UNITED STATES
SPACE FORCE

Determining Strategic Improvements to Space Launch

By Leveraging Model Based Digital Twins

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WR Dynamic Spaceport Model

Mirroring the broader industry, **the Western Range (WR) is experiencing significant increases in demand** to accommodate both US government and commercial space needs

This WR Dynamic Spaceport Model project built **a dynamic model of WR capacity that can provide the decision support needed to make investments** that increase capacity on the range

The estimated current capacity of the WR is ~70-75 launches per year with the current launch vehicle mix and, ~91-95 launches per year under the potential future launch vehicle mix (increased capacity due to a more varied launch mix and infrequent heavy vehicle launches)

An initial suite of interventions (consisting of 5 SoTF projects and 5 additional interventions) **has been identified**, which could enable the WR to achieve **a capacity of ~121-125 launches per year**

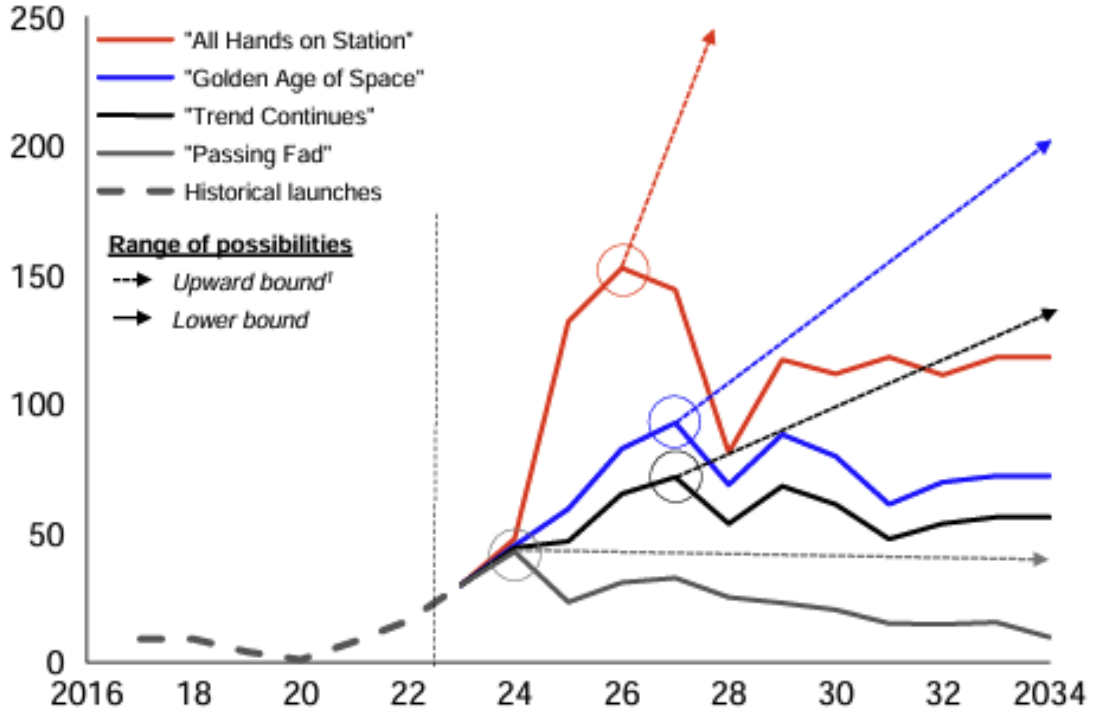
Objectives for today's discussion

1. Recap project objectives for WR Dynamic Spaceport Model
2. Share update on development progress
3. Review model outputs of operational bottlenecks and interventions (before and after interventions)

Increasing Launch Demand

The four spacelift demand scenarios capture a range of potential futures, with peak demand forecasted in ~2026-2027

Total launch demand, # launches



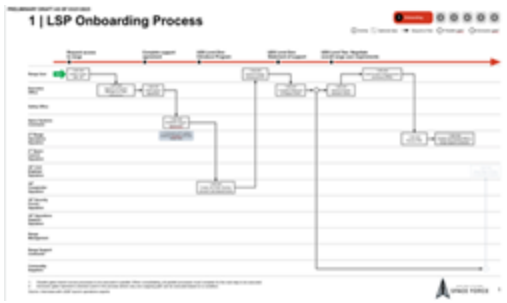
Outputs are ranges of potential outcomes

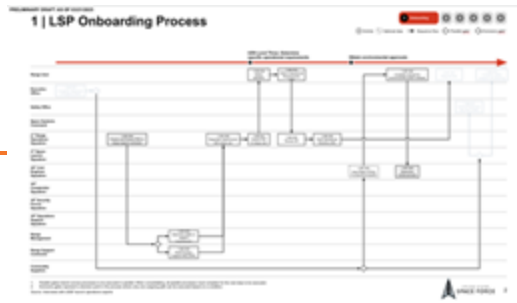
Scenario	Emerging implications for WR
"All Hands on Station" *(Significant increase from Base case)*	• Peak demand reaches **~153 launches per year in 2026E**, implying 1 launch every **~2.4 days** • **LEO concepts materialize in full without delays**, coupled with an **increase in defense payloads**
"Golden Age of Space" *(Moderate increase from Base case)*	• Peak demand reaches **~93 launches per year in 2027E**, implying 1 launch every **~3.9 days** • **Commercial space industry growth continues to accelerate** beyond known constellations
"Trend continues" *(Base case)*	• Peak demand reaches **~72 launches per year in 2027E**, implying 1 launch every **~5.1 days** • **Planned large commercial constellations come online** with typical delays
"Passing Fad" *(Decrease from Base case)*	• Peak demand reaches ~43 launches per year in 2024E, implying 1 launch every **~8.5 days** • **Downward shift in support for commercial space industry** and significant absorption of demand by other spaceports

