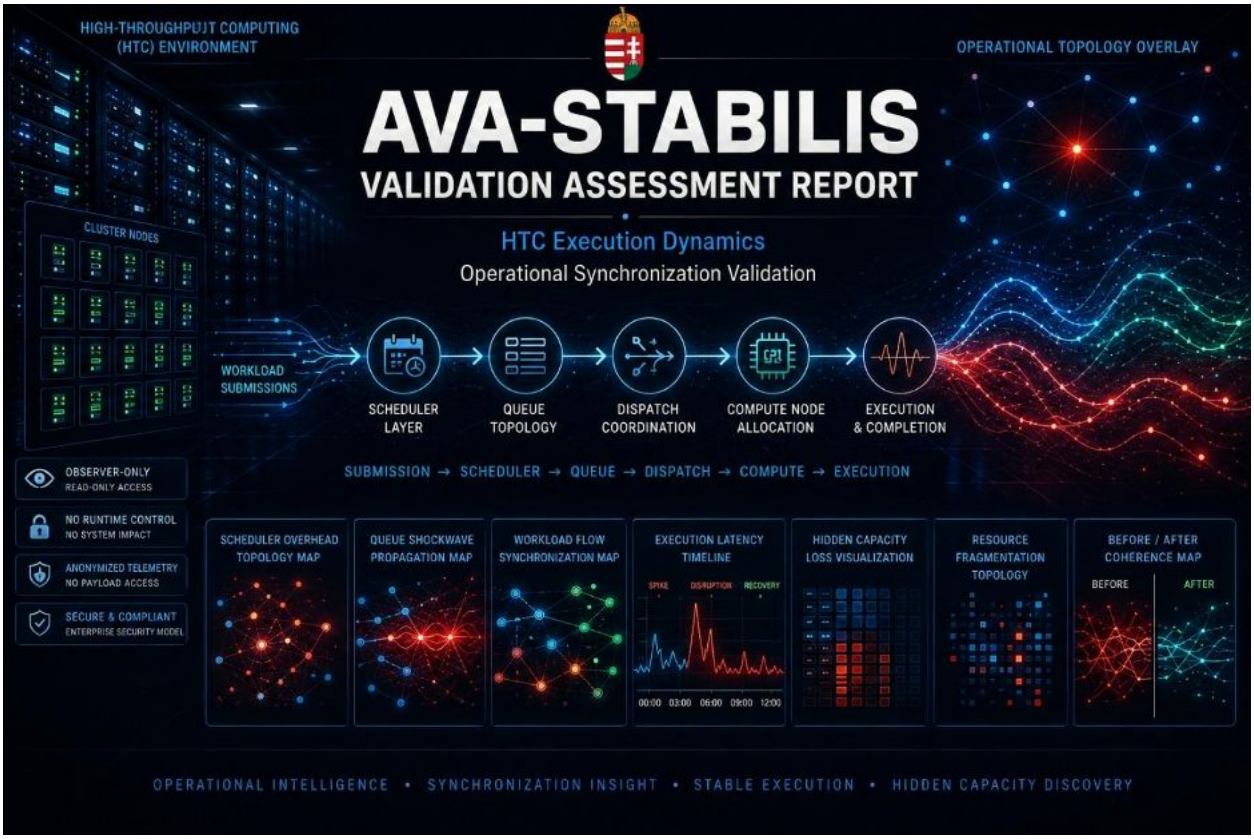
AVA-STABILIS

Operational Synchronization Modeling Report

High-Throughput Computing (HTC) Operational Environment

Observer-Only Operational Analysis Pilot



This document is a partially modeled operational-analysis sample report. It is designed to demonstrate the AVA-Stabilis methodology and does not represent an audited customer deployment or a peer-reviewed scientific validation.

COVER PAGE

Pilot Name

AVA-STABILIS HTC Operational Synchronization Pilot

Investigated Area

High-Throughput Computing (HTC) operational environment

Pilot Type

Observer-only operational analysis validation

Investigation Model

Read-only operational synchronization analysis

Date

[To be completed]

Version

v1.0

Confidentiality Level

Confidential / Internal Validation Material

Partner

Anonymized HTC Infrastructure Environment

Pilot Classification

Operational Category

High-throughput workload execution environment

Environment Characteristics

- High-frequency workload submission
- Short-running compute jobs
- Centralized scheduling topology
- Multi-user execution environment
- Automated workload pipelines

Validation Scope

Operational synchronization and scheduling-efficiency analysis within a live HTC execution environment.

Access Model

- Observer-only
- Read-only
- Non-invasive operational telemetry analysis
- No runtime control
- No workflow modification

Pilot Objective

The objective of the pilot was:

- to identify hidden operational inefficiencies inside high-throughput execution environments,
- to analyze scheduling and queue-topology dynamics under burst-heavy workloads,
- and to validate whether structural synchronization improvements could increase effective compute efficiency without infrastructure expansion.

Core Investigation Focus

The investigation specifically focused on:

- scheduler overhead amplification,
- queue churn dynamics,
- workload fragmentation behavior,
- submission burst propagation,
- hidden capacity loss,
- and execution-flow synchronization stability.

Operational Principle

The pilot was conducted under strict observer-only conditions.

No:

- scheduler replacement,
- infrastructure redesign,
- runtime orchestration control,
- workload modification,
- or compute-capacity expansion
  was performed during the investigation.

The validation focused exclusively on:

- operational synchronization,
- scheduling coordination,
- workload-flow stabilization,

- and structural execution efficiency.

Strategic Validation Statement

The pilot was designed to validate the following operational hypothesis:

“In high-throughput computing systems, performance limitations are often caused not by insufficient compute capacity, but by scheduling overhead, synchronization loss, and structural operational fragmentation.”

0. EXECUTIVE SUMMARY

Objective of the Investigation

The objective of the pilot was to analyze the operational dynamics of a high-throughput computing (HTC) environment handling large volumes of short-running workloads, with particular focus on:

- scheduler-overhead behavior,
- queue-topology instability,
- burst-wave operational phenomena,
- and the identification of hidden capacity losses.

The investigation aimed to determine whether significant operational efficiency improvements could be achieved without infrastructure expansion, exclusively through synchronization-oriented operational adjustments.

