



Modeling Operations Costs for Human Exploration Architectures



Dr. Robert Shishko

Caltech/NASA Jet Propulsion Laboratory

Copyright © 2013 California Institute of Technology. Government sponsorship acknowledged



Presentation Outline

- ➔ • Introduction: Why Are Operations Costs Important?
- A Brief History of Operations Cost Modeling for SSF, ISS
 - Model for Estimating Space Station Operations Costs (MESSOC)
- Evolution for the Constellation Program and Beyond
 - Exploration Architectures Operations Cost Model (ExAOCM)



Why Worry About Operations Costs in HSF Programs?

- Operations and support (O&S) costs for human spaceflight have not received the same attention in the cost estimating community as have development costs.
- For HSF programs, operations costs can be a majority of life-cycle costs (LCC)
- Program decisions made early can often have profound effects, both positive and negative, on the level of O&S costs required for the remainder of the program.
- Choosing a system architecture/design based solely on development cost has been detrimental to NASA in the past.



How Does Operations Cost Modeling Support HSF SE?

- Helps establish that a credible, affordable architecture exists
- Helps define the program LCC and Pareto surface
- Perform trades between development cost and operations cost
 - Subsystem technology trades
 - Photovoltaic (PV) vs. Solar Dynamic (SD)
 - Hydrazine vs. cryogenic
 - Supportability and commonality trades
 - Optimal repair level analysis (ORLA)
 - Reliability requirements
 - Commonality at what level
- Perform trades between operations cost and operational risks
 - Resupply cycle and pre-positioned supplies vs. PLOM
 - Robotic assistance/EVAs vs. PLOC
 - ISS ops cost model and PRA required common data



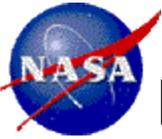
What's Different in Modeling HSF Operations Costs From Development Costs?

- No historical database of previous programs from which to develop statistical relationships or draw statistical conclusions
- Need a Concept of Operations with sufficient clarity
 - DRMs
 - Flight rates, operational timelines, and key events
 - End-to-end communications strategy
 - Integrated logistics support (ILS) strategy
 - Operational facilities
- Time is important
- Model scope is important and often not clearly defined from a modeling point-of-view
- Many heterogeneous functions
- Data are program-specific, early guesses (uncertainty)
- Experts and data are dispersed among many organizations



Presentation Outline

- Introduction: Why Are Operations Costs Important?
- ➡ • A Brief History of Operations Cost Modeling for SSF, ISS
 - Model for Estimating Space Station Operations Costs (MESSOC)
- Evolution for the Constellation Program and Beyond
 - Exploration Architectures Operations Cost Model (ExAOCM)



Earlier Efforts at Modeling HSF Operations Costs: Space Station Freedom c. 1985-1990

- A Design-To-Cost Imperative
 - SSF PM wanted a significant DTC capability that would support design and operations trade studies
 - JPL asked to bring its systems engineering/analysis expertise to bear
 - DTC turned into DTLCC
 - Needed to build a model whose scope was recurring Phase E costs (no systems development/production, ops capability development, or facilities construction)
 - Had to do more than just Phase E costs because DTLCC required it!
 - Needed to know the logistics load on the transportation system (STS)
 - Needed to know the workload on the crew (“human” subsystem)
 - That also dictated the level of detail required by the model.
- Model for Estimating Space Station Costs (MESSOC)
 - Stand-alone capability, but part of the DTLCC model, called SDTM



MESSOC Development Strategy

- Recognize that operations involves many different functional areas*
- Emphasize causal relationships in algorithms and equations
- Capture interactions among represented functional areas
- Build on existing NASA/DoD models (see next slides)
 - Logistics
 - Training
 - Orbital mechanics
 - Launch vehicle performance
- Recognize dynamic year-to-year relationships to accommodate changes in Station configuration and operations activities
- Document algorithms/equations thoroughly and consistently for cost analyst training and software maintenance/improvement

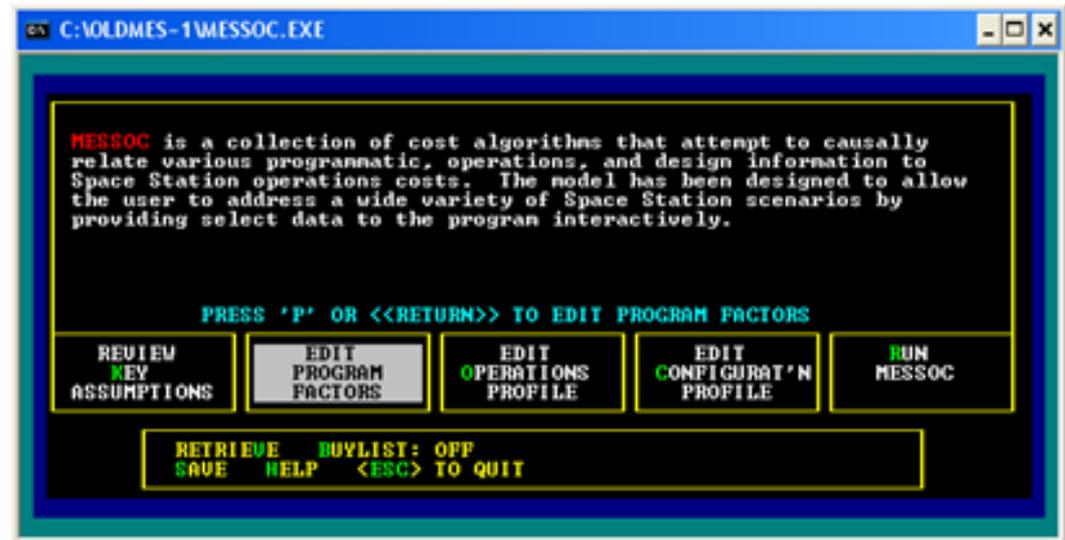
*An official operations (Phase E) WBS was not available.



The Results:

Space Station Freedom c. 1985-1990

- Development environment
 - DOS 3.0
 - Programmed in TurboPascal
 - Separate database in dBase III+
- Less-than-friendly user interface
- Limited data available
- Extensive verification and validation activities, both independent and within SSF





MESSOC Adapted to Space Station Program Changes

- Oct 1986 (Ver. 1.2) First demonstrated at JSC
- Apr 1987 (Ver. 1.3) Incorporated CETF
- Dec 1987 (Ver. 1.4) Incorporated SSOTF
- Oct 1988 (Ver. 2.0) Validation version
- Dec 1989 (Ver. 2.1) First controlled version
- Dec 1990 (Ver. 2.2) Second controlled version

- Dec 2000 (Ver. 3.0) First version for ISS
- Oct 2001 (Ver. 3.1) IMCE/CAST* version
- Aug 2002 (Ver. 3.16) ICE version**
- July 2006 (Ver. 3.18) CEV version w/updated logistics

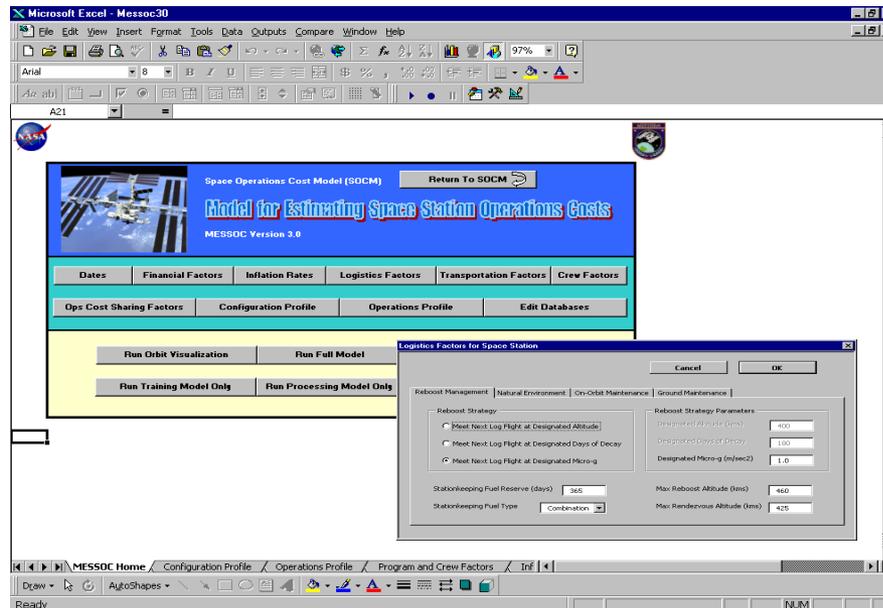
*IMCE = ISS Management and Cost Evaluation Task Force
CAST = Cost Analysis Support Team

**Ver. 3.17 was OSP version, but was never finished



Earlier Efforts at Modeling HSF Operations Costs: International Space Station c. 1998-2003

- MESSOC was re-programmed in Excel 2003 VBA
 - Used modern GUIs for user inputs and selections, and help files
 - Databases were structured as fully relational data tables
 - All data tables were in Excel spreadsheets fully integrated with MESSOC
 - Algorithm documentation in HTML fully integrated with Excel
- Logistics data tables also available in Access 2002





What Did I Learn?

- The structure of MESSOC made changes and additions very difficult.
 - Adding new systems usually required many code changes, requiring re-verification of results.
 - Couldn't change the WBS without major surgery to the code, again very time-intensive and error-prone.
 - Handling dynamic cost drivers was clumsy at best.
 - Difficult to train new users, though the Excel I/F was more comfortable (familiar?).
- Operations and logistics data, if not initially done right, becomes a CM nightmare; more importantly, it casts doubt on cost estimates.
- Probably going to need algorithms that function at different levels of detail and data availability depending on program maturity
- Software easily becomes obsolete. Good documentation is essential for long-term preservation, but not sufficient
- Opportunities to validate HSF operations cost models are rare.



Presentation Outline

- Introduction: Why Are Operations Costs Important?
- A Brief History of Operations Cost Modeling for SSF, ISS
 - Model for Estimating Space Station Operations Costs (MESSOC)

- 
- Evolution for the Constellation Program and Beyond
 - Exploration Architectures Operations Cost Model (ExAOCM)

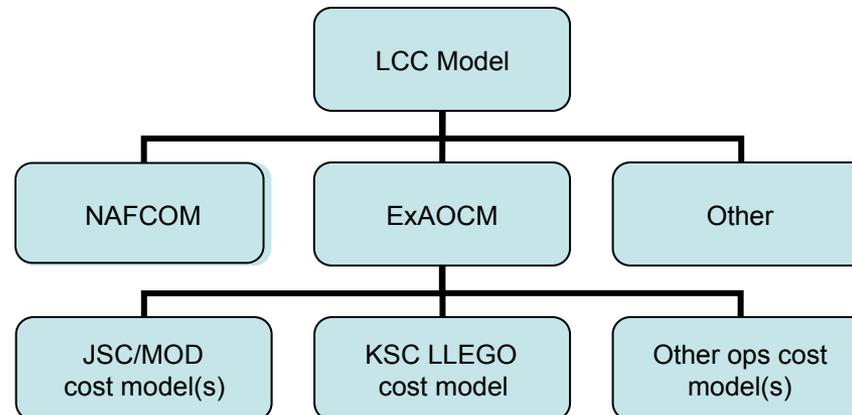


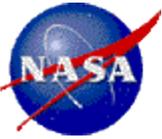
Exploration Architectures Operations Cost Model

Key Questions

- **What is ExAOCM?**

- Model for estimating operations costs for any exploration architecture that is capable of supporting integrated trade studies
- Scope is recurring Phase E costs (no systems development/production, ops capability development, or facilities construction)
- One of several models needed to calculate LCC





