Spacecraft Optimization Layout and Volume (SOLV)

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Purpose

- Overview of SOLV Development
- Demonstration of SOLV version 2.0
  - A Use Case Walk-Thru

SOLV Project Overview

Spacecraft Optimization Layout and Volume (SOLV) delivered prototype model (v1.0) for NRA HERO grant closure in May 2018.

SOLV Extension (SOLVe) Task was funded by the HRP HFBP Element to extend the model's applicability to additional DRMs to ensure coverage for future projects/programs, and improve model capability and credibility for risk reduction.

Phase One Specific Aims: [Completed on 1/31/2019]

- Extend the SOLV computational model applicability to additional DRMs.
- Conduct a SOLV Workshop.

Phase Two Specific Aims: [Code delivery - 9/30/19, Documentation delivery - 12/31/19]

- Based on inputs from the workshop, improve SOLV's credibility levels in targeted areas as per NASA-STD-7009A, and enhance SOLV's capabilities for risk reduction and to provide immediately useful features.

SOLV Model

SOLV's Intended Purpose: Support early conceptual design phases by providing estimates of habitat volumes and a range of layout options to help inform design

- Primary: Volume estimation tool
- Secondary: Provide context to the volume estimations, including layout visualization and a means to heuristically assess goodness

Task volume dataset used to generate gradient cuboid representations of tasks

Overlap packing problem algorithm used to generate multiple efficient layouts

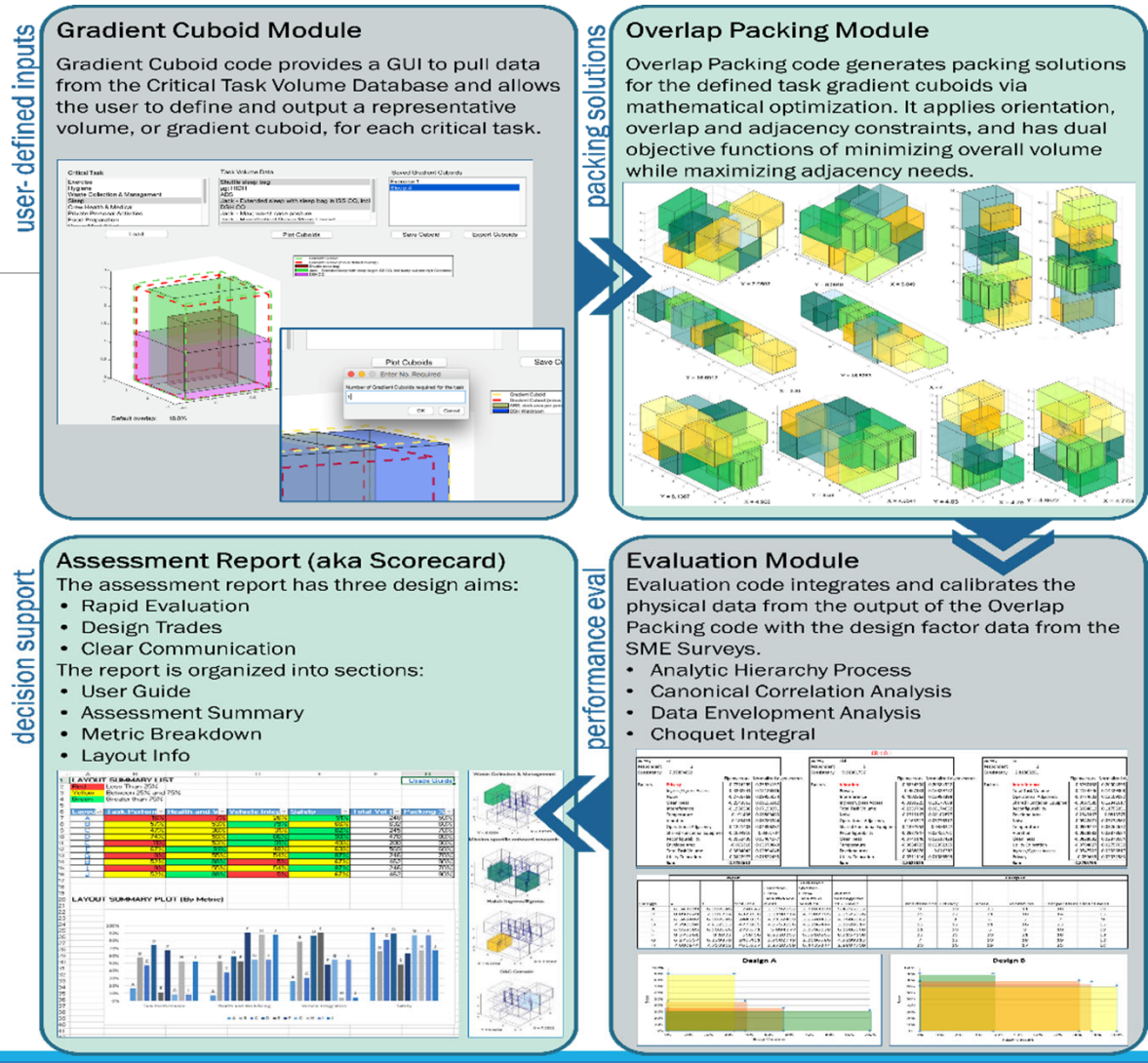
Scoring system provides feedback to model user about “goodness” of each layout

- “Goodness” determined based on Analytic Hierarchy Process and Decision Theory math
- SME inputs used to determine weighting of factors (e.g., functional colocation, privacy, acoustics, cleanliness)
- SME inputs used to assess hypothetical layouts against factors as part of the process to train the model

SOLV Modules

The SOLV model consists of four modules, with a driver code that integrates them:

- Gradient Cuboid Module
- Overlap Packing Module
- Evaluation Module
- Assessment Report (Scorecard)

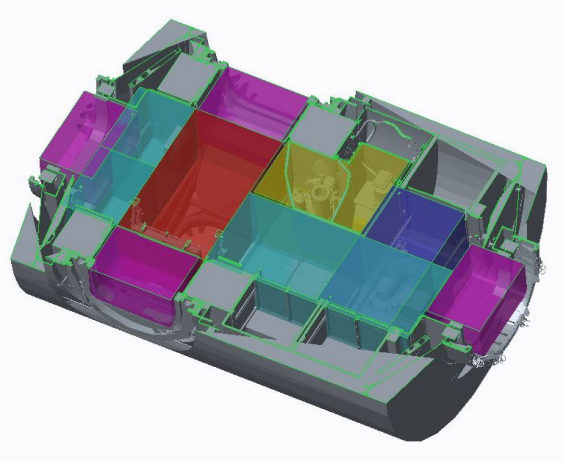


SOLV Extension Task - Summary of Work

1. Deployed new surveys in 2018 to collect additional SME data to establish factor weighting and scoring system, in the context of additional design reference missions.
   - Phase 1: Factor Priority and Interactions Effects Survey
   - Phase 2: Manual Layout Evaluation Survey
2. Conducted a two-day workshop (11/13-11/14/2018) with key owner, user and stakeholder communities to gain acceptance of the model, review products and prioritize improvement goals.
3. Maintained Credibility Score of 2 for Verification for model v2.0 by performing new verification testing of the updated requirements, and submitting verification data to Software Quality Assurance (QA) for a initial compliance assessment against JPR 7150.2A.
4. Maintained scores of 1 for Uncertainty Characterization and 2 for Results Robustness for model v2.0 using an expanded cuboid set.
5. Increased the validation factor for the volume estimation portion of the SOLV model from credibility level 1 to 2 by performing equivalent volume comparisons of SOLV outputs with selected real-world referent designs, and performed initial validation of process and tool use by leveraging validation session results from the 2018 workshop [Additional details provided].

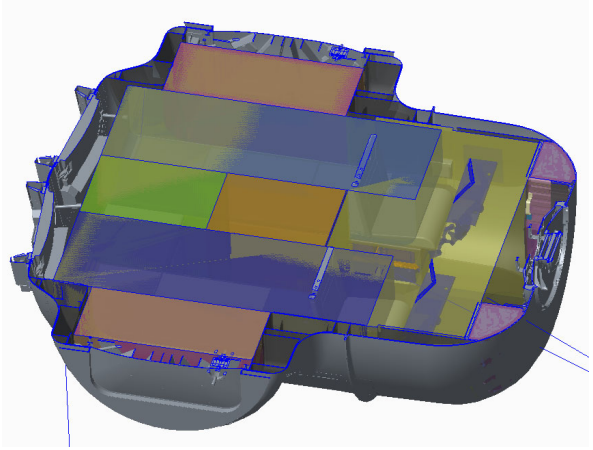
DRM Categories

Selected Referents for Validation



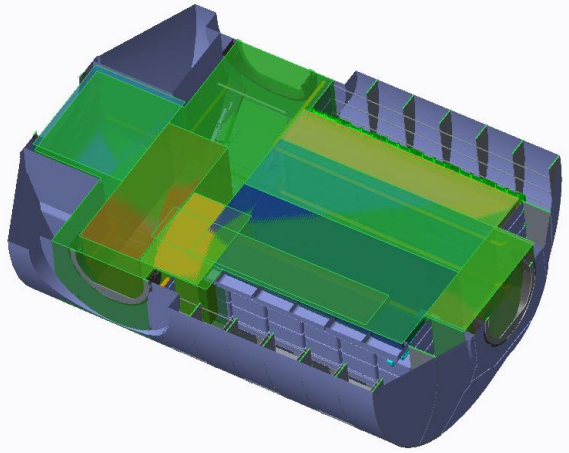
ISS NODE 3

- Launched in 2010
- Provides 6 berthing locations, exercise, storage, crew hygiene and waste collection, and life support systems.
- ***Representative flight vehicle referent***



MMSEV2B/HABITABLE AIRLOCK (HAL)

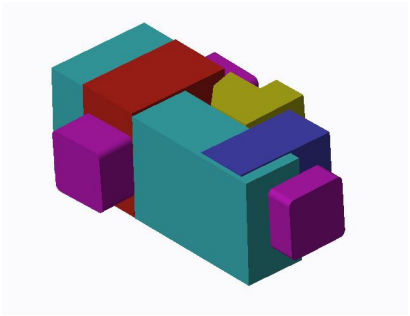
- Project went through several reconfigurations/repurposing
- Precursor MMSEV projects built prototypes for the annual Desert RATS analog mission simulations.
- ***Representative ground analog referent***

