Towards a Decision Support System for Space Flight Operations

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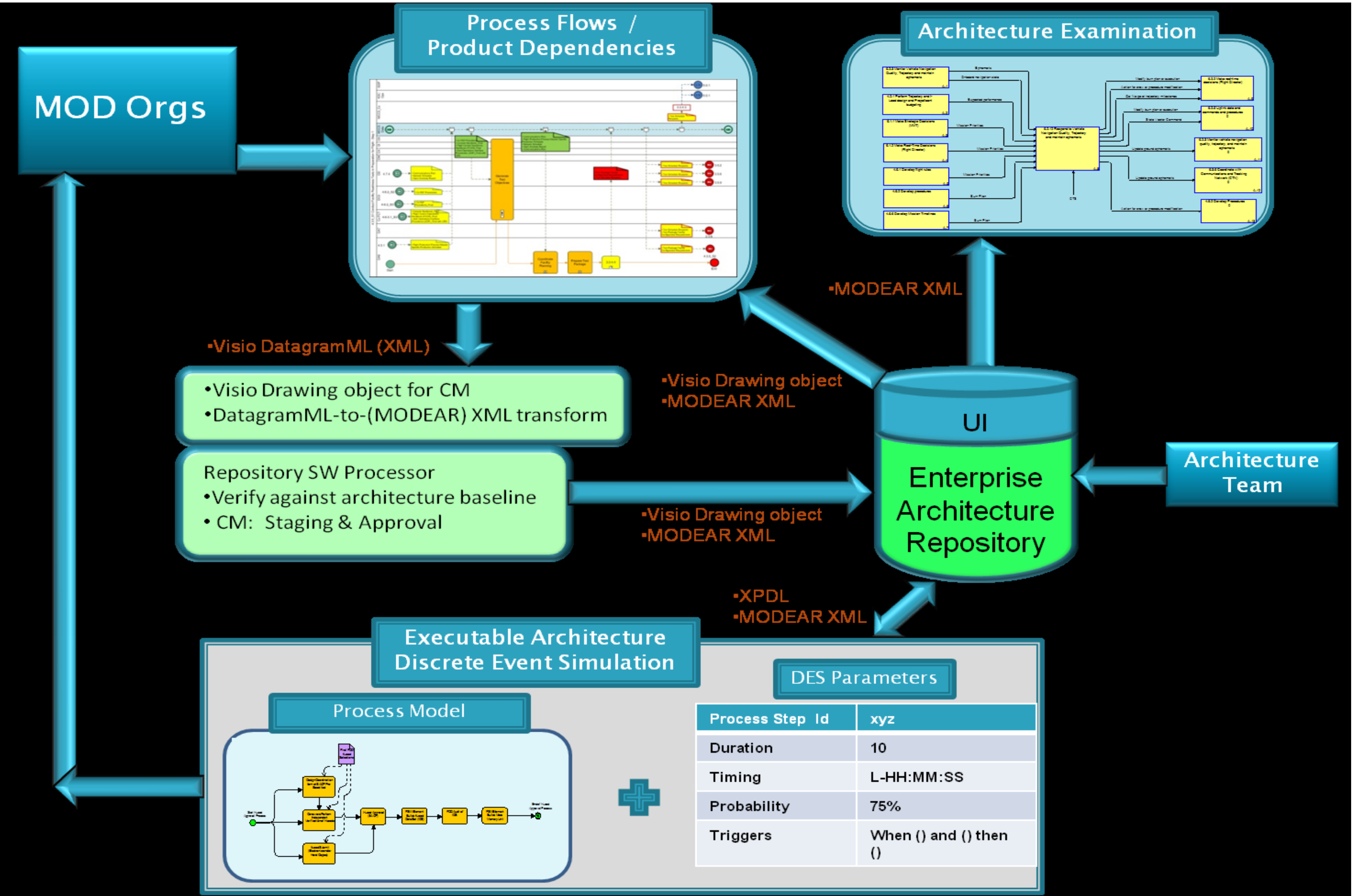
Context

- The Mission Operations Directorate (MOD) at the Johnson Space Center (JSC) has put in place a Model Based Systems Engineering (MBSE) technological framework for the development and execution of the Flight Production Process (FPP).
  - This framework has provided much added value and return on investment to date.

- The vision is to enhance this framework to enable its application for uncertainty management, decision support and optimization of the design and execution of the FPP by the program.

- The paper provides a roadmap for the four increments of this vision.
  - These increments include (1) the existing capabilities (2) hardware and software system components and interfaces with the NASA ground system, (3) uncertainty management and (3) re-planning and automated execution.
  - Each of these increments provides value independently; but some may also enable building of a subsequent increment.