Exploration Architectures Operations Cost Model

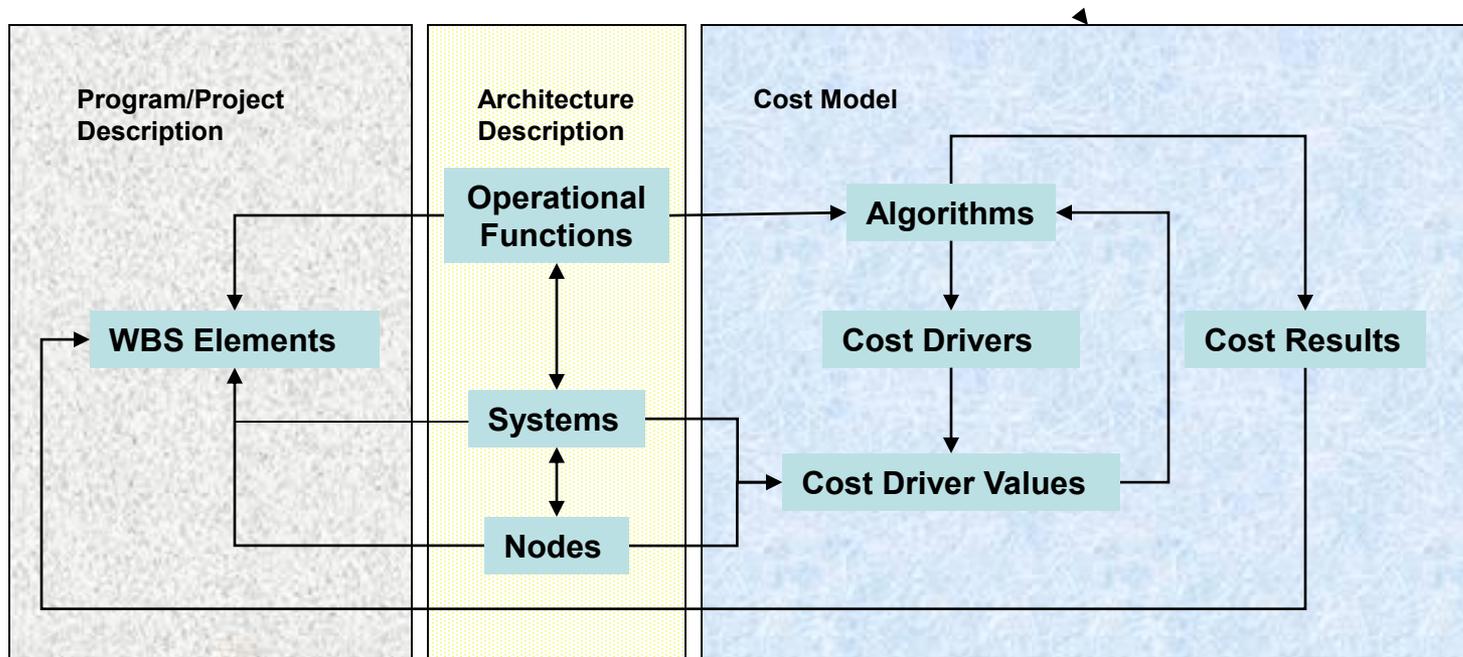
Key Questions

- **What's the approach?**

- ExAOCM draws upon developments in architecture frameworks and system-of-systems thinking.
- DoDAF concepts, language, and formalisms provide a natural way of conceptualizing an exploration operations cost model (and other complex SoS)
 - Operational Nodes (OV-2)
 - Operational Functions/Activities (OV-5)
 - Systems (System Nodes (SV-1) and System Functions (SV-4))
 - Operational Functions/Activities to Systems/System Functions (SV-5)
 - Milestones (System Evolution (SV-8) and System Technology Forecast (SV-9))
 - **Cost Drivers (Not in DoDAF. ExAOCM adds this.)**
- Develop the cost estimate based on causal/engineering relationships and/or analogy with ISS.



Conceptual Flow From Exploration Architecture To Costed Operations WBS



Note: "Systems" box also encompasses "systems nodes" and "systems functions."



Relationship to Other DoDAF “Products”

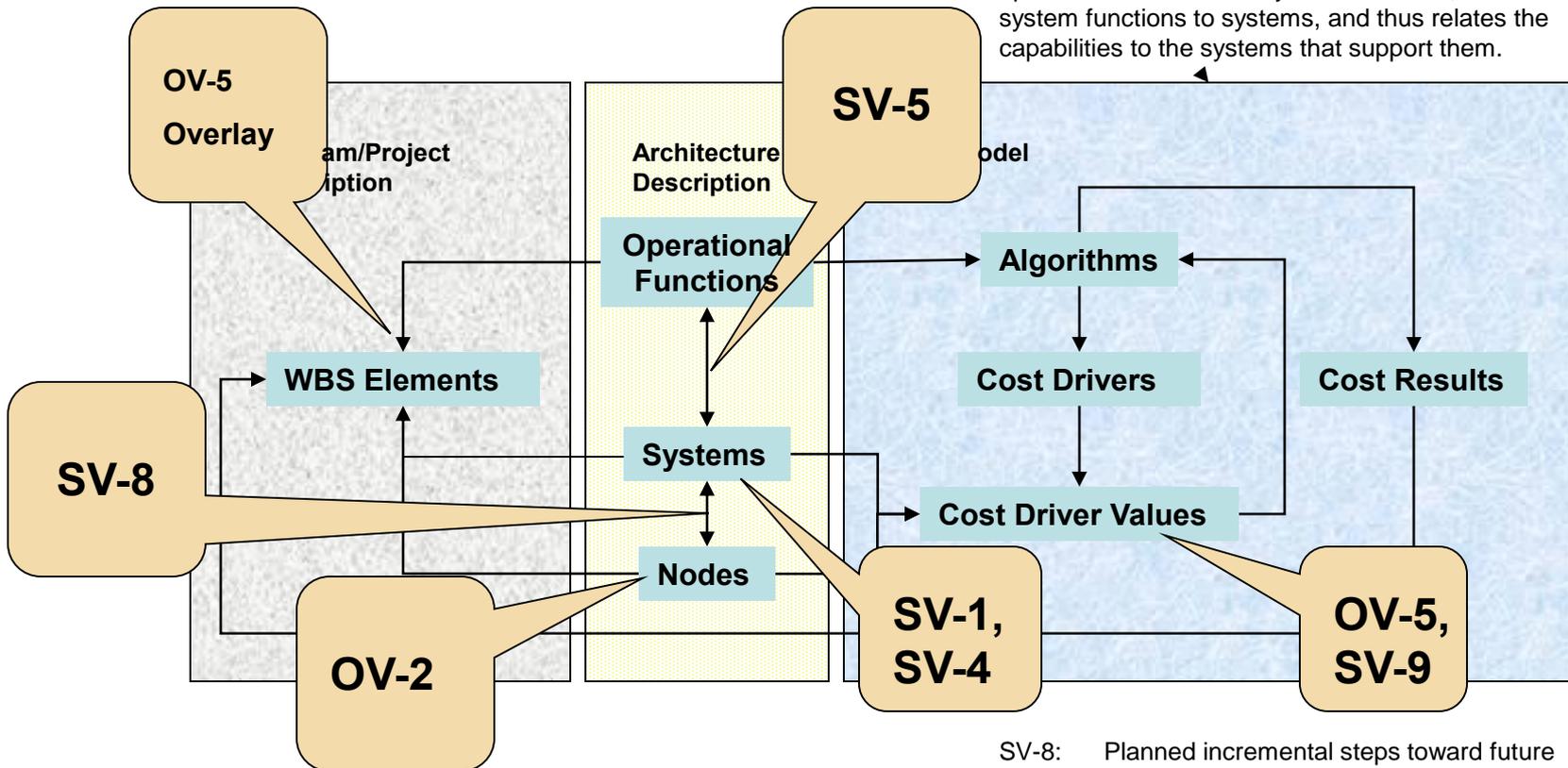
OV-2: Operational nodes, connectivity, and information exchange needlines between nodes

OV-5: Capabilities, operational activities, relationships among activities, inputs, and outputs; overlays can show cost, performing nodes, or other pertinent information

SV-1: Identification of systems nodes, systems, and system items and their interconnections, within and between nodes

SV-4: Functions performed by systems and the system data flows among system functions

SV-5: Maps capabilities to operational activities, operational activities to system functions, and system functions to systems, and thus relates the capabilities to the systems that support them.



SV-8: Planned incremental steps toward future implementation

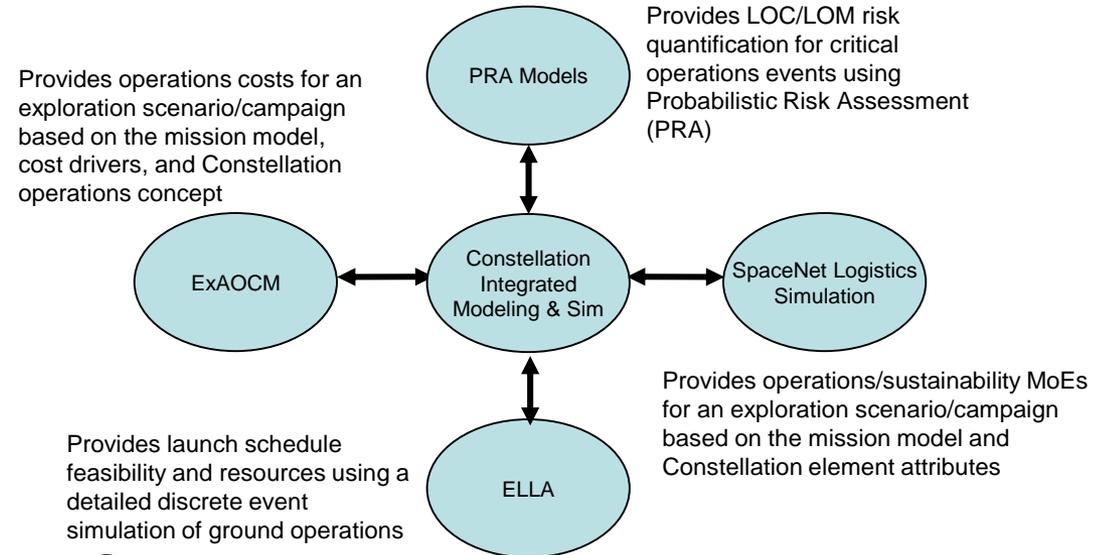
SV-9: Emerging technologies that are expected to be available