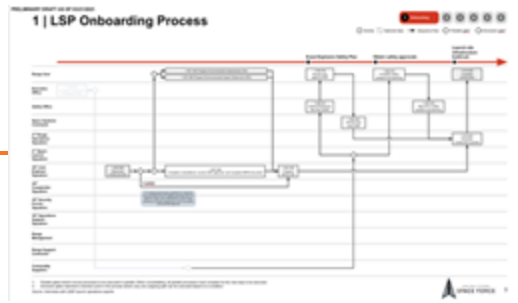
1 WR Dynamic Spaceport Strategy

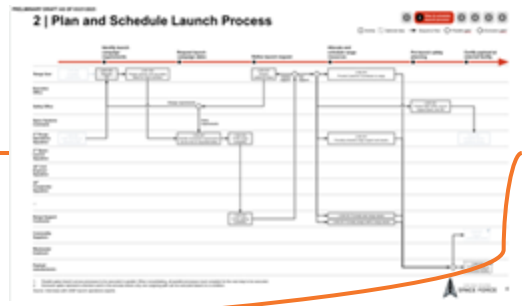
	Phase 1: Nov – Dec	Phase 2: Jan – Mar	Phase 3: Apr - Sep
	Map launch process, map persona journey, create capacity model delivery roadmap, adapt demand model, low fidelity design	**Develop capacity model, run scenarios from input files, high fidelity design, model hosting**	**Configure Ark solution for front-end interactions with the model, model enhancements, data integrations**
Key activities	• Adapt ER process map for WR • Gather data to inform capacity model structure • Develop a delivery roadmap for capacity model • Adapt ER demand model for WR • Identify set of needed critical input files and begin data intake file • Determine user personas and jobs-to-be-done • Document the hypothesized user journey for Ark • Initiate low fidelity design of user journeys and collect feedback	• Code changes specific to WR processes • Define Quality Assurance metrics and test realism of the baseline process timing with stakeholders • Select interventions / courses of action (COAs) to increase launch capacity by addressing bottlenecks • Estimate max launch capacity under current state • Model capital investments and capacity changes • Finalize MVP capacity model and summary-level communication materials • Transition designs to high-fidelity wireframes • Prototype of Ark simulation capability with model	• Continue to configure the Ark interface for the demand and capacity models • Perform bi-weekly feedback sessions to collect user input • Integrate key external datasets for increased accuracy • Conduct training series by persona ○ Decision maker: ≤ 1 day; Analyst: 1-2 days; Maintainer: 2-3 days
Deliverables	• Delivery roadmap • Demand model • Persona profiles: Decision Maker, Analyst, Model Maintainer • Documented user journeys • Low-fidelity wireframes for primary user flows	• MVP WR capacity model, code package, and documentation • WR investment COAs and roadmap • WR Launch Capacity Strategy • High-fidelity wireframes and prototypes	• Fully functional interface for capacity modeling in Ark • Interactive dashboard for scenario results • Performance benchmarks and validation reports for the model • Detailed technical and user training documentation

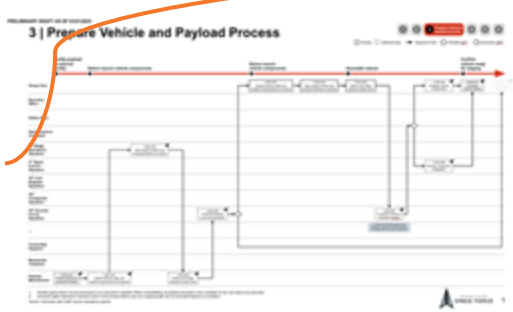
Western Range Launch Process

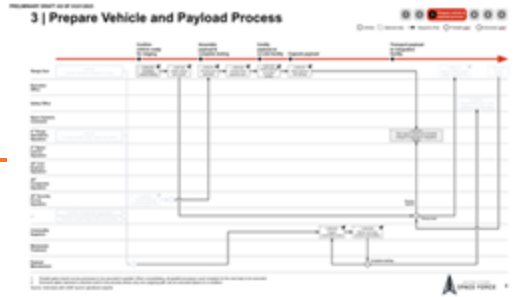


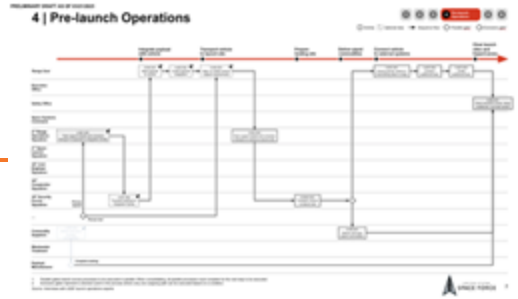


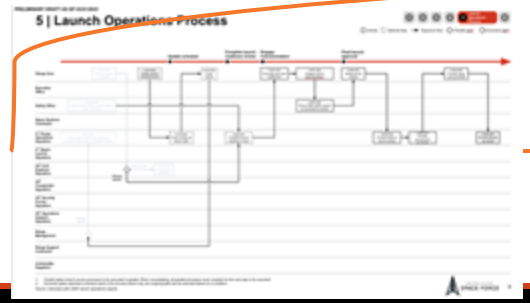


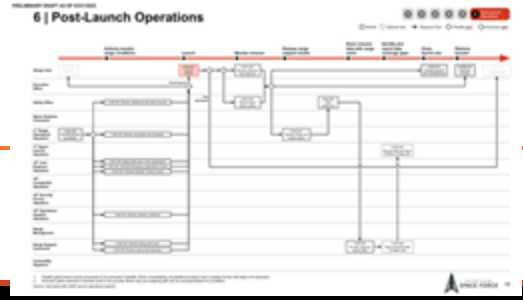












2 The outputs shown today incorporate more detail across all aspects of model development (e.g., process, resources required)