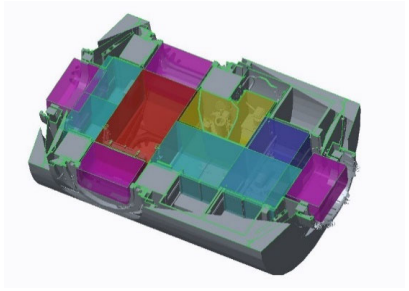


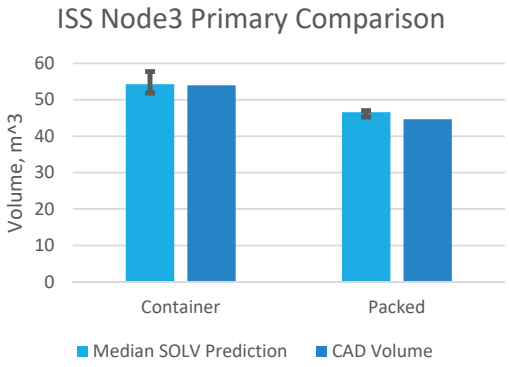
GATEWAY GEN 2

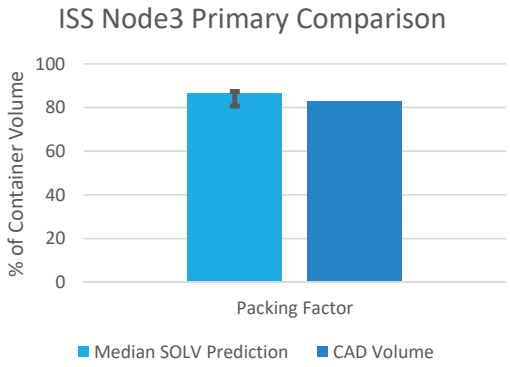
- An early iteration of the Gateway Habitation Element as part of the Internal Architecture Study.
- ***Representative paper design referent***

Example Validation Results Referent #1: ISS Node 3





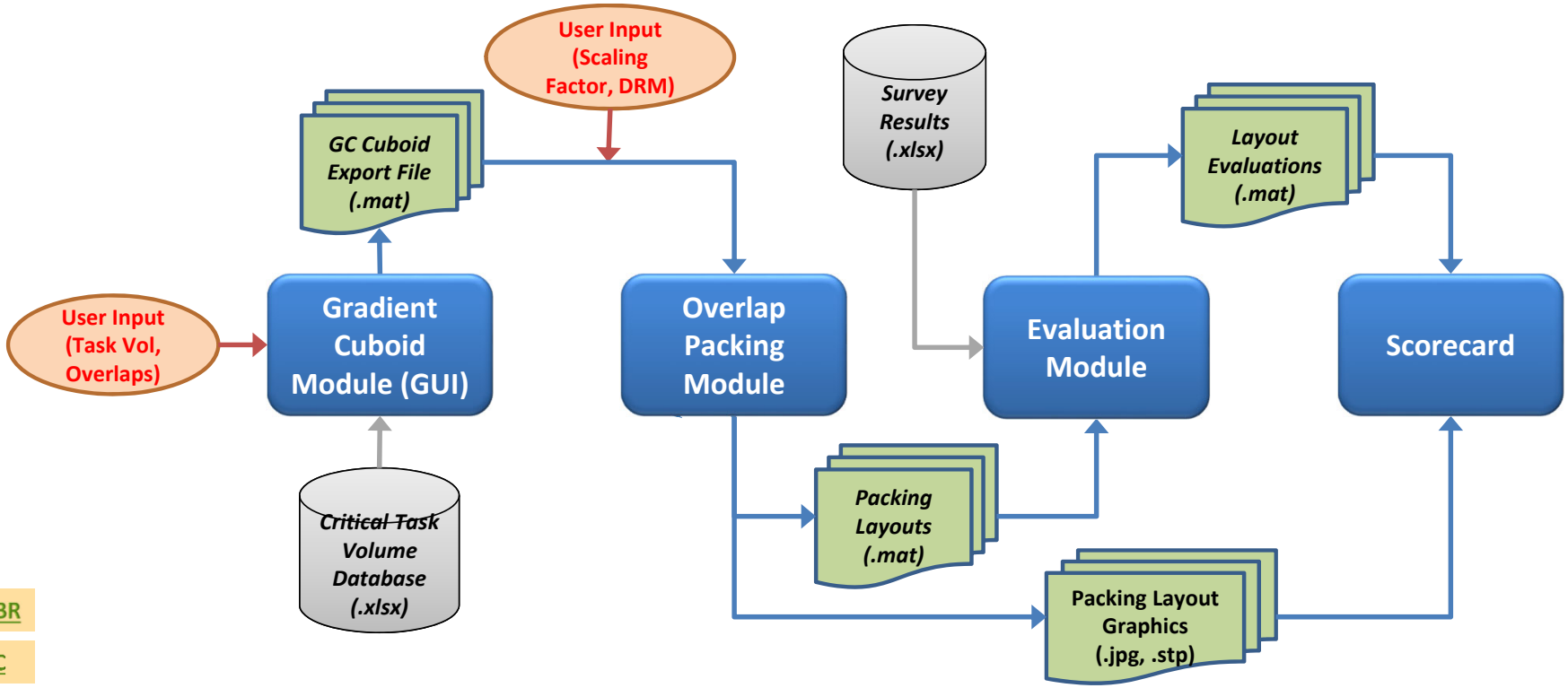




- Primary: CTVD and SOLV-Defined overlap.
- Findings:
  - SOLV median container volume within 1% of the referent
  - SOLV median packed volume is within 4% of the referent
  - SOLV median Packing factor within 4% of the referent
  - The referent falls within the range of the volume solutions produced by SOLV.

Nomenclature:
Container Volume: Minimum container volume that can envelope a layout.
Packed Volume: Total aggregate of all task volumes (accounting for overlap).
Packing Factor: Ratio of Packed Volume to Container Volume

Model Demonstration Demo: Code Flow



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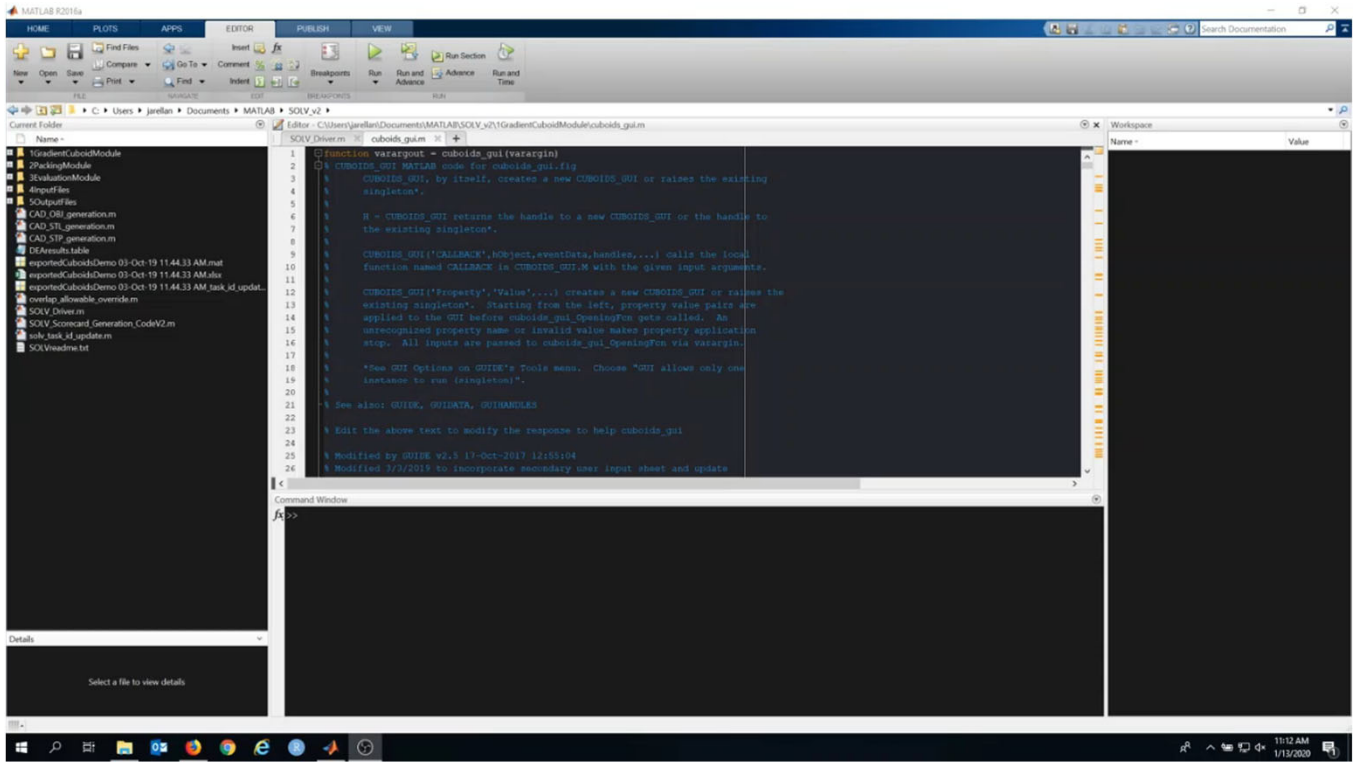
Primary SOLV Use Case Domain

Use Case Name	Estimate Volume of A Habitat – (Primary SOLV Use Case Domain)	
Use Case Scope	Estimate volume of a habitat to serve as starting point for conceptual design for a newly established program.	
Primary Actor	Mission Architect Systems Engineer	
Scenario	The habitat is a part of an orbital platform that supports a 4-crew, 90-day mission. It must have sufficient volume to support a minimal set of mission tasks	
	Exercise	Hygiene
	Waste Collection and Management	Sleep (4)
	Crew Health & Medical	Private Personal Activities
	Food Preparation	Group Meet and Eat
	D&C Console	Mission-Specific Onboard Research
	Hatch Ingress/Egress	