First Increment: Existing Capabilities (1/2)



Process Step Id	xyz
Duration	10
Timing	L-HH:MM:SS
Probability	75%
Triggers	When () and () then ()

First Increment: Existing Capabilities (2/2)

- A language for the capture, representation and storage of architecture and design information for the operations view of FPP has been developed, established and is currently in use.

- This language is the basis for an ontology that has constituted the schema for an SQL database, the Mission Operations Directorate Enterprise Architecture Repository (MODEAR).

- MODEAR is in operation and is currently providing support for upcoming missions.

  - The FPP allows us to put together, from left to right, the orchestration of the processes needed to plan, train and fly each spacecraft mission.

  - The two most significant products we immediately get from MODEAR are the product exchange matrix and the integrated schedule.
    - The product exchange matrix tells us about all the dependencies internal and external to the organization.
    - The internal PEM includes the dependencies between the various divisions within MOD
    - The external PEM includes the dependencies with other organizations. Examples include software requirements, program requirements, networks and communications, data exchanged with other entities such as Avionics & software, the CAIB, etc.
      - This information is then communicated with external partners and is very effective for collaboration purposes.

- The process flow diagrams associated with each of the key functions within the FPP are generated and updated in Visio by the Subject Matter Experts (SMEs).

  - These process flow diagrams are the primary means for the SMEs to convey architecture information to MODEAR.
  - Using helper applications, MODEAR works interactively with Microsoft Visio to, one hand, provide the latest repository data to experts working on the Visio diagrams and on the other hand, conduct consistency checking on the new data created by them before uploading to the database.
  - MODEAR facilitates the export of data associated with architectural artifacts to customized architecture development tools.

Second Increment: MOD System Components and the NASA Ground System(1/3)

- MOD at JSC is part of the NASA-wide ground systems operation.
- The FPP has been focused on the operations pertinent to MOD.
  - The hardware and software which is required for pre-mission planning, training and mission execution is distributed across MOD, the agency and external entities.
  - The current ontology and data structure associated with MODEAR includes only the workflow related to the operations viewpoint and data flow processes, as well as some level of mapping between these and the system components used for their performance.
  - Visibility into the system level elements of the hardware and software system elements and interfaces that is used for performing the tasks and managing these resources further helps to enhance productivity and optimizes the system for the metrics of interest, such as cost, reliability and time to complete.
  - Therefore the next immediate step involved in this effort is the extension of the MODEAR data model to allow for defining the system level architectural artifacts, the capture of the data associated with these elements and their connection to the tasks being performed.

Second Increment: MOD System Components and the NASA Ground System(2/3)