Exploration Architectures Operations Cost Model

Key Questions

- **How did it fit into the Cx IM&S picture?**



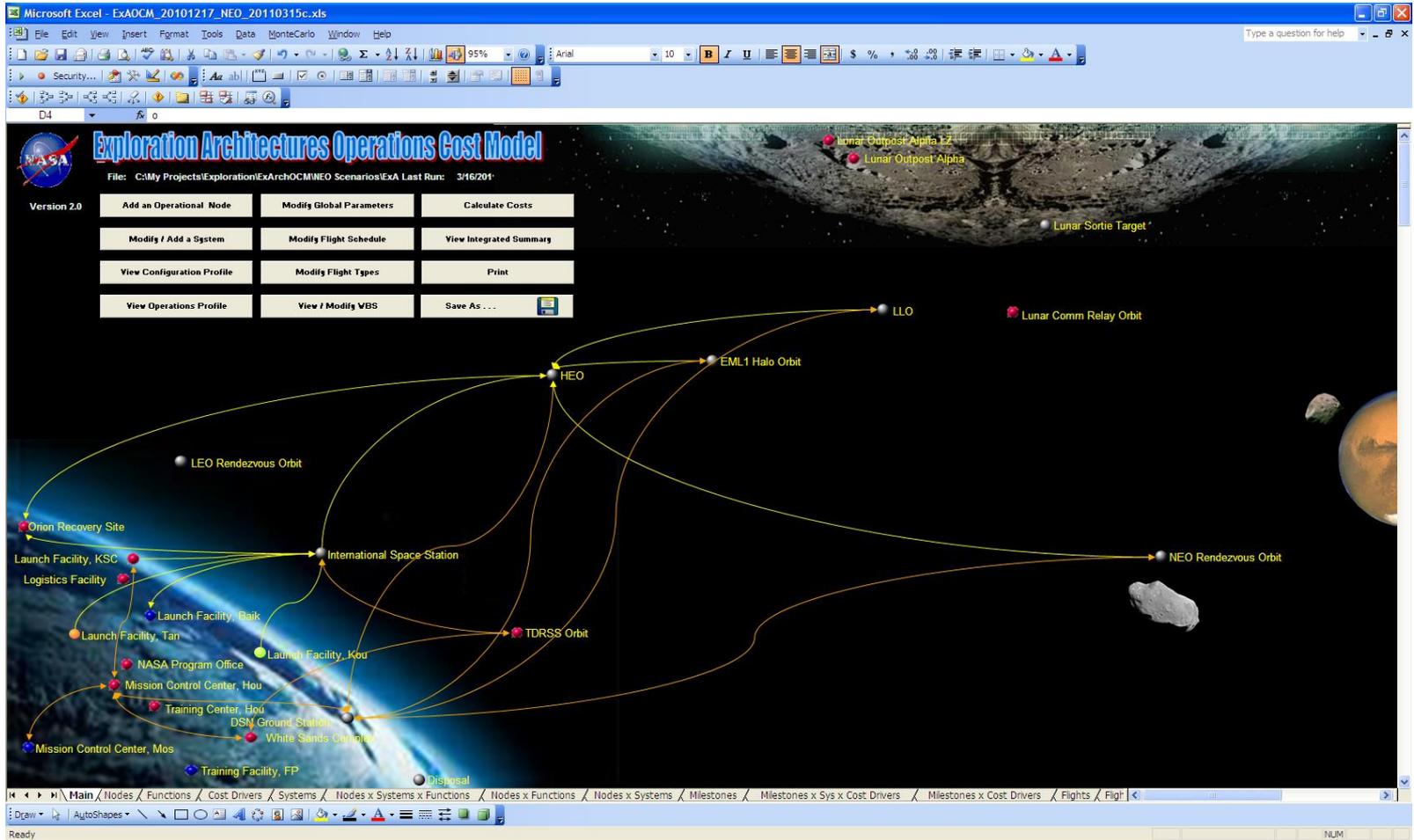
- **What were some uses?**

- Lunar Architecture Team-2 (2007)
- Cx Architecture Team-Lunar (2008)
- Strategic Analysis Team (2009)
- Lunar-Mars Integration Team (2010)
- NEO campaign costs (2011)

- **How does the user/analyst interact with the model?**



Main User Interface is a High-Level Graphic (OV-2)





Main User Interface is a High-Level Graphic (OV-2)

Microsoft Excel - ExAOCM_V2.0_Baseline_NEO_20110425a.xls

File Edit View Insert Format Tools Data MonteCarlo Window Help

Security... Arial 10 100% \$ %

E4

Exploration Architectures Operations Cost Model

File: C:\My Projects\Exploration\ExArchOCM\NEO Scenarios\ExA Last Run: 3/31/2011

Version 2.0

Add an Operational Node	Modify Global Parameters	Calculate Costs
Modify / Add a System	Modify Flight Schedule	View Integrated Summary
View Configuration Profile	Modify Flight Types	Print
View Operations Profile	View / Modify WBS	Save As ...

Milestones x Cost Drivers / Flights / Flight Types / Needlines / WBS / Integrated Summary / Configuration Profile / Operations Profile / Inflation Parameters / System Assessment Summary / Alt View Moon

Ready NJM



Building an Ops Work Breakdown Structure (WBS)

Microsoft Excel - ExAOCM_20101217_NEO_20110315c.xls

File Edit View Insert Format Tools Data MonteCarlo Window Help

95% Arial 10

Security...

D4

Exploration Architectures Operations Cost Model

File: C:\My Projects\Exploration\ExArchoCM\NEO Scenarios\ExA Last Run: 3/16/2011

Version 2.0

Add an Operational Node	Modify Global
Modify / Add a System	Modify Flight Type
View Configuration Profile	Print
View Operations Profile	View / Modify WBS
	Save As ...

Click Here

Orion Recovery Site

Launch Facility, KSC

Logistics Facility

Launch Facility, Tan

NASA Program Office

Mission Control Center, Hou

Training Center, Hou

DSN Ground Station

White Sands Complex

Mission Control Center, Mos

Training Facility, FP

International Space Station

TDRSS Orbit

LEO Rendezvous Orbit

HEO

EML1 Halo Orbit

LLO

Lunar Outpost Alpha

Lunar Outpost Alpha 1,2

Lunar Comm Relay Orbit

Lunar Sortie Target

NEO Rendezvous Orbit

Disposal

Main / Nodes / Functions / Cost Drivers / Systems / Nodes x Systems x Functions / Nodes x Functions / Nodes x Systems / Milestones / Milestones x Sys x Cost Drivers / Milestones x Cost Drivers / Flights / Flight

Draw / AutoShapes

Ready

NUM



A WBS and Illustrative Cost Model Results

Microsoft Excel - ExAOCM_20051118B.xls

File Edit View Insert Format Tools Data Window Help

75% Arial 10 B I U

Q115 =0+Q116+Q117

Exploration Architectures Operations Cost Model
Last Run: 11/18/2005 5:03:49 PM

Work Breakdown Structure Elements			FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17
TOTAL (\$FY65M)			\$ 282.95	\$ 308.14	\$ 310.58	\$ 308.21	\$ 306.68	\$ 296.80	\$ 282.88	\$ 273.3
2.0	Systems Engineering, Analysis, and Integration		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
3.0	Spacecraft		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
4.0	Operations		\$ 282.95	\$ 308.14	\$ 310.58	\$ 308.21	\$ 306.68	\$ 296.80	\$ 282.88	\$ 273.3
4.1	Mission Integration		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
4.2	Medical Operations		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
4.3	Mission Operations		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
4.3.1	Management and Administration		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 248.75	\$ 247.8
4.3.2	Mission Facilities		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 94.19	\$ 94.1
4.3.2.1	Integrated Planning System		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 28.78	\$ 28.7
4.3.2.1.1	IPS Management		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 0.98	\$ 0.9
4.3.2.1.2	IPS Development and Integration		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 5.43	\$ 5.4
4.3.2.1.3	IPS Operations		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 11.37	\$ 11.3
4.3.2.1.4	IPS Maintenance		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 7.50	\$ 7.5
4.3.2.1.4.1	HW Maintenance		\$ 7.50	\$ 3.87	\$ 3.87	\$ 3.87	\$ 3.87	\$ 3.87	\$ 3.87	\$ 3.8
4.3.2.1.4.2	SW Maintenance		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
4.3.2.1.5	IPS Sustaining Engineering		\$ -	\$ 10.99	\$ 10.99	\$ 10.99	\$ 10.99	\$ 10.99	\$ 10.99	\$ 10.9
4.3.2.2	Mission Control Center		\$ 65.41	\$ 65.41	\$ 65.41	\$ 65.41	\$ 65.41	\$ 65.41	\$ 65.41	\$ 65.4
4.3.2.2.1	MCC Management		\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.9
4.3.2.2.2	MCC Development and Integration		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
4.3.2.2.3	MCC Operations		\$ 42.06	\$ 42.06	\$ 42.06	\$ 42.06	\$ 42.06	\$ 42.06	\$ 42.06	\$ 42.0
4.3.2.2.3.1	Telemetry Processing		\$ 28.81	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 28.8
4.3.2.2.3.2	Commanding		\$ 13.25	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 13.2
4.3.2.2.4	MCC Maintenance		\$ 11.37	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 11.3
4.3.2.2.4.1	HW Maintenance		\$ 7.50	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 7.5
4.3.2.2.4.2	SW Maintenance		\$ 3.87	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 3.8
4.3.2.2.5	MCC Sustaining Engineering		\$ 10.99	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 10.9
4.3.3	Training		\$ 80.17	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 80.9
4.3.3.1	Training Plans, Proc. Dev., Scheduling, and Instruction		\$ 22.62	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 23.3
4.3.3.1.1	Training Management		\$ 4.24	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 4.3
4.3.3.1.2	Training Plans and Procedure Development		\$ 0.91	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 0.9
4.3.3.1.2.1	EVA and Robotics Pre-flight Support		\$ 0.64	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 0.6
4.3.3.1.2.2	Crew Systems, TV, and Mech Pre-flight Support		\$ 0.27	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 0.2
4.3.3.1.3	Instruction		\$ 17.26	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 17.8
4.3.3.1.3.1	EVA and Robotics Training		\$ 0.07	\$ 0.07	\$ 0.07	\$ 0.07	\$ 0.07	\$ 0.07	\$ 0.07	\$ 0.0
4.3.3.1.3.2	Crew/FC Core Training		\$ 12.79	\$ 13.3	\$ 13.72	\$ 13.72	\$ 13.72	\$ 13.72	\$ 13.72	\$ 13.3
4.3.3.1.3.3	FC Certification Training		\$ 4.40	\$ 4.40	\$ 4.40	\$ 4.40	\$ 4.40	\$ 4.40	\$ 4.40	\$ 4.4
4.3.3.1.4	Training Planning and Scheduling		\$ 0.21	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.9
4.3.3.2	Training and Evaluation Facilities		\$ 57.55	\$ 57.55	\$ 57.55	\$ 57.55	\$ 57.55	\$ 57.55	\$ 57.55	\$ 57.5
4.3.3.2.1	FCT		\$ 28.78	\$ 28.78	\$ 28.78	\$ 28.78	\$ 28.78	\$ 28.78	\$ 28.78	\$ 28.7
4.3.3.2.1.1	FCT Management		\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.9
4.3.3.2.1.2	FCT Development and Integration		\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
4.3.3.2.1.3	FCT Operations		\$ 5.43	\$ 5.43	\$ 5.43	\$ 5.43	\$ 5.43	\$ 5.43	\$ 5.43	\$ 5.4
4.3.3.2.1.4	FCT Maintenance		\$ 11.37	\$ 11.37	\$ 11.37	\$ 11.37	\$ 11.37	\$ 11.37	\$ 11.37	\$ 11.3
4.3.3.2.1.4.1	HW Maintenance		\$ 7.50	\$ 7.50	\$ 7.50	\$ 7.50	\$ 7.50	\$ 7.50	\$ 7.50	\$ 7.5
4.3.3.2.1.4.2	SW Maintenance		\$ 3.87	\$ 3.87	\$ 3.87	\$ 3.87	\$ 3.87	\$ 3.87	\$ 3.87	\$ 3.8
4.3.3.2.1.5	FCT Sustaining Engineering		\$ 10.99	\$ 10.99	\$ 10.99	\$ 10.99	\$ 10.99	\$ 10.99	\$ 10.99	\$ 10.9
4.3.3.2.2	SMTF		\$ 28.78	\$ 28.78	\$ 28.78	\$ 28.78	\$ 28.78	\$ 28.78	\$ 28.78	\$ 28.7
4.3.3.2.2.1	SMTF Management		\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.98	\$ 0.9

Main Menu Print Assessment

File: C:\My Projects\Exploration\ExArch\OCMEz\AOCM_20051118B.xls

WBS Work Area

Illustrative Cost Results Only

Main \ Nodes \ Functions \ Systems \ Cost Drivers \ Nodes x Systems x Functions \ Nodes x Functions \ Nodes x Systems \ Missions \ Needlines \ WBS \ Intec

Ready Sum= \$ 426.38 NUM



Developing an Operations WBS

- Create an Operational Function, e.g., SW maintenance
- Think system-based WBS, not organizational-based WBS
- Think of each leaf in terms of how could one estimate the resources needed to perform that function or produce that output
- For example:
 - Mission Control Center system
 - SW maintenance cost = $f(\text{number of SLOCs, annual programmer productivity, . . .})$
 - HW maintenance cost = $g(\text{availability requirement, MTBF, MTTR, . . .})$
 - Real-time mission execution = $\phi(\text{number of flight controller positions, on-console duty cycle, . . .})$



Building an HSF Architecture: Add/Modify a Node

Microsoft Excel - ExAOCM_20101217_NEO_20110315c.xls

File Edit View Insert Format Tools Data MonteCarlo Window Help

95% Arial 10

Security...

