THE UNIVERSITY OF TEXAS AT EL PASO

Test scheduling

NG / UTEP Final Presentation
Dec 8, 2025

Agenda

- Team introduction
- Mission Overview
- Concept of Operations
- Requirements
  - Requirement Flow down
  - Requirement Verification and Validation
- Trade Studies
- Design Concept
- Integration and Test
- Risk Assessment
- Proposed Future Work

Team Introductions

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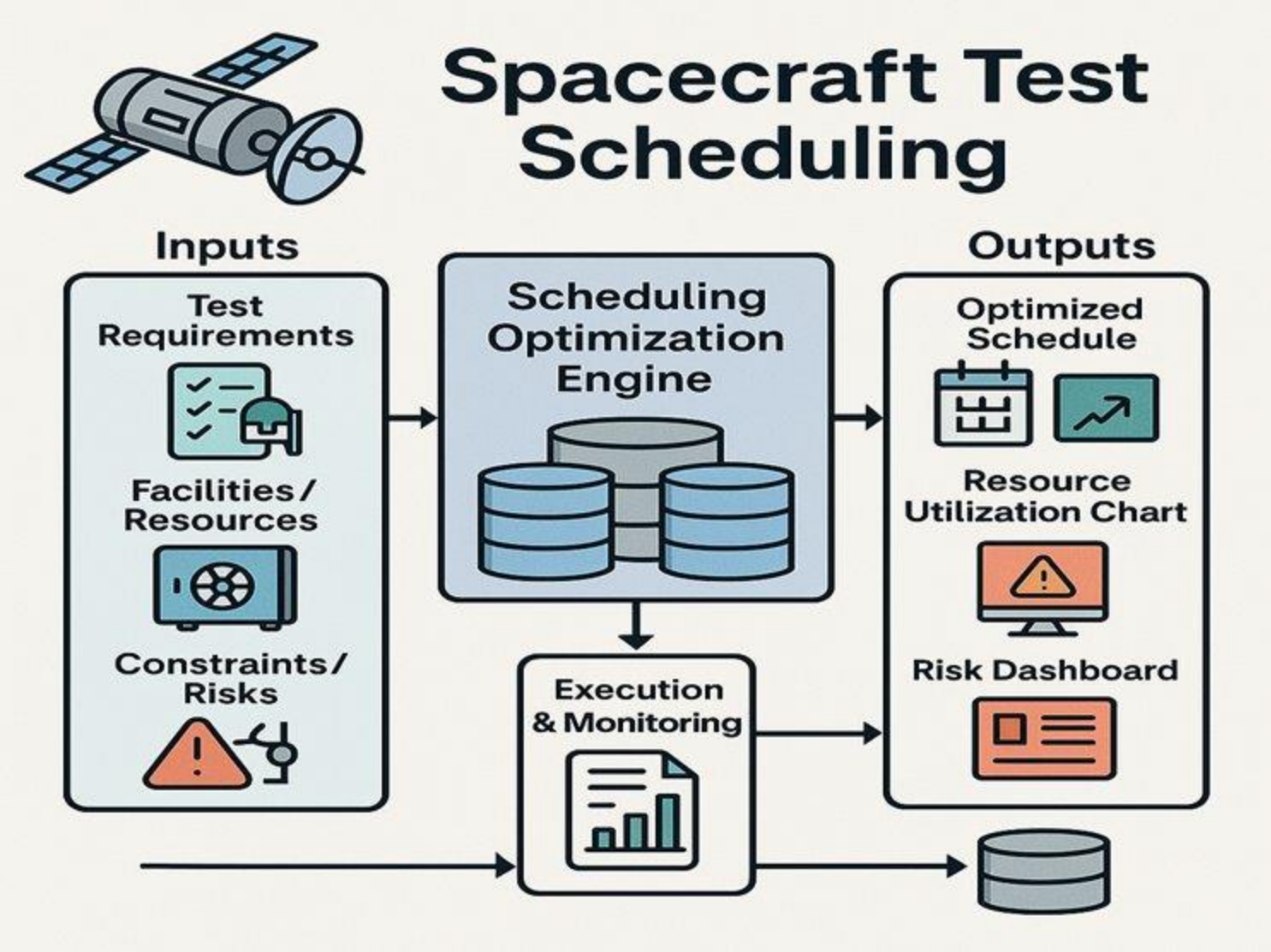
Mission Overview

-Coordinate TVAC, EMI, Dynamics, and Propulsion testing with limited facilities.

-Goal is to test spacecrafts through environmental and functional testing, all while keeping chambers occupied and staying on a deadline.

Concept of Operations



Requirements

1.	Top-Level Requirement	
1.1	**Scheduling & Optimization Engine**	
1.1.1	**Precedence Compliance**	The tool shall enforce all test-flow precedence rules, including Alignments before Dynamics, Deployments after Dynamics, Propulsion after all environmental tests (TVAC, Dynamics, and EMI when required), FIST before Final Closeouts, and GSE compatibility before FIST.
1.1.2	**Resource-Constrained Scheduling**	The tool shall schedule tests only when the required resource lane is available and within its defined capacity
1.1.3	**Makespan Minimization**	The tool shall compute a schedule that minimizes the overall makespan subject to all constraints.
1.1.4	**Multi-Spacecraft Support**	The tool shall support scheduling for at least N spacecraft in a single integrated schedule.

Requirements

1.2	**Resource & Calendar Management**	
1.2.1	**Capacity Configuration**	The tool shall manage resource capacities, lanes, and working calendars for all test facilities.
1.2.2	**Lane-Level Modeling**	The tool shall model individual resource lanes with independent availability.
1.2.3	**Working-Day Calendar**	The tool shall support a working-day calendar with the option to skip weekends and non-working days.
1.2.4	**Test Duration Handling**	The tool shall use configurable test durations based on the defined nominal

Requirements

1.3	**Outage & Re-planning Management**	
1.3.1	**Resource Outage Modeling**	The tool shall allow the user to define date-based outages for specific resources and lanes
1.3.2	**Spacecraft Outage Modeling**	The tool shall allow the user to define spacecraft-specific outages during which a spacecraft cannot start new tests.
1.3.3	**Automatic Re-planning**	The tool shall automatically recompute a feasible schedule when outages or delays are applied, while continuing to minimize makespan.
1.3.4	**Scenario Comparison**	The tool shall support running a baseline schedule and a replanned schedule for comparison under different outage scenarios.