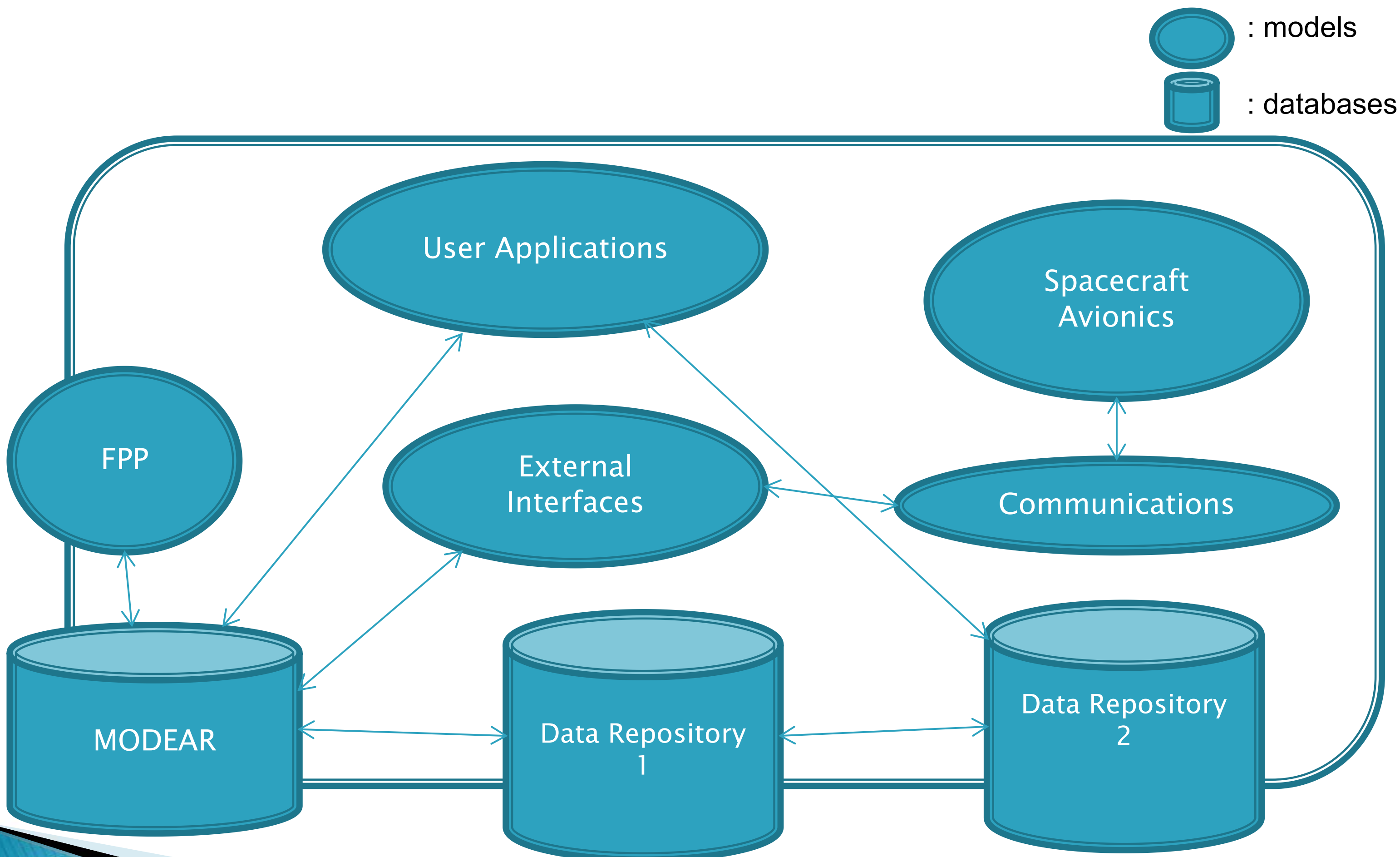
- The ontology that has been designed for the FPP must also interface and interact with representations associated with the rest of the MOD as well as the NASA-wide ground system.

- The next generation Mission Control Center (MCC) at JSC, which includes some of the hardware and software used for the generation of the flight products, and which is responsible for the generation and execution of commands to the spacecraft, currently has a variety of requirements, design documentation and system modeling associated with it.

- Other elements of the human spaceflight operations (including the Spacecraft System Avionics, Communications System, User Applications, etc.) each have their own associated system models as well.

- Therefore, there exists a distributed data structure associated with the various ground systems for spaceflight operations; and the intricate dependencies between the various elements are being designed and developed.

Second Increment: MOD System Components and the NASA Ground System(3/3)



Third Increment: Uncertainty Management(1/4)

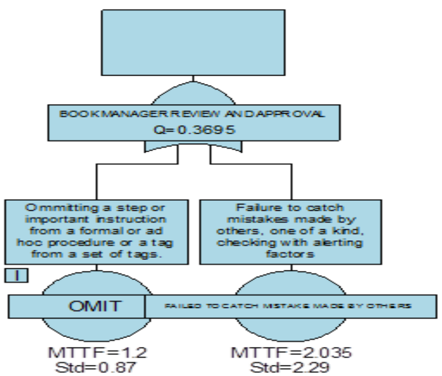
- Uncertainty may be due to the following reasons:
  - Inaccuracies in the design
    - SME's might have left out activities during the design process.
    - System design without proper consideration of the operations profile and activities for the system.
    - Their estimate of time and resources for the performance of activities may be inaccurate.
  - Changes in requirements
    - Requirements for the mission in question may change and result in changes to the FPP process.
  - Resource availability
    - Resources such as humans, hardware or software may not be 100% available. This in itself may cause a delay in the completion of associated activities.
  - Errors in performing tasks

Third Increment: Uncertainty Management(2/4)

