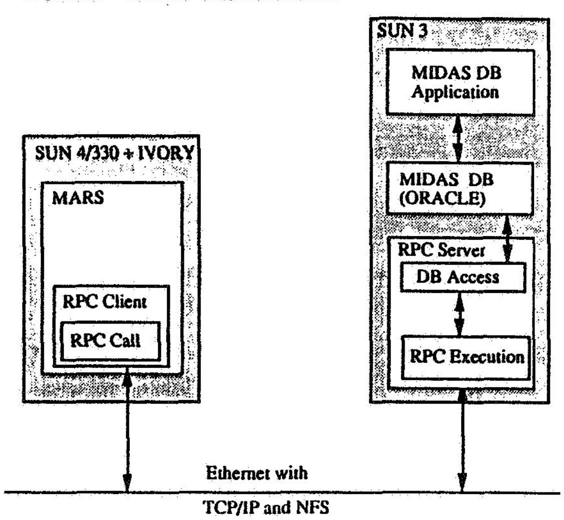

Fig. 3 Toolset Architecture

Both machines were connected by Ethernet utilising the Network File System (NFS) S/W from SUN which also supports Remote Procedure Calls (RPCs). Using this mechanism data can be exchanged between MARS (as the client) and MIDAS (as a database server). For example if MARS wants to read data from the database it specifies as input parameters for a READ RPC the type (key) of data and those requested data are transfered as return parameters. To perform the execution of the RPC's on the SUN a server software was implemented. This server handles the execution of all the specified procedures. It accesses the database via SQL statements. The complete architecture is depicted in Fig. 3. The server and all remote procedures are implemented in PRO*C or directly in C, while the calling of procedures from within MARS is implemented in LISP.

4. PLANNING DATA ANALYSIS

The approach to generate planning data includes 3 main steps:

- o Definition of **generic** crew activities library which can be reused for any mission cargo set.
- o Definition/selection of the **mission cargo set** to be transported by HERMES and operated by the crew including all items for:
  - a selected nominal MTFF servicing mission
  - a selected MTFF contingency mission
- o Definition of **specific** crew activities database based on generic data and the selected mission cargo set.

Only those crew activities were subject for planning which start with docking of HERMES to MTFF and ending with de-docking of HERMES.

4.1 Generic Operations Definitions

All generic crew activities have been structured hierarchically into phase, task, subtask and activity level. The 1st level of the resulting crew activities breakdown is shown in Fig. 4.

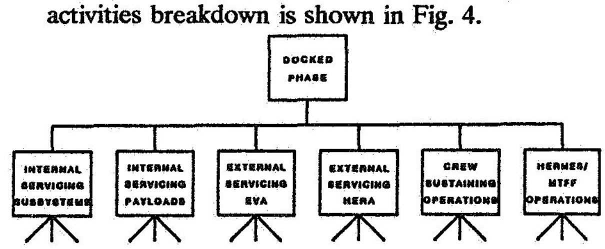

Fig. 4 Activity Breakdown (1st Level)

The complete breakdown resulted in a total of 80 subtasks and 431 generic activities. An example of the activities breakdown established for the exchange of a failed video modulator (internal servicing of communication subsystem) is also given in Fig. 1.

4.2 Mission Cargo Sets

The required items/tasks to be installed/accomplished by the crew are determined by the **HERMES** and **MTFF** system capabilities as well as by the servicing concept, strategy and constraints (see chap.1). The 20 **Mission Cargo Sets** (MCS) for the first 10 years of operation have been generated by means of a Monte Carlo Simulation. Out of these a representative MCS has been selected for the detailed planning.
For the 114 ORU's of the selected mission a rough accomodation analysis to derive the operational properties of the different ORU's has been performed including an Exchange Task Time Assessment as well as an ORU criticality analysis to derive priority information to be used by the planning system in case of conflicts.