Click Here

Exploration Cost Model

File: C:\My Projects\Exploration\ExAOCM\NEO Scenarios\ExA Last Run: 3/16/2011

Version 2.0

Add an Operational Node	Modify Global Parameters	Calculate Costs
Modify Add a System	Modify Flight Schedule	View Integrated Summary
View Configuration Profile	Modify Flight Types	Print
View Operations Profile	View / Modify VBS	Save As ...

Orion Recovery Site
Launch Facility, KSC
Logistics Facility
Launch Facility, Tan
Launch Facility, Baik
Launch Facility, Kour
NASA Program Office
Mission Control Center, Hou
Training Center, Hou
Mission Control Center, Mos
Training Facility, FP
International Space Station
HEO
EML1 Halo Orbit
LLO
Lunar Outpost Alpha 1,2
Lunar Outpost Alpha
Lunar Sortie Target
Lunar Comm Relay Orbit
TDRSS Orbit
NEO Rendezvous Orbit
Disposal

Main / Nodes / Functions / Cost Drivers / Systems / Nodes x Systems x Functions / Nodes x Functions / Nodes x Systems / Milestones / Milestones x Sys x Cost Drivers / Milestones x Cost Drivers / Flights / Flight

Draw AutoShapes

Ready NUM



Building an HSF Architecture: Add/Modify a Node

Microsoft Excel - ExAOCM_20101217_NEO_20110315c.xls

File Edit View Insert Format Tools Data MonteCarlo Window Help

95% Arial 10

File: C:\My Projects\Exploration\ExArchoCM\NEO Scenarios\ExA Last Run: 3/16/2011

Version 2.0

Add an Operational Node	Modify Global Parameters	Calculate Costs
Modify Add a System	Modify Flight Schedule	View Integrated Summary
View Configuration Profile	Modify Flight Types	Print
View Operations Profile	View / Modify VBS	Save As ...

Exploration Architectures Operations Cost Model

Nodes

Node ID: 21

Node Name:

Partner ID: Joint

Location:

Node Placement:

Label On Left (T/F)

Functional Area:

SpaceNet Node ID:

Source/Comments:

OK

Cancel

Main / Nodes / Functions / Cost Drivers / Systems / Nodes x Systems x Functions / Nodes x Functions / Nodes x Systems / Milestones / Milestones x Sys x Cost Drivers / Milestones x Cost Drivers / Flights / Flight

Ready



Building an HSF Architecture: Add/Modify a System

Microsoft Excel - ExAOCM_20101217_NEO_20110315c.xls

File Edit View Insert Format Tools Data MonteCarlo Window Help

95% Arial 10

Click Here

Version 2.0

Add an Operational Node	Modify Global Parameters	Calculate Costs
Modify / Add a System	Modify Flight Schedule	View Integrated Summary
View Configuration Profile	Modify Flight Types	Print
View Operations Profile	View / Modify VBS	Save As ...

Orion Recovery Site
Launch Facility, KSC
Logistics Facility
Launch Facility, Tan
NASA Program Office
Mission Control Center, Hou
Training Center, Hou
DSN Ground Station
White Sands Complex
Mission Control Center, Mos
Training Facility, FP
International Space Station
TDRSS Orbit
LEO Rendezvous Orbit
HEO
EML1 Halo Orbit
LLO
Lunar Comm Relay Orbit
Lunar Outpost Alpha
Lunar Outpost Alpha L2
Lunar Sortie Target
NEO Rendezvous Orbit

Main / Nodes / Functions / Cost Drivers / Systems / Nodes x Systems x Functions / Nodes x Functions / Nodes x Systems / Milestones / Milestones x Sys x Cost Drivers / Milestones x Cost Drivers / Flights / Flight

Draw AutoShapes

Ready NUM



Building an HSF Architecture: Create/Modify a Relationship

Microsoft Excel - ExAOCM_20101217_NEO_20110315c.xls

File Edit View Insert Format Tools Data MonteCarlo Window Help

95% Arial 10

File: C:\My Projects\Exploration\ExArchoCM\NEO Scenarios\ExA Last Run: 3/16/2011

Version 2.0

Add an Operational Node	Modify Global Parameters	Calculate Costs
Modify / Add a System	Modify Flight Schedule	View Integrated Summary
View Configuration Profile	Modify Flight Types	Print
View Operations Profile	View / Modify VBS	Save As ...

Click Here

LEO Rendezvous Orbit

Orion Recovery Site

Launch Facility, KSC

Logistics Facility

Launch Facility, Tan

Launch Facility, Baik

Launch Facility, Kour

NASA Program Office

Mission Control Center, Hou

Training Center, Hou

Mission Control Center, Mos

International Space Station

TDRSS Orbit

White Sands Complex

Training Facility, FP

Disposal

HEO

EML1 Halo Orbit

LLO

Lunar Comm Relay Orbit

Lunar Outpost Alpha

Lunar Outpost Alpha 1,2

Lunar Sortie Target

NEO Rendezvous Orbit

Main / Nodes / Functions / Cost Drivers / Systems / Nodes x Systems x Functions / Nodes x Functions / Nodes x Systems / Milestones / Milestones x Sys x Cost Drivers / Milestones x Cost Drivers / Flights / Flight

Draw / AutoShapes

Ready

NUM



Building an HSF Architecture: Create/Modify a Relationship

Microsoft Excel - ExAOCM_20101217_NEO_20110315c.xls

File Edit View Insert Format Tools Data MonteCarlo Window Help

Type a question for help

95% Arial 10

D4

Exploration Architectures Operations Cost Model

File: C:\My Projects\Exploration\ExArchoCM\NEO Scenarios\ExA Last Run: 3/16/2011

Version 2.0

Add an Operational Node	Modify Global Parameters	Calculate Costs
Modify / Add a System	Modify Flight Schedule	View Integrated Summary
View Configuration Profile	Modify Flight Types	Print
View Operations Profile	View / Modify VBS	Save As ...

LEO Rendezvous

Orion Recovery Site

Launch Facility, KSC

Logistics Facility

Launch Facility, Baik

Launch Facility, Tan

NASA Program Office

Mission Control Center, Hou

Training Center, Hou DSN

Mission Control Center, Mos

Training Facility, FP

Disposal

Lunar Outpost Alpha-L2

Lunar Outpost Alpha

Lunar Sortie Target

LLO

Lunar Comm Relay Orbit

NEO Rendezvous Orbit

Modify A Node

Node Name: Lunar Outpost Alpha

Select an Action: Add or Modify a Milestone for This Node

- Change Node Name or Attributes
- Add or Modify a Milestone for This Node
- Assign an Ops Function to This Node
- Assign or Modify a System at This Node
- Assign an Ops Function to a System at This Node
- Add or Modify a System Quantity at This Node
- Add or Modify a Cost Driver at This Node
- Add or Modify a System Cost Driver at This Node
- Add or Modify a Needline at This Node
- Delete a Needline at This Node
- Delete This Node

OK

Cancel

Main / Nodes / Functions / Cost Drivers / Systems / Nodes x Systems x Functions / Nodes x Functions / Nodes x Systems / Milestones / Milestones x Sys x Cost Drivers / Milestones x Cost Drivers / Flights / Flight

Draw / AutoShapes

Ready

NUM



Building an HSF Architecture: Create/Modify a Relationship

The screenshot displays a workflow in Microsoft Excel for the 'Exploration Architectures Operations Cost Model'. The main application window shows a navigation menu with options like 'Add an Operational Node', 'Modify Global Parameters', and 'Calculate Costs'. A 'Modify A Node' dialog box is open, showing the 'Node Name' as 'Lunar Outpost Alpha' and the 'Select an Action' dropdown set to 'Add or Modify a Milestone for This Node'. A 'Milestones' dialog box is also open, showing a table with the following data:

Milestones		Record 1 of 40
Milestone ID	17	
Milestone Name	Lunar Outpost EOM	
Milestone Type	EOM	
Node ID	Lunar Outpost Alpha	
Milestone Date	10/1/2051	
Source/Comments		

The background of the application shows a network diagram of various mission nodes such as 'Orion Recovery Site', 'Launch Facility, KSC', 'Logistics Facility', 'Launch Facility, Baikonur', 'Launch Facility, Tan', 'NASA Program Office', 'Mission Control Center, Houston', 'Training Center, Houston DSN', 'Mission Control Center, Moscow', and 'Training Facility, Florida'. The diagram is overlaid on a space-themed background with images of the Moon and Mars.



Building an HSF Architecture: Create/Modify a Relationship

Microsoft Excel - ExAOCM_20101217_NEO_20110315c.xls

File Edit View Insert Format Tools Data MonteCarlo Window Help

95% Arial 10

File: C:\My Projects\Exploration\ExArchoCM\NEO Scenarios\ExA Last Run: 3/16/2011

Version 2.0

Add an Operational Node	Modify Global Parameters	Calculate Costs
Modify / Add a System	Modify Flight Schedule	View Integrated Summary
View Configuration Profile	Modify Flight Types	Print
View Operations Profile	View / Modify VBS	Save As ...

Exploration Architectures Operations Cost Model

LEO Rendezvous

Orion Recovery Site

Launch Facility, KSC

Logistics Facility

Launch Facility, Baikonur

Launch Facility, Tan

NASA Program Office

Mission Control Center, Houston

Training Center, Houston

Mission Control Center, Moscow

Training Facility, Florida

Disposal

Lunar Outpost Alpha 1,2

Lunar Outpost Alpha

Lunar Sortie Target

LLO

Lunar Comm Relay Orbit

NEO Rendezvous Orbit

Modify A Node

Node Name: Lunar Outpost Alpha

Select an Action: Add or Modify a Needline at This Node

- Change Node Name or Attributes
- Add or Modify a Milestone for This Node
- Assign an Ops Function to This Node
- Assign or Modify a System at This Node
- Assign an Ops Function to a System at This Node
- Add or Modify a System Quantity at This Node
- Add or Modify a Cost Driver at This Node
- Add or Modify a System Cost Driver at This Node
- Add or Modify a Needline at This Node
- Delete a Needline at This Node
- Delete This Node

OK

Cancel

Main \ Nodes \ Functions \ Cost Drivers \ Systems \ Nodes x Systems x Functions \ Nodes x Functions \ Nodes x Systems \ Milestones \ Milestones x Sys x Cost Drivers \ Milestones x Cost Drivers \ Flights \ Flight

Draw AutoShapes

Ready NUM



Building an HSF Architecture: Create/Modify a Relationship

The screenshot shows a Microsoft Excel spreadsheet titled "ExAOCM_20101217_NEO_20110315c.xls" with the "Exploration Architectures Operations Cost Model" application overlaid. The application window features a menu bar with options like "Add an Operational Node", "Modify Global Parameters", and "Calculate Costs". The main area displays a network diagram with nodes such as "Orion Recovery Site", "Launch Facility, KSC", "Logistics Facility", "Launch Facility, Baikonur", "Launch Facility, Tan", "NASA Program Office", "Mission Control Center, Houston", "Training Center, Houston", "Mission Control Center, Moscow", and "Training Facility, Florida".