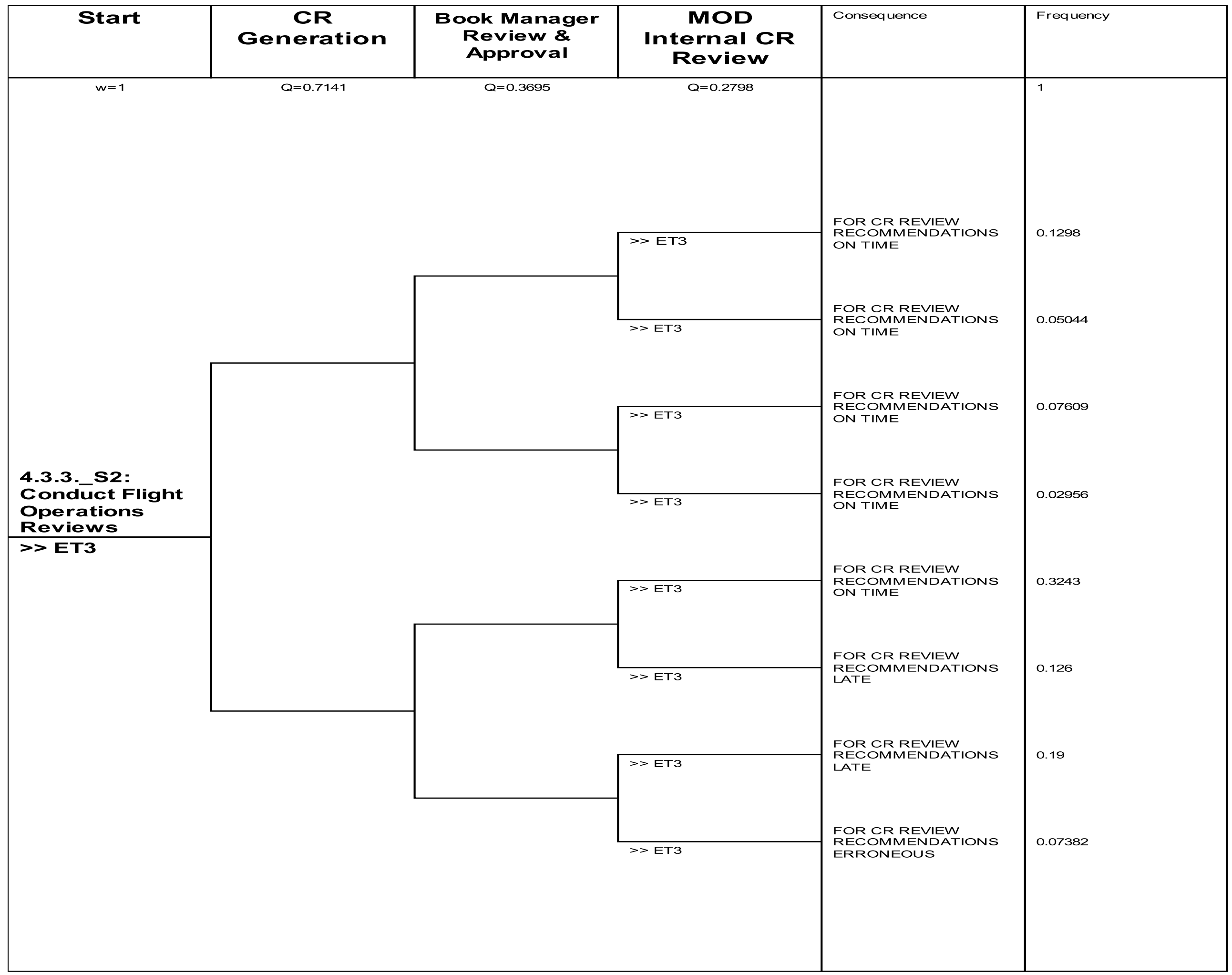
- Our initial suggested approach for managing these uncertainties is to build Probabilistic Risk Assessment (PRA) models for each of the Process Flow Diagrams (PFDs) on the critical path.
  - According to the Pareto Principal, roughly 80% of the uncertainty is due to roughly 20% of the processes. The idea here is that those 20% are the processes on the critical path. Once these PRA models are built, the team will deliberate on the causes of delay or error for these PFDs.

- For demonstration purposes, we consider a sample PFD which includes the sequence of activities: Change Request (CR) Generation, Book Manager Review & Approval, MOD Internal CR review.

Sample Event Sequence Diagram for the PFD "Conduct Flight Operations Reviews"



Sample Fault Tree associated with the event "Book Manager Review & Approval"



Third Increment: Uncertainty Management(3/4)

- Another significant uncertainty involved is the estimate of the costs involved.

- The suggested approach for cost modeling is to map the elements of the functional breakdown for the generic FPP project into the WBS elements of projects for which there are available cost data and use that as a basis for cost estimation.

- While this result provides an estimate for the labor costs associated with the FPP, the facility costs can be derived by using the operational profile of the facility components that are generated from the simulation analysis.

- Some of the possible outputs of the cost modeling effort include:
  - An estimate for the labor costs associated with the development of the FPP for the project in question.
    - Uncertainty distribution for the estimate.
  - A list of the key cost drivers for the FPP.
  - An estimate for the facility costs associated with the FPP.
    - Uncertainty distribution for the estimate.