SOLV Gradient Cuboid GUI

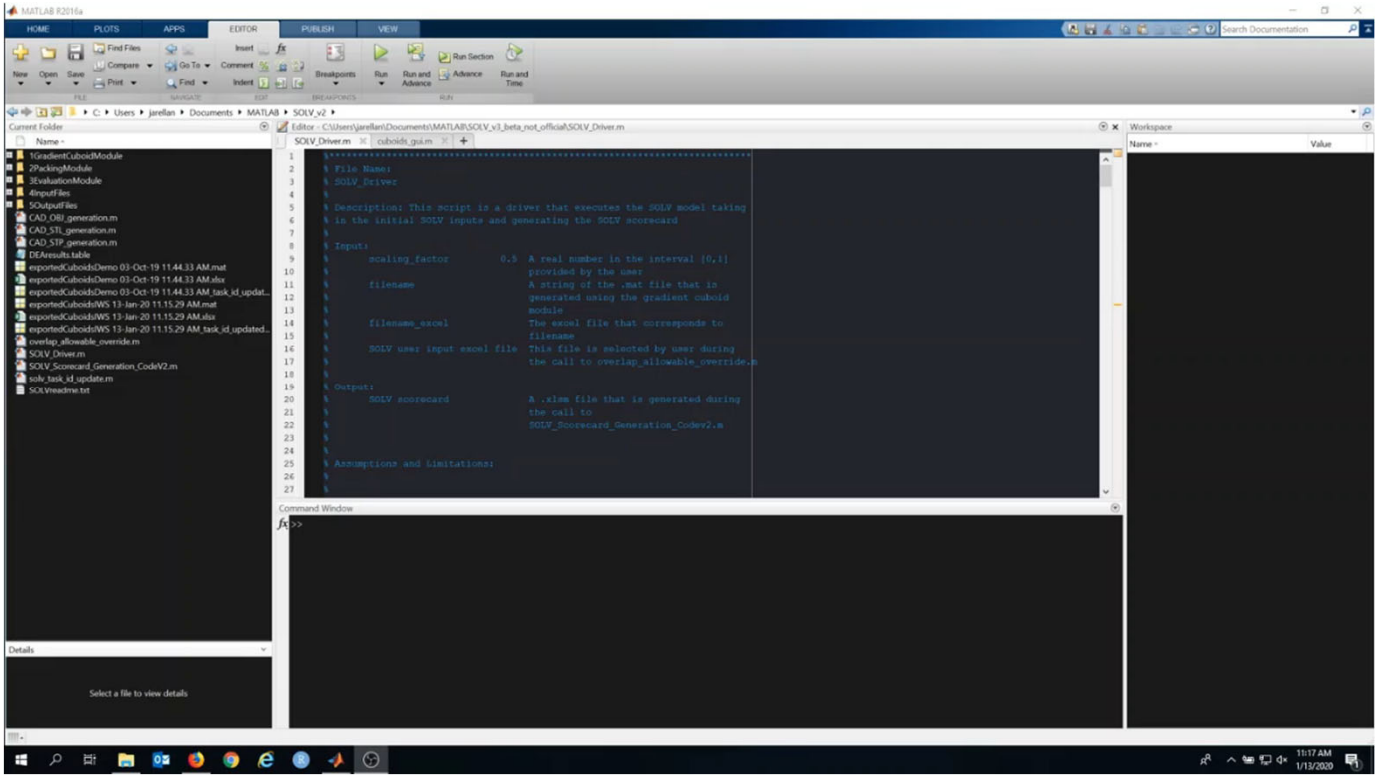


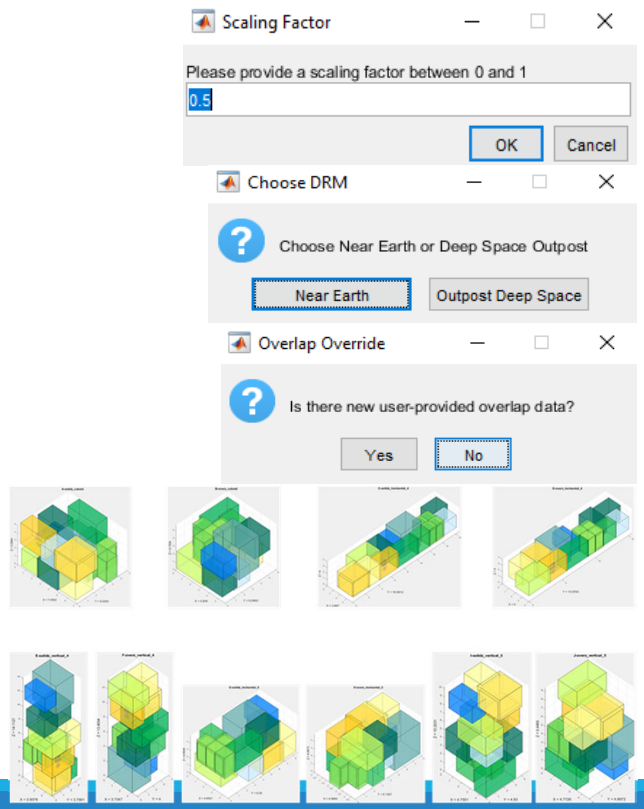
SOLV Input Selection			Critical Task	Op Scenario (3rd Tier Input)	Gravity Condition	Basis of Assumptions	Total Task Volume	Total Task Dimensions (Derived			Supplemental Notes
Indicate # of Cuboid (Per Task)	Select Data point to be included (X)	Notes						Length (m)	Width (m)	Height (m)	
1	X	Use User Defined	Exercise	Aerobic	2	Aerobic-T2, Max (Jack)	6.45	2.02	1.12	2.29	Task volume based on Jack analysis of
			Exercise	Aerobic	2	Aerobic-CEVIS, Max	4.36	1.86	1.26	1.41	Operational worksite volume for operating
			Exercise	Aerobic	2	Aerobic, Max (HSIR-D)	3.12	1.56	1.20	2.65	Volume estimates reference CEV-T-70024
	X	Use User Defined	Exercise	Resistive	2	Resistive-ARED, Max	10.90	2.81	1.38	2.50	Task volume based on Jack analysis of
			Exercise	Aerobic AND resistive	1	A&R-Physical Fitness	3.67	1.54	1.54	2.25	Volume estimates reference ABS Guide for
			Exercise	Aerobic AND resistive	2	A&R-ROCKY, Max	3.97	1.72	1.34	2.78	Estimates based on motion capture data
			Exercise	Aerobic AND resistive	2	A&R-ATLAS	6.08	1.79	1.79	3.50	ATLAS is "dual ROCKY" candidate system for
1			Hygiene	Partial Hygiene	0	Partial-	1.64	1.29	0.98	2.40	Task volume based on Jack analysis of
			Hygiene	Partial Hygiene	0	Partial-Leg Shaving,	1.54	1.35	0.84	1.17	Task volume based on Jack analysis of
			Hygiene	Partial Hygiene	0	Partial-Hair Washing,	1.48	1.21	1.02	2.48	Task volume based on Jack analysis of
			Hygiene	Partial Hygiene	0	Partial Body Cleaning	4.35	1.32	2.48	2.57	Body Volume for Partial Body Cleaning in µg
	X	Use User Defined	Hygiene	Whole Body Hygiene	0	Whole-Upper/Lower	3.50	1.22	0.91	2.18	Task volume based on Jack analysis of
	X	Use User Defined	Hygiene	Whole Body Hygiene	1	Whole-Shower Stall	1.14	1.05	1.05	2.72	Volume estimates reference ABS Guide for
			Hygiene	Whole Body Hygiene	1	Whole-Shower Stall	3.78	1.17	1.17	2.51	Volume estimates reference Architectural

Critical_Task	Basis_of_Assumptions	Gravity_Condition	Length_m	Width_m	Height_m	Volume_m3	Notes
Exercise	New Operational Scenario 1	2	2.5	1.5	2.75	10.31	
Exercise	New Operational Scenario 2	2	3	1.5	2.75	12.38	
Hygiene	New Operational Scenario 1	2	1.5	2	1.5	4.50	
Hygiene	New Operational Scenario 2	2	1.75	2	1.75	6.13	
Sleep	New Operational Scenario 1	2	1.5	1.5	1.5	3.38	
Group Meet & Eat	New Operational Scenario 1	2	2.5	2.5	2.5	15.63	

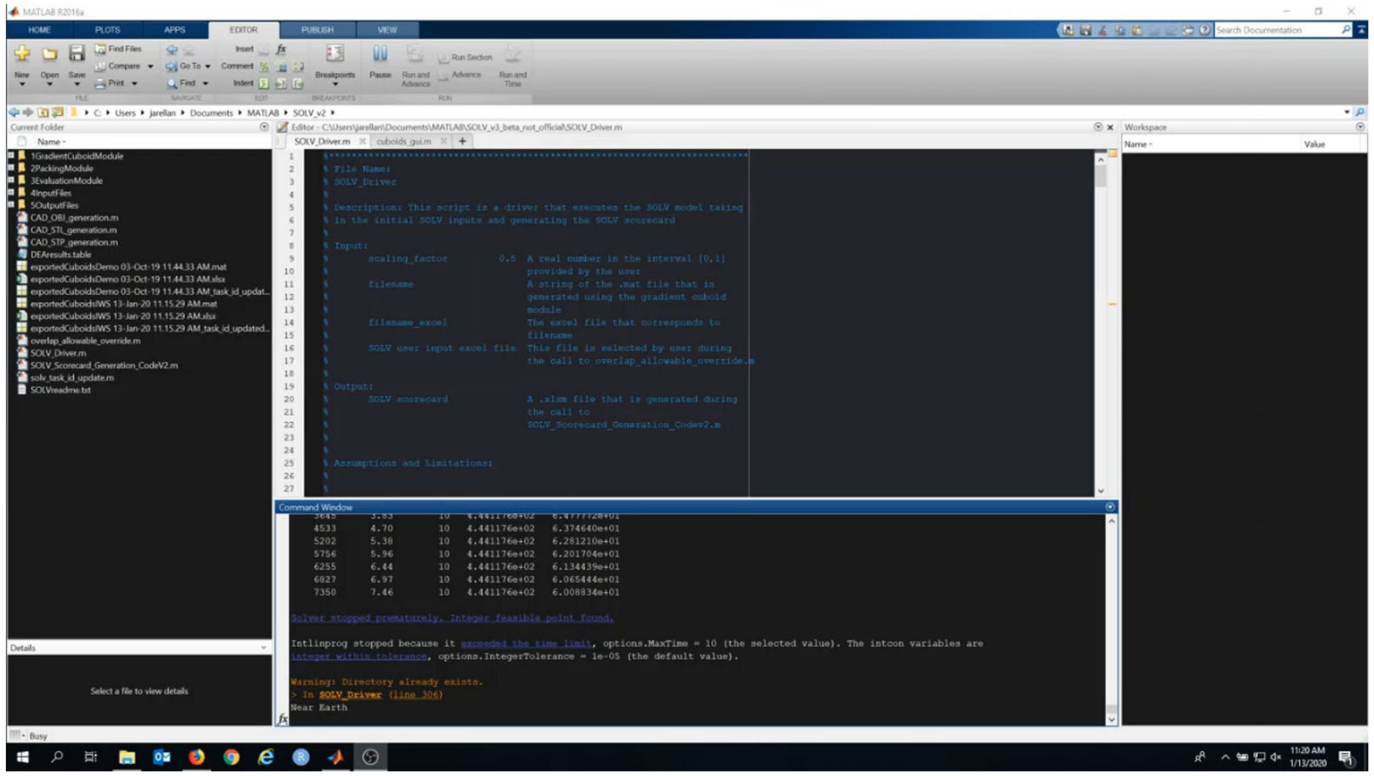
Task1	Task2	OverlapValue_percen	Notes
Exercise	Crew Health & Medical	55	
Hygiene	Exercise	55	
Sleep	Private Personal Activities	70	
Food Preparation	Group Meet & Eat	35	