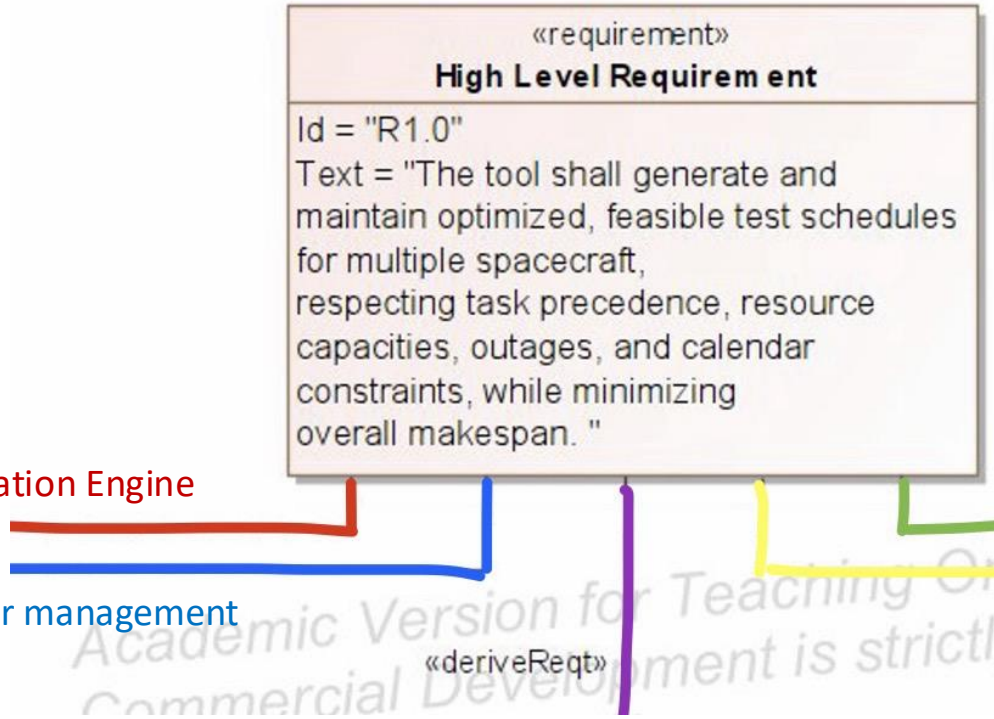
Requirements

1.4	**Persistent Configuration Storage**	
1.4.1	**1.4.1 – Persistent Configuration Storage**	The tool shall store configuration data (spacecraft list, test durations, resource capacities, outages) for reuse between runs.
1.4.2	**1.4.2 – Input Validation**	The tool shall validate user inputs , date ranges, capacities, non-negative durations) and provide error messages for invalid entries
1.4.3	**1.4.3 – Traceability to Requirements**	The tool shall maintain traceability between configuration parameters and the requirements they satisfy

Requirements

1.5	**Visualization, Export, and User Interface**	
1.5.1	**Gantt Chart Visualization**	The tool shall display a Gantt chart showing each spacecraft's test sequence, start and end dates, and resource lane usage
1.5.2	**Tabular Output Export**	The tool shall export the detailed schedule (task, spacecraft, resource lane, start, end) to a CSV file.
1.5.3	**Gantt Export**	The tool shall export the Gantt chart to an image file format (PNG) for use in reports and presentations.
1.5.4	**Interactive Parameter Editing**	The tool shall provide a user interface that allows editing capacities, outages, and the number of spacecraft without modifying the underlying code.

Requirements Flowdown



1.1 Schedule and optimization Engine

1.2 Resource and calendar management

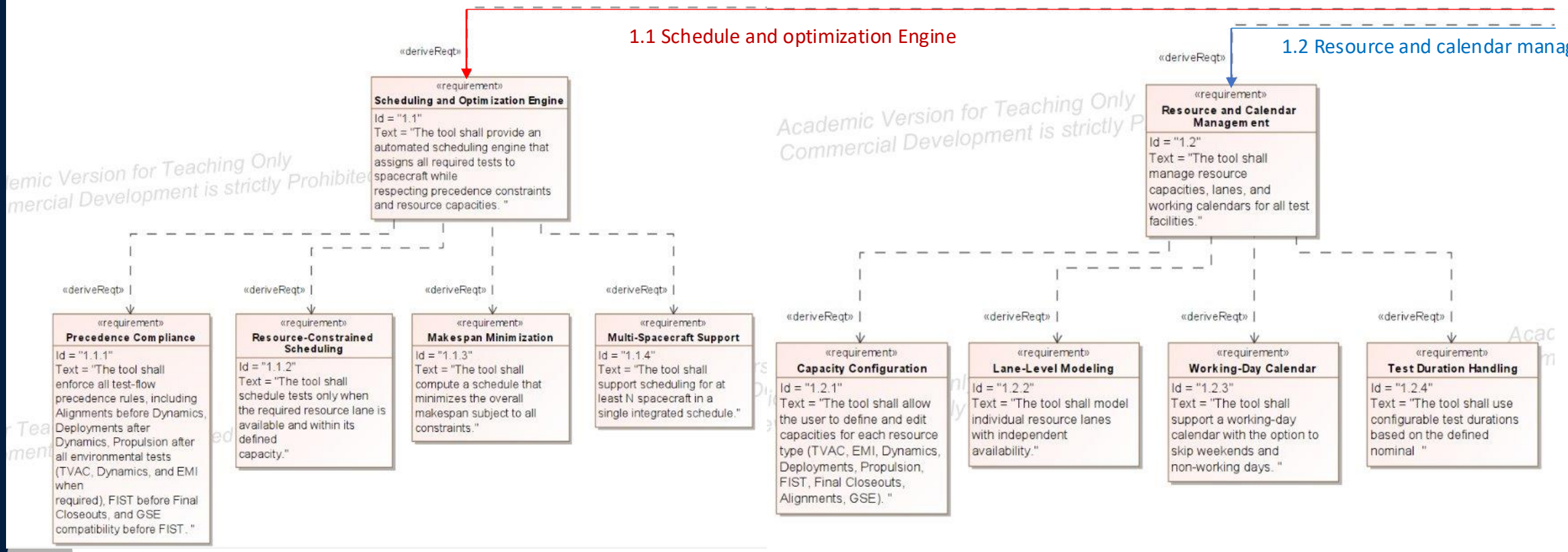
1.3 Outage and re-planning management

1.4 Persistent configuration storage

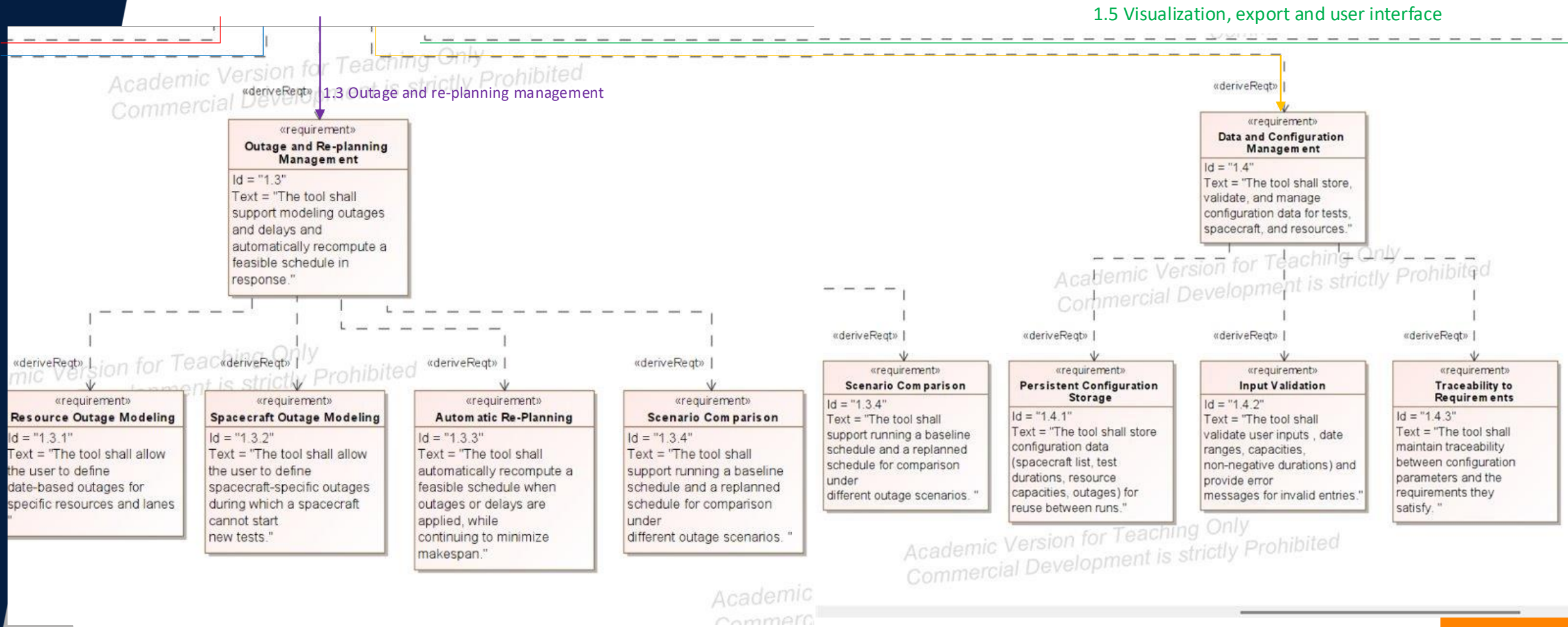
1.5 Visualization, export and user interface