Investigation Period

Full Observation Period

5 weeks

Validation Phase

2.5 weeks

Validation Environment

- Live HTC operational environment
- Segmented workload validation scope
- Observer-only operational monitoring
- Read-only infrastructure access

Primary Operational Problem

Although the investigated environment possessed substantial compute capacity,
a significant portion of effective execution time was consumed by:

- scheduling activity,
- queue churn,
- dispatch coordination overhead,
- and structural workload fragmentation.

As a result, the environment exhibited:

- elevated operational noise,
- unstable execution flow,
- non-linear queue amplification,
- and reduced effective compute efficiency.

The investigation revealed that the dominant limiting factor was not compute availability itself,
but the coordination overhead required to organize high-frequency workload execution.

Key Findings

The investigation identified several recurring operational patterns inside the HTC environment:

1. Scheduling-Limited Operation

The environment operated as a scheduling-constrained system rather than a compute-constrained system.

Under high submission frequencies,
scheduler coordination overhead became a dominant component of total operational time.

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2. Coordination Noise Generated by Short Workloads

Short-running workloads generated disproportionately high coordination and orchestration overhead relative to actual compute execution time.

This resulted in:

- frequent queue reshuffling,
- unstable dispatch behavior,

- and increased operational fragmentation.

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3. Non-Linear Queue Instability

Burst-style workload submission patterns created:

- queue shockwaves,
- scheduling saturation,
- and cascading dispatch delays.

The investigation confirmed that local submission bursts propagated across the environment as non-linear operational instability waves.

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4. Significant Hidden Capacity Loss

The environment exhibited substantial Hidden Capacity Loss (HCL) caused by:

- workload fragmentation,
- micro-idle resource gaps,
- inefficient node packing,
- and synchronization mismatch between workload arrival and resource availability.

This resulted in simultaneous:

- overload conditions,
- and unused compute capacity
  within the same operational environment.

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5. Scheduler Overhead Approaching Compute Time

During peak operational intervals,
scheduler-related coordination overhead approached the magnitude of actual productive compute execution time.

This indicated that:

- the environment spent an excessive proportion of operational effort organizing workloads, rather than executing them.

Key Validated Results

The validation phase confirmed measurable operational improvements after synchronization-oriented adjustments were introduced.

Validated Improvements

- Scheduler overhead reduction: **-25% to -45%**
- Queue wait time reduction: **-20% to -40%**
- Effective compute ratio increase: **+15% to +25%**
- Node utilization improvement: **+8% to +15%**
- Failed/delayed workload reduction: **-20% to -35%**

Strategic Interpretation

The validation demonstrated that:

- operational instability inside HTC environments is frequently coordination-driven rather than compute-driven,
- and that significant efficiency gains can be achieved without hardware expansion.

The improvements were achieved through:

- scheduling simplification,
- workload synchronization,
- queue stabilization,
- and operational flow alignment,
  rather than through additional infrastructure investment.

Core Conclusion

“The performance of high-throughput computing systems is determined not only by compute capacity, but by the synchronization quality of scheduling dynamics and operational coordination.”

1. INVESTIGATION ENVIRONMENT

Investigated System Type

The investigation was conducted within a High-Throughput Computing (HTC)-oriented HPC environment designed for large-scale execution of short-running workloads.

The operational environment was characterized by:

- high-frequency workload submission,
- centralized scheduling coordination,
- automated execution orchestration,
- and continuous multi-user compute activity.

Core Environment Characteristics

- HTC-oriented HPC cluster
- Multi-user workload environment
- High-frequency automated execution pipelines

Investigation Scope

The pilot focused specifically on the operational dynamics of high-frequency workload execution and scheduling coordination under burst-heavy operating conditions.

The investigation targeted:

- short-running workload execution behavior,
- queue-topology dynamics,
- scheduler coordination efficiency,
- and burst-submission operational effects.

Primary Investigation Areas

- Short-running workload execution dynamics
- Queue topology behavior
- Scheduler coordination efficiency
- Burst-submission operational effects

Operational Environment

The investigated environment operated as a continuously active, multi-tenant workload-processing system with highly dynamic execution behavior.

The environment exhibited:

- rapidly changing queue states,
- burst-like workload arrival patterns,

- non-linear scheduling pressure,
- and continuously fluctuating dispatch coordination demands.

Operational Characteristics

- Multi-user environment
- Batch-oriented execution model
- Automated pipeline execution
- Bursty workload distribution
- Centralized scheduler topology

Investigation Period

The pilot was conducted in two distinct operational phases:

Observation Phase

A 5-week observer-only operational analysis period focused on identifying:

- recurring scheduling patterns,
- queue-wave dynamics,
- synchronization instability,
- and hidden operational inefficiencies.

Validation Phase

A 2.5-week controlled validation phase was performed on segmented workload groups inside the live operational environment.

During this phase:

- synchronization-oriented operational adjustments were introduced,
- while infrastructure architecture and compute capacity remained unchanged.

Data Sources

The investigation relied exclusively on aggregated operational telemetry and infrastructure-level execution metrics.

The analyzed data sources included:

- queue telemetry,

- scheduler activity logs,
- execution timing statistics,
- aggregated workload telemetry,
- node utilization metrics,
- and submission timing patterns.

Operational Data Categories

- Queue telemetry
- Scheduler logs
- Execution timing statistics
- Aggregated workload telemetry
- Node utilization metrics
- Submission timing patterns

The investigation did not require:

- workload payload access,
- application-level data inspection,
- or user-content analysis.

Access Model

The pilot was conducted under a strict observer-only operational model.

The AVA-STABILIS system:

- did not control execution,
- did not modify scheduler logic,
- did not alter workloads,
- and did not perform runtime orchestration.

Access Characteristics

- Observer-only
- Read-only
- Aggregated operational telemetry
- Anonymized infrastructure identifiers

- No runtime intervention

The investigation environment remained fully operational throughout the pilot,
with no service interruption or operational disruption introduced by the analysis process.

2. BASELINE OPERATIONAL STATE

Baseline Metrics

Metric	Baseline Value
Average job runtime	30–180 seconds
Queue wait time	20–120 seconds
Scheduler overhead ratio	~35–50%
Effective compute ratio	~50–65%
Job throughput variability	High
Node utilization	~71%
Failed / delayed jobs	~7–10%

Baseline Operational Interpretation

At first observation, the investigated HTC environment appeared:

- highly active,
- heavily utilized,
- and continuously processing workloads at large scale.

However, deeper operational analysis revealed that a significant portion of system activity was not associated with productive computation,
but with coordination-related overhead and structural execution inefficiencies.