Two dialog boxes are open:

- Modify A Node:** The "Node Name" field is set to "Lunar Outpost Alpha". The "Select an Action" dropdown menu is open, showing options: "Add or Modify a Needline at This Node", "Change Node Name or Attributes", "Add or Modify a Milestone for This Node", "Assign an Ops Function to This Node", "Assign or Modify a Milestone", "Assign an Ops Function", "Add or Modify a Milestone", "Add or Modify a Milestone", "Add or Modify a Milestone", "Delete a Milestone", and "Delete This Node".
- Needlines:** The "Sink Node ID" is "Lunar Outpost Alpha". The "Source Node ID" is "Lunar Outpost Alpha LZ". The "Needline Type" dropdown is open, showing options: "One-way Logistics", "Two-way Logistics", "One-way Communications", "Two-way Communications", and "Positioning".



Building an HSF Architecture: Create/Modify a Relationship

Microsoft Excel - ExAOCM_20101217_NEO_20110315c.xls

File Edit View Insert Format Tools Data MonteCarlo Window Help

95% Arial 10

Security... Az ab |

D4

Exploration Architectures Operations Cost Model

File: C:\My Projects\Exploration\ExArchoCM\NEO Scenarios\ExA Last Run: 3/16/2011

Version 2.0

Add an Operational Node	Modify Global Parameters	Calculate Costs
Modify / Add a System	Modify Flight Schedule	View Integrated Summary
View Configuration Profile	Modify Flight Types	Print
View Operations Profile	View / Modify VBS	Save As ...

LEO Rendezvous
Orion Recovery Site
Launch Facility, KSC
Logistics Facility
Launch Facility, Baikonur
Launch Facility, Tan
NASA Program Office
Mission Control Center, Houston
Training Center, Houston
Mission Control Center, Moscow
Training Facility, Florida
Disposal
Lunar Outpost Alpha 1, 2
Lunar Outpost Alpha
Lunar Sortie Target
LLO
Lunar Comm Relay Orbit
NEO Rendezvous Orbit

Modify A Node

Node Name: Lunar Outpost Alpha

Select an Action: Add or Modify a System Cost Driver at This Node

- Change Node Name or Attributes
- Add or Modify a Milestone for This Node
- Assign an Ops Function to This Node
- Assign or Delete a System at This Node
- Assign an Ops Function to a System at This Node
- Add or Modify a System Quantity at This Node
- Add or Modify a Cost Driver at This Node
- Add or Modify a System Cost Driver at This Node**
- Add or Modify a Needline at This Node
- Delete a Needline at This Node
- Delete This Node

OK Cancel

Ready NUM



Building an HSF Architecture: Create/Modify a Relationship

Microsoft Excel - ExAOCM_20101217_NEO_20110315c.xls

File Edit View Insert Format Tools Data MonteCarlo Window Help

Type a question for help

95% Arial 10

Exploration Architectures Operations Cost Model

File: C:\My Projects\Exploration\ExArchoCM\NEO Scenarios\ExA Last Run: 3/16/2011

Version 2.0

Add an Operational Node	Modify Global Parameters	Calculate Costs
Modify / Add a System	Modify Flight Schedule	View Integrated Summary
View Configuration Profile	Modify Flight Types	Print
View Operations Profile	View / Modify VBS	Save As ...

LEO Rendezvous Orbit

Orion Recovery Site

Launch Facility, KSC

Logistics Facility

Launch Facility, Baikonur

Launch Facility, Tan

NASA Program Office

Mission Control Center, Houston

Training Center, Houston

DSN Ground Station

Mission Control Center, Moscow

White Sands Complex

Training Facility, Florida

Disposal

Lunar Outpost Alpha 1,2

Lunar Outpost Alpha

Lunar Sortie Target

LLO

Lunar Comm Relay Orbit

NEO Rendezvous Orbit

Milestone x Sys x Cost Driver

Milestone x Sys x Cost Driver

Node ID	Lunar Outpost Alpha
Milestone ID	Flt 2020-A (IOC)
System ID	LAT Solar Power Unit
Cost Driver ID	system_quantity
Cost Driver Value	
Cost Driver Distribution ID	None
Distribution String	
Cost Driver Units	
Source/Comments	

OK

Cancel

Main / Nodes / Functions / Cost Drivers / Systems / Nodes x Systems x Functions / Nodes x Functions / Nodes x Systems / Milestones / Milestones x Sys x Cost Drivers / Milestones x Cost Drivers / Flights / Flight

Ready



Building an HSF Architecture: Define/Modify Flight Types

Microsoft Excel - ExAOCM_20101217_NEO_20110315c.xls

File Edit View Insert Format Tools Data MonteCarlo Window Help

95% Arial 10

Security...

D4

Exploration Architectures Operations Cost Model

File: C:\My Projects\Exploration\ExArchoCM\... Version 2.0

Add an Operational Node	Modify G...	
Modify / Add a System	Modify Flight Schedule	View Integrated Summaries
View Configuration Profile	Modify Flight Types	Print
View Operations Profile	View / Modify VBS	Save As ...

Click Here

Orion Recovery Site
Launch Facility, KSC
Logistics Facility
Launch Facility, Tan
NASA Program Office
Mission Control Center, Hou
Training Center, Hou
DSN Ground Station
White Sands Complex
Mission Control Center, Mos
Training Facility, FP
International Space Station
TDRSS Orbit
LEO Rendezvous Orbit
HEO
EML1 Halo Orbit
LLO
Lunar Outpost Alpha
Lunar Outpost Alpha 1,2
Lunar Comm Relay Orbit
Lunar Sortie Target
NEO Rendezvous Orbit
Disposal

Main / Nodes / Functions / Cost Drivers / Systems / Nodes x Systems x Functions / Nodes x Functions / Nodes x Systems / Milestones / Milestones x Sys x Cost Drivers / Milestones x Cost Drivers / Flights / Flight

Draw / AutoShapes

Ready NUM



Building an HSF Architecture: Define/Modify Flight Types

Microsoft Excel - ExAOCM_20101217_NEO_20110315c.xls

File Edit View Insert Format Tools Data MonteCarlo Window Help

Type a question for help

95%

Arial 10

D4

Exploration Architectures Operations Cost Model

File: C:\My Projects\Exploration\ExArchoCM\NEO Scenarios\ExA Last Run: 3/16/2011

Version 2.0

Add an Operational Node	Modify Global Parameters	Calculate Costs
Modify / Add a System	Modify Flight Schedule	View Integrated Summary
View Configuration Profile	Modify Flight Types	Print
View Operations Profile	View / Modify VBS	Save As...

LEO Rendezvous

Orion Recovery Site

Launch Facility, KSC

Logistics Facility

Launch Facility, Baikonur

Launch Facility, Tananarive

NASA Program Office

Mission Control Center, Houston

Training Center, Houston

Mission Control Center, Moscow

Training Facility

mm Relay Orbit

Lunar Outpost Alpha 1,2

Lunar Outpost Alpha

Lunar Sortie Target

NEO Rendezvous Orbit

Flight Types

Record 2 of 15

Flight Type ID	13
Flight Type Name	Lunar Outpost Buildup
Partner ID	U.S.
Departure Node ID	Launch Facility, KSC
Destination Node ID	Lunar Outpost Alpha
Crew Size	0
Carrier System ID	Cargo Lunar Lander Vehicle
LV System ID	Cargo Launch Vehicle (CaLV)
Nominal Duration (days)	
Planned EVAs (two-person)	
Surface Duration (days)	
Source/Comments	

Apply

OK

Cancel

NUM



Building an HSF Architecture: Create/Modify a Manifest

Microsoft Excel - ExAOCM_20101217_NEO_20110315c.xls

File Edit View Insert Format Tools Data MonteCarlo Window Help

95% Arial 10

Security...

Version 2.0

File: C:\My Projects\Exploration\ExArchoCM\NEO

Click Here

Add an Operational Node	Modify Global Parameters	Calculate Costs
Modify / Add a System	Modify Flight Schedule	View Integrated Summary
View Configuration Profile	Modify Flight Types	Print
View Operations Profile	View / Modify VBS	Save As ...

Orion Recovery Site

Launch Facility, KSC

Logistics Facility

Launch Facility, Tan

Launch Facility, Baik

Launch Facility, Kour

NASA Program Office

Mission Control Center, Hou

Training Center, Hou

DSN Ground Station

White Sands Complex

Mission Control Center, Mos

Training Facility, FP

Disposal

International Space Station

LEO Rendezvous Orbit

HEO

EML1 Halo Orbit

LLO

Lunar Outpost Alpha 1.2

Lunar Outpost Alpha

Lunar Comm Relay Orbit

Lunar Sortie Target

NEO Rendezvous Orbit

TDRSS Orbit

Main / Nodes / Functions / Cost Drivers / Systems / Nodes x Systems x Functions / Nodes x Functions / Nodes x Systems / Milestones / Milestones x Sys x Cost Drivers / Milestones x Cost Drivers / Flights / Flight

Draw / AutoShapes

Ready

NUM



Building an HSF Architecture: Create/Modify a Manifest

Microsoft Excel - ExAOCM_20101217_NEO_20110315c.xls

File Edit View Insert Format Tools Data MonteCarlo Window Help

95% Arial 10

Security... | Az ab |

D4

Exploration Architectures Operations Cost Model

File: C:\My Projects\Exploration\ExArchoCM\NEO Scenarios\ExA Last Run: 3/16/2011

Version 2.0

Add an Operational Node	Modify Global Parameters	Calculate Costs
Modify / Add a System	Modify Flight Schedule	View Integrated Summary
View Configuration Profile	Modify Flight Types	Print
View Operations Profile	View / Modify VBS	Save As...

Flights

Record 1 of 4

Flight ID	95
Flight Type ID	Lunar Outpost Buildup
Nominal Flight Start Date	1/21/2021
Nominal Flight Arrival Date	
Payload Manifested	HAB 3, HAB 4, SPU, 12kW 200m Cable,
	<input checked="" type="checkbox"/> Include In Ops Profile (T/F)
Source/Comments	LAT Option 2-July 6mt Lander Baseline Flt

Apply OK Cancel

LEO Rendezvous
Orion Recovery Site
Launch Facility, KSC
Logistics Facility
Launch Facility, Baikonur
Launch Facility, Tananarive
NASA Program Office
Mission Control Center, Houston
Training Center, Houston
Mission Control Center, Moscow
Training Facility, Florida
White Sands Complex
DSN Ground Station
Disposal
Lunar Outpost Alpha 1, 2
Lunar Outpost Alpha
Lunar Sortie Target
Relay Orbit
NEO Rendezvous Orbit