Commercial Development
Academic Version for Teaching Only
Commercial Development is strictly Prohib

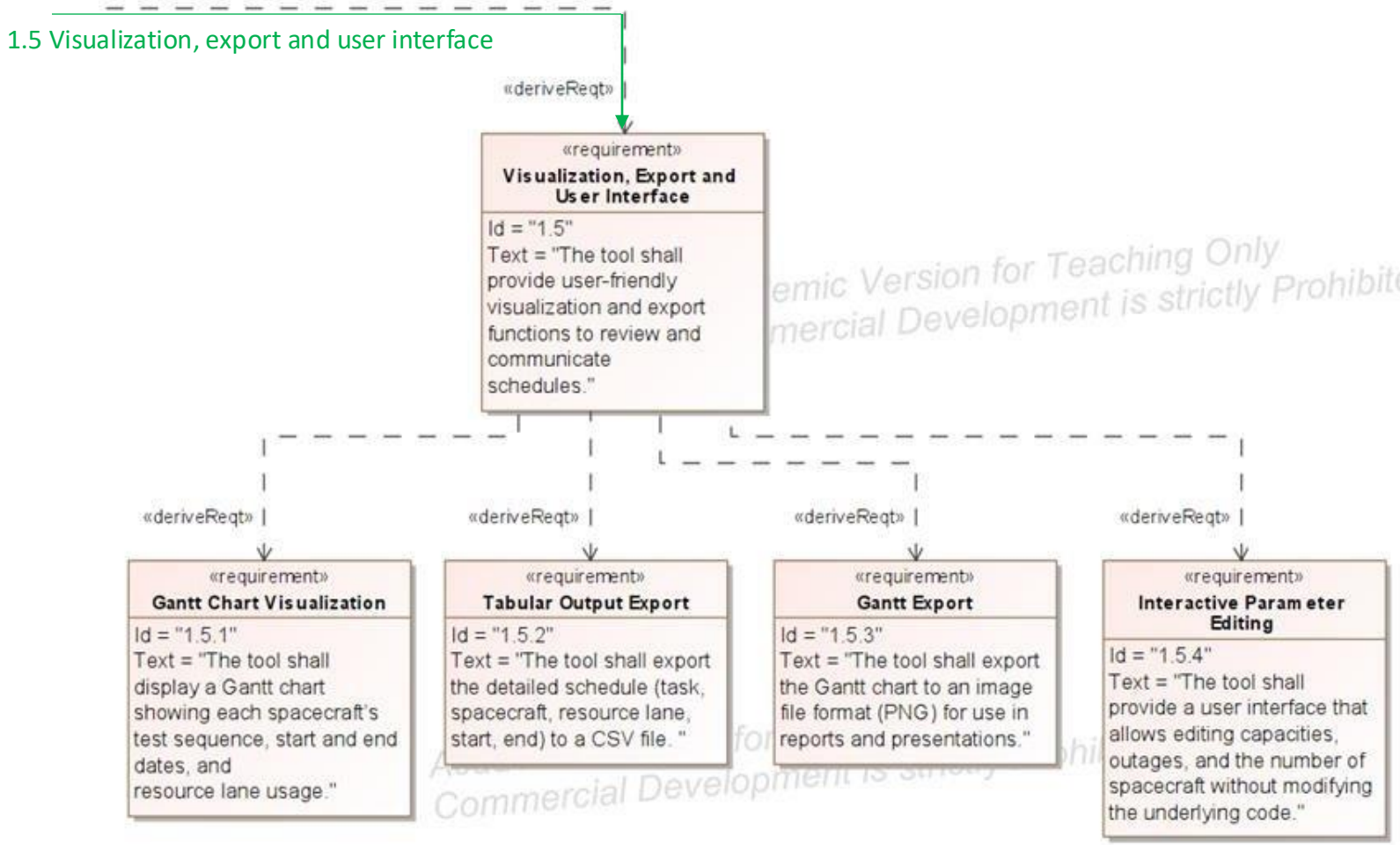
Requirements Flowdown



Requirements Flowdown

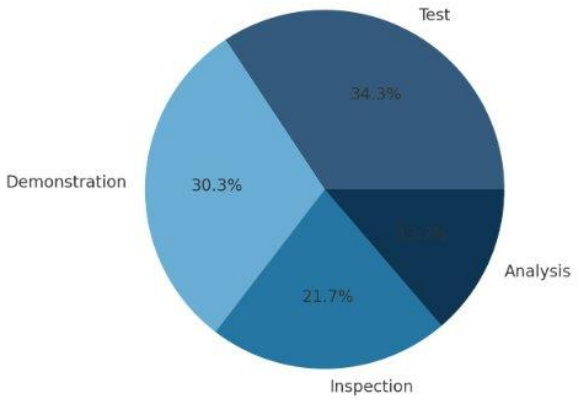


Requirements Flowdown



Requirement V&V

Req ID	Requirement Description	Test	Analysis	Demo	Inspection
1.3	Outage modeling & automatic re-planning	✔	✔	✔	
1.3.1	Resource Outage Modeling	✔		✔	
1.3.2	Spacecraft Outage Modeling	✔		✔	
1.3.3	Automatic Re-planning	✔	✔	✔	
1.3.4	Scenario Comparison			✔	✔
1.4	Store & manage configuration data				✔
1.4.1	Persistent Configuration Storage	✔			✔
1.4.2	Input Validation	✔			✔
1.4.3	Traceability to Requirements		✔		✔
1.5	Provide visual & export functions			✔	✔
1.5.1	Gantt Chart Visualization	✔		✔	
1.5.2	Tabular Output Export	✔			✔
1.5.3	Gantt Export (PNG)	✔		✔	
1.5.4	Interactive Parameter Editing	✔		✔	