	Phase 1	Phase 2	Phase 3
Launch process map and data	Initial WR launch process map	Final WR launch process map	Refined WR data points, as needed from model Quality Assurance
Archetypes and launch process granularity	Preliminary set of 6 range operations archetypes	All 110+ WR process steps modeled Current (3) spacelift launch and ballistics archetypes modeled	All 110+ WR process steps modeled (6) range operations archetypes modeled[3], as well as aeronautical missions
Resources required for each process step	N/A	16,000+ WR data points collected[1,2]	Refined data points and added data for interventions
Generation and running of launch manifests	N/A	Single manifest reflective of current state operations (49 spacelift, 4 ballistics)	Future-scenario launch manifest (e.g., 120 launches of specified archetypes)
Bottlenecks identification	Consolidated set of potential bottlenecks from SME input	Preliminary list of current bottlenecks from model	Finalized list of current and potential future bottlenecks

1. Includes ~8,000 haul route data points, ~7,000 range asset data points (e.g., equipment, infrastructure), ~1,000 time duration data points, ~200 personnel data points, 8 consumables data points
2. Model is currently using <100 ER data points for which WR data points have not yet been available
3. 6 range operations are inclusive of select future-state archetypes

Launch Model Architypes

Can be modeled as interventions

Launch vehicle archetypes						Sectors served			Booster/vehicle recovery	Modeled at ER
Archetype	**Class**	**Illustrative LV**	**Provisioning[1]**	**LV Index**	**Site**	**Commercial**	**Defense**	**Civil**		
High frequency launches	**Medium**	Falcon 9	AFTS	SLMSP-1	SLC-4E, SLC-6	✓	✓	✓	✓	✓
Regular launches	**Light[4]**	Alpha	AFTS	SLLSP-1	SLC-2W	✓	✓	✓	○	✓
		Minotaur	FTS	SLLFP-1	SLC-8, TP-01	○	✓	✓	○	○
	Heavy	Falcon Heavy	AFTS	SLHSP-1	SLC-6	✓	✓	✓	✓	✓
		New Glenn	AFTS	SLHSP-2	SLC-9 / 14	✓	✓	✓	✓	✓
	Medium / Heavy	Vulcan[2]	AFTS	SLMSP-2	SLC-3E	✓	✓	✓	○	✓
Ballistics tests		MMIII, GBI, PrSM[3], Sentinel	FTS	BTFP-1	TP-01, LF(s)[5]	○	✓	○	○	○

Each launch vehicle and payload combination above can become direct inputs into the capacity model

Aeronautical missions can be modeled as non-launch resource allocation

1. Provisioning refers to the use of an autonomous or manual Flight Termination System (FTS)
2. Expected to replace Atlas V and Delta IV Heavy (SLC-3E and 6)
3. Precision Strike Missile (PrSM)
4. BL's RS1 removed as no longer planned for range
5. LF-02/03/04/08/09/10/21/23/24/26

3

WR Capacity Model Demo

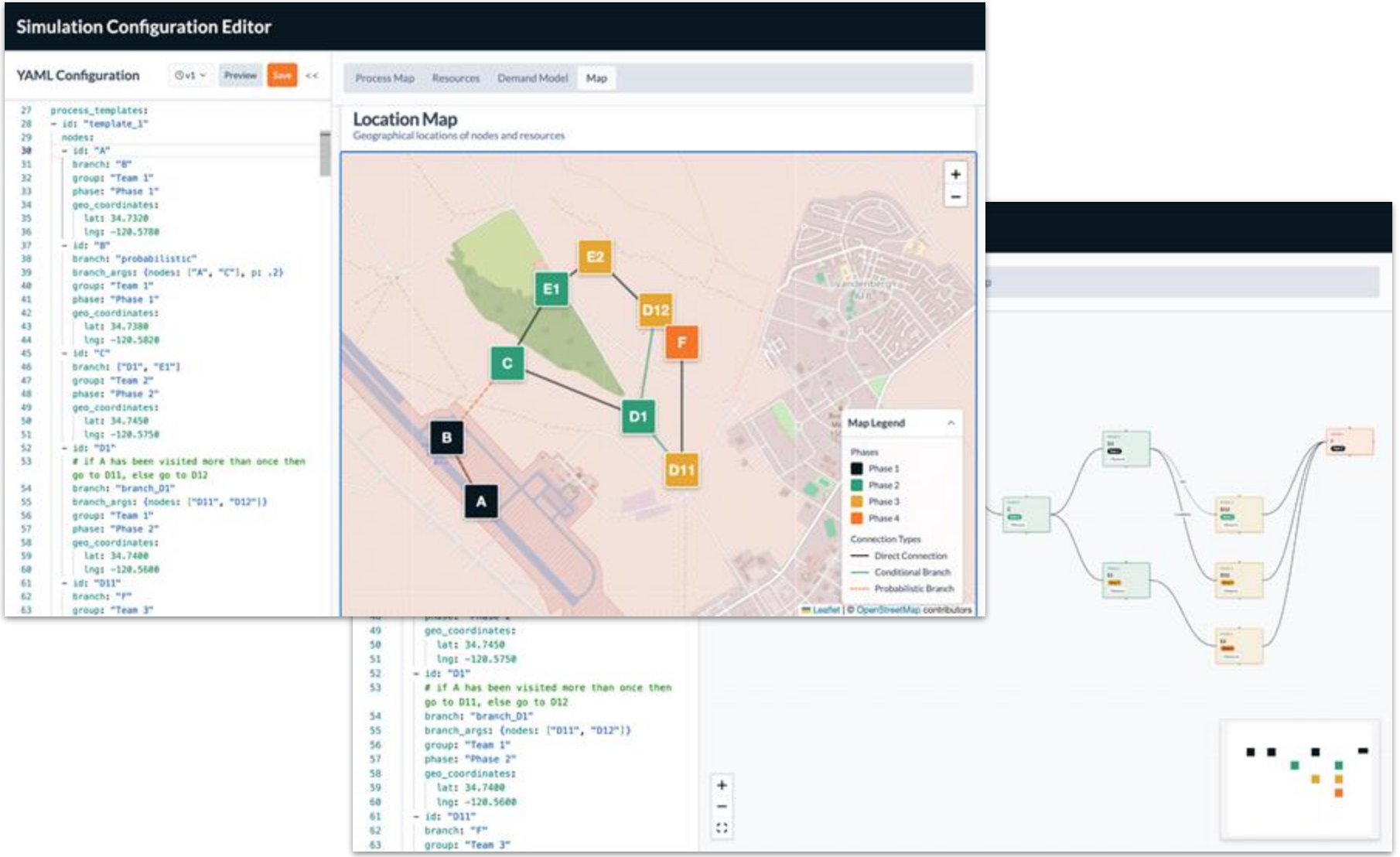
Before and after outputs

4 Ark Configuration for WR Dynamic Spaceport Strategy and Analytics Model

+ **LOW-CODE MODELING**
  Simplified syntax for defining process templates, resources, and all other properties