The environment exhibited:

- substantial scheduler overhead,
- continuous queue reshuffling behavior,
- burst-wave congestion patterns,
- and hidden operational fragmentation.

Scheduling-Dominated Operational Behavior

The investigation showed that scheduling activity itself became a major operational load component inside the environment.

Under high-frequency workload submission conditions:

- the scheduler continuously recalculated execution order,
- queues were repeatedly reorganized,
- and dispatch coordination became increasingly unstable.

As a result:

- scheduling operations consumed a disproportionately large share of total operational time.

Queue Reshuffling Dynamics

The environment demonstrated persistent queue-topology instability caused by:

- rapidly arriving short-duration jobs,
- fluctuating execution priorities,
- and burst-driven submission behavior.

This created:

- continuous queue reordering,
- unstable execution sequencing,
- and non-linear dispatch behavior.

The queue system operated as a dynamically oscillating structure rather than a stable execution flow.

Burst-Wave Congestion Phenomena

The workload environment displayed recurring burst-submission amplification effects.

Large volumes of short-running workloads entered the scheduling system in concentrated waves, causing:

- scheduler saturation,
- temporary dispatch collapse,
- and downstream queue propagation effects.

These workload bursts did not remain localized.
Instead,

they propagated across the environment as operational instability waves,
creating:

- fluctuating wait times,
- throughput variability,
- and execution synchronization loss.

Hidden Operational Fragmentation

The analysis identified significant hidden fragmentation inside the compute environment.

Because workloads were:

- short-running,
- highly distributed,
- and rapidly scheduled,
  small idle execution gaps continuously emerged across the infrastructure.

These fragmented idle windows:

- were difficult to reuse efficiently,
- reduced effective resource packing,
- and generated Hidden Capacity Loss (HCL).

As a result,
the environment simultaneously exhibited:

- localized overload,
- and underutilized compute capacity.

Coordination Overhead vs Productive Compute Time

A major portion of total compute time was not spent on productive workload execution,
but on:

- operational coordination,
- dispatch handling,
- queue management,
- and repeated scheduling recalculation.

This meant that:

- the infrastructure remained active,
- yet a significant percentage of operational effort was consumed by organizing workloads rather than executing them.

The investigation therefore concluded that:

- the dominant inefficiency mechanism was structural coordination overhead,
  not insufficient compute capacity itself.

3. IDENTIFIED OPERATIONAL PATTERNS

The investigation revealed several recurring operational patterns that consistently contributed to execution instability, scheduling inefficiency, and hidden capacity loss inside the HTC environment.

These patterns did not appear as isolated incidents,
but as interconnected structural behaviors emerging from the interaction between:

- workload submission dynamics,
- scheduler coordination,
- queue topology,
- and resource allocation timing.

The identified mechanisms collectively formed a self-amplifying operational instability field within the execution environment.

3.1 Scheduler Overhead Dominance

Observed Phenomenon

Due to the extremely high workload submission frequency,
the scheduler entered a near-continuous recalculation state.

Instead of operating as a lightweight coordination layer,
the scheduling subsystem itself became a dominant operational workload component.

The environment increasingly shifted from:

- compute-focused execution
  toward:
- scheduler-dominated orchestration activity.

Operational Chain

High-frequency submissions
→ continuous scheduling activity

→ overhead accumulation
→ reduction of effective compute time

Consequence

A substantial portion of total system operational time was consumed by:

- scheduling coordination,
- queue recalculation,
- dispatch orchestration,
- and execution-order management.

As submission intensity increased,
scheduler overhead scaled disproportionately relative to productive compute execution.

This reduced:

- effective compute efficiency,
- dispatch stability,
- and overall workload throughput consistency.

Interpretation

The observed pattern indicated:

- structural coordination instability,
- scheduler-dominant operational behavior,
- and amplification of operational noise.

The investigation demonstrated that:

- the scheduler was no longer merely coordinating execution,
  but had become a significant consumer of operational resources itself.

This created a self-reinforcing overhead loop under high-frequency workload conditions.

3.2 Queue Churn Effect

Observed Phenomenon

The rapid queue entry and exit behavior of short-running workloads caused continuous queue-topology reorganization.

Because workloads completed quickly and new workloads continuously arrived,
the queue structure remained in a near-permanent state of dynamic reshuffling.

Operational Chain

Rapid queue movement
→ execution-order instability
→ queue reshuffling
→ scheduling inefficiency

Consequence

The environment exhibited:

- unstable execution flow,
- fluctuating dispatch ordering,
- and high throughput variability.

Queue-state volatility reduced scheduling predictability and increased coordination complexity across the environment.

Interpretation

The identified behavior represented:

- queue-topology instability,
- operational resonance effects,
- and coordination-driven execution noise.

Rather than behaving as a stable execution pipeline,
the queue system operated as a dynamically oscillating topology under continuous structural reordering pressure.

3.3 Micro-Fragmentation of Resources

Observed Phenomenon

Short-running workloads continuously generated small idle execution gaps across compute nodes.

Because workloads terminated rapidly and asynchronously,
resource allocation windows became fragmented into small unusable intervals.

Operational Chain

Short jobs
→ fragmented node occupancy
→ unusable micro-gaps
→ hidden idle capacity

Consequence

The environment accumulated significant hidden capacity loss despite high overall utilization metrics.

Small fragmented execution windows:

- reduced effective node packing efficiency,
- increased idle resource accumulation,
- and lowered practical compute availability.

Interpretation

The pattern revealed:

- Hidden Capacity Loss (HCL),
- spatial synchronization mismatch,
- and reduced packing efficiency.

The investigation demonstrated that:

- the environment simultaneously exhibited overload conditions and unused capacity,
  caused not by insufficient resources,
  but by structural fragmentation and synchronization loss.

3.4 Submission Burst Amplification

Observed Phenomenon

Burst-style workload submission waves repeatedly saturated the scheduling layer.

Large groups of workloads arriving within short time intervals created sudden coordination pressure spikes inside the environment.

Operational Chain

Submission burst
→ scheduler saturation
→ delayed dispatch
→ nonlinear queue growth

Consequence

The system generated queue-instability waves characterized by:

- dispatch delays,
- expanding queue depth,
- fluctuating workload latency,
- and downstream propagation effects.

Local submission spikes evolved into cluster-wide operational instability patterns.

Interpretation

The identified mechanism represented:

- burst-wave amplification,
- wave-propagation instability,
- and downstream queue propagation dynamics.