Trade Studies

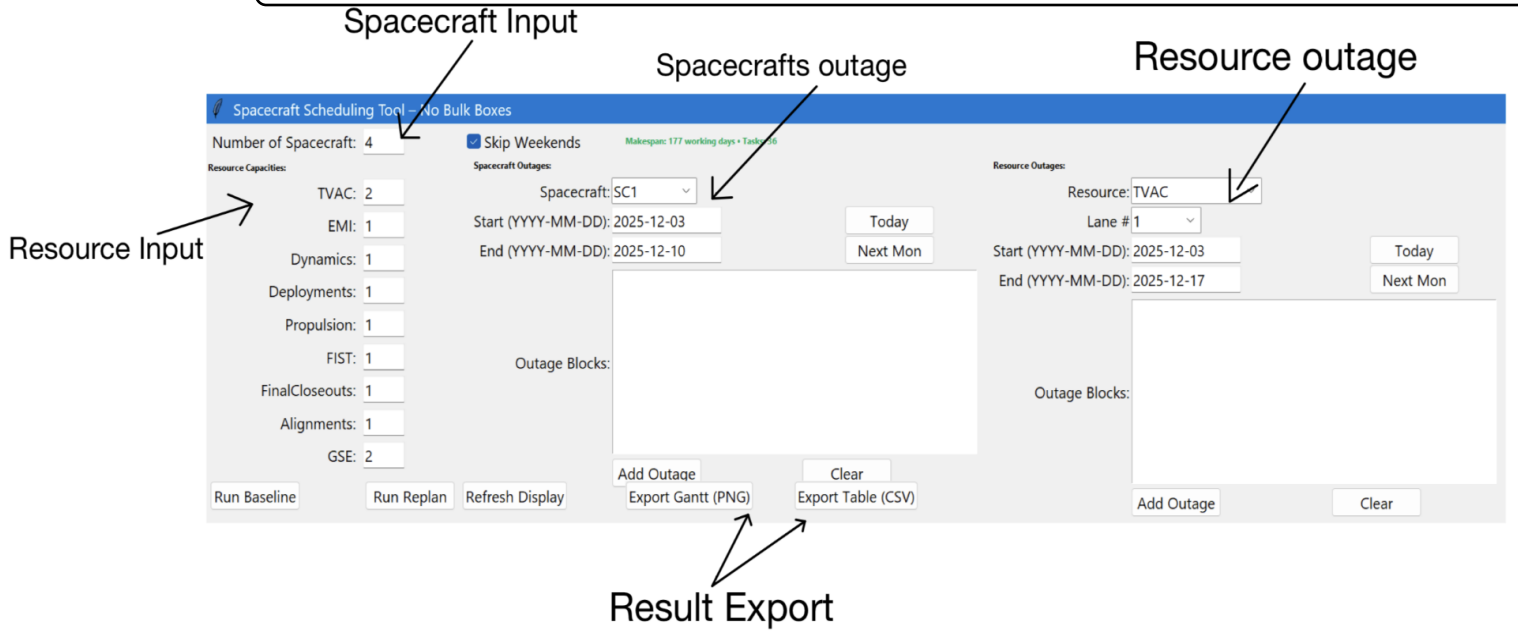
Option	Compute Time	Flexibility	Conflict Resolution	Re-Plan Speed	Complexity	Enterprise Value	Trade Score
Python	Very High	Very High	High	Very High	Medium	Very High	92
IBM	Very High	High	Very High	High	High	Very High	88
LINDO	High	High	High	High	High	High	82
Primavera P6	High	Medium	High	Medium	High	Very High	78
KNIME Analytics Platform	Medium–High	Very High	Medium–High	High	Medium	High	76
MS Project	Medium	Medium	Medium	Medium	Medium	Medium	68

Trade Studies

Option	Refresh Rate	Data Transparency	User Load	Integration Ease	Aesthetic Quality	Enterprise Value	Trade Score
Static KPI Dashboards	Slow	Low	Low	Very Easy	Medium	Medium	**66.3**
Interactive Gantt	**Medium–Fast**	**High**	**Medium**	**Medium–High**	**High**	**Very High**	**93.0**
Digital Twin Simulation View	Fast	Very High	Medium	Complex	Very High	High	**89.4**
Predictive Analytics Dashboard	Medium	High	Medium–High	Medium	Very High	Very High	**85.5**
Operations Control Center	Fast	Medium–High	Low	Medium	Medium–High	Very High	**82.7**

Design

Spacecraft Input	To able input the number of testing Spacecraft
Result Input	To able input the available testing facilities
Spacecraft Outage	To able input the spacecraft that need maintenance or not arrive on time for the testing and its duration date
Facility Outage	To be able to input the facilities shutdown and the duration date
Gantt Chart & Table	The result will be exported to PNG file for the GANTT and excel file for table



Integration and Test

Category	Description
Integration Plan	1. Combine subsystems: Scheduling Engine, Replanning Module, Resource Allocation, Data Management, Dashboard. 2. Integrate dashboard to display Gantt charts and resource queues. 3. Validate data flow between modules.
Testing Approach	• **Functional Test:** Verify task sequencing and constraints. • **Stress Test:** Simulate 20 spacecraft under limited resources. • **Failure Scenario Test:** Simulate chamber outage for replanning. • **Performance Test:** Ensure schedule generation < 1 hour.
Resourced needed	**Software:** Python **Data:** Spacecraft test durations, facility matrix.
Expected outcome	Integrated tool automates spacecraft test flow, replans dynamically, and optimizes facility use.