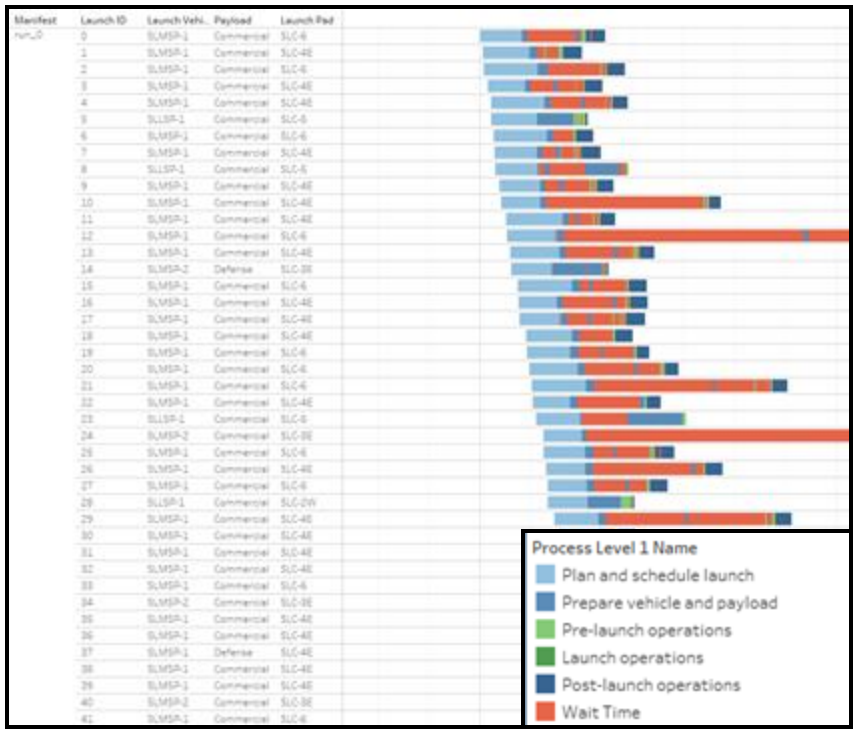
+ **DATA INTEGRATION**
  Ability to define model property values in configuration files or integrate with sources

+ **INSTANT UPDATES IN ARK**
  Updated configurations with version history of previous models and associated scenario outputs



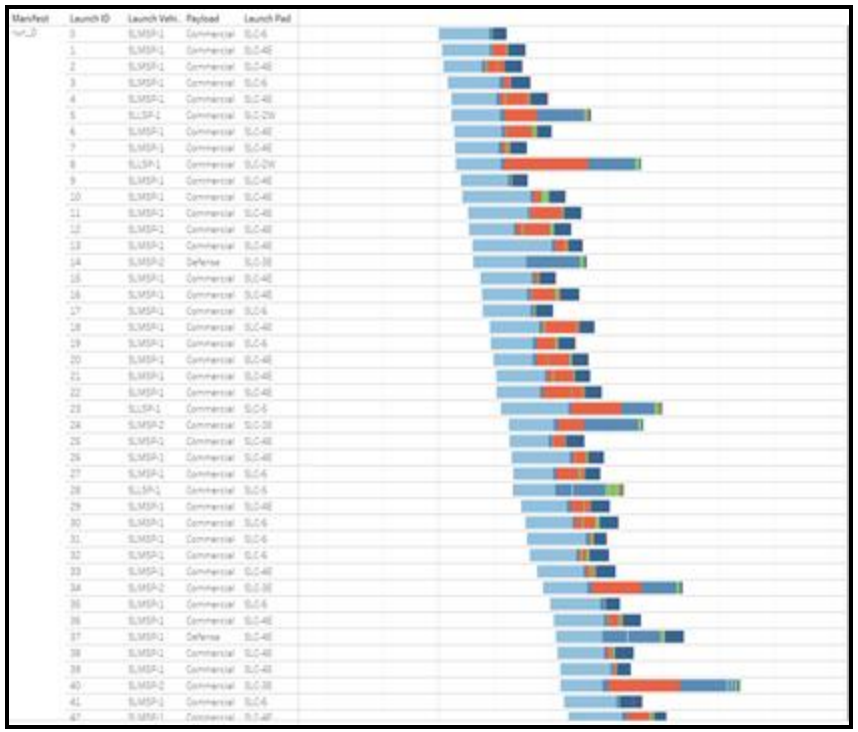
3 The capacity model simulates reduced wait time with modeled Spaceport of the Future projects and additional interventions