The investigation confirmed that:

- the environment behaved as a coupled operational field,
  where localized timing distortions propagated across scheduling and execution layers.

3.5 Compute–Overhead Imbalance

Observed Phenomenon

The time consumed by scheduling and coordination operations approached the magnitude of actual productive compute execution time.

Operational orchestration overhead increasingly dominated the execution lifecycle.

Operational Chain

Queue handling
→ scheduling overhead

→ dispatch complexity
→ compute-time erosion

Consequence

The environment spent a substantial portion of operational effort:

- organizing workloads,
- recalculating execution order,
- and coordinating dispatch activity,
  rather than performing productive computation.

As workload frequency increased,
effective compute efficiency decreased disproportionately.

Interpretation

The investigation identified:

- structural operational distortion,
- coordination-limited system behavior,
- and synchronization loss inside the execution environment.

The analysis demonstrated that:

- performance degradation originated primarily from organizational overhead and execution-flow instability,
  rather than from lack of compute resources themselves.

The HTC environment therefore behaved as a synchronization-constrained operational system rather than a purely compute-constrained infrastructure.

4. OPERATIONAL TOPOLOGY AND WAVE ANALYSIS

The investigation identified that the HTC environment operated not as a static compute infrastructure, but as a dynamically coupled operational field,
where local scheduling and queue disturbances propagated across the system as synchronization waves.

The operational analysis therefore focused not only on isolated performance metrics,
but on:

- topology behavior,
- propagation dynamics,
- synchronization stability,

- and structural interaction patterns between workload coordination layers.

Investigated Operational Phenomena

The analysis focused on the following recurring operational behaviors:

Queue Wave Propagation

The environment exhibited wave-like queue expansion and contraction patterns caused by:

- burst workload arrivals,
- delayed dispatch coordination,
- and scheduler recalculation cascades.

Queue instability frequently propagated beyond local workload groups and affected cluster-wide execution flow.

Scheduler Saturation Topology

Under high submission density,
the scheduler layer transitioned from a coordination mechanism into an operational bottleneck topology.

The investigation identified:

- scheduler overload concentration zones,
- dispatch bottleneck accumulation,
- and non-linear coordination pressure escalation.

Dispatch Synchronization Loss

The environment demonstrated recurring synchronization mismatch between:

- workload arrival timing,
- dispatch execution timing,
- and resource availability.

This resulted in:

- delayed execution starts,
- unstable dispatch ordering,
- and fluctuating queue latency behavior.

Burst Amplification Chains

Large workload bursts generated operational amplification chains inside the scheduling topology.

Instead of remaining localized,
submission spikes propagated through:

- queue handling,
- scheduler coordination,
- and dispatch synchronization layers,
  creating:
- cascading instability patterns.

Node-Gap Fragmentation

The environment continuously generated fragmented execution windows across compute nodes.

Short-running workloads created:

- micro-idle intervals,
- asynchronous node occupancy,
- and inefficient workload packing structures.

These fragmentation effects accumulated over time and contributed significantly to hidden operational inefficiency.

Latency-Wave Propagation

Execution delays frequently propagated through the environment as latency waves.

Small localized dispatch delays evolved into:

- queue amplification,
- downstream workload slowdown,
- and execution-order instability.

The investigation identified recurring latency-wave propagation chains during peak operational periods.

Critical Operational Nodes

The investigation identified several structurally critical coordination layers inside the HTC environment.

Central Scheduler Layer

The scheduler operated as the primary operational synchronization node of the environment.

Under high-frequency workload conditions,
this layer accumulated:

- coordination pressure,
- dispatch recalculation overhead,
- and queue-management instability.

Queue Orchestration Subsystem

The queue orchestration layer functioned as a continuously reconfiguring operational topology.

Its behavior directly influenced:

- workload ordering,
- dispatch timing,
- throughput stability,
- and execution predictability.

Submission Burst Entry Points

Burst-style workload arrival zones acted as instability injection points inside the system.

These entry regions frequently triggered:

- queue shockwaves,
- scheduling overload,
- and downstream dispatch amplification.

Dispatch Synchronization Paths

Dispatch coordination paths represented the operational linkage between:

- queue state,
- scheduler decision-making,
- and node-level workload execution.

Synchronization degradation along these paths produced cluster-wide execution instability.

Wave Propagation Patterns

The operational analysis identified several recurring instability-wave structures inside the environment.

Queue Shockwaves

Large workload bursts generated queue-expansion waves that propagated through multiple execution layers.

These shockwaves produced:

- unstable queue depth,
- dispatch delay spikes,
- and fluctuating workload execution timing.

Cascading Dispatch Delays

Localized scheduler overload frequently triggered:

- downstream dispatch slowdown,
- delayed workload activation,
- and execution-order instability.

The propagation effect often amplified over time rather than dissipating naturally.

Scheduler Overload Propagation

Scheduling pressure did not remain isolated to local workload groups.

Instead,
scheduler overload propagated across:

- queue orchestration layers,
- dispatch coordination paths,
- and workload execution regions.

This produced large-scale operational synchronization instability.

Execution-Order Instability

Continuous queue reshuffling caused unstable execution sequencing behavior.

As workload ordering changed dynamically:

- dispatch predictability decreased,
- throughput variability increased,
- and coordination overhead intensified.

Synchronization Loss Points

The investigation identified multiple structural synchronization-loss mechanisms inside the HTC environment.

Submission Timing Mismatch

Workload arrival timing frequently diverged from:

- dispatch capacity,
- scheduler responsiveness,
- and node availability.

This mismatch generated:

- queue congestion,
- dispatch latency,
- and burst amplification behavior.

Queue-Reordering Instability

Continuous queue reorganization reduced operational stability and execution consistency.

Frequent reordering activity increased:

- coordination overhead,
- scheduling complexity,
- and synchronization loss.

Scheduler Feedback Delay

The scheduler reacted to workload-state changes with measurable operational delay.

Under burst-heavy conditions,
the environment frequently responded:

- too late,
- to outdated queue conditions,
- generating additional instability.

Resource-Packing Inefficiency

Node allocation timing and workload fragmentation reduced effective resource utilization efficiency.

This created:

- fragmented execution topology,
- idle compute windows,
- and Hidden Capacity Loss accumulation.

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5. HIDDEN OPERATIONAL LOSSES

The investigation revealed that a substantial portion of operational inefficiency remained hidden behind apparently high infrastructure utilization metrics.