4.3 Specific Operations Definition

Based on the generated MCS information a mission specific database has been set up. The major steps were:

- o definition of a suitable task structure to allow the re-use of the existing substructures of the generic database to the extent possible,
- o setup of the lower level task/activities structures by:
  - importing
  - modification
  - duplication

  as appropriate for the specific mission demands,
- o tuning of the generic planning information imported from the generic database according to the mission specific constraints, e.g. time constraint information, resources and resource usage,
- o specification of the resource availabilities,
- o definition of the targets (orbital opportunities) in the form of time-histories.

The resulting mission specific database includes 32 Tasks, 399 Subtasks and 1741 Activities.

The same exercise was performed for a contingency mission which has been based on the nominal mission defined before. The assumptions for this mission have been:

- o repair of a micro meteorite impact in the outer shell of the MTFF
- o repair to be performed by means of EVA
- o exact location and extent of the problem is not known a priori, thus requiring inspection activities with remote manipulator
- o specific repair tools had to be included

The database for this mission includes 24 Tasks, 252 Subtasks and 966 Activities.

5. CREW WORKLOAD ANALYSIS

The generation of conflict free schedules of activities defined in the mission database has been performed for the nominal as well as for the contingency mission.
Another important analysis was the variation of operationally sensitive parameters in order to investigate selected contingency scenarios and options to change mission rules.

For the nominal mission the following variations of operationally sensitive parameters have been performed:

- o **Crew Task Change**
  The Mission Engineer has been removed from all subsystem servicing activities and the Pilot and Commander got the same priority to perform subsystem servicing.
- o **MCS Reduction**
  Some cargo items could not be accomodated physically in HERMES. The corresponding crew activities have been removed from the schedule.
- o **Crew Sickness**
  The Mission Engineer is not available on the first servicing day for about 4 hours due to space sickness.
- o **Communication Dropout**
  RF - Communication between HERMES / MTFF and ground is interrupted for 3 hours on the 4th mission day.

The generated schedule for the nominal mission showed that with the a priori defined crew allocation to the mission activities only 35 % of the science payloads could be processed. Valuable statistical functions for exploitation of the available crew resources resulted in the following numbers:

- o Commander = 61.6 %
- o Pilot = 62.9 %
- o Mission Engineer = 84.9 %

These numbers gave indications to assign more tasks in the science payload area to the Commander and to the Pilot, which resulted in

Planning Results Summary	Nominal Mission "M4"	M4 Planning Options					Contingency Mission "M4C"
		Crew Task Change	MCS Reduction	Crew Sickness Case A	Crew Sickness Case B	Comms Dropout	
Total Mission Time [d/h/m]	11 d 8h 27 m	8d	10d11h48m	11d7h53m	11d12h30m	11d11h11m	8d
Total Mission Time [min]	16347	11520	15108	16313	16590	16511	11520
△ Time to " M4" [min]	N/A	-4827	-1239	-34	+243	+164	N/A
Database Size: Phases	1	1	1	1	1	1	1
Tasks	32	32	32	32	32	32	24
Subtasks	399	399	385	399	399	399	252
Activities	1741	1741	1676	1741	1741	1741	966
Crew Usage: Commander	61,6%	89,4%	62,9%	62,1%	61,3%	61,0%	74,4%
Pilot	62,9%	87,2%	63,9%	63,5%	62,7%	62,4%	75,5%
Mission-E.	84,9%	84,6%	85,5%	83,6%	84,2%	84,1%	81,4%
Subsystem Servicing: Start Time	1d2h35m	1d2h35m	1d2h35m	1d2h35m	1d2h35m	1d2h35m	3d3h25m
End Time	5d8h16m	5d11h16m	5d5h50m	5d6h12m	5d11h50m	5d10h40m	7d2h14m
Serviced ORUs	100%	100%	100%	100%	100%	100%	100%
Payload Servicing: Start Time	5d8h16m	1d2h55m	5d5h50m	5d6h12m	5d11h15m	5d10h40m	N/A
End Time	11d2h4m	6d10h18m	10d5h25m	10d14h33m	11d6h5m	11d4h48m	
Serviced ORUs	35%	100%	48%	35%	30%	32%	

Tab.1 Summary of Planning Results

a 100 % accomplishment of all tasks. Table 1 indicates the results obtained by the other variations.