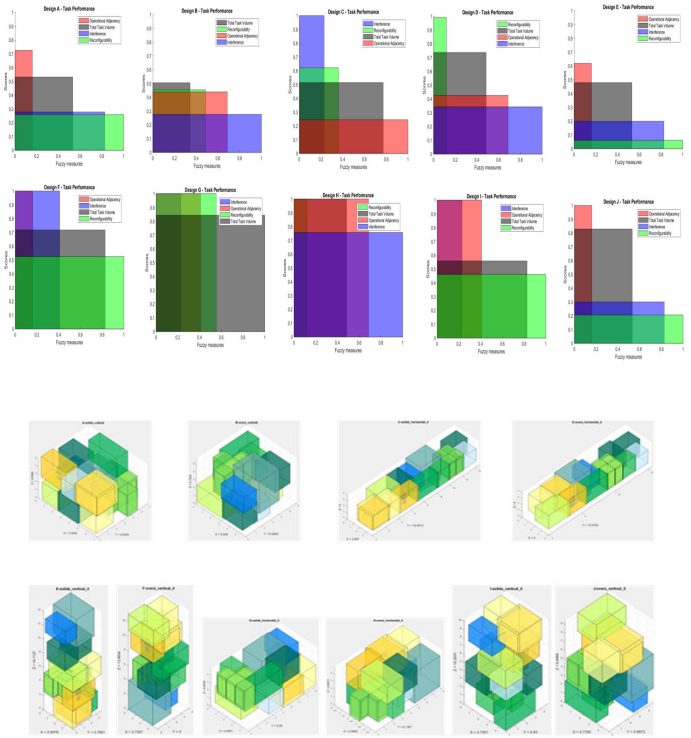
SOLV Packing Module



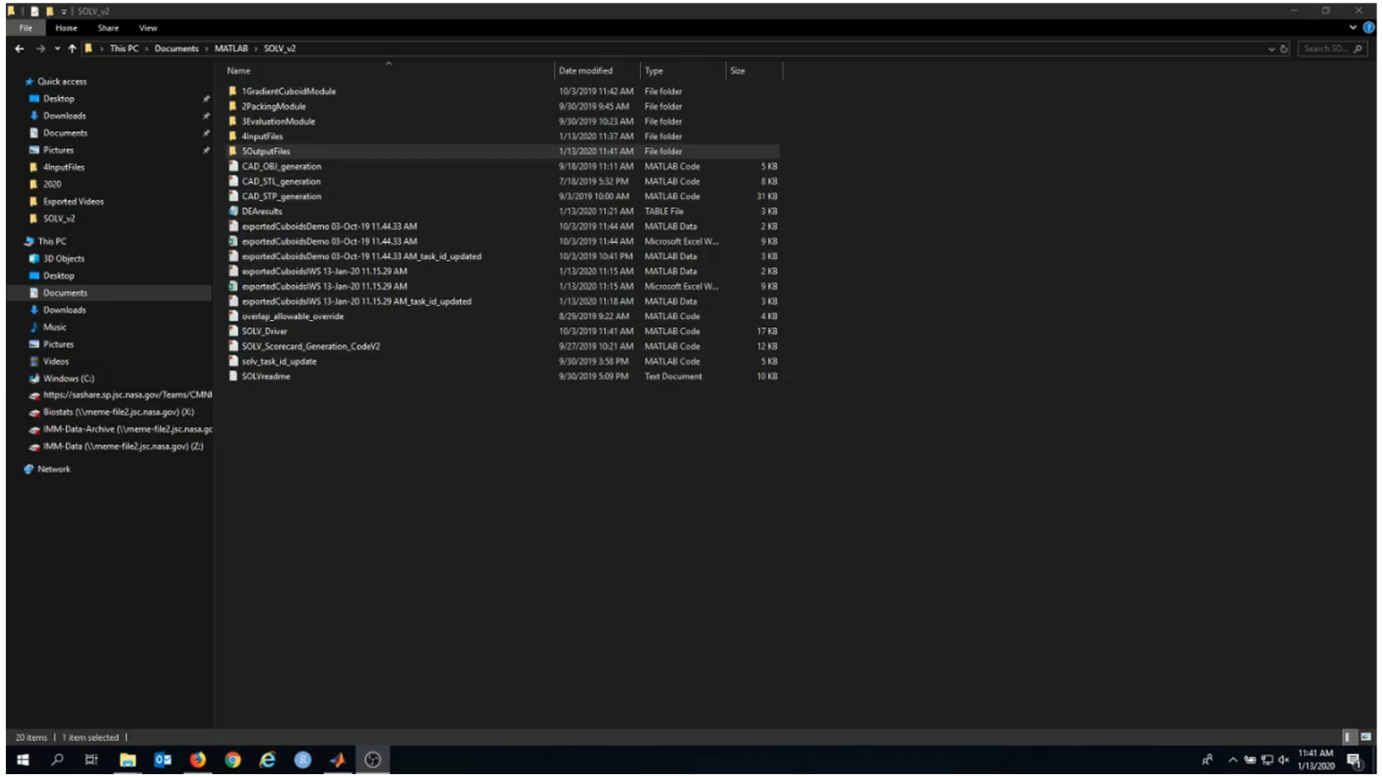


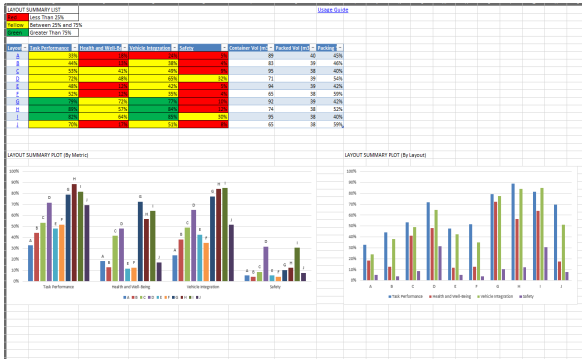
SOLV Evaluation Module

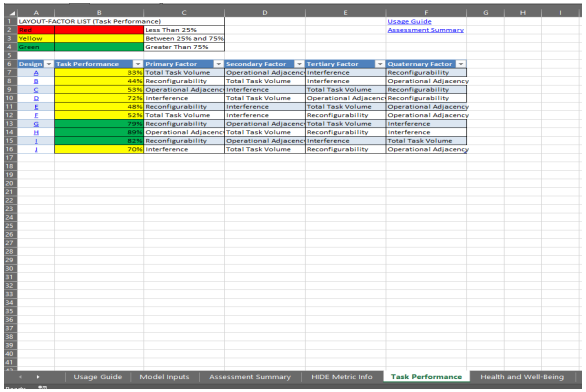




SOLV Scorecard







Additional Use Case Categories

Use Case Category	Example Scenarios
Perform refined and targeted volume estimates	• Provide answers on how much volume is needed for an exploration mission • Perform volume trades based on changes in specific parameters.
Support iterative design process	• Use SOLV output to develop VR mockup for HITL testing • Use SOLV to generate prototype layout/volume for research • Use SOLV to support pre-phase A activities for existing projects (HESTIA, MMSEV, BAA)
Tool Integration	• Develop gradient cuboids for other layout design tools • Use SOLV to check existing CAD models and validate mockup studies
Functional Allocation	• Use SOLV to recommend allocation of tasks across modules, vehicle elements, levels.
Checking/verifying a design meets requirements (“Smart Buyer”)	• Use SOLV to inform BAA NextStep design assessment. • Consider SOLV as a form of verification by analysis, rather than as inputs into standards.
Terrestrial/Analog Design	• Antarctic habitats and other volume-constrained, extreme environment habitat design

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Looking Ahead

Transition-to-Use (TtU)

SOLV Primary Use Scenarios:

- Perform refined and targeted volume estimates
- Support iterative design process
- Checking/verifying a design meets requirements (“Smart Buyer”)

SOLV Use Logistics:

- SOLV will be service request-based
- SOLV will stay local and sit on a JSC server, and managed by HHPIT

TtU Tasks:

- NPR7150.2 Compliance
  - QA Audit
- Software Purchase
  - Gurobi or CPLEX – Single-use license that ‘node-lock’ the license on server with floating usage for multiple users.
- Secure support from IT organization.
- Establish tool ownership.

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Slide 16

CM(LI7 add use cases, what customer will want to use for. what is comfort level for model validation
Chen, Maijinn (JSC-SF3)[WYLE LABORATORIES, INC.], 9/3/2019

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Input Collection Sheet

- Instruction Sheet
- CTVD data point selection
  - Allows user to select CTVD data points, specify the use of user-defined data points and number of cuboids per task

	A	B	C	D	E	F	G	R	S	T	U	AE
1	SOLV Input Selection			Critical Task	Op Scenario (3rd Tier Input)	Gravity Condition	Basis of Assumptions	Total Task Volume	Total Task Dimensions (Derived			Supplemental Notes
3	Indicate # of Cuboid (Per Task)	Select Data point to be included (X)	Notes						Length (m)	Width (m)	Height (m)	
4	1	X	Use User Defined	Exercise	Aerobic	2	Aerobic-T2, Max (Jack)	6.45	2.02	1.12	2.29	Task volume based on Jack analysis of
5				Exercise	Aerobic	2	Aerobic-CEVIS, Max	4.36	1.86	1.26	1.41	Operational worksite volume for operating
6				Exercise	Aerobic	2	Aerobic, Max (HSIR-D)	3.12	1.56	1.20	2.65	Volume estimates reference CEV-T-70024
7		X	Use User Defined	Exercise	Resistive	2	Resistive-ARED, Max	10.90	2.81	1.38	2.50	Task volume based on Jack analysis of
8				Exercise	Aerobic AND resistive	1	A&R-Physical Fitness	3.67	1.54	1.54	2.25	Volume estimates reference ABS Guide for
9				Exercise	Aerobic AND resistive	2	A&R-ROCKY, Max	3.97	1.72	1.34	2.78	Estimates based on motion capture data
10				Exercise	Aerobic AND resistive	2	A&R-ATLAS	6.08	1.79	1.79	3.50	ATLAS is "dual ROCKY" candidate system for
11	1			Hygiene	Partial Hygiene	0	Partial-	1.64	1.29	0.98	2.40	Task volume based on Jack analysis of
12				Hygiene	Partial Hygiene	0	Partial-Leg Shaving,	1.54	1.35	0.84	1.17	Task volume based on Jack analysis of
13				Hygiene	Partial Hygiene	0	Partial-Hair Washing,	1.48	1.21	1.02	2.48	Task volume based on Jack analysis of
14				Hygiene	Partial Hygiene	0	Partial Body Cleaning	4.35	1.32	2.48	2.57	Body Volume for Partial Body Cleaning in µg
15		X	Use User Defined	Hygiene	Whole Body Hygiene	0	Whole-Upper/Lower	3.50	1.22	0.91	2.18	Task volume based on Jack analysis of
16		X	Use User Defined	Hygiene	Whole Body Hygiene	1	Whole-Shower Stall	1.14	1.05	1.05	2.72	Volume estimates reference ABS Guide for
17				Hygiene	Whole Body Hygiene	1	Whole-Shower Stall	3.78	1.17	1.17	2.51	Volume estimates reference Architectural
				Hygiene	Whole Body Hygiene	0	Whole-Wash station	1.42	1.12	1.12	2.57	Estimates from Table 18-5 in "Human

Input Collection Sheet

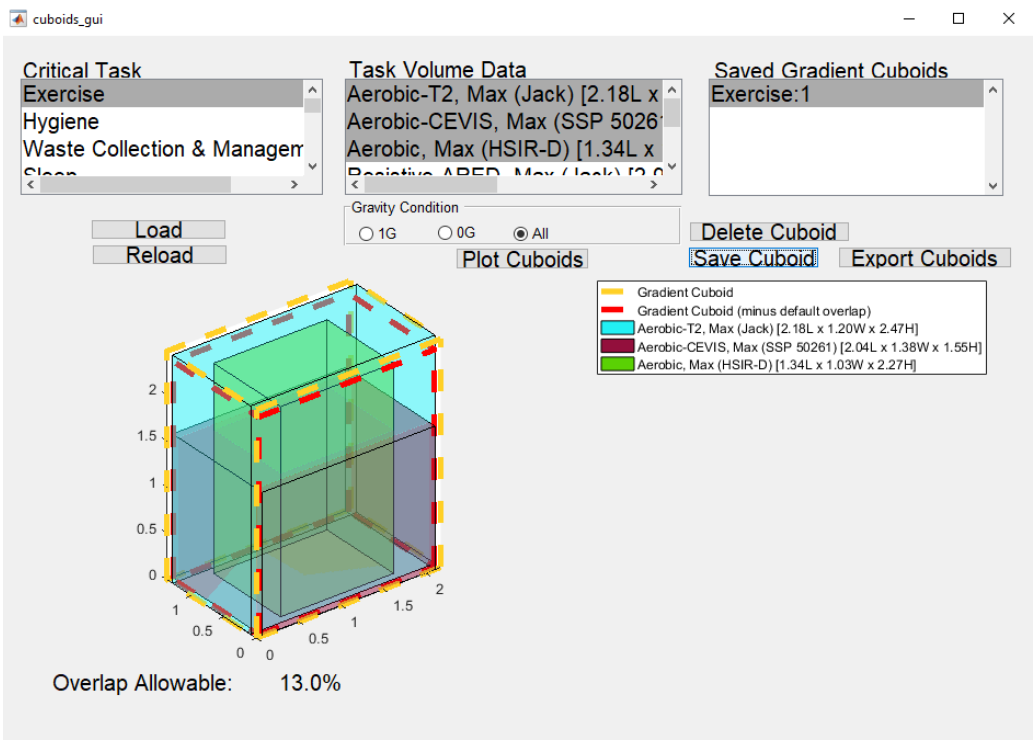
- New Task data points
  - User-defined task data points: Task, name, gravity condition, and dimensions
- Task overlap allowable
  - User-defined task pairwise overlap allowable