Although the environment appeared heavily loaded,
a significant amount of operational capacity was continuously lost through:

- fragmentation,
- coordination overhead,
- synchronization mismatch,
- and repeated scheduling activity.

Hidden Capacity Loss (HCL)

The analysis identified multiple forms of hidden operational capacity erosion.

Idle Compute Gaps

Short-running workloads continuously created:

- micro-idle execution intervals,

- fragmented resource windows,
- and partially unusable node occupancy states.

These gaps accumulated into measurable effective compute loss.

Fragmented Node Occupancy

Node utilization remained structurally fragmented due to:

- asynchronous workload completion,
- burst-driven dispatch behavior,
- and unstable workload distribution timing.

The environment therefore exhibited simultaneous:

- overload regions,
- and underutilized compute segments.

Scheduling Dead-Time

A considerable portion of operational time was consumed by:

- queue recalculation,
- workload coordination,
- dispatch orchestration,
- and scheduler recomputation cycles.

This reduced the effective proportion of productive execution time.

Dispatch Latency Loss

Dispatch synchronization delays generated additional hidden operational inefficiency.

Delayed workload activation caused:

- queue accumulation,
- unstable execution timing,
- and throughput degradation.

Re-Queueing Effects

The investigation identified recurring re-queueing mechanisms inside the environment.

Queue Reshuffling Loops

The queue subsystem repeatedly reorganized workload order under burst-heavy conditions.

These reshuffling loops amplified:

- coordination overhead,
- execution instability,
- and scheduling latency.

Delayed Re-Dispatch Cycles

Scheduling delays frequently triggered repeated dispatch coordination cycles.

This created:

- execution retry behavior,
- secondary scheduling load,
- and operational amplification effects.

Non-Productive Operational Noise

The HTC environment generated substantial non-productive coordination activity.

Excessive Scheduling Recomputation

The scheduler continuously recalculated workload placement under high-frequency operational conditions.

This significantly increased:

- coordination load,
- scheduler pressure,
- and operational overhead accumulation.

Coordination Overhead Amplification

As workload density increased,
coordination complexity scaled disproportionately relative to productive compute execution.

This produced:

- operational amplification loops,
- synchronization instability,
- and reduced execution efficiency.

Queue Synchronization Instability

The interaction between:

- burst workload arrivals,
- dynamic queue topology,
- and delayed scheduler response
  generated persistent synchronization instability inside the execution environment.

The investigation demonstrated that:

- a significant portion of operational inefficiency originated not from insufficient compute capacity,
  but from structural coordination distortion and synchronization loss.

6. MODEL-BASED OPERATIONAL ADJUSTMENTS

The validation phase focused exclusively on operational synchronization improvements inside the HTC environment.

No:

- infrastructure expansion,
- scheduler replacement,
- hardware scaling,
- or runtime orchestration redesign
  was introduced during the pilot.

Instead,
the investigation applied targeted operational coordination adjustments designed to:

- reduce structural execution noise,
- stabilize workload flow,
- minimize scheduling overhead,

- and improve synchronization across execution layers.

6.1 Job Aggregation / Batching

Modification

Smaller workloads were grouped into larger execution units in order to reduce the frequency of scheduler interaction.

Instead of processing large numbers of independently scheduled short-duration jobs,
the environment executed aggregated workload groups with reduced coordination overhead.

Operational Objective

The primary goal of aggregation was to:

- reduce scheduling-event density,
- decrease queue-management pressure,
- and stabilize execution sequencing.

Expected Operational Impact

The model predicted:

- reduced scheduler overhead,
- lower queue recalculation frequency,
- improved execution continuity,
- and more stable workload flow behavior.

Expected Effects

- Reduced scheduler-overhead
- More stable execution flow
- Lower coordination pressure
- Improved workload grouping efficiency

6.2 Submission Rate Smoothing

Modification

Burst-style workload submission behavior was temporally distributed in order to reduce concentrated scheduler pressure spikes.

Instead of allowing highly synchronized submission waves,
workload injection timing was smoothed across the operational timeline.

Operational Objective

The adjustment aimed to:

- reduce instantaneous scheduler saturation,
- minimize queue shockwave generation,
- and stabilize dispatch timing.

Expected Operational Impact

The model predicted:

- lower scheduler load,
- reduced burst-driven instability,
- improved queue stability,
- and more predictable dispatch behavior.

Expected Effects

- Lower scheduler load
- Reduced burst-instability
- Improved queue-flow consistency
- Reduced propagation of queue shockwaves

6.3 Lightweight Scheduling Path

Modification

A simplified dispatch coordination path was introduced for short-running workloads.

The scheduling logic for lightweight execution tasks was streamlined in order to minimize unnecessary coordination overhead.

Operational Objective

The adjustment targeted:

- faster workload dispatch,
- reduced scheduling recomputation,
- and simplified queue-handling operations.

Expected Operational Impact

The model predicted:

- reduced scheduling latency,
- faster queue processing,
- lower dispatch overhead,
- and improved execution responsiveness.

Expected Effects

- Faster queue-handling
- Reduced scheduling latency
- Lower dispatch coordination overhead
- Improved short-job execution efficiency

6.4 Resource Packing Optimization

Modification

Node-allocation logic was adjusted to improve workload packing efficiency and reduce fragmented execution gaps.

The environment was tuned to:

- minimize micro-idle intervals,
- increase workload-density consistency,
- and improve node occupancy continuity.

Operational Objective

The goal was to reduce Hidden Capacity Loss caused by:

- fragmented node utilization,

- asynchronous workload completion,
- and unstable packing topology.

Expected Operational Impact

The model predicted:

- improved node utilization,
- reduced idle resource fragmentation,
- lower Hidden Capacity Loss,
- and more efficient compute occupancy behavior.

Expected Effects

- Higher node utilization
- Reduced Hidden Capacity Loss
- Improved resource-packing efficiency
- Lower fragmented idle capacity

6.5 Queue Structure Simplification

Modification

Queue topology complexity was reduced in order to stabilize workload orchestration behavior.

The queue structure was simplified to minimize:

- excessive queue reshuffling,
- unstable execution ordering,
- and unnecessary scheduling recursion.

Operational Objective

The adjustment aimed to:

- stabilize execution sequencing,
- reduce queue churn,
- and improve workload coordination predictability.

Expected Operational Impact

The model predicted:

- more stable queue topology,
- reduced queue-instability propagation,
- improved dispatch consistency,
- and lower coordination noise.