Scenario: base[1] operations infrastructure and no interventions



Capacity: ~91-95

Scenario: future infrastructure with interventions implemented



~121-125

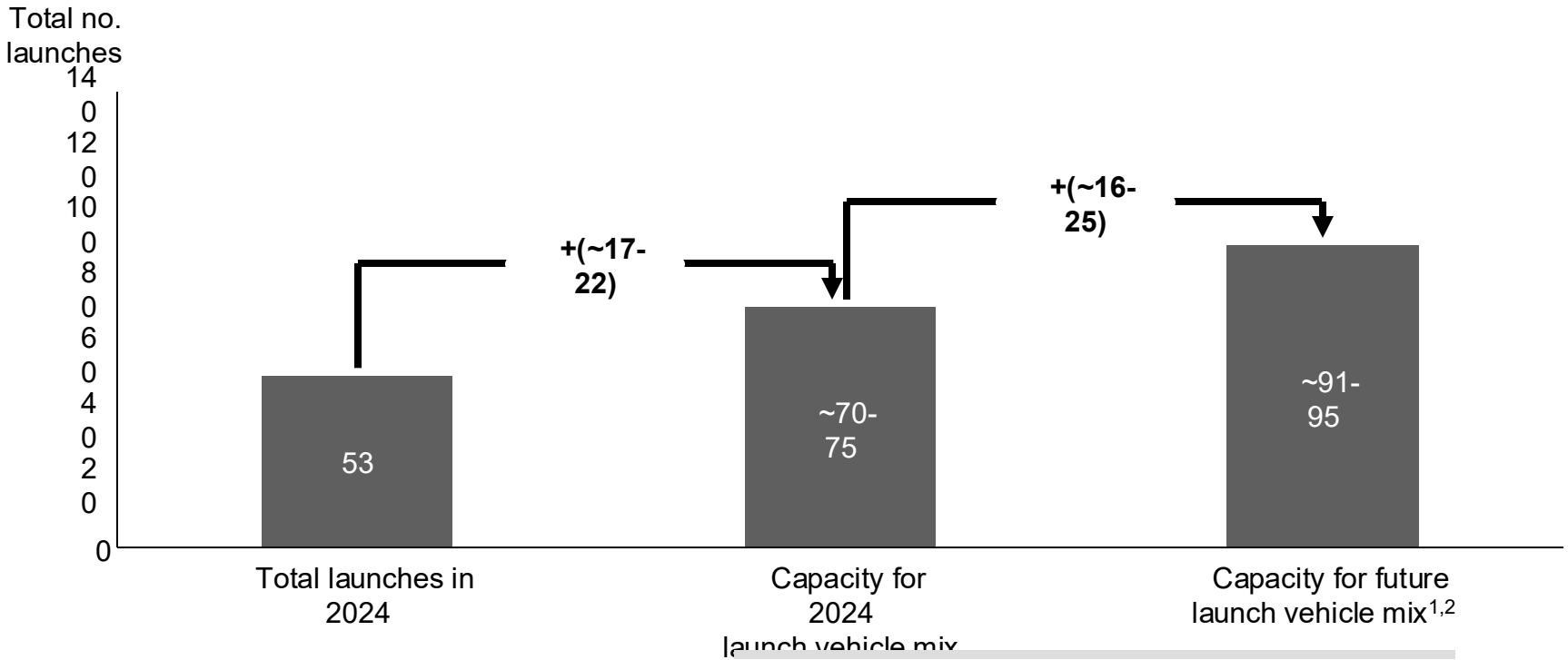
Each row represents a single launch campaign; colors represent phases of the launch process

1. Includes SLC-3, 5, 6, and 14 required to model future launch vehicles SLMSP-2, SLLSP-1, SLMSP-1/SLHSP-1, and SLHSP-2, respectively

3 Base infrastructure: at capacity, WR can support ~70-75 launches of the 2024 launch mix and ~91-95 of the expected future launch mix

Estimated launch capacity of the WR for current and future launch mix

Scenario: Base infrastructure, with no interventions



See detailed launch manifest in Appendix

1. Includes SLC-3, 5, 6, and 14 required to model future launch vehicles SLMSP-2, SLLSP-1, SLMSP-1/SLHSP-1, and SLHSP-2, respectively
2. Final model runs were conducted with future launch mix scaled up to ~160 launches

Key takeaways

- 2024 was a record year for the WR with 53 launches achieved
- Range capacity increases to ~91-95 launches for the future launch mix with base infrastructure. This can be explained by two factors:
  1) While the future launch mix includes more resource-intensive archetypes (e.g., SLHSP-1), these launches are relatively infrequent
  2) Future launch mix is more varied and reduces the impact of archetype-dependent bottlenecks