	A	B	C	D	E	F	G	H
1	Critical_Task	Basis_of_Assumptions	Gravity_Condition	Length_m	Width_m	Height_m	Volume_m3	Notes
2	Exercise	New Operational Scenario 1	2	2.5	1.5	2.75	10.31	
3	Exercise	New Operational Scenario 2	2	3	1.5	2.75	12.38	
4	Hygiene	New Operational Scenario 1	2	1.5	2	1.5	4.50	
5	Hygiene	New Operational Scenario 2	2	1.75	2	1.75	6.13	
6	Sleep	New Operational Scenario 1	2	1.5	1.5	1.5	3.38	
7	Group Meet & Eat	New Operational Scenario 1	2	2.5	2.5	2.5	15.63	
8								
9								

Task1	Task2	OverlapValue_percen	Notes
Exercise	Crew Health & Medical	55	
Hygiene	Exercise	55	
Sleep	Private Personal Activities	70	
Food Preparation	Group Meet & Eat	35	

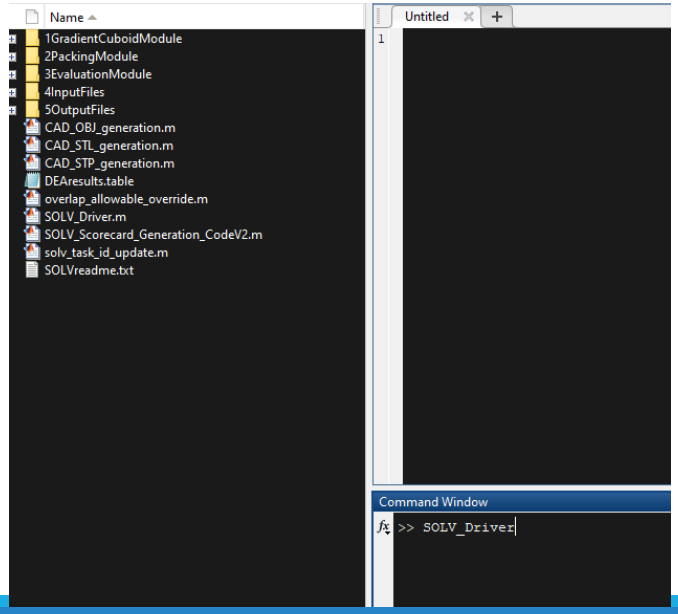
SOLV GUI

- Load/Reload the CTVD and input collection sheet
- Select task volume data and plot potential cuboids
- Save/Delete and Export cuboids

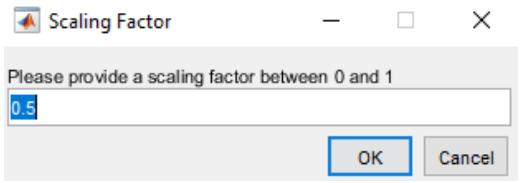


SOLV Driver

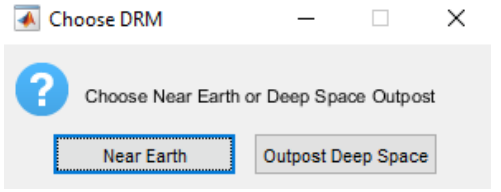
- SOLV Driver (Recommended optimization time limit is 8 hrs per layout)



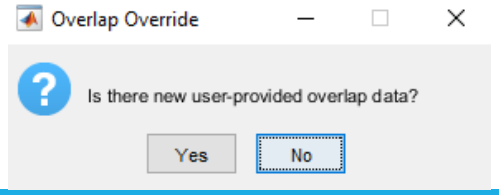
- Scaling Factor



- Choose DRM



- Task Overlap Allowable information



SOLV Scorecard

- Usage Guide
  - Brief overview of Scorecard sheets
- Mode Inputs
  - Description of DRM and selected task volume data

	A	B	C	D
1	Exercise	Aerobic-T2, Max (Jack) [2.18L x 1.20W x 2.47H]	DRM Categories	Near-Earth DRM
2	Hygiene	Partial-Hair/Upper/Lower Washing, Max (Jack) [1.05L x 0.80W x 1.95H]	Applicable Mission Type	ISS, NEA, Gateway Lunar
3	Waste Collection & Management	Collection-Shuttle WMS (Mockup) [1.37L x 0.73W x 1.83H]	Example Vehicle Type	Multi Elements: ISS, Gateway Hab
4	Sleep	Shuttle sleep [0.76L x 0.76W x 1.91H]	Habitable Vol/Layout Characteristic	Mix of dedicated/non-dedicated funtional areas
5	Crew Health & Medical	PHE-Max, 2 Crew (Jack) [2.26L x 1.47W x 2.17H]	Typical Duration Range	Mid-Duration (<12 months)
6	Private Personal Activities	Clothing Don/Doff Volume, Max (Jack) [0.83L x 0.75W x 1.93H]	Typical Crew Size	4+
7	Food Preparation	Food Prep Volume, 1 crew (HIDH) [1.99L x 1.06W x 2.06H]	SOLV Applicability	Yes
8	Group Meet & Eat	Skylab Wardroom, 3 Crew (NASA TM) [2.52L x 2.52W x 2.52H]		
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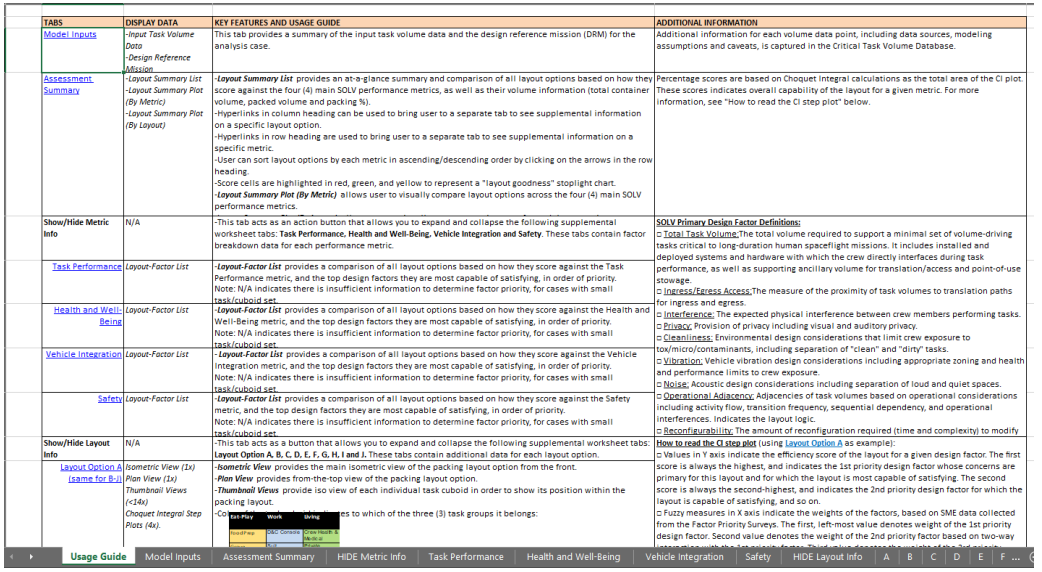
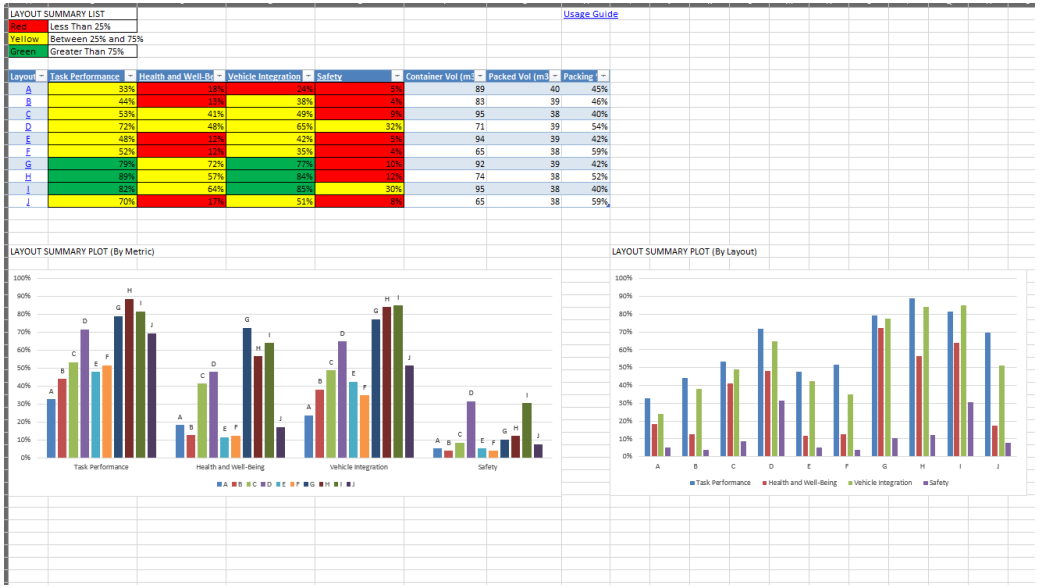