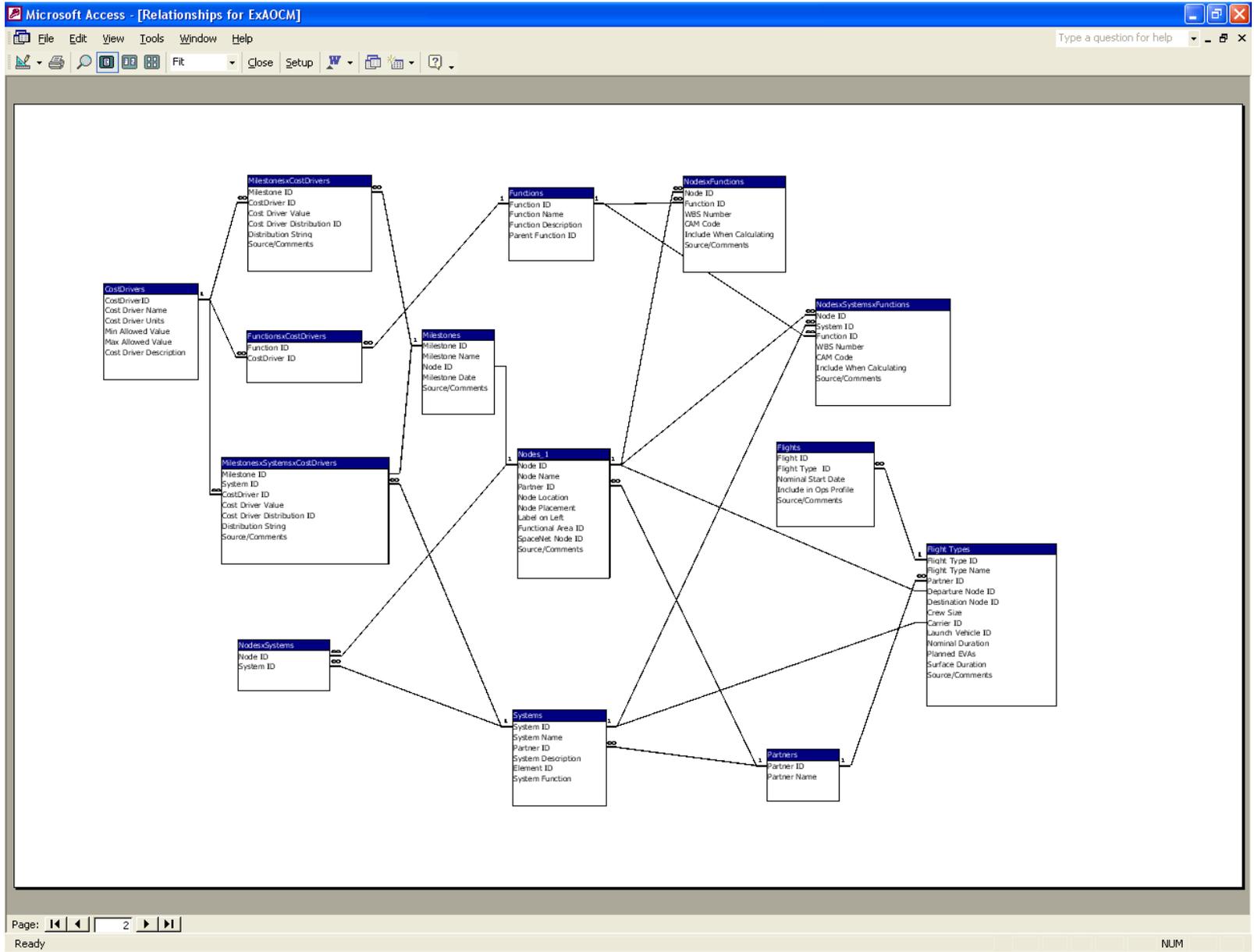
Main / Nodes / Functions / Cost Drivers / Systems / Nodes x Systems x Functions / Nodes x Functions / Nodes x Systems / Milestones / Milestones x Sys x Cost Drivers / Milestones x Cost Drivers / Flights / Flight