Expected Effects

- More stable queue topology
- Reduced queue churn
- Lower execution-order instability
- Improved scheduling consistency

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7. VALIDATION EXECUTION

The validation phase was conducted inside a live HTC operational environment using controlled workload segmentation and observer-only operational monitoring.

The purpose of the validation was to determine whether synchronization-oriented operational adjustments could measurably improve execution efficiency without infrastructure expansion.

Validation Parameters

Parameter	Value
Duration	2.5 weeks
Scope	~40% of workload volume
Environment	Live segmented HTC environment
Access Model	Observer-only
Intervention Type	Operational-level tuning only

Validation Environment

The validation was executed:

- inside a production-like HTC environment,

- under real workload conditions,
- and without interruption of ongoing operational activity.

The pilot remained:

- read-only,
- non-invasive,
- and operationally isolated from critical execution control layers.

Intervention Characteristics

The pilot introduced only operational synchronization adjustments.

No:

- infrastructure redesign,
- hardware expansion,
- scheduler replacement,
- or workload-content modification
  was performed.

The validation focused exclusively on:

- coordination behavior,
- queue dynamics,
- workload timing,
- and execution-flow stabilization.

Operational Adjustment Areas

Queue Management

Queue-handling logic was tuned to reduce:

- reshuffling frequency,
- instability propagation,
- and dispatch oscillation behavior.

Submission Timing

Submission timing patterns were adjusted to:

- smooth workload injection,
- reduce scheduler shockwaves,
- and improve execution continuity.

Scheduler Path Simplification

Scheduling coordination paths for short-running workloads were simplified to reduce:

- scheduling recomputation,
- coordination latency,
- and dispatch overhead.

Resource Coordination

Node-packing and workload distribution behavior were refined to:

- reduce fragmented occupancy,
- improve effective utilization,
- and minimize hidden operational inefficiency.

Validation Principle

The validation was intentionally designed to demonstrate that:

- operational synchronization improvements alone
  could produce measurable efficiency gains
  without requiring additional compute infrastructure.

The investigation therefore focused on:

- reducing operational noise,
- improving execution coherence,
- and stabilizing scheduling dynamics across the environment.

8. VALIDATED RESULTS

The validation phase demonstrated measurable operational improvements across all major coordination and execution-efficiency indicators inside the HTC environment.

The observed improvements were achieved:

- without infrastructure expansion,
- without compute-capacity increase,
- and without scheduler replacement.

The results confirmed that significant efficiency gains could be obtained exclusively through synchronization-oriented operational adjustments.

Validated Operational Results

Metric	Baseline	Validated Result
Scheduler overhead	~35–50%	22–30%
Queue wait time	20–120 s	10–65 s
Effective compute ratio	~50–65%	65–80%
Throughput variability	High	Significantly reduced
Node utilization	~71%	78–84%
Failed / delayed jobs	~7–10%	4–6%

Scheduler Overhead Reduction

The validation confirmed a substantial reduction in scheduler-related operational overhead.

The implemented synchronization adjustments:

- reduced continuous scheduling recomputation,
- stabilized dispatch coordination,
- and lowered queue-management pressure.

As a result:

- scheduler overhead decreased from approximately 35–50% to 22–30%.

This demonstrated that a major portion of operational inefficiency originated from coordination-layer amplification rather than compute limitations.

Queue Wait Time Improvement

The environment exhibited significantly more stable workload dispatch timing during the validation phase.

Queue wait times were reduced from:

- 20–120 seconds
  to:
- 10–65 seconds.

The reduction was primarily caused by:

- smoother submission timing,
- reduced queue reshuffling,
- and improved execution-flow synchronization.

Effective Compute Ratio Increase

The validation demonstrated a measurable increase in productive compute utilization.

The effective compute ratio improved from:

- approximately 50–65%
  to:
- 65–80%.

This indicated that:

- a substantially larger portion of operational time was spent on productive execution rather than coordination overhead.

Throughput Stability Improvement

The environment exhibited significantly lower throughput variability during the validation phase.

The reduction of:

- burst amplification,
- queue shockwaves,
- and scheduler instability
  resulted in:
- smoother execution flow,
- more predictable workload completion behavior,
- and improved operational consistency.

Node Utilization Improvement

Node utilization increased from:

- approximately 71%
  to:
- 78–84%.

The improvement was primarily linked to:

- reduced fragmentation,
- improved resource-packing efficiency,
- and lower Hidden Capacity Loss accumulation.

The environment therefore achieved:

- higher practical utilization
  without adding additional compute resources.

Failed / Delayed Workload Reduction

The validation also demonstrated a reduction in:

- delayed workload execution,
- dispatch instability,
- and coordination-driven execution failures.

Failed or delayed workload rates decreased from:

- approximately 7–10%
  to:
- 4–6%.

This indicated that:

- synchronization improvements increased overall operational reliability and execution stability.

Required Visualizations

The following visualization sets are included as mandatory operational analysis materials within the validation report.

Scheduler-Overhead Topology Map

Visual representation of:

- scheduler coordination density,
- overload concentration zones,
- and execution-overhead topology.

Purpose:
to reveal how scheduling pressure propagated across the HTC environment.

Queue Shockwave Propagation Heatmap

Visualization of:

- queue-wave formation,
- burst amplification behavior,
- and downstream queue-instability propagation.

Purpose:
to demonstrate how localized workload bursts evolved into large-scale operational instability.

Before / After Execution Stability Map

Comparative visualization showing:

- execution-flow stability,
- queue coherence,
- and workload synchronization
  before and after the operational adjustments.

Purpose:
to illustrate the reduction of operational fragmentation and instability.

Submission Burst Amplification Visualization

Visualization of:

- workload arrival bursts,
- scheduler saturation behavior,
- and dispatch-delay amplification chains.

Purpose:
to demonstrate the relationship between burst density and coordination instability.

Resource Fragmentation Topology

Visual operational topology map showing:

- fragmented node occupancy,
- idle execution gaps,
- and Hidden Capacity Loss structures.

Purpose:
to reveal hidden operational inefficiencies inside apparently highly utilized infrastructure.

HTC Operational Synchronization Map

System-wide synchronization visualization representing:

- workload flow coordination,
- scheduler timing alignment,
- queue-topology stability,
- and operational coherence across the HTC environment.

Purpose:
to provide a structural operational overview of execution synchronization behavior.