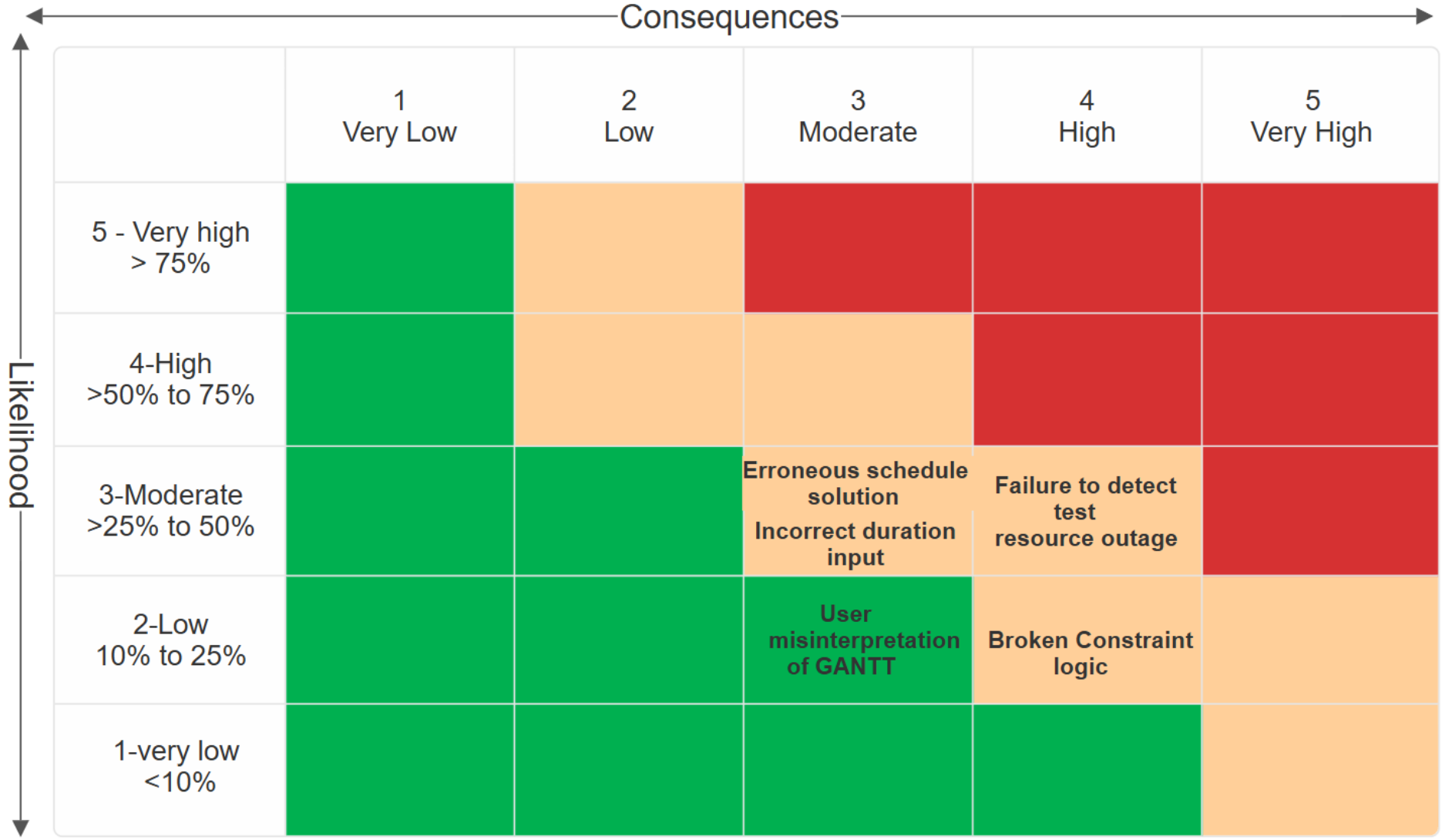
Risk Assessment

Cons.	1 – Very Low	2 – Low	3 – Moderate	4 – High	5 – Very High
Safety	No injury / no physical harm	Minor risk through miscommunication	Non-critical mishandling of operations	Stressful conditions due to planning chaos	Program-level unsafe decisions (only indirect)
Technical	Minimal or no impact	Small reduction in algorithm performance	Reduced allocation quality, some constraints unmet	Significant degradation of schedule solution	Tool outputs unusable / loss of trust
Schedule	<1 week delay	1–3 week delay	1–2 month delay of milestones	2–5 month cumulative delay	>5 month delay of deliverables

Level	Probability
1 — Very Low	< 10%
2 — Low	10–25%
3 — Moderate	25–50%
4 — High	50–75%

#	Risk	Reason	Effect	Mitigation	Risk Level (Likelihood, Consequence)
1	Failure to detect test resource outage	Tool does not recognize TVAC/EMI chamber downtime or SC blockage	Backlog, incorrect reallocation, cascading schedule delays	Add outage detection triggers and partial replanning windows	**3,4**
2	Erroneous schedule solution	Algorithm selects suboptimal sequence or violates hidden constraints	Idle TVAC/Dynamics while spacecraft queue grows	Validate with baseline schedules; run benchmark scenarios	**3,3**
3	Incorrect duration inputs	Real test durations differ from assumptions	Over/under utilization; drift of entire facility timeline	Calibration after each campaign; duration sanity checks	**3,3**
4	User misinterpretation of Gantt	Misunderstanding of dependencies or resource limits	Manual override → task chaos → conflicts	SOP, tooltips, constraint violation highlights, locked tasks	**2,3**
5	Broken constraint logic	Precedence rule coded incorrectly (e.g., Deployments before Dynamics)	Invalid or unsafe schedules; loss of confidence	Unit testing per constraint; requirement ID traceability	**2,4**

Risk Assessment



Tool Demonstration

```
DEFAULT_DAYS = {
    "TVAC": 4 * 7,
    "EMI": 3 * 7,
    "Dynamics": 2 * 7,
    "Deployments": int(1.5 * 7),
    "Propulsion": 1 * 7,
    "FIST": 3 * 7,
    "FinalCloseouts": 1 * 7,
    "Alignments": 3,
    "GSE": 3,
```

```
DEFAULT_CAPACITY = {
    "TVAC": 2,
    "EMI": 1,
    "Dynamics": 1,
    "Deployments": 1,
    "Propulsion": 1,
    "FIST": 1,
    "FinalCloseouts": 1,
    "Alignments": 1,
    "GSE": 2,
```

```
PREDS = {
    "Alignments": set(),
    "TVAC": set(),
    "EMI": set(),
    "Dynamics": {"Alignments"},
    "Deployments": {"Dynamics"},
    "GSE": set(),
    "Propulsion": {"TVAC", "EMI", "Dynamics"},
    "FIST": {"Propulsion", "GSE"},
    "FinalCloseouts": {"FIST"},
```

Tool Demonstration

What This Tool Is ?

- Automates spacecraft environmental test schedules
- Handles precedence, resources, outages, and calendars
- Designed for 4 → 20 spacecraft
- Produces optimized Gantt charts & analysis outputs

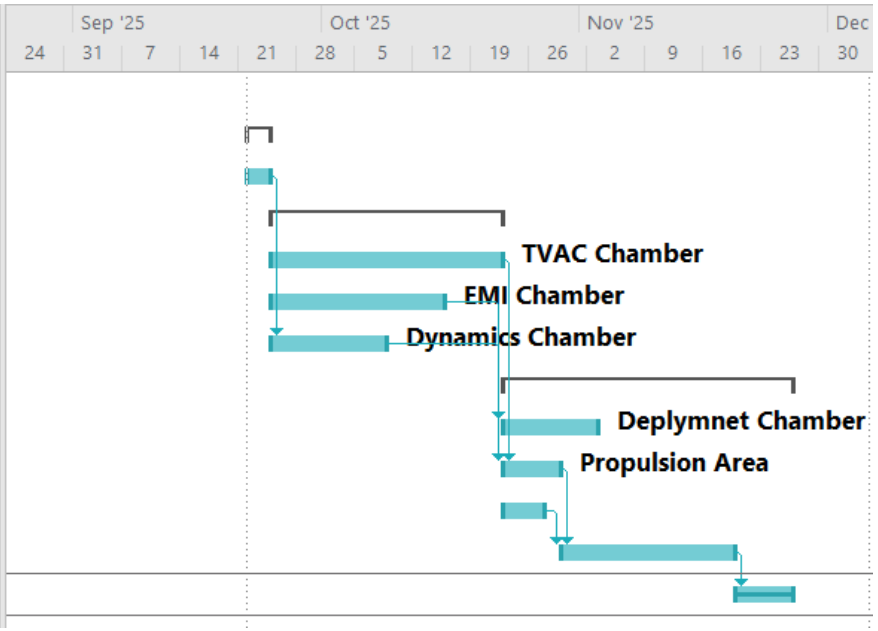
Why Manual Scheduling Fails

Why Manual Scheduling Fails

Limitations of MS Project / Hand Scheduling

- Cannot handle random failures or outages
- Pushes all tasks to the right → long delays
- Breaks precedence logic easily
- Hard to reroute spacecraft dynamically
- Impossible for 10–20 spacecraft