Draw | AutoShapes

Ready NUM

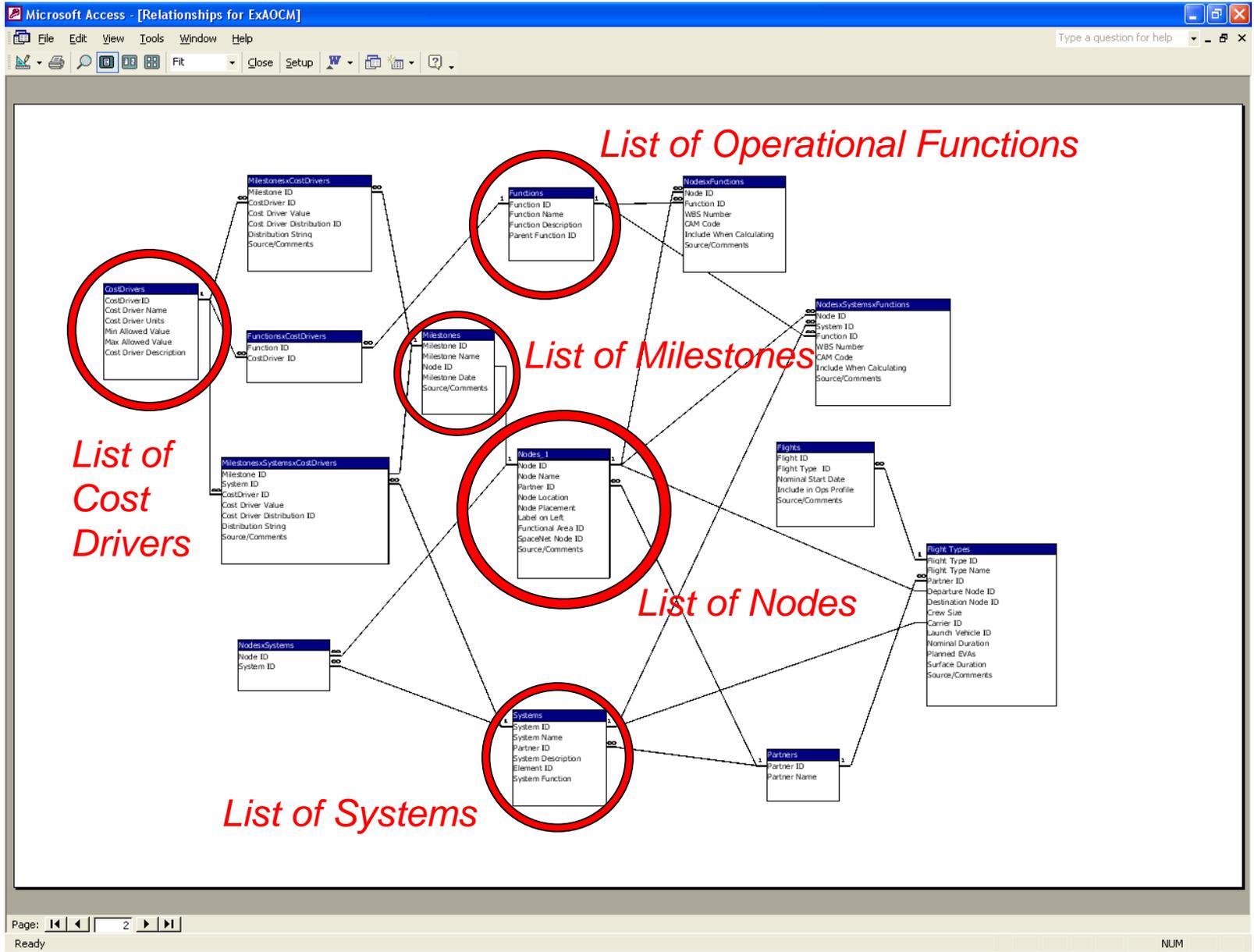


Datatables in ExAOCM



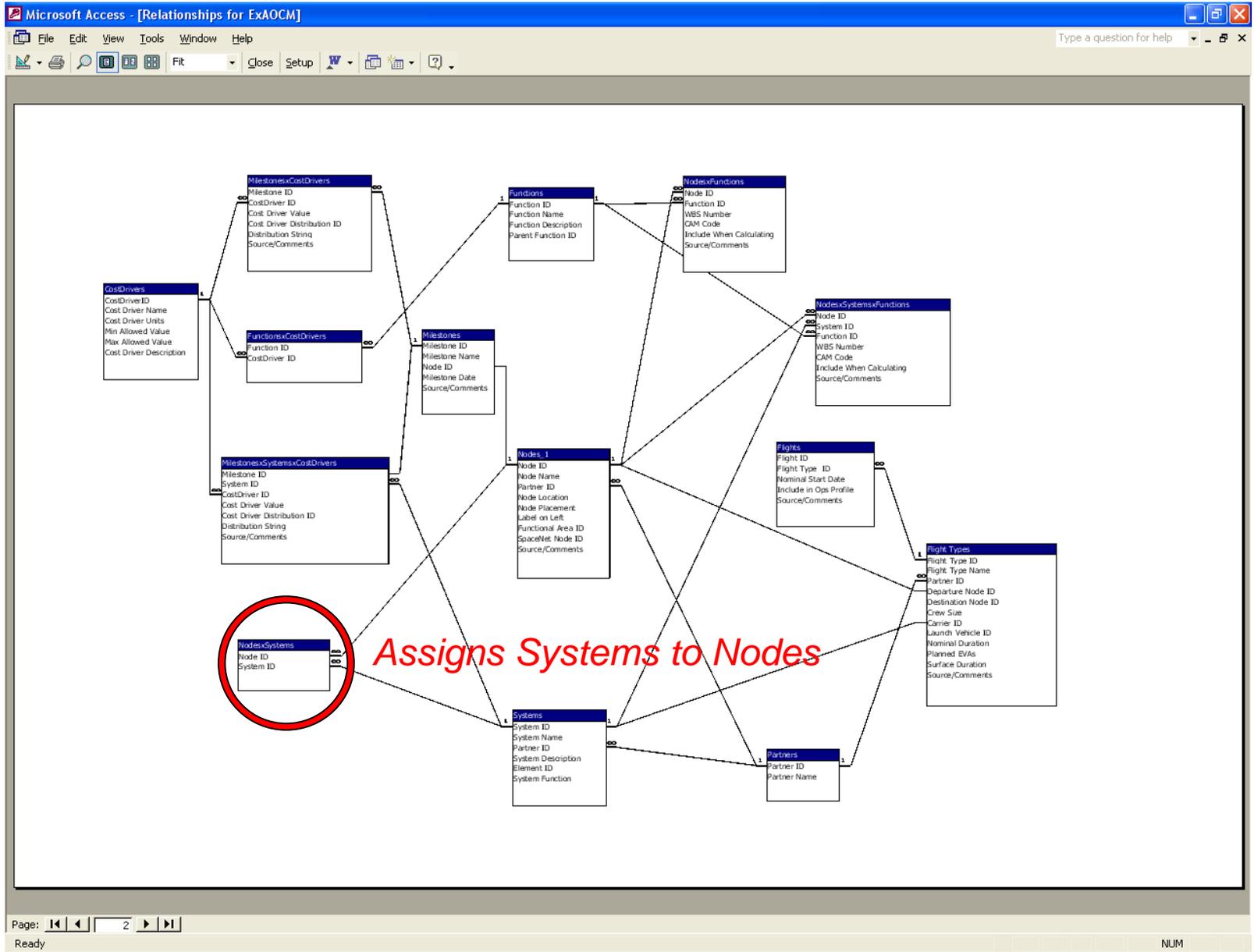


Datatables in ExAOCM



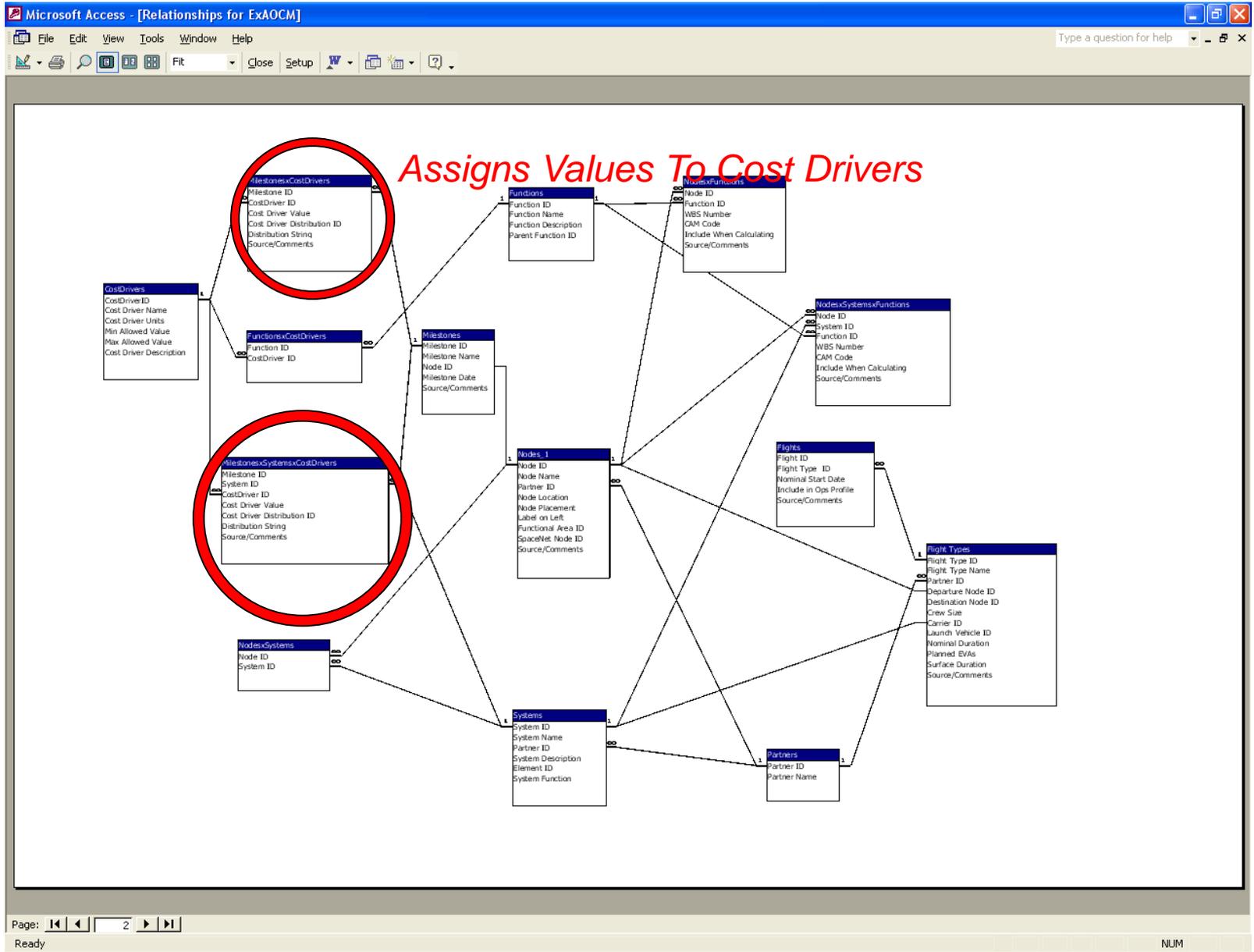


Datatables in ExAOCM



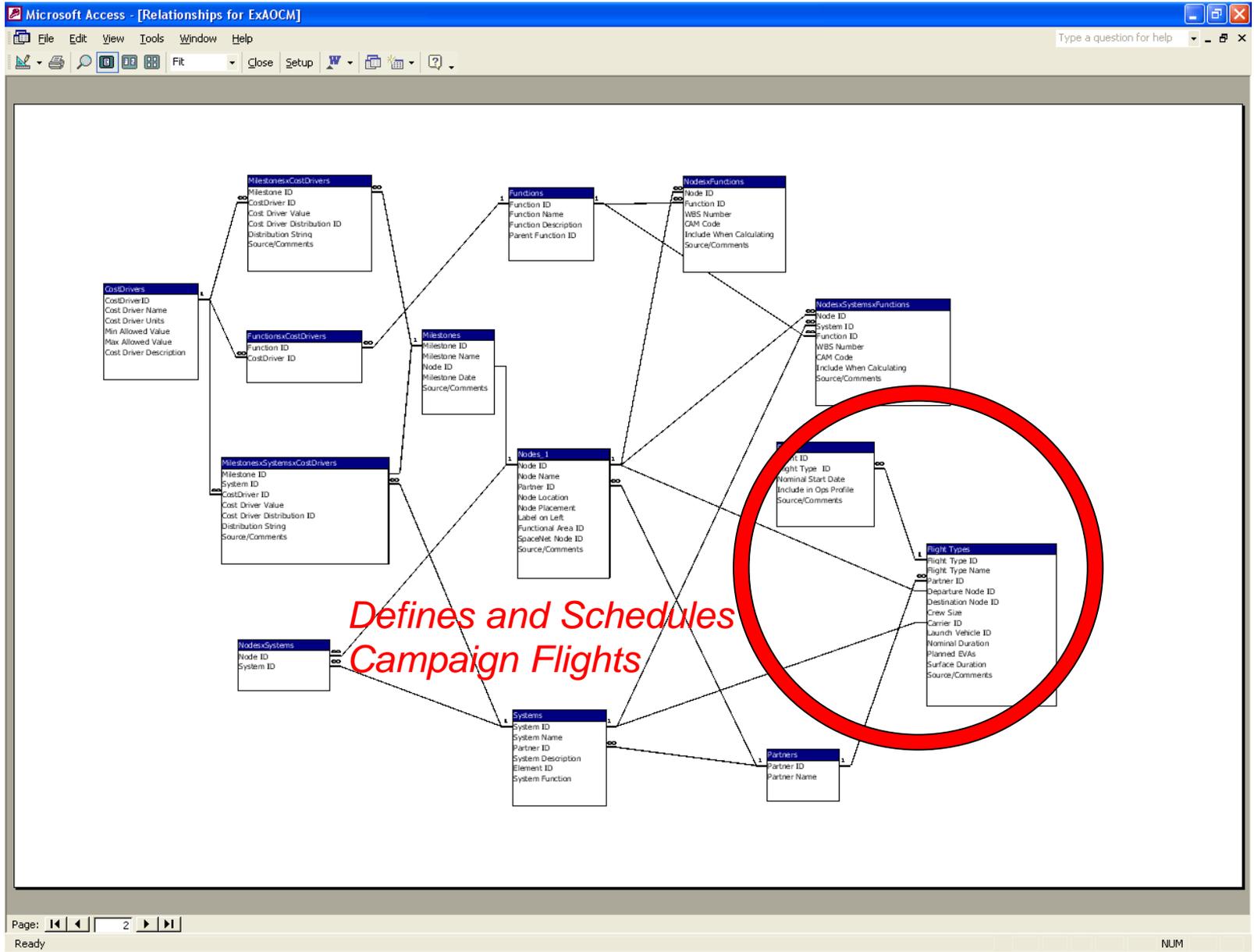


Datatables in ExAOCM





Datatables in ExAOCM





Example Databtable in ExAOOCM Systems

Systems

Describes System By Content, Type, System Function

System ID	System Name	System Short Name	Partner ID	System Description	System Type	System Function
1	Extra-Vehicular Activity System	EVA	1	EMU, LSS, SAFER, EVA tools, translation aids	1	Supports external maintenance and scienc
2	Integrated Planning System	IPS	1	HW/SW for mission timelining and execution	4	Supports flight planning and execution
3	Mission Control Center Facility	MCC-A	1	Flight control front and backrooms	4	Supports flight preparation and execution
4	Flight Controller Training Facility	FCT	1	Flight controller consoles and communications for training	4	Supports flight controller training
5	Shuttle Mission Training Facility	SMTF	1	SST, NSS, GNS, Fixed Base and Motion Base sims	6	Supports flight crew training
6	FDD Infrastructure System		1	Flight design and dynamics H/W and S/W development environmer	4	Supports flight design

System Ownership



Example Datatable in ExAOCM Milestones

Milestones

Describes Architecture Milestone By Node and Programmatic Date



Milestone ID	Milestone Name	Node ID	Node Name	Milestone Date	Source/Comments
1	Assembly Complete	1	International Space Station	2010.75	
2	CEV IOC	1	International Space Station	September-13	Begin CEV flights to ISS
3	EOM	1	International Space Station	10/1/2020	Proposed decommissioning
4	Flt 2019-A	2	Lunar Outpost Alpha	July-19	Unmanned test flight
5	Flt 2020-A (IOC)	2	Lunar Outpost Alpha	February-20	Human lunar return and Initial Operational Capability
6	Flt 2020-B	2	Lunar Outpost Alpha	August-20	
7	Flt 2021-A	2	Lunar Outpost Alpha	February-21	
8	Flt 2021-B	2	Lunar Outpost Alpha	August-21	
9	Flt 2022-A	2	Lunar Outpost Alpha	January-22	
10	Flt 2022-B	2	Lunar Outpost Alpha	August-22	
11	Flt 2023-A	2	Lunar Outpost Alpha	January-23	
12	Flt 2023-B	2	Lunar Outpost Alpha	August-23	Begin permanent human occupancy
13	Flt 2024-A	2	Lunar Outpost Alpha	January-24	
14	Flt 2024-B	2	Lunar Outpost Alpha	August-24	
15	Flt 2025-A	2	Lunar Outpost Alpha	January-25	
16	Flt 2025-B (FOC)	2	Lunar Outpost Alpha	August-25	Full Operational Capability



Example Datatable in ExAOCM

Cost Drivers

Cost Drivers

Describes Cost Driver

Cost Driver ID	Cost Driver Name	Cost Driver Units Type	Min Allowed Value	Max Allowed Value	Cost Driver Description
1	hw_invest_cost	4	0		Investment cost for hardware assets
2	mass_effective	8	0		Mass of element/system
3	sw_kslocs	2	0		Software source lines of code in thousands excluding comments
4	mgmt_support_factor	2	0		1 Management and administration overhead factor
5	prog_volatility	2	0		2 Program/project volatility considering schedule, payload, or mission changes
6	mission_complexity	2	0.7		1.7 Mission complexity relative to STS mission
7	cev_vehicle_complexity	2	0.7		1.7 CEV complexity relative to STS
8	grd_system_complexity	2	0.7		1.7 Ground system complexity relative to STS ground system
9	num_monitored_cev_systems	1	0		Number of console positions driven by CEV system
10	telemetry_automation_factor	2	0.7		1.7 Degree of telemetry automation relative to STS
11	command_automation_factor	2	0.7		1.7 Degree of command automation relative to STS