3 A suite of interventions were modeled to address primary bottlenecks for future launch mix

HIGHLY PRELIMINARY **NON-EXHAUSTIVE**

Spaceport of the Future projects

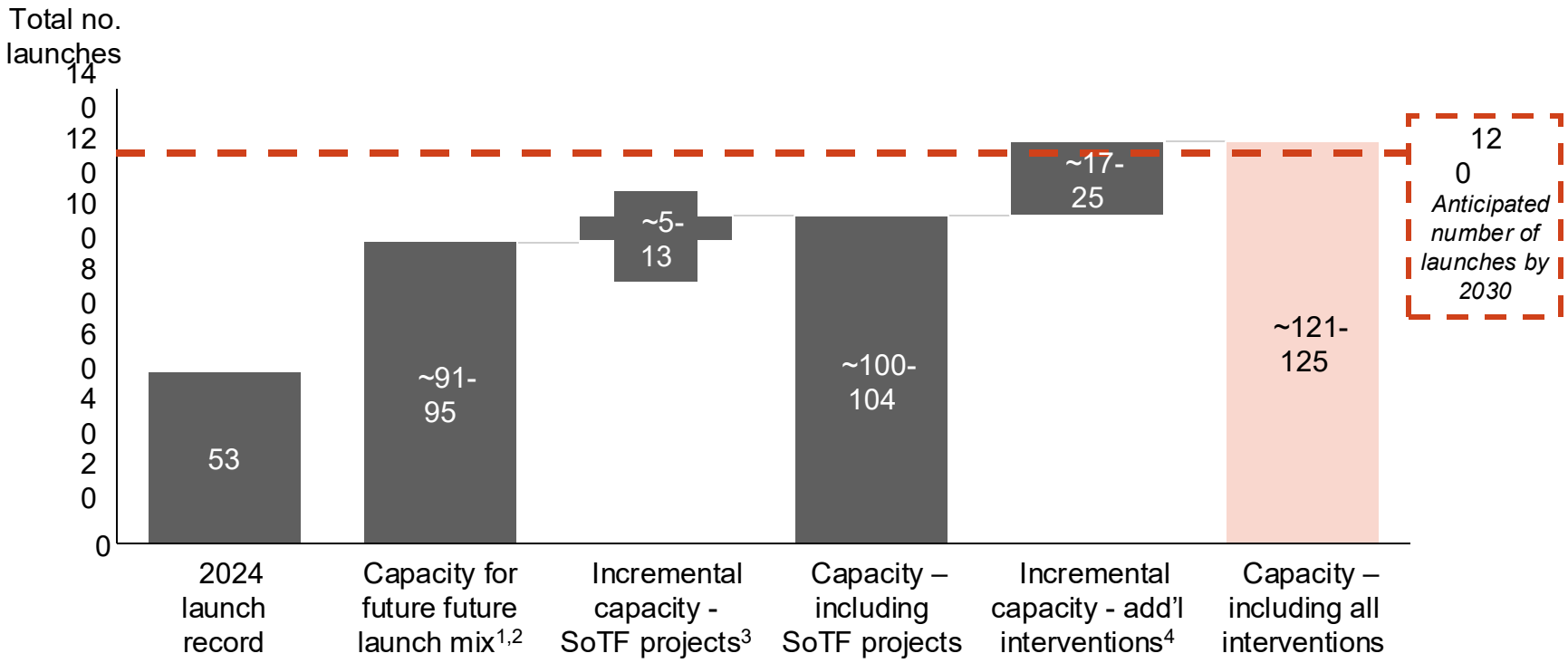
Process step[1]	Preliminary bottlenecks	Interventions (non-exhaustive)
1.007.004 Prepare Environmental Assessment (EA) or Environmental Impact Statement (EIS), complete consultations, receive DAF approval, and complete NEPA document[2]	Long process time required to obtain environmental approvals, influenced by external policy and external agency[3] timelines for consultations	Reduce environmental approval timeline by 50%
2.004.001 Provide Customer Countdown + Formally schedule range support / assets, task range assets, assign staff	Limited capacity for payload processing	Increase payload processing facility capacity (e.g., by 12 bays with construction of 4 payload processing facilities) with minimal resource protection risk
	Limited capacity at SLC-4E Vehicle Assembly Hanger and Delta IV Storage (i.e., Building 398)	Reallocate Horizontal Integration Facility and construct new integration facility on South Base
3.009.001 Deliver and store trucked commodities	Limited throughput at Lompoc Gate due to inspection of trucks carrying commodities	Construct entry control point at South Gate to increase speed of access to South Base (e.g., increase inspection points by 1) for truck inspection
4.003.003 Transport vehicle to launch site	Limited capacity for launch from SLC-4E	Allocate an additional SLC (e.g., SLC-6) for high-volume vehicle archetype[4]
4.007.001 Monitor weather conditions to determine go/no-go	Limited weather personnel to launch weather balloons	Increase weather personnel by 5 FTE
5.001.001 Engage launch instrumentation - 6.002.001 Release range and untask assets	Limited fire department personnel to support rapid turn around between sequential launches	Increase fire personnel by 39 FTE (for additional two shifts)

1. Process step numbering reflects process map
2. Based on SME input; onboarding bottlenecks will not be observed in the base model as it is modeled as a separate process
3. Agencies involved in collaboration of step include California Coastal Commission, NOAA Fisheries, State Historic Preservation Office (SHPO), U.S. Fish and Wildlife Service
4. SLMSP-1 is expected to utilize SLC-6 starting this year; this is modeled as part of future base infrastructure as it is in progress

3 Future infrastructure: Spaceport of the Future and additional interventions have the potential to increase range capacity to ~121-125 for a future launch mix

Estimated launch capacity of the WR for future launch mix

Scenario: Base and future infrastructure, with defined interventions



1. Includes SLC-3E, 5, 6, and 14 required to model future launch vehicles SLMSP-2, SLLSP-1, SLMSP-1/SLHSP-1, and SLHSP-2, respectively
2. Final model runs were conducted with future launch mix scaled up to ~160 launches
3. Of the SoTF projects, additional payload processing facilities (i.e., the Mission Development Zone) contribute an incremental capacity of ~3-8 launches.
4. Independent of SoTF projects, additional interventions modeled contribute an incremental capacity of ~17-21 launches. The above scenario indicates additional capacity due to synergies between SoTF projects and additional interventions.

Key takeaways

- Using base infrastructure[1], the range has a capacity of ~91-95 of the future launch mix
- SoTF projects and additional interventions are expected to increase range capacity to ~121-125 launches
- Changes in the future state expected to have the greatest impact on capacity are:
  - Increased payload processing facility capacity
  - Allocating an additional integration facility to SLMSP-1 and SLHSP-1
  - Increasing throughput of trucked commodities

3 Map of potential interventions to increase WR launch capacity

(#) SoTF projects[1]

(#) Additional interventions

Process improvements

(1) Reduce environmental approval timeline by 50%

Personnel augmentation

(2) Increase weather personnel by 5 FTE

(3) Increase fire personnel by 39 FTE (for additional two shifts)