Task Name	Duration	Start	Finish	Predecessors	Resource Names	Ac
SPACECRAFT1						
Pre-dynamics Prep	**0.6 wks**	**Mon 9/22/25**	**Wed 9/24/25**			
Alignments	3 days	Mon 9/22/25	Wed 9/24/25			
Environmental tests	**4 wks**	**Thu 9/25/25**	**Wed 10/22/2**			
TVAC Test	4 wks	Thu 9/25/25	Wed 10/22/25		TVAC Chamber	
EMI Test	3 wks	Thu 9/25/25	Wed 10/15/25		EMI Chamber	
Dynamics Test	2 wks	Thu 9/25/25	Wed 10/8/25	3	Dynamics Chambe	
Post environmental	**5 wks**	**Thu 10/23/25**	**Wed 11/26/2**			
Deployment Test	1.5 wks	Thu 10/23/25	Mon 11/3/25	7	Deplymnet Chamb	
Propulsion Test	1 wk	Thu 10/23/25	Wed 10/29/25	5,6,7	Propulsion Area	
GSE Test	3 days	Thu 10/23/25	Mon 10/27/25			
FIST Test	3 wks	Thu 10/30/25	Wed 11/19/25	10,11		
Final Closeouts	1 wk	Thu 11/20/25	Wed 11/26/25	12		



What the Tool *Can Do*

Key Capabilities

- Generates baseline schedules instantly
- Runs dynamic re-plans when anything breaks
- Manages multi-lane chambers (TVAC Lane 1 vs Lane 2
- Automatically reroutes spacecraft
- Prevents overbooking
- Exports Gantt and data tables (PNG/CSV)

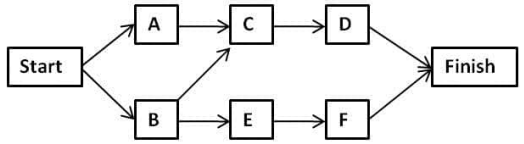
How It Works: 3 Layers of Logic

1. Precedence Logic

•Alignments → TVAC → Dynamics → Deployments → Propulsion → FIST → Final Closeouts

•Rules never break

•Ensures safe and compliant test order



Precedence Diagram Method (PDM)

2. Resource Availability

•Tracks chamber capacities & lanes

•Reroutes spacecraft if one resource is offline

•Queues when necessary

•Never overbooks

3. Scheduling Optimization

•Fills open chambers immediately

•Moves *only* the delayed spacecraft, not the whole flow

•Minimizes total makespan

Outage Handling (What Makes the Tool Unique)

When a Chamber Breaks:

- User selects outage dates
- Tool marks the lane as unavailable
- Scheduler automatically:
  - reroutes to another lane
  - shifts spacecraft to another test (if allowed)
  - queues them temporarily
- Re-plan takes seconds

When a Spacecraft Slips:

- Tool only moves that spacecraft
- Others continue testing normally

Output: Optimized Gantt Chart

Visualization Features

- Actual calendar dates (weekends shaded)
- All spacecraft shown in parallel
- Task labels include resource lane
- Gantt updates after each re-plan
- Export as PNG

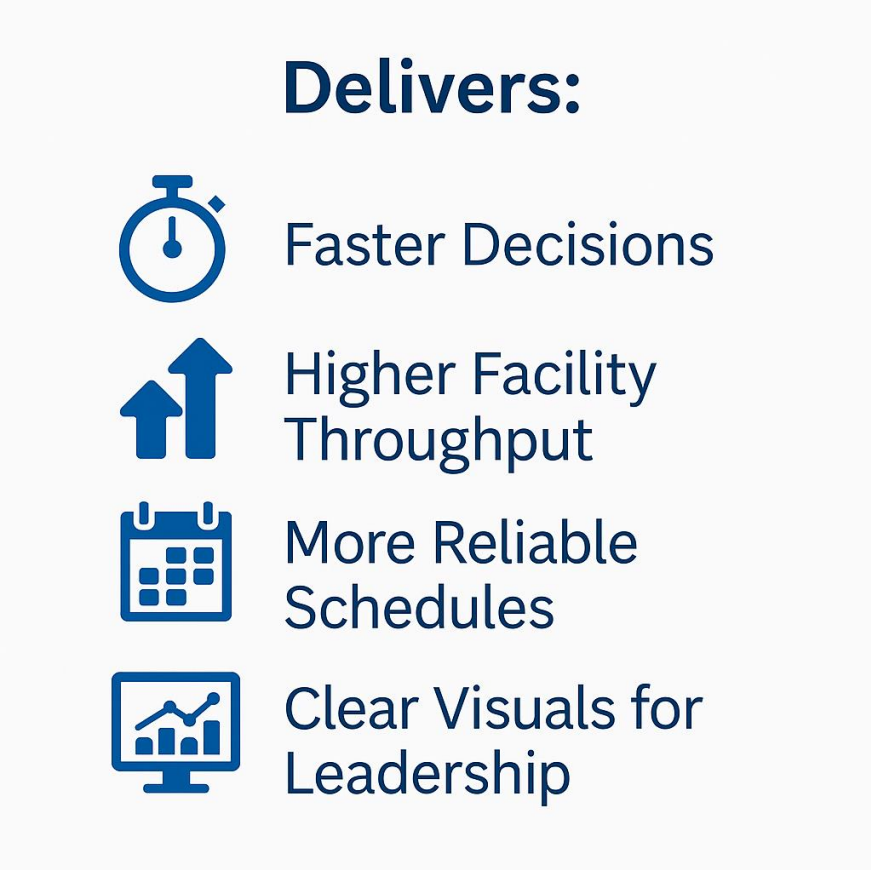
Operational Benefits

Why This Tool Matters

- Reduces schedule slip and cost
- Increases chamber utilization
- Reduces human error
- Enables running ‘what-if’ simulations
- Supports scaling to large constellations

Summary

The tool automatically builds and maintains a feasible, optimized spacecraft test schedule — even when resources fail or spacecraft slip



Real Operational Situation

*Environmental testing for a constellation of **8 spacecraft** (SC1–SC8)

Each spacecraft must complete the following sequence:

1.Alignments →
2.TVAC (2 lanes) →
3.EMI (1 chamber) →
4.Dynamics (1 chamber) →
5.Deployments (1 station) →
6.Propulsion (1 stand) →
7.FIST →
8.Final Closeouts

Key facility capacities:

- TVAC: **2 lanes (Lane 1 and Lane 2)**
- All others: **1 resource each**
- GSE available: **2 units**
- Weekends skipped

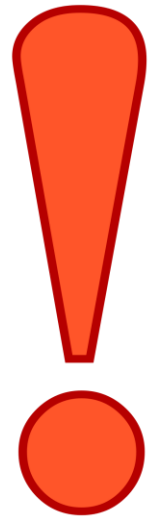
Goal: **Minimize campaign duration and maintain flow despite failures**.