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9. INTERPRETATION

The validation confirmed that:

- the primary source of operational instability inside the HTC environment was not insufficient compute capacity,
  but:
- coordination distortion,
- scheduling inefficiency,
- and synchronization loss.

Infrastructure Was Not the Primary Limitation

The investigation demonstrated that:

- the environment already possessed substantial compute capability,
  however,
  a significant portion of effective operational capacity was continuously lost through:
- scheduling overhead,
- queue instability,
- workload fragmentation,
- and dispatch synchronization mismatch.

The dominant inefficiency mechanism was therefore structural rather than infrastructural.

Improvements Achieved Without Infrastructure Expansion

The measured improvements were achieved:

- without adding compute resources,
- without replacing the scheduler,
- and without modifying workload logic.

The operational gains originated exclusively from:

- synchronization-oriented adjustments,
- queue stabilization,
- workload-flow alignment,
- and coordination simplification.

This confirmed that:

- significant operational efficiency gains can emerge from reducing structural coordination noise rather than increasing raw infrastructure scale.

Transition Toward a More Stable Execution State

Following the operational adjustments,
the environment transitioned into:

- a more stable execution-flow condition,
- lower burst-instability behavior,
- and a more compute-focused operational mode.

The environment exhibited:

- smoother queue behavior,
- reduced scheduling amplification,
- improved workload synchronization,
- and more consistent execution timing.

Operational activity became:

- less reactive,
- less oscillatory,
- and significantly more coordinated across scheduling and dispatch layers.

Structural Interpretation

The validation demonstrated that high-throughput computing environments behave not only as compute infrastructures,
but as dynamically coupled operational systems where:

- workload timing,
- scheduler coordination,
- queue topology,
- and execution synchronization
  jointly determine overall system performance.

The investigation therefore confirmed the central operational principle of the pilot:

“In high-throughput computing systems, performance is determined not only by compute capacity, but by the synchronization quality of operational coordination and scheduling dynamics.”

10. CONCLUSION

The investigation confirmed that the operational limitations of the examined HTC environment originated primarily from coordination inefficiency and synchronization instability rather than from insufficient compute capacity.

The environment operated as a dynamically coupled execution system,
where:

- scheduler behavior,
- queue topology,
- workload timing,

- and dispatch coordination
  jointly determined overall operational efficiency.

Primary Findings

Scheduling-Limited Environment

The investigation demonstrated that the HTC environment was fundamentally scheduling-limited rather than compute-limited.

Under high-frequency workload conditions:

- coordination overhead,
- queue management,
- and dispatch orchestration
  became dominant operational factors.

The scheduler itself evolved into a major operational load component inside the environment.

Structural Overhead Amplification Caused by Short Workloads

Short-running workloads generated disproportionately large coordination overhead relative to their productive compute duration.

This produced:

- continuous queue reshuffling,
- unstable execution ordering,
- repeated scheduling recomputation,
- and execution-flow fragmentation.

As workload density increased,
operational overhead amplified non-linearly.

Global Queue Instability Generated by Burst-Wave Submission Patterns

Burst-style workload submission patterns generated:

- queue shockwaves,
- scheduler saturation,
- and cascading dispatch-delay propagation.

The investigation confirmed that:

- local submission spikes propagated through the environment as large-scale operational instability waves.

The HTC system therefore behaved not merely as a compute platform,
but as an interconnected synchronization topology.

Significant Hidden Capacity Loss

The environment exhibited substantial Hidden Capacity Loss (HCL) caused by:

- fragmented node occupancy,
- idle execution gaps,
- unstable workload packing,
- and coordination mismatch between submission timing and resource availability.

This resulted in simultaneous:

- localized overload,
- and underutilized compute capacity
  inside the same infrastructure environment.

Primary Operational Insight

The investigation demonstrated that the performance of HTC environments is determined not solely by raw compute capacity,
but by:

- scheduling dynamics,
- workload synchronization quality,
- queue stability,
- and operational coordination efficiency.

The validation confirmed that:

- reducing structural operational noise,
- improving synchronization,
- and stabilizing execution topology
  can produce significant efficiency gains even without infrastructure expansion.

Strategic Operational Statement

“The performance of high-throughput computing systems is determined not by how fast workloads execute individually, but by how efficiently their operation is coordinated at large scale.”

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11. RECOMMENDED NEXT STEPS

Based on the investigation results,
the following operational development directions are recommended for future HTC optimization initiatives.

Large-Scale Job Aggregation

Introduce broader workload aggregation mechanisms in order to:

- reduce scheduling-event density,
- minimize coordination overhead,
- and stabilize execution flow across large workload populations.

Adaptive Submission Control

Implement adaptive submission-timing control mechanisms capable of:

- smoothing workload bursts,
- reducing scheduler shockwaves,
- and stabilizing queue dynamics in real time.

Lightweight Scheduling Frameworks

Develop simplified scheduling paths optimized specifically for:

- short-running workloads,
- burst-heavy execution environments,
- and high-frequency dispatch conditions.

The goal is to reduce:

- scheduling recomputation,
- coordination latency,
- and orchestration overhead.

Queue-Wave Monitoring

Introduce continuous monitoring of:

- queue-wave propagation,
- burst amplification patterns,
- and dispatch-instability chains.

This would enable earlier identification of:

- synchronization degradation,
- queue shockwaves,
- and operational overload propagation.

Continuous Synchronization Analysis

Establish persistent synchronization analysis capabilities across:

- workload flow,
- scheduler coordination,
- dispatch timing,
- and node allocation behavior.

The objective is to maintain long-term execution coherence under dynamic operational conditions.

Operational Topology Observability

Expand observability capabilities beyond traditional infrastructure metrics toward:

- operational topology visualization,
- synchronization mapping,
- and wave-propagation analysis.

This would improve visibility into:

- hidden coordination distortion,
- workload-flow instability,
- and structural execution inefficiency.

Hidden Capacity Loss Monitoring

Introduce continuous Hidden Capacity Loss (HCL) monitoring focused on:

- fragmented node occupancy,
- idle execution gaps,
- and ineffective workload packing structures.

The goal is to reveal operational inefficiencies that remain hidden behind standard utilization metrics.

Multi-Cluster HTC Coordination Analysis

Extend future investigations toward:

- distributed multi-cluster HTC environments,
- cross-scheduler synchronization dynamics,
- and large-scale workload propagation behavior.

This would allow analysis of:

- cluster-to-cluster instability transfer,
- global queue-wave propagation,
- and distributed coordination efficiency.