TABS	DISPLAY DATA	KEY FEATURES AND USAGE GUIDE	ADDITIONAL INFORMATION
Model Inputs	-Input Task Volume Data -Design Reference Mission	This tab provides a summary of the input task volume data and the design reference mission (DRM) for the analysis case.	Additional information for each volume data point, including data sources, modeling assumptions and caveats, is captured in the Critical Task Volume Database.
Assessment Summary	-Layout Summary List -Layout Summary Plot (By Metric) -Layout Summary Plot (By Layout)	-***Layout Summary List*** provides an at-a-glance summary and comparison of all layout options based on how they score against the four (4) main SOLV performance metrics, as well as their volume information (total container volume, packed volume and packing %). -Hyperlinks in column heading can be used to bring user to a separate tab to see supplemental information on a specific layout option. -Hyperlinks in row heading are used to bring user to a separate tab to see supplemental information on a specific metric. -User can sort layout options by each metric in ascending/descending order by clicking on the arrows in the row heading. -Score cells are highlighted in red, green, and yellow to represent a "layout goodness" stoplight chart. -***Layout Summary Plot (By Metric)*** allows user to visually compare layout options across the four (4) main SOLV performance metrics.	Percentage scores are based on Choquet Integral calculations as the total area of the CI plot. These scores indicates overall capability of the layout for a given metric. For more information, see "How to read the CI step plot" below.
Show/Hide Metric Info	N/A	-This tab acts as an action button that allows you to expand and collapse the following supplemental worksheet tabs: **Task Performance, Health and Well-Being, Vehicle Integration and Safety**. These tabs contain factor breakdown data for each performance metric.	**SOLV Primary Design Factor Definitions:** ▫ Total Task Volume:The total volume required to support a minimal set of volume-driving tasks critical to long-duration human spaceflight missions. It includes installed and deployed systems and hardware with which the crew directly interfaces during task performance, as well as supporting ancillary volume for translation/access and point-of-use stowage. ▫ Ingress/Egress Access:The measure of the proximity of task volumes to translation paths for ingress and egress. ▫ Interference: The expected physical interference between crew members performing tasks. ▫ Privacy: Provision of privacy including visual and auditory privacy. ▫ Cleanliness: Environmental design considerations that limit crew exposure to tox/micro/contaminants, including separation of "clean" and "dirty" tasks. ▫ Vibration: Vehicle vibration design considerations including appropriate zoning and health and performance limits to crew exposure. ▫ Noise: Acoustic design considerations including separation of loud and quiet spaces. ▫ Operational Adjacency: Adjacencies of task volumes based on operational considerations including activity flow, transition frequency, sequential dependency, and operational interferences. Indicates the layout logic. ▫ Reconfigurability: The amount of reconfiguration required (time and complexity) to modify
Task Performance	*Layout-Factor List*	-***Layout-Factor List*** provides a comparison of all layout options based on how they score against the Task Performance metric, and the top design factors they are most capable of satisfying, in order of priority. Note: N/A indicates there is insufficient information to determine factor priority, for cases with small task/cuboid set.	
Health and Well-Being	*Layout-Factor List*	-***Layout-Factor List*** provides a comparison of all layout options based on how they score against the Health and Well-Being metric, and the top design factors they are most capable of satisfying, in order of priority. Note: N/A indicates there is insufficient information to determine factor priority, for cases with small task/cuboid set.	
Vehicle Integration	*Layout-Factor List*	-***Layout-Factor List*** provides a comparison of all layout options based on how they score against the Vehicle Integration metric, and the top design factors they are most capable of satisfying, in order of priority. Note: N/A indicates there is insufficient information to determine factor priority, for cases with small task/cuboid set.	
Safety	*Layout-Factor List*	-***Layout-Factor List*** provides a comparison of all layout options based on how they score against the Safety metric, and the top design factors they are most capable of satisfying, in order of priority. Note: N/A indicates there is insufficient information to determine factor priority, for cases with small task/cuboid set.	
Show/Hide Layout Info	N/A	-This tab acts as a button that allows you to expand and collapse the following supplemental worksheet tabs: **Layout Option A, B, C, D, E, F, G, H, I and J.** These tabs contain additional data for each layout option.	**How to read the CI step plot** (using Layout Option A as example): ▫ Values in Y axis indicate the efficiency score of the layout for a given design factor. The first score is always the highest, and indicates the 1st priority design factor whose concerns are primary for this layout and for which the layout is most capable of satisfying. The second score is always the second-highest, and indicates the 2nd priority design factor for which the layout is capable of satisfying, and so on. ▫ Fuzzy measures in X axis indicate the weights of the factors, based on SME data collected from the Factor Priority Surveys. The first, left-most value denotes weight of the 1st priority design factor. Second value denotes the weight of the 2nd priority factor based on two-way
Layout Option A (same for B-J)	*Isometric View (1x)* *Plan View (1x)* *Thumbnail Views (<14x)* *Choquet Integral Step Plots (4x).*	-***Isometric View*** provides the main isometric view of the packing layout option from the front. -***Plan View*** provides from-the-top view of the packing layout option. -***Thumbnail Views*** provide iso view of each individual task cuboid in order to show its position within the packing layout. -Co[illegible]es to which of the three (3) task groups it belongs:	

Usage Guide | Model Inputs | Assessment Summary | HIDE Metric Info | Task Performance | Health and Well-Being | Vehicle Integration | Safety | HIDE Layout Info | A | B | C | D | E | F ...

SOLV Scorecard

- Assessment Summary
  - Metric Scores for each layout
  - Task Performance, Health and Well-Being, Vehicle Integration, Safety
  - Container and Packed Volume



LAYOUT SUMMARY LIST — Usage Guide

Red	Less Than 25%
Yellow	Between 25% and 75%
Green	Greater Than 75%

Layout	Task Performance	Health and Well-Be	Vehicle Integration	Safety	Container Vol (m3	Packed Vol (m3	Packing
A	33%	18%	24%	5%	89	40	45%
B	44%	13%	38%	4%	83	39	46%
C	53%	41%	49%	9%	95	38	40%
D	72%	48%	65%	32%	71	39	54%
E	48%	13%	43%	5%	94	39	42%
F	52%	12%	35%	4%	65	38	59%
G	79%	72%	77%	10%	92	39	42%
H	89%	57%	84%	12%	74	38	52%
I	82%	64%	85%	30%	95	38	40%
J	70%	17%	51%	8%	65	38	59%

SOLV Scorecard

- Individual Metric Sheets
  - Metric Score
  - Contributing Factors

	A	B	C	D	E	F	G	H	I
1	LAYOUT-FACTOR LIST (Task Performance)					Usage Guide			
2	Red		Less Than 25%			Assessment Summary			
3	Yellow		Between 25% and 75%						
4	Green		Greater Than 75%						
5									
6	Design	Task Performance	Primary Factor	Secondary Factor	Tertiary Factor	Quaternary Factor			
7	A	33%	Total Task Volume	Operational Adjacenc	Interference	Reconfigurability			
8	B	44%	Reconfigurability	Total Task Volume	Interference	Operational Adjacency			
9	C	53%	Operational Adjacenc	Interference	Total Task Volume	Reconfigurability			
10	D	72%	Interference	Total Task Volume	Operational Adjacenc	Reconfigurability			
11	E	48%	Reconfigurability	Interference	Total Task Volume	Operational Adjacency			
12	F	52%	Total Task Volume	Interference	Reconfigurability	Operational Adjacency			
13	G	79%	Reconfigurability	Operational Adjacenc	Total Task Volume	Interference			
14	H	89%	Operational Adjacenc	Total Task Volume	Reconfigurability	Interference			
15	I	82%	Reconfigurability	Operational Adjacenc	Interference	Total Task Volume			
16	J	70%	Interference	Total Task Volume	Reconfigurability	Operational Adjacency			

Usage Guide | Model Inputs | Assessment Summary | HIDE Metric Info | Task Performance | Health and Well-Being

SOLV Scorecard

- Layout Sheets
  - Layout thumbnails
  - Choquet Integrals

SOLV Verification

V2.0 Verification Test milestones:

- 5/17/2019 Finalized updated test requirements/cases/steps.
- 6/28/2019 Completed verification testing of GC module and Packing module.
- 7/9/2019, 7/11/2019 Completed team review of test results.
- 7/16/2019 Completed verification testing of Evaluation module.
- 8/9/2019 Completed verification testing of Driver/Scorecard module.
- 8/12/2019 Completed delivery of verification document to QA for audit.

Module Testing Scope Change:

- Updated existing requirements, test cases and steps.
- Added new requirements, test cases and steps.
  - GC module – Added two (2) additional requirements
  - Overlap Packing - Added three (3) additional requirements
  - Evaluation module - Added nine (9) additional requirements
  - Driver/Scorecard - Added five (5) additional requirements

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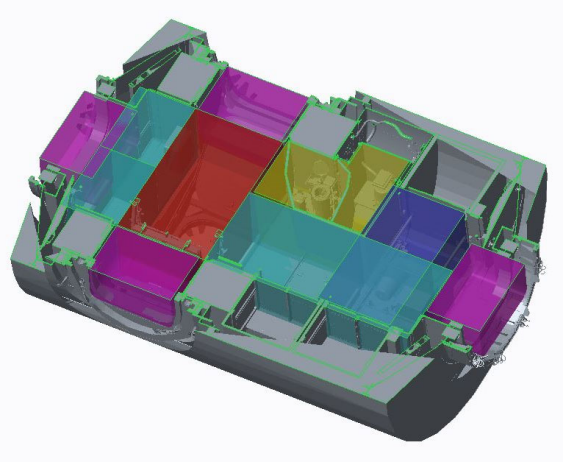
SOLV Verif Test Document

SOLV Validation

Philosophy:

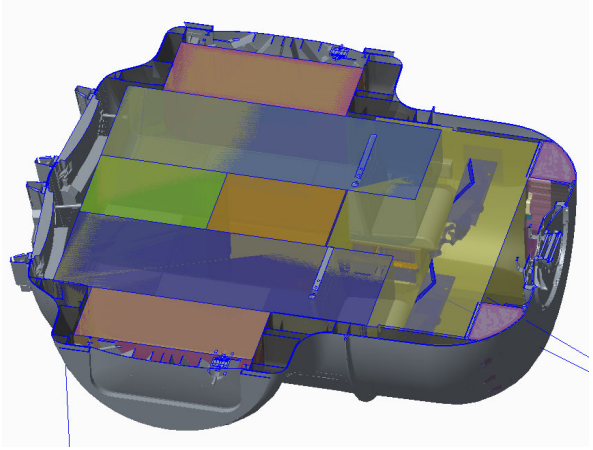
- Plan and execute validation of SOLV output to determine the degree to which it represents the real world system in the context of the intended use of the model
- Primary use case of SOLV is its use as an early design phase volume estimation tool
- Two principal strategies:
  1. Compare SOLV volume estimates with selected referents, i.e. existing spacecraft designs, by establishing a common parameters, inputs and constraints.
  2. Provide evidence that the tool provides a structured and repeatable process for volume estimation based on habitat design standards and best practices, and supports work- and decision-flow for early phases of mission/habitat planning and design.