INITIAL CONDITIONS

Spacecraft Ready Dates

- SC1 → Day 0
- SC2 → Day 4
- SC3 → Day 10
- SC4 → Day 15
- SC5 → Day 20
- SC6 → Day 25
- SC7 → Day 30
- SC8 → Day 35

Test	Duration
Alignments	3 days
TVAC	28 days
EMI	21 days
Dynamics	14 days
Deployments	10.5 days
Propulsion	7 days
FIST	21 days
Final Closeouts	7 days

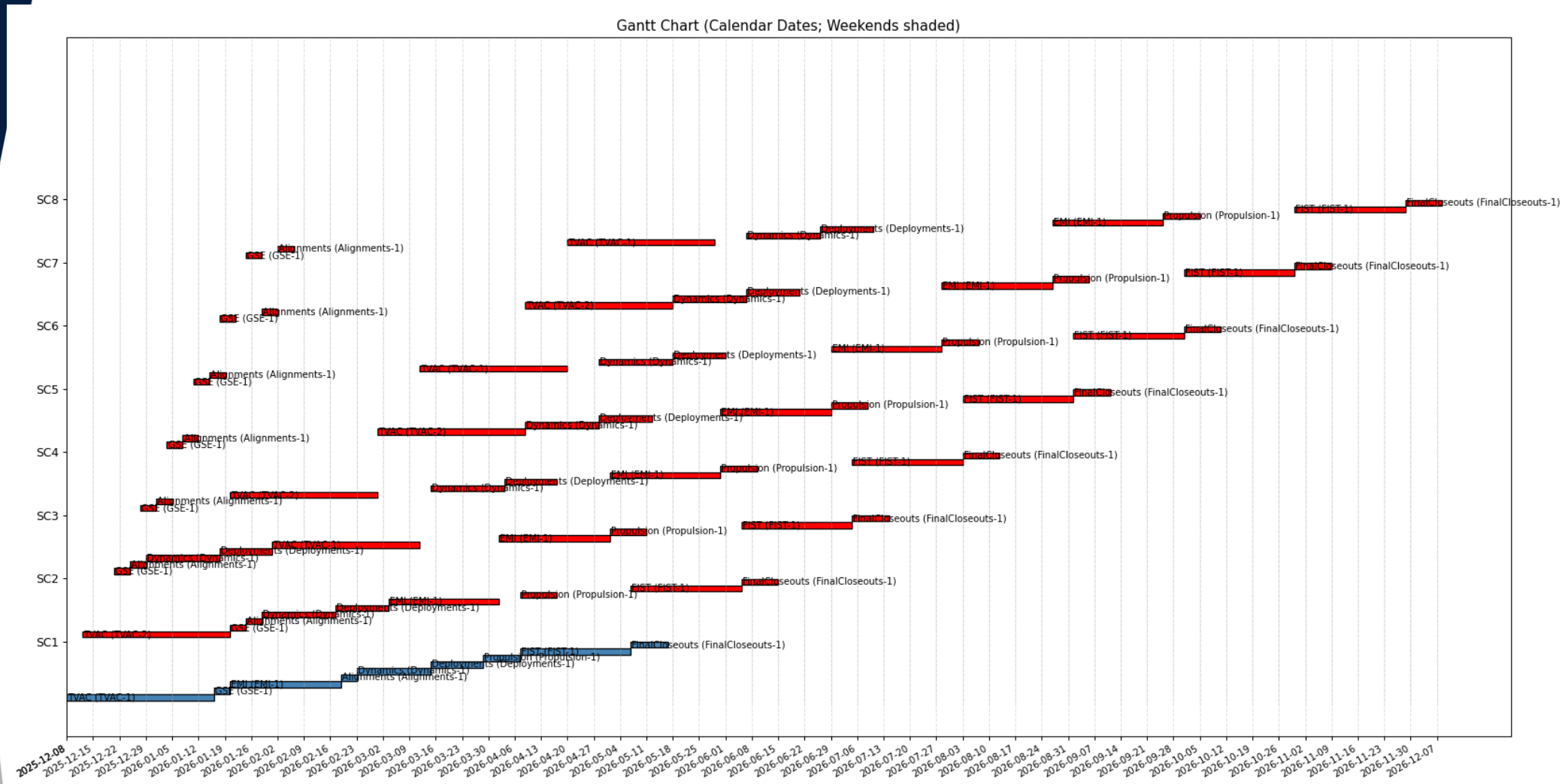


Outage Blocks:

SC1: 2025-12-07 → 2025-12-08 (wdays 0-0)
SC2: 2025-12-07 → 2025-12-11 (wdays 0-3)
SC3: 2025-12-07 → 2025-12-19 (wdays 0-9)
SC4: 2025-12-07 → 2025-12-26 (wdays 0-14)
SC5: 2025-12-07 → 2026-01-02 (wdays 0-19)
SC6: 2025-12-07 → 2026-01-09 (wdays 0-24)
SC7: 2025-12-07 → 2026-01-16 (wdays 0-29)
SC8: 2025-12-07 → 2026-01-23 (wdays 0-34)

Baseline

Makespan: 261 working days

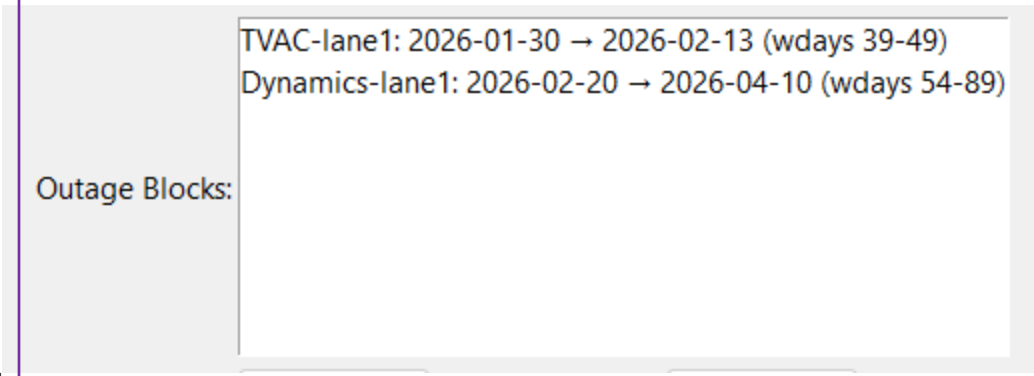


	A	B	C	D	E	F
1	Spacecraft	Task	Start Date	End Date	ResourceLane	Duration
2	SC1	TVAC	12/7/2025	1/14/2026	TVAC-1	28
3	SC1	GSE	1/14/2026	1/19/2026	GSE-1	3
4	SC1	EMI	1/19/2026	2/17/2026	EMI-1	21
5	SC1	Alignments	2/17/2026	2/20/2026	Alignments-1	3
6	SC1	Dynamics	2/20/2026	3/12/2026	Dynamics-1	14
7	SC1	Deployments	3/12/2026	3/26/2026	Deployments-1	10
8	SC1	Propulsion	3/26/2026	4/6/2026	Propulsion-1	7
9	SC1	FIST	4/6/2026	5/5/2026	FIST-1	21
10	SC1	FinalCloseouts	5/5/2026	5/14/2026	FinalCloseouts-1	7
11	SC2	TVAC	12/10/2025	1/19/2026	TVAC-2	28
12	SC2	GSE	1/19/2026	1/22/2026	GSE-1	3
13	SC2	Alignments	1/22/2026	1/27/2026	Alignments-1	3
14	SC2	Dynamics	1/27/2026	2/16/2026	Dynamics-1	14
15	SC2	Deployments	2/16/2026	3/2/2026	Deployments-1	10
16	SC2	EMI	3/2/2026	3/31/2026	EMI-1	21
17	SC2	Propulsion	4/6/2026	4/15/2026	Propulsion-1	7
18	SC2	FIST	5/5/2026	6/3/2026	FIST-1	21
19	SC2	FinalCloseouts	6/3/2026	6/12/2026	FinalCloseouts-1	7