Third Increment: Uncertainty Management(4/4)

- When the third increment has been completed, the iteration process with the SAT team will include brainstorming about the risks and sensitivities of the system.

- This information will be collected and included in a PRA model and a cost model by a modeling expert on the SAT team and the results of the PRA/Cost-risk model will be deliberated upon and iterated in order to develop optimal margin allocation strategies.

- The main difference is that there will be a risk and cost-risk assessment module in the loop and instead of just one baseline design, there will be several alternatives, each with a specific risk and cost profile.

Fourth Increment: Re-Planning and Automated Execution(1/4)

- This increment is dependent on the second implement and complimentary to the third increment.

- It is necessary to have information about the system hardware and software components within the models in order to conduct automated re-planning and execution.

- Furthermore, re-planning, in particular is an approach for managing uncertainties and hence complimentary to the third increment.

Fourth Increment: Re-Planning and Automated Execution(2/4)

- Risk based margin allocation (possible after increment three) was suggested as an initial approach for managing uncertainty.
  - This is due to the fact that additional margins allocated to sensitive areas of the design provide for the resources needed for re-planning.
- When there are errors or inaccuracies in the design, or when the requirements change, there is a need for the team to conduct a re-plan and re-design the template accordingly.
  - Currently, this is done in a completely manual way. The team actually has to convene, discuss the issue being addressed and form a plan for changing the design to accommodate it.
  - This re-planning process can be semi or mostly automated in time.
- Much of the knowledge that the SAT team uses for the re-planning process has been captured within MODEAR.
  - Formalizing this data and representing it in a format that would be amenable to automated optimization is the first step towards automated re-planning.
- The next step would be the development of heuristics and use of planning algorithms for the creation of the re-planning engine.

Fourth Increment: Re-Planning and Automated Execution(3/4)

Type of Uncertainty	Type of Change Required	Approach	Level of Automation
Requirement Change	Design Change	Re-planning	Mostly automated
Delta between the design versus the actual	Resource allocation change.	Margin management, Re-planning	Mostly automated
Flight Schedule Change	Date changes	Re-planning	Mostly automated
Personnel Availability	Resource allocation change.	Re-planning	Mostly automated
Resource Availability	Resource allocation change.	Re-planning	Mostly automated
Mission Profile Change	Design Change	Re-planning	Semi-automated
Other Change Requests	Design or resource allocation changes	Re-planning or Margin Management	Semi-automated

Fourth Increment: Re-Planning and Automated Execution(4/4)

- Once increment four has been completed, we have a Decision Support System that aids in the design, development, maintenance and management of the FPP.
- The selected baseline design will be executed semi-automatically with the commands going directly from the MLNE to the applications or humans responsible for performing the tasks.
- The metrics associated with the tasks will be collected and if there are discrepancies, the re-planner will develop a suggested re-plan for achieving the mission goals.
- The re-planner is analogous to the GPS system in a car. When it turns out that the path is different from the initially planned path, it finds an alternative path to the destination.
- The MLNE would then be analogous to a driver who can drive automatically for the most part but needs the actual human driver to supervise its performance and take charge as appropriate.
- Since the MLNE will be in communication with relevant applications, their status will also be automatically registered for the purpose of maintenance activities.

DSS-FPP Elements and TAMU

Function	Tool	Approach
Data Collection	Process Flow Diagrams, Visio	Visio Module – SME inputs
Integration	MODEAR	MODEAR consistency checker/ integration approach
Requirements Analysis	MODEAR ++	Transfer requirements into structured ontology and integrate with the rest of the system
Critical Path Analysis	COTS tools/ Scheduling Application	Standard CPM/ Scenario Analysis via Networks.
Architecture Development	COTS tool	DODAF
Optimization	Planner/ To be developed	AI Planning Algorithms
Synthesis	SAT Team	Team Consensus/ Discussions
Uncertainty Management	Re-Planner/ To be developed Isograph Reliability Workbench	AI Planning Algorithms Probabilistic Risk Assessment
Execution	MLNE (COTS tool) / To be developed	Automated Execution

Summary & Conclusions

- This paper explains the steps involved in extending a newly developed technological infrastructure into a full-on Decision Support System to support the development of Flight Products in a semi-automatic and optimal manner.
- The vision for this development reflects a developmental framework for MODEAR and the FPP model, which is divided into four increments, where the first increment has already been accomplished and is operational.
- It is important to point out that this first increment is already providing much added value and the expectation is for each of the remaining increments to have significant value and return on investment in and of themselves.
- Nonetheless, the way they have been designed, there is some level of dependency between these increments and each builds on the previous ones quite productively.

Acknowledgements

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