Selected Referents



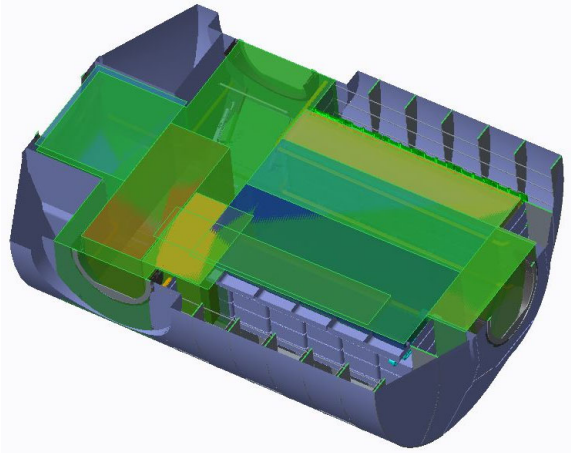
ISS NODE 3

- Launched in 2010
- Provides 6 berthing locations, exercise, storage, crew hygiene and waste collection, and life support systems.
- ***Representative flight vehicle referent***



MMSEV2B/HABITABLE AIRLOCK (HAL)

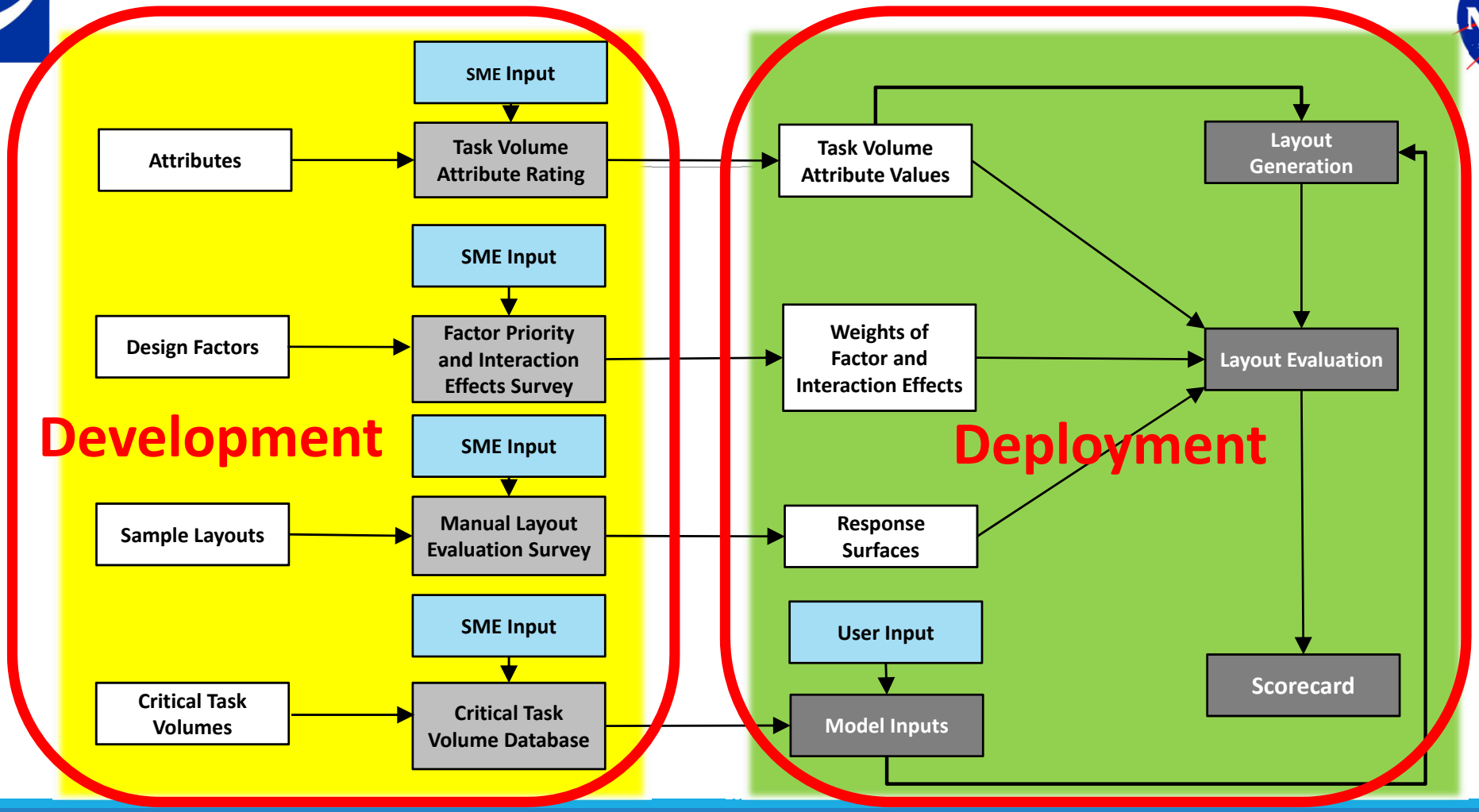
- Project went through several reconfigurations/repurposing
- Precursor MMSEV projects built prototypes for the annual Desert RATS analog mission simulations.
- ***Representative ground analog referent***



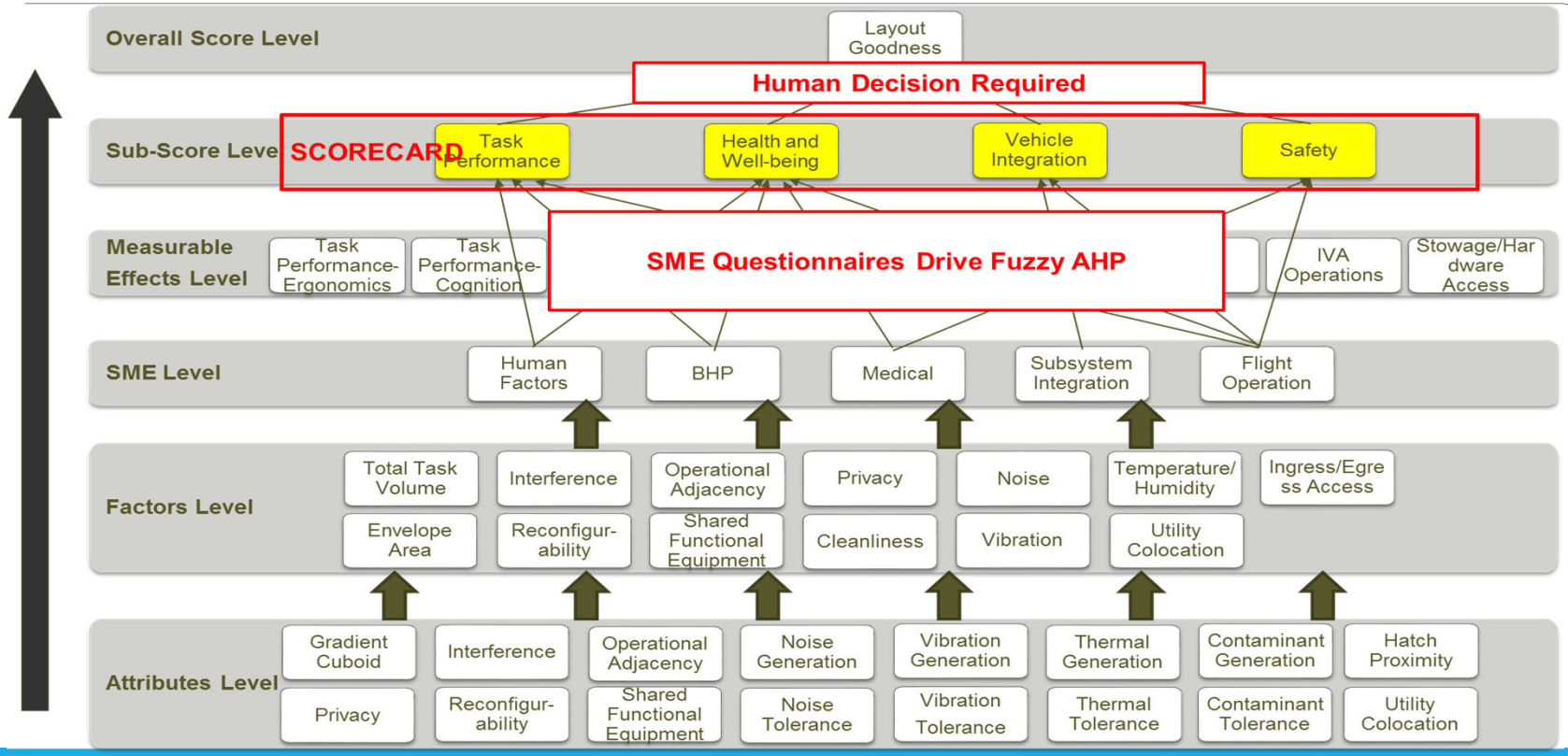
GATEWAY GEN 2

- An early iteration of the Gateway Habitation Element as part of the Internal Architecture Study.
- ***Representative paper design referent***

SOLV Overview



SOLV Metric Hierarchy



7009A Credibility Level Definitions

Goals for NASA-STD-7009A Credibility Scores (11/14/2016)

Factor	Min Level	7009A Level Definitions
Data pedigree	2	Most data are known and traceable to formal documentation. Processes to establish significant data are known. Uncertainties in all data are at least estimated.
Verification	2	The model is correctly implemented as determined by documented verification practices, which evaluate all components, features, capabilities, and couplings of the model. Documented methods are used to assess model errors. Most of the important model errors satisfy program/project-specified requirements.
Validation	1	The model is conceptually validated. The problem statement (intended use) is clearly stated & well-understood, and the conceptual model, requirements, & specifications are correct and sufficiently address the problem.
Input Pedigree	2	Most input data are known and traceable to formal documentation. Processes to establish significant data are known. Uncertainties in all data are at least estimated.
Uncertainty Characterization	1	Sources of input uncertainty have been identified with qualitative estimates of the uncertainty. Their impact on output uncertainties and uncertainty propagation have not been addressed.
Results Robustness	1	Sensitivity of M&S results for the RWS is estimated by analogy with the quantified sensitivity of similar problems of interest.
Use History	1	Model is new or has major changes from previously used versions, or proposed use has major differences from previous uses; however, the model, changes, and uses are documented.
M&S Management	1	Roles and responsibilities are defined in the context of an M&S process that is informally documented. Requirements for M&S products are informally documented. CM of M&S products is established and applied using informal methods.

SOLV 7009A Compliance

Factor	Min Level	Self Assess v1.0 (2018)	Self Assess v2.0 (2019)	Evidence of Compliance
Data pedigree	2	2	2	Survey administration details and analysis details are documented in the Technical Description Document and Phase I Report. Evidence: Survey design and outcomes in 2018 FDR (slide 17-20) and Phase I Report.
Verification	2	2	2	Software verification – Test it's doing what you want it to do. Computation verification – Test the calculations produces acceptable errors. The V&V Document captures the test processes and test results. Every component separately evaluated. Evidence: 2018 FDR (slide 55-57), SOLV-003 V&V Document, 2019 Test Document submitted for QA audit.
Validation	1	1	2	Conceptual Model must address Problem Statement. Evidence: Conceptual model documented in the Technical Description Document, and reviewed in the Proposal and via conference paper publication (IEEE Space). 2019 Validation Document captures summary of these methods and results of referent comparisons.
Input Pedigree	2	2	3	Input Data Document, encompassed within the Technical Description Document, captures pedigree of task volume inputs and attributes and the range of data points for a subset (10% of database) to demonstrate uncertainty estimates. The User Guide provides information to the end user regarding permissible uses of the model. Evidence: Survey design and outcomes per CTVD-R3 illustrated on 2018 FDR (slide 14 - 16), 2018 SOLV Workshop Technical Review (Phase I Report).
Uncertainty Characterization	1	1	1	Sources of input uncertainty have been identified with qualitative estimates. Evidence: Technical Description Document captures identification and qualitative assessment of uncertainties and variations in the following data: task volumes, overlap allowables, adjacency factors and AHP survey data. 2019 sensitivity analysis results documented in 2019 FDR.
Results Robustness	1	2	2	Estimate Sensitivity by analogy to the RWS. Evidence: Systematic parameter sensitivity study performed identifying many parameter sensitivities as outlined in 2018 FDR (slides 58-59) and 2019 FDR.
Use History	1	1	1	User Guide documents example use cases for this new model. Evidence: New Model
M&S Management	1	1	1	Informal Process applied. Evidence: Development follows plan laid out in proposal; SharePoint and Subversion for configuration management; all testing activities coordinated through test plan development; regular coordination meetings and reviews.

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SOLVe Phase One - Surveys

Phase 1 Factor Priority and Interactions Effects Survey was completed in November 2018.