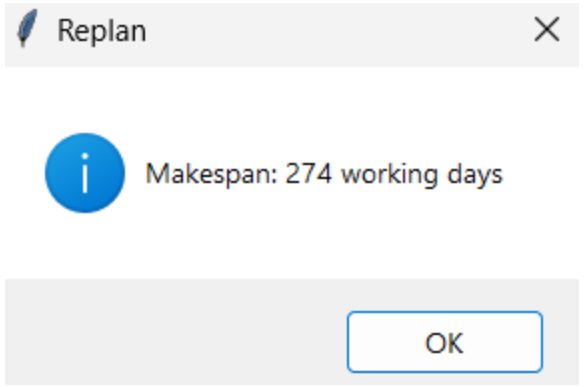
- **1. Enables deeper analysis in Excel or other tools**
- **2. Provides traceability and auditability**
- **3. Supports integration with other engineering workflows**

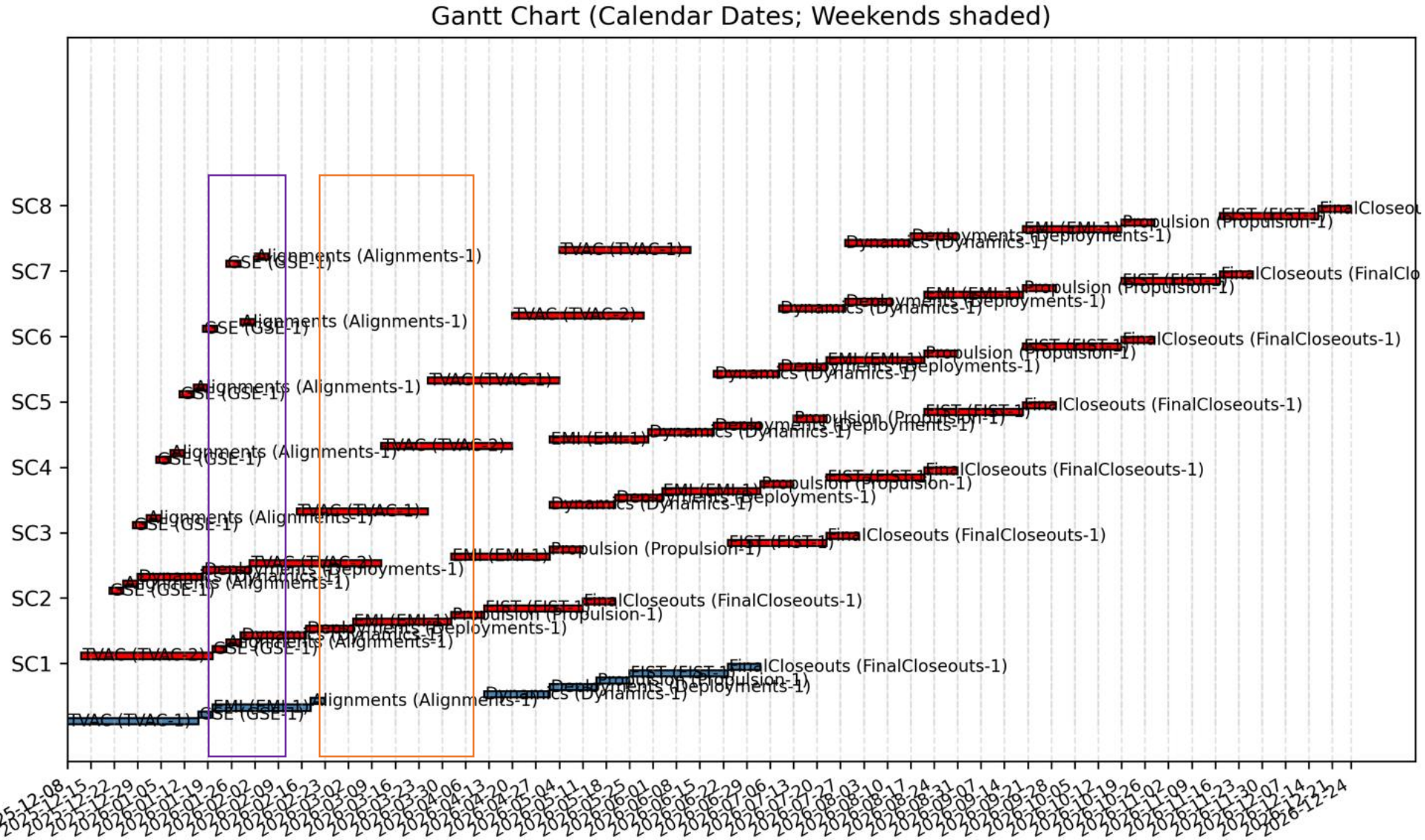
Introduce Resource Outages (Stress the Tool)

Major Outage #1: TVAC Lane-1 fails for 14 days
Outage: 2026-01-30→ 2026-02-13
Expected behavior:
•Tool removes TVAC Lane-1 from capacity
•Re-routes eligible spacecraft into **TVAC Lane-2**
•Others are queued
•Facilities like EMI/Dynamics stay busy
•Makespan increases *only for affected spacecraft*, not all



Major Outage #2: Dynamics chamber fails
Outage: 2026-02-20 → 2026-04-10
Expected behavior:
•Tool pauses any spacecraft waiting for Dynamics
•Keeps TVAC and EMI full
•Automatically shifts spacecraft to next allowed tasks
•Moves only those blocked — not entire constellation




Gantt Chart (Calendar Dates; Weekends shaded)
SC8
SC7
SC6
SC5
SC4
SC3
SC2
SC1
Alignments (Alignments-1)
GSE (GSE-1)
TVAC (TVAC-1)
TVAC (TVAC-2)
EML (EML-1)
Dynamics (Dynamics-1)
Deployments (Deployments-1)
Propulsion (Propulsion-1)
FIST (FIST-1)
FinalCloseouts (FinalCloseouts-1)

Real Operational Situation Conclusions

1. Tool handled a complex 8-spacecraft campaign
Generated a valid baseline respecting all precedence and resource limits.
2. Outages were absorbed without collapsing the schedule (261 days to 274 days after repplaning)
•TVAC Lane-1 outage → rerouted to Lane-2 / queued efficiently
•Dynamics outage → delayed only affected spacecraft
3. High facility utilization maintained
Chambers stayed busy; flow continued even during failures.
4. Demonstrated scalability and operational value
Shows readiness for larger constellations and real aerospace testing environments.

*This scenario demonstrates that our Scheduling Tool is not just a Gantt generator — it's an operational decision engine capable of maintaining schedule integrity, maximizing facility usage, and minimizing program delays under real-world conditions.

Proposed Future Work

- The tool should be able to add a spacecraft partway through an ongoing test schedule.
- The tool needs the capability to register all holidays, festival days, and other days when it is not working days
- The tool should allow selecting which tests will be performed for each spacecraft
- The tool should allow adding additional tests along with their associated constraints

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Q&A