Infrastructure interventions

(4A) Improve infrastructure to Mission Development Zone PPF3 site

(4B) Improve infrastructure to Mission Development Zone PPF1, 2, and 4 sites

(5) Construct entry control point at South Gate

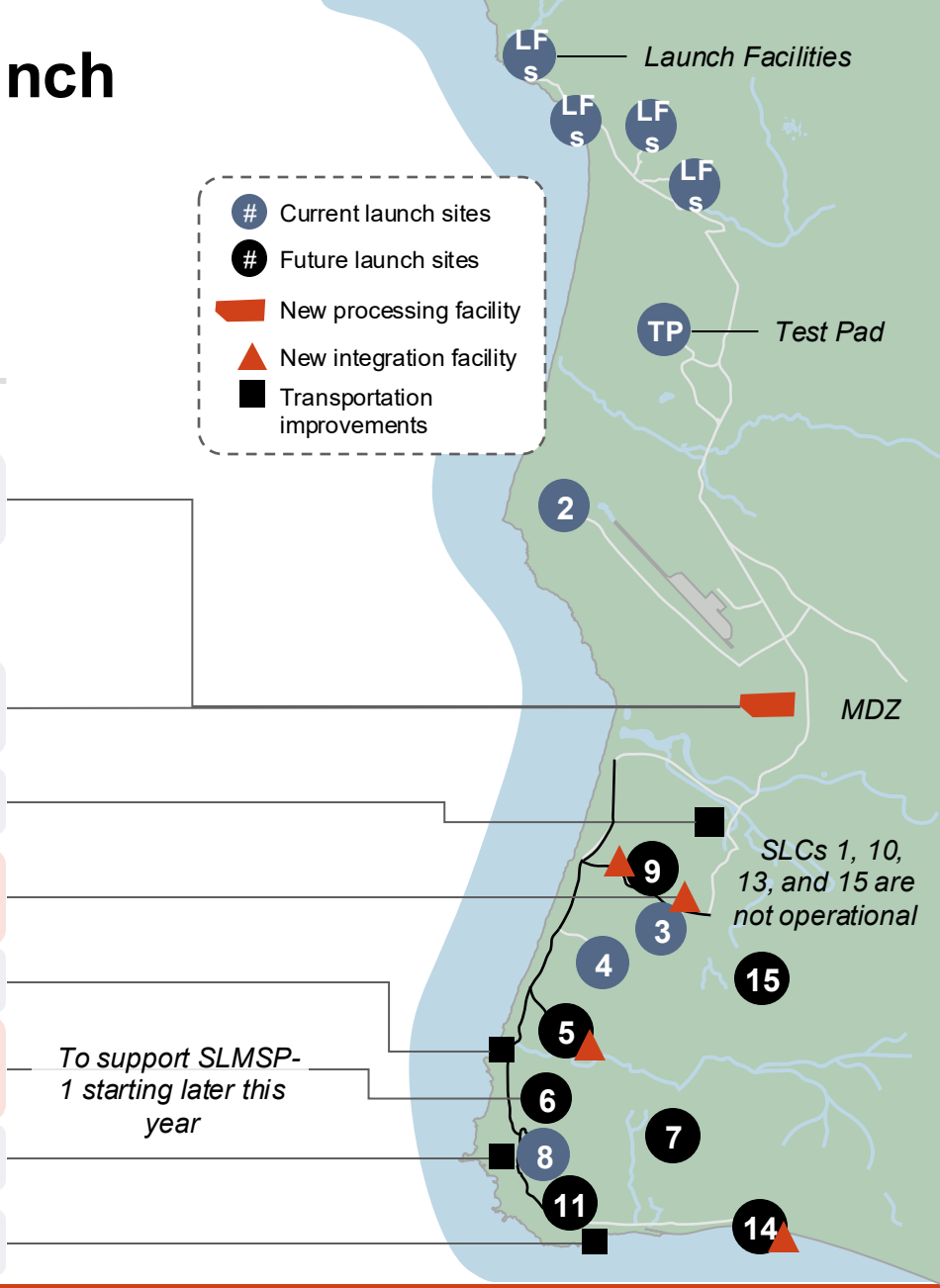
(6) Reallocate Horizontal Integration Facility and construct new integration facility on South Base

(7) Improve Coast Road and Bear Creek Road

(8) Allocate an additional SLC (e.g., SLC-6) for high-volume vehicle archetype[2]

(9) Improve rail spur

(10) Improve harbor



1. Only includes interventions that likely increase launch capacity
2. SLMSP-1 is expected to utilize SLC-6 starting this year; this is modeled as part of future base infrastructure as it is in progress

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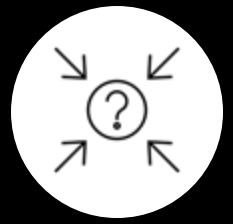
Model Improvements and Spaceport Impacts

Future investments



Questions Answered

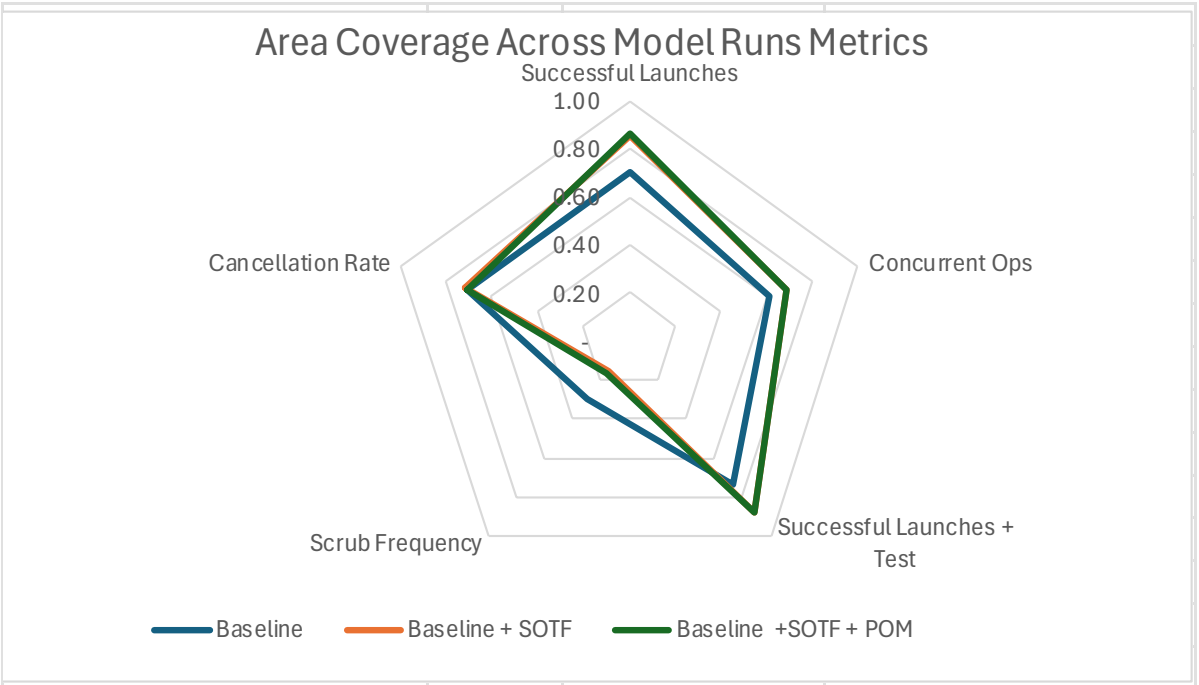
Capacity Found

Observed Results From Phase 2

- Drastic Improvement from Baseline to SOTF (21% increase in launch thru put) with an increase in Scrubs (20%)