- Developed three DRM categories of SOLV.
- Conducted 4 discussion sessions to finalize strategies for data collection and analysis for design factor priority and interactions effects.
  - Completed analysis of existing model dataset to determine the required delta for additional data collection and analysis
- **Completed 9 group survey sessions with 21 SMEs (including 1 crew subject), collecting 30 survey responses overall.**
  - Pairwise comparisons for SOLV's 9 design factors and 8 design factor pairs were performed in the context of two Design Reference Mission categories (Near-Earth and Deep Space/Outpost) and four SOLV layout performance metrics (Task Performance, Health and Well-Being, Vehicle Integration and Safety).

SOLVe Phase One - Surveys

Phase 2 Manual Layout Evaluation Survey was completed in December 2018.

- Conducted 3 discussion sessions to finalize strategies for data collection and analysis for manual layout evaluation.
  - Phase 2 Survey was designed to strengthen our existing SME database on layout factor scoring for improved correlations.
  - Based on analysis of 2017 results, areas of the database that require more data points were identified and targeted for the 2018 survey.
    - A “divide-and-conquer” strategy was employed to reduce the total number of pairwise a subject needs to compare.
- **Completed 5 group survey sessions with 10 SMEs (including 1 crew subject), collecting 60 survey responses overall.**
- Pairwise comparisons for SOLV's 10 sample layouts were performed to score their performance against SOLV’s 9 design factors.

SOLVe Phase One - 2018 SOLV Workshop

Specific Aim: Conduct SOLV Workshop

Objective: To bring together key representatives of future owner, user and stakeholder communities for the SOLV model to:

- Gain acceptance of the model
- Help review SOLV products
- Prioritize improvement goals for the model's next phase of development.

The 2018 SOLV Workshop was held on November 13 and 14, 2018, at JSC.

The two-day workshop was well-attended by over 30 representatives and subject matter experts from different organizations and programs:

HFBP	LARC	Gateway
JSC/SF	MSFC	American Bureau of Shipping
GRC		

SOLV Sensitivity Analysis

All Data/Files Must be Uploaded Here:				Team Documents > Model Development > Module Verification > Sensitivity Analysis						John: Fill In Values Here									Rich/Churlzu: Fill In Values Here		John/Claudia: Fill In Values Here			
Test #	**GC Input Variation**	**Overlap Allowable Variation**	**Vol/Adj Scaling Factor Variation**	**Gradient Cuboids Output File** *(POC: John A)*	**File Uploaded** (Y?)	**Packing Layout Output File** *(POC: Rich/Churlzu)*	**File Uploaded** (Y?)	**Scorecard Output File** *(POC: John/Claudia)*	**File Uploaded** (Y?)	**Group Meet and Eat Cuboid OA (%)**	**Recreation Cuboid OA (%)**	**Mission-Specific Work Cuboid OA (%)**	**Crew Health and Medical Cuboid OA (%)**	**Waste Collection Cuboid OA (%)**	**Food Prep Cuboid OA (%)**	**Exercise Cuboid OA (%)**	**Sleep Cuboid 1 OA (%)**	**Sleep Cuboid 2 OA (%)**	**Total Packing Container Volume (m3)**	**Packed Volume (m3)**	**Task Performance Metric Score (%)**	**Health and Well-Being Metric Score (%)**	**Vehicle Integration Metric Score (%)**	**Safety Metric Score (%)**
1	Case 1	Case 1	Case 1	MinPlus10.mat	Y	1_1_1_ MinPlus10XY01.mat	Y	1_1_1_ MinPlus10XY01s.xls	Y	55	66	33	44	33	33	33	33	33	23.6429	19.1881	53%	13%	40%	37%
2	Case 1	Case 1	Case 2	MinPlus10.mat		1_1_2_ MinPlus10XY05.mat	Y	1_1_2_ MinPlus10XY05s.xls	Y										27.2651	19.4343	51%	8%	36%	33%
3	Case 1	Case 1	Case 3	MinPlus10.mat		1_1_3_ MinPlus10XY09.mat	Y	1_1_3_ MinPlus10XY09s.xls	Y										32.8189	19.7261	35%	15%	25%	28%
4	Case 1	Case 2	Case 1	MinMinus10.mat	Y	1_2_1_ MinMinus10XY01.mat	Y	1_2_1_ MinMinus10XY01s.xls	Y	45	54	27	36	27	27	27	27	27	24.2785	19.5168	72%	12%	56%	36%
5	Case 1	Case 2	Case 2	MinMinus10.mat		1_2_2_MinMinus10XY05.mat	Y	1_2_2_MinMinus10XY05s.xls	Y										27.9663	19.6175	38%	8%	27%	26%
6	Case 1	Case 2	Case 3	MinMinus10.mat		1_2_3_ MinMinus10XY09.mat	Y	1_2_3_ MinMinus10XY09s.xls	Y										33.7391	19.9619	40%	9%	26%	22%
7	Case 1	Case 3	Case 1	MinPlus10.mat		1_3_1_ MinPlus10XYZ01.mat	Y	1_3_1_ MinPlus10XYZ01s.xls	Y										23.6429	19.0654	77%	19%	57%	41%
8	Case 1	Case 3	Case 2	MinPlus10.mat		1_3_2_ MinPlus10XYZ05.mat	Y	1_3_2_ MinPlus10XYZ05s.xls	Y										27.2651	19.2208	76%	15%	55%	34%
9	Case 1	Case 3	Case 3	MinPlus10.mat		1_3_3_ MinPlus10XYZ09.mat	Y	1_3_3_ MinPlus10XYZ09s.xls	Y										32.8189	19.7261	39%	12%	27%	18%
10	Case 1	Case 4	Case 1	MinMinus10.mat		1_4_1_ MinMinus10XYZ01.mat	Y	1_4_1_ MinMinus10XYZ01s.xls	Y										24.2785	19.4506	65%	6%	46%	27%
11	Case 1	Case 4	Case 2	MinMinus10.mat		1_4_2_ MinMinus10XYZ05.mat	Y	1_4_2_ MinMinus10XYZ05s.xls	Y										27.9663	19.7034	48%	37%	41%	12%
12	Case 1	Case 4	Case 3	MinMinus10.mat		1_4_3_ MinMinus10XYZ09.mat	Y	1_4_3_ MinMinus10XYZ09s.xls	Y										33.7391	19.9619	37%	9%	31%	7%
13	Case 1	Case 5	Case 1	MinBase.mat	Y	1_5_1_ MinBaseXY01.mat	Y	1_5_1_ MinBaseXY01s.xls	Y	50	60	30	40	30	30	30	30	30	23.9642	19.3669	55%	35%	47%	34%
14	Case 1	Case 5	Case 2	MinBase.mat		1_5_2_ MinBaseXY05.mat	Y	1_5_2_ MinBaseXY05s.xls	Y										27.6197	19.6009	58%	36%	48%	16%
15	Case 1	Case 5	Case 3	MinBase.mat		1_5_3_ MinB													33.2840	19.8457	34%	8%	28%	7%
16	Case 1	Case 6	Case 1	MinBase.mat		1_6_1_ MinB													23.9642	19.2669	58%	24%	44%	24%
17	Case 1	Case 6	Case 2	MinBase.mat		1_6_2_ MinB													27.6197	19.3919	56%	33%	42%	12%
18	Case 1	Case 6	Case 3	MinBase.mat		1_6_3_ MinB													33.2840	19.8112	65%	27%	53%	15%
19	Case 2	Case 1	Case 1	MaxPlus10.mat	Y	2_1_1_ Maxl													119.4798	102.7245	18%	7%	17%	5%
20	Case 2	Case 1	Case 2	MaxPlus10.mat		2_1_2_ Maxl													158.5966	105.3243	12%	3%	10%	2%
21	Case 2	Case 1	Case 3	MaxPlus10.mat		2_1_3_ Maxl													191.6243	104.2887	34%	23%	23%	8%
22	Case 2	Case 2	Case 1	MaxMinus10.mat	Y	2_2_1_ Maxl													120.8997	103.8888	25%	12%	15%	7%
23	Case 2	Case 2	Case 2	MaxMinus10.mat		2_2_2_ Maxl													159.7646	105.9402	37%	56%	26%	23%
24	Case 2	Case 2	Case 3	MaxMinus10.mat		2_2_3_ Maxl													193.0161	105.1168	59%	24%	40%	10%
25	Case 2	Case 3	Case 1	MaxPlus10.mat		2_3_1_ Maxl													108.3917	98.5231	26%	15%	15%	7%
26	Case 2	Case 3	Case 2	MaxPlus10.mat		2_3_2_ Maxl													127.4804	102.3942	43%	19%	28%	9%
27	Case 2	Case 3	Case 3	MaxPlus10.mat		2_3_3_ Maxl													186.7030	101.9927	54%	17%	37%	8%
28	Case 2	Case 4	Case 1	MaxMinus10.mat		2_4_1_ Maxl													111.3146	100.6790	50%	28%	29%	11%
29	Case 2	Case 4	Case 2	MaxMinus10.mat		2_4_2_ Maxl													143.1023	104.2375	45%	80%	32%	44%
30	Case 2	Case 4	Case 3	MaxMinus10.mat		2_4_3_ Maxl													189.0011	103.2719	47%	24%	31%	9%
31	Case 2	Case 5	Case 1	MaxBase.mat	Y	2_5_1_ Maxl													119.9411	103.3150	55%	78%	58%	83%
32	Case 2	Case 5	Case 2	MaxBase.mat		2_5_2_ Maxl													159.1844	105.6352	43%	36%	46%	31%
33	Case 2	Case 5	Case 3	MaxBase.mat		2_5_3_ Maxl													192.3243	104.7074	40%	37%	39%	24%
34	Case 2	Case 6	Case 1	MaxBase.mat		2_6_1_ Maxl													109.7078	99.6034	69%	84%	70%	52%
35	Case 2	Case 6	Case 2	MaxBase.mat		2_6_2_ Maxl													128.4718	102.9637	59%	33%	58%	25%
36	Case 2	Case 6	Case 3	MaxBase.mat		2_6_3_ Maxl													187.8568	102.6173	40%	37%	37%	42%

Test Cases for Gradient Cuboid Input Variation:

Case 1: Minimum: Single Smallest Datapoint from the Dataset for Each Task.

Case 2: Maximum: All Datapoints from the Dataset for Each Task.

Case 3: Midrange: Midrange Number of Midrange Datapoints from the Dataset for Each Task.

Test Cases for Overlap Allowable Variation:

Case 1: Apply a 10% Increase in Volume to Overlap Allowable for Each Task. Apply to Layouts with XY Overlap.

Case 2: Apply a 10% Decrease in Volume to OA for Each Task. Apply to Layouts with XY Overlap.

Case 3: Apply a 10% Increase in Volume to OA for Each Task. Apply to Layouts with XYZ Overlap.

Case 4: Apply a 10% Decrease in Volume to OA for Each Task. Apply to Layouts with XYZ Overlap.

Case 5: Apply Baseline OA to Layouts with XY Overlap.

Case 6: Apply Baseline OA to Layouts with XYZ Overlap.

Test Cases for Volume/Adjacency Scaling Factor Variation:

Case 1: Apply Scaling Factor of 0.1

Case 2: Apply Scaling Factor of 0.5

Case 3: Apply Scaling Factor of 0.9

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