Cost Driver Units

Minimum and Maximum Allowed Values



Example Datable in ExAOCM Milestones x Systems x Cost Drivers

Systems

Cost Drivers

Describes System Cost Driver Value And Uncertainty At This Milestone

Milestone ID	System ID	Cost Driver ID	Milestone Name	Node Name	System Name	Cost Driver Name	Cost Driver Value	Cost Driver Distribution ID	Distribution String	Cost Driver Units
27	16	4	IOC	Mission Control Center, Hou	Mission Control Center Facility	sw_kslocs	3651	6	8.2,0.41	kslocs/workyear
27	16	136	IOC	Mission Control Center, Hou	Mission Control Center Facility	mod_gen_coeff	239032	6	12.38,0.62	workhours/year
27	16	185	IOC	Mission Control Center, Hou	Mission Control Center Facility	sw_vol_factor	1			real, dimensionless
27	16	18	IOC	Mission Control Center, Hou	Mission Control Center Facility	sw_maint_factor	47	6	3.85,0.19	kslocs/workyear
27	17	4	IOC	Mission Control Center, Hou	Mission Integrated Planning System	sw_kslocs	2835	6	7.95,0.4	kslocs/workyear
27	17	136	IOC	Mission Control Center, Hou	Mission Integrated Planning System	mod_gen_coeff	78936	6	11.28,0.56	workhours/year
27	17	185	IOC	Mission Control Center, Hou	Mission Integrated Planning System	sw_vol_factor	1			real, dimensionless
27	17	18	IOC	Mission Control Center, Hou	Mission Integrated Planning System	sw_maint_factor	300	6	5.7,0.29	kslocs/workyear
27	18	4	IOC	Mission Control Center, Hou	Mission Data Reconfiguration System	sw_kslocs	350	6	5.86,0.29	kslocs/workyear
27	18	136	IOC	Mission Control Center, Hou	Mission Data Reconfiguration System	mod_gen_coeff	19871	6	9.9,0.49	workhours/year
27	18	185	IOC	Mission Control Center, Hou	Mission Data Reconfiguration System	sw_vol_factor	1			real, dimensionless
27	18	18	IOC	Mission Control Center, Hou	Mission Data Reconfiguration System	sw_maint_factor	47	6	3.85,0.19	kslocs/workyear
29	20	4	IOC	Training Center, Hou	Training Simulator System	sw_kslocs	3730	6	8.22,0.41	kslocs/workyear
29	20	136	IOC	Training Center, Hou	Training Simulator System	mod_gen_coeff	119551	6	11.69,0.58	workhours/year
29	20	137	IOC	Training Center, Hou	Training Simulator System	iss_crdw_mod_fit_coeff	5564	6	8.62,0.43	workhours/launch
29	20	139	IOC	Training Center, Hou	Training Simulator System	lunar_crdw_mod_fit_coeff	8161	6	9.01,0.45	workhours/mission
29	20	185	IOC	Training Center, Hou	Training Simulator System	sw_vol_factor	1			real, dimensionless
29	20	18	IOC	Training Center, Hou	Training Simulator System	sw_maint_factor	300	6	5.7,0.29	kslocs/workyear
29	20	180	IOC	Training Center, Hou	Training Simulator System	flts_in_flow_prop_0	0.44	6	-0.82,0.04	percent/year
29	20	181	IOC	Training Center, Hou	Training Simulator System	flts_in_flow_prop_1	0.37	6	-0.99,0.05	percent/year
29	20	182	IOC	Training Center, Hou	Training Simulator System	flts_in_flow_prop_2	0.19	6	-1.66,0.08	percent/year
29	21	137	IOC	Training Center, Hou	Space Vehicle Mockup Facility	iss_crdw_mod_fit_coeff	10516	6	9.26,0.46	workhours/launch
29	21	138	IOC	Training Center, Hou	Space Vehicle Mockup Facility	iss_cargo_mod_fit_coeff	10516	6	9.26,0.46	workhours/launch
29	21	139	IOC	Training Center, Hou	Space Vehicle Mockup Facility	lunar_crdw_mod_fit_coeff	15424	6	9.64,0.48	workhours/mission

IOC Milestone For Mission Control Center, Houston



Example Datable in ExAOCM

Nodes x Systems x Functions

Systems Assigned To Each Node

Assigned WBS and CAM Code

Node ID	System ID	System Name	Function ID	Function Name	WBS	CAM Code	Include When Calculating (T/F)	Source/Comments
1	2	Integrated Planning System	2	Facility/System Management	4.3.2.1.1	DA	TRUE	
1	2	Integrated Planning System	3	Facility/System Operations	4.3.2.1.3	DA	TRUE	
1	2	Integrated Planning System	4	Facility/System Hardware Maintenance	4.3.2.1.4.1	DA	TRUE	
1	2	Integrated Planning System	5	Facility/System Software Maintenance	4.3.2.1.4.2	DA	TRUE	
1	2	Integrated Planning System	6	Facility/System Sustaining Engineering	4.3.2.1.5	DA	TRUE	
1	3	Mission Control Center Facility	2	Facility/System Management	4.3.2.2.1	DA	TRUE	
1	3	Mission Control Center Facility	3	Facility/System Operations	4.3.2.2.3	DA	TRUE	
1	3	Mission Control Center Facility	4	Facility/System Hardware Maintenance	4.3.2.2.4.1	DA	TRUE	
1	3	Mission Control Center Facility	5	Facility/System Software Maintenance	4.3.2.2.4.2	DA	TRUE	
1	3	Mission Control Center Facility	6	Facility/System Sustaining Engineering	4.3.2.2.5	DA	TRUE	
8	4	Flight Controller Training Facility	2	Facility/System Management	4.3.3.2.1.1	DA	TRUE	
8	4	Flight Controller Training Facility	3	Facility/System Operations	4.3.3.2.1.3	DA	TRUE	
8	4	Flight Controller Training Facility	4	Facility/System Hardware Maintenance	4.3.3.2.1.4.1	DA	TRUE	
8	4	Flight Controller Training Facility	5	Facility/System Software Maintenance	4.3.3.2.1.4.2	DA	TRUE	
8	4	Flight Controller Training Facility	6	Facility/System Sustaining Engineering	4.3.3.2.1.5	DA	TRUE	
8	5	Shuttle Mission Training Facility	2	Facility/System Management	4.3.3.2.2.1	DA	TRUE	
8	5	Shuttle Mission Training Facility	3	Facility/System Operations	4.3.3.2.2.3	DA	TRUE	
8	5	Shuttle Mission Training Facility	4	Facility/System Hardware Maintenance	4.3.3.2.2.4.1	DA	TRUE	
8	5	Shuttle Mission Training Facility	5	Facility/System Software Maintenance	4.3.3.2.2.4.2	DA	TRUE	
8	5	Shuttle Mission Training Facility	6	Facility/System Sustaining Engineering	4.3.3.2.2.5	DA	TRUE	
1	6	FDD Infrastructure System	2	Facility/System Management	4.3.4.3.3.1	DA	TRUE	
1	6	FDD Infrastructure System	3	Facility/System Operations	4.3.4.3.3.3	DA	TRUE	
1	6	FDD Infrastructure System	4	Facility/System Hardware Maintenance	4.3.4.3.3.4.1	DA	TRUE	
1	6	FDD Infrastructure System	5	Facility/System Software Maintenance	4.3.4.3.3.4.2	DA	TRUE	
1	6	FDD Infrastructure System	6	Facility/System Sustaining Engineering	4.3.4.3.3.5	DA	TRUE	

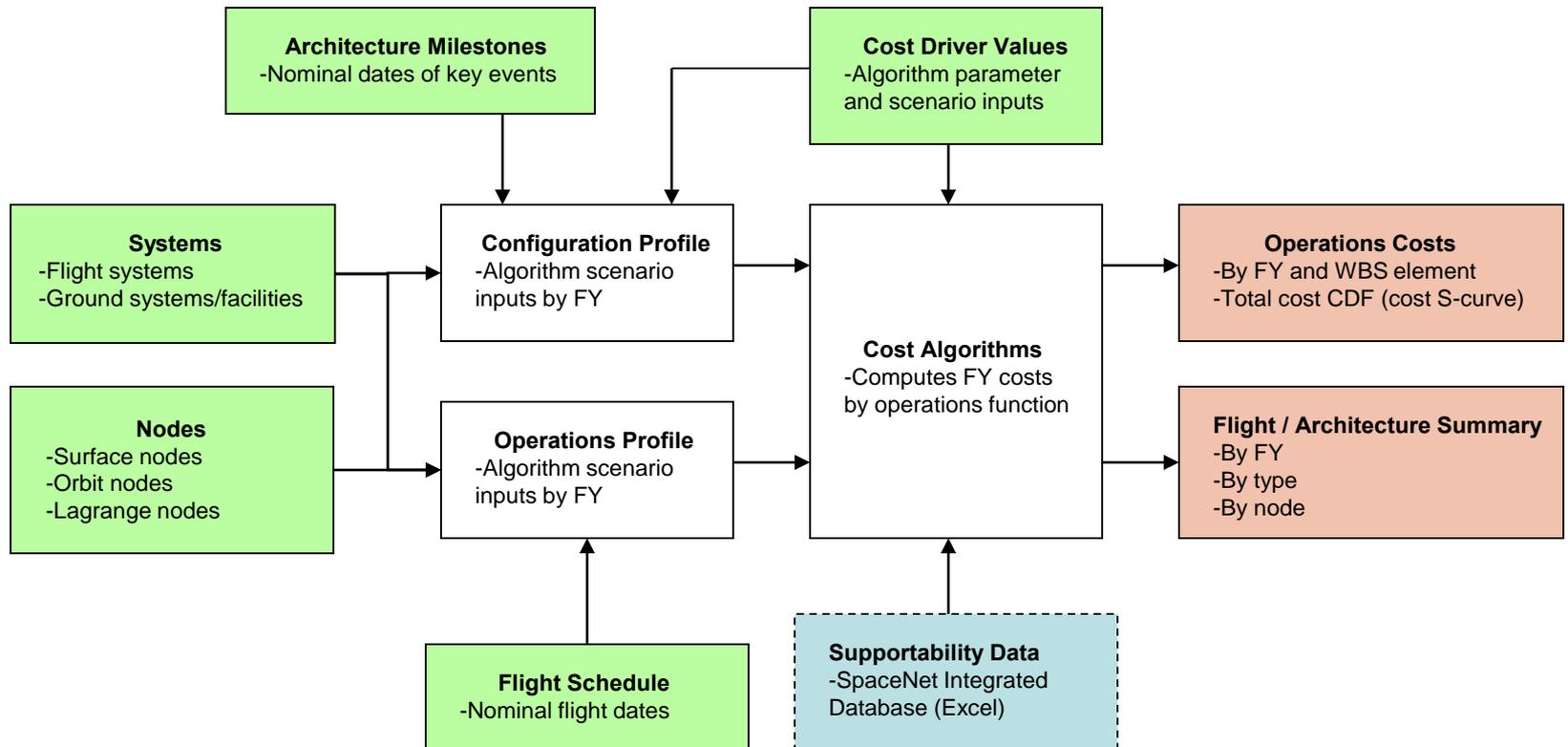
Mission Control Center, Houston

Operational Functions

Training Center, Houston

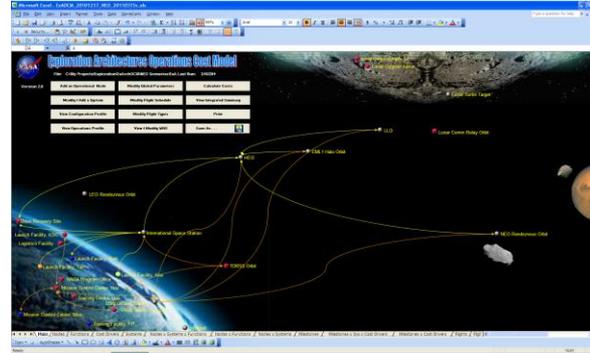
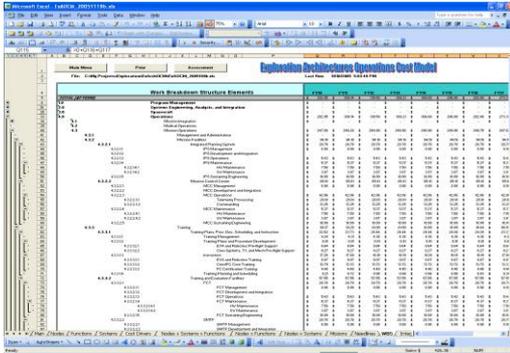


ExAOCM Inputs/Outputs





Summary



For ORU i in Station Element e resupply and return :

$$Truereplace / day_{i,e} = \sum_{p \in P(i,e)} \left(\frac{24DC_p K_p}{MTBF_p} \right) QPA_p (1 - RIO_p)$$

$$Truereplace / resupplycycle_{i,p,add} = (Truereplace / day_{i,p,add}) (days / resupplycycle_{e,p}) \equiv \lambda_{i,p,t}$$