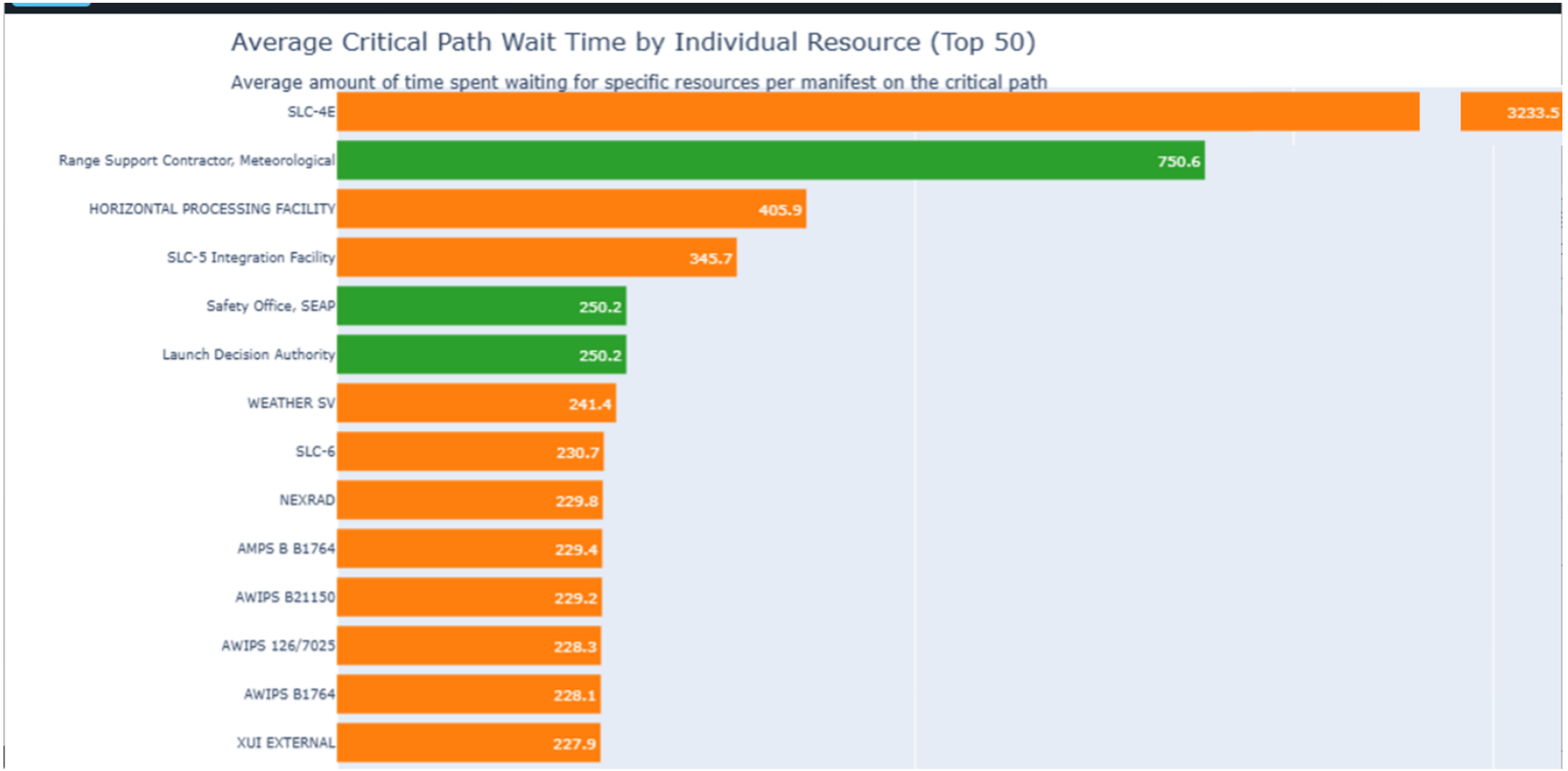
Successful Lauches			
	Baseline	Baseline + SOTF	Baseline +SOTF + POM
MIN	68	88	88
Q1	80	97	101
AVG	85	103	104
Q3	90	109	107
MAX	98	120	117

Concurrent Ops			
	Baseline	Baseline + SOTF	Baseline +SOTF + POM
MIN	6	7	7
Q1	9	10	10
AVG	9	10	10
Q3	10	11	11
	12	13	13



Average of the Metric	Baseline	Baseline + SOTF	Baseline +SOTF + POM
Successful Launches	85	103	104
Concurrent Ops	9	10	10
Successful Launches + Test	110	132	133
Scrub Frequency	49	59	59
Cancellation Rate	3	3	3

Baseline + SOFT + POM Improvements



Cross Run Wait Time Comparison

Overall, we see resource wait times go down but personnel resource ramp up then decline.

Indicates POM and Personnel investments are impactful to increasing capacity even by 1-2 Launches.

Major Drivers in Wx and CES have largest impact on launch (i.e., MUST Fight for positional adds)

	Baseline Wait Time	Baseline + SOTF Wait Time	Baseline + SOTF + POM Wait Time
SLC 4E	9885	3500	3233
30 CE	5680	0	0
HPF	2018	376	405
SLC 4W	1053	0	0
Range Ctr	436	865	750
Astrotech	251	0	0
IPF	251	0	0
Safety SEAP	145	288	250
LDA	145	288	250
Weather SV	134	281	241
Solid Motor Building	129	0	0

WR Capacity Model Live Demo

Q&A Session