6. OTHER SYSTEM APPLICATIONS

MARS has shown its versatility and operational capabilities in a number of different application areas. The first important application field was the planning of manned and unmanned space missions on tactical as well as on executional level. This also covers the application as described in this paper. Furthermore, **MARS** was used to perform dynamic payload accomodation based on information contained in payload configuration databases (such as the COLUMBUS P/L Database CPDB) and to analyse alternative accomodations [ref 4].

In a study on future autonomous space systems **MARS** was used as a building block for autonomous scheduling and rescheduling. Complemented by a diagnosis system and spacecraft simulator the system was able to demonstrate the capabilities of a fully autonomous spacecraft that reacts to malfunctions by diagnosing its internal status, initiates appropriate recovery actions and finally replans the rest of its mission according to the new situation [ref 5].

Current activities comprise the development of interface software and the rework of planning data originally compiled for the **MIPS (Mission Planning System)** used to plan the next German Spacelab Mission (D2) to be launched early next year. For this application **MARS** is intended to be validated during the mission in terms of its performance and operational capabilities by comparing **MARS** with the built-in scheduler (ESP, Experiment Scheduling Program) of the MIPS system in replanning situations. For this purpose **MARS** is extended to be able to deal with the same input and output data formats as the ESP system. Former studies have already shown the advantages of **MARS** as an automatic and interactive scheduling tool wrt ESP, but this will have to be justified during that real mission.

Another recent project is the utilisation of **MARS** for the planning of the ARIANE4 second stage and booster production and integration that is performed at ERNO premises.

Under the product name **PARS** (for Project Activities and Resource Scheduler) the MARS system will also be made available commercially on SUN workstations until end of this year.

Distributed Planning

The COLUMBUS mission planning concept is currently still under definition. MARS can support an operational scenario which is based on two important principles:

o the distributed Ground Segment Infrastructure and
o the hierarchical system for its management

According to the hierarchy of the distributed planning environment there will exist a tree structure of logical nodes each with its own MARS system, each responsible for the planning of a specific logical node or mission center in the hierarchy. Within a logical node the activities are structured itself in a tree hierarchy as described for the mission planning database editor. In a top-down procedure each center allocates resource envelopes to its lower level centers over the network, so that these can generate their own local schedules and timelines. Afterwards these local timelines will be integrated in a bottom up approach into the higher level timelines. This MARS features can also be applied to any type of project planning, where the problem at hand must be decomposed and solved by severalplanning teams, working closely together.

7. CONCLUSION

The results of the project have clearly shown that such a planning system can be an essential tool throughout the lifecycle of a space project, starting with the initial definition of the space infrastructure until and within the operational phase. In the very early project phases trade-offs can be performed to assist in the design of the spacecrafts and payloads. What-if scenarios can be worked out to identify bottlenecks in the system design by analysing operational scenarios (timelines).

The planning system used in this study compared to other commercially available systems, e.g. for project planning, has the ability to handle different kinds of resources, e.g. to handle stocking tasks by filling intermediate stores. It can be interfaced with other software and databases through its programming language interface and the possibility exists to extend its intrinsic functionality to implement any upcoming and very specialised requirements, e.g. for additional project specific resource types.

These features would allow the cost effective application of MARS in other very demanding scheduling domains where resources are a limiting factor and the timespan for execution of tasks is restricted, such as:

o Production planning, scheduling of production tasks, interleaving of multiple production lines
o Transportation planning
o Logistics planning

Future alternative hardware platforms for the planning tool MARS will be any UNIX based system that supports a Common Lisp environment with multitasking capability and X window system interface using CLIM and CLOS (e.g. SUN workstations). This will achieve the goal of principal hardware independence for MARS and derivatives (PARS) and will be finished in 1992.

8. ACKNOWLEDGEMENTS

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SENER, Bilbao - Spain
CISET , Rome - Italy

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