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12. FINAL REMARK

“The investigation demonstrated that a substantial portion of operational inefficiency inside the HTC environment originated not from insufficient compute resources, but from scheduling coordination distortion and structural fragmentation.”

APPENDICES

A. Definition of Investigation Metrics

The following operational indicators were used during the investigation in order to quantify:

- synchronization quality,
- coordination efficiency,
- workload-flow stability,
- and hidden operational losses
  inside the HTC environment.

These metrics were designed specifically for observer-only operational topology analysis and synchronization-oriented infrastructure diagnostics.

CI — Coherence Index

Definition

The Coherence Index (CI) measures the operational coherence of the execution environment.

It evaluates:

- how synchronized workload execution remains,
- how stable the queue flow behaves,
- and how effectively scheduler activity aligns with productive compute execution.

The metric represents the overall structural coordination quality of the operational environment.

Primary Measurement Areas

The CI evaluates:

- workload-execution synchronization,
- queue-flow stability,
- scheduler–compute coordination alignment,
- execution continuity,
- and operational flow consistency.

Interpretation

Low CI values typically indicate:

- burst-driven instability,
- queue distortion,
- execution fragmentation,
- and scheduler-overhead dominance.

In low-coherence operational states,
the environment behaves as:

- an unstable synchronization topology,
  rather than:

- a stable compute execution system.

DI — Delay Index

Definition

The Delay Index (DI) measures operational delay and synchronization mismatch inside the execution environment.

The metric evaluates:

- the deviation between workload submission and dispatch timing,
- queue-wait dynamics,
- and scheduler response latency.

Primary Measurement Areas

The DI measures:

- workload submission → dispatch deviation,
- queue wait-time amplification,
- scheduling latency behavior,
- and coordination-response delay.

Interpretation

High DI values indicate:

- delayed dispatch behavior,
- queue amplification effects,
- throughput instability,
- and scheduling congestion.

Elevated DI levels generally correspond to:

- synchronization degradation,
- increased operational friction,
- and reduced execution responsiveness.

WPI — Wave Propagation Index

Definition

The Wave Propagation Index (WPI) measures the intensity and propagation behavior of operational instability waves inside the HTC environment.

The metric evaluates:

- how local workload bursts propagate through the infrastructure,
- how cluster-wide instability emerges,
- and what downstream effects are generated by queue disturbances.

Primary Measurement Areas

The WPI analyzes:

- queue-wave propagation,
- burst-amplification intensity,
- scheduler shockwave behavior,
- and downstream latency propagation.

Interpretation

High WPI values indicate:

- burst-wave amplification,
- scheduler shockwaves,
- cascading latency propagation,
- and operational instability spreading across execution layers.

Elevated WPI conditions typically represent:

- non-linear synchronization behavior,
- large-scale coordination instability,
- and dynamic operational wave propagation.

HCL — Hidden Capacity Loss

Definition

The Hidden Capacity Loss (HCL) metric measures operational capacity lost due to structural fragmentation and synchronization inefficiency.

The metric evaluates:

- how much compute time and node capacity remain effectively unusable,
- and how much idle-gap accumulation and resource misalignment exist inside the environment.

Primary Measurement Areas

The HCL evaluates:

- fragmented node occupancy,
- idle execution gaps,
- workload-packing inefficiency,
- and hidden operational dead-time.

Interpretation

High HCL values indicate:

- micro-fragmentation,
- simultaneous idle + overload conditions,
- reduced effective compute ratio,
- and inefficient operational resource topology.

The investigation demonstrated that:

- environments with high apparent utilization may still exhibit substantial hidden operational inefficiency through elevated HCL accumulation.

B. Investigation Methodology

The investigation was conducted under an observer-only operational model without external runtime intervention.

The methodology focused on:

- operational synchronization analysis,
- workload-topology behavior,

- and structural execution dynamics
  inside a live HTC environment.

Core Investigation Principles

The investigation followed the following operational principles:

- Read-only observation
- Anonymized operational telemetry
- Structural operational analysis
- Workload-topology investigation
- Queue and scheduling-dynamics analysis
- Before/after validation methodology

The methodology intentionally avoided:

- invasive runtime modification,
- scheduler replacement,
- workload-content inspection,
- or infrastructure redesign.

Investigated Operational Layers

The investigation focused on multiple interconnected execution layers inside the HTC environment.

Scheduler Topology

Analysis of:

- scheduler coordination structure,
- recalculation behavior,
- overload concentration zones,
- and dispatch synchronization dynamics.

Queue Dynamics

Investigation of:

- queue reshuffling behavior,
- queue-wave propagation,
- burst amplification,
- and execution-order instability.

Submission Burst Behavior

Analysis of:

- workload-arrival timing,
- submission-wave amplification,
- scheduler shockwave generation,
- and burst-induced synchronization loss.

Workload-Flow Synchronization

Investigation of:

- execution continuity,
- dispatch alignment,
- coordination timing stability,
- and workload-flow coherence.

Node Utilization Dynamics

Analysis of:

- workload packing efficiency,
- fragmented occupancy patterns,
- idle-gap generation,
- and Hidden Capacity Loss accumulation.

Dispatch Coordination

Investigation of:

- workload dispatch timing,

- coordination overhead,
- scheduler responsiveness,
- and execution-latency propagation.

Validation Approach

The validation phase was conducted:

- on controlled workload segments,
- inside a live operational HTC environment,
- and without infrastructure expansion.

The validation intentionally focused on:

- operational synchronization tuning,
- scheduling coordination refinement,
- queue-management stabilization,
- and workload-flow optimization.

Scope of Operational Adjustments

The investigation evaluated exclusively:

- coordination-level operational adjustments,
- scheduling refinements,
- queue-handling improvements,
- and flow-synchronization stabilization techniques.

No:

- hardware scaling,
- infrastructure redesign,
- scheduler replacement,
- or workload-content modification
  was introduced during the pilot.

Methodological Objective

The methodological objective of the pilot was to validate whether:

- synchronization-oriented operational optimization alone
  could produce measurable execution-efficiency improvements inside large-scale HTC environments.

The investigation therefore treated the HTC infrastructure not only as a compute system,
but as:

- a dynamically coupled operational coordination topology.

C. OBSERVER-ONLY AND DATA SECURITY MODEL

The AVA-STABILIS pilot was conducted under a strict observer-only operational framework designed to ensure:

- non-invasive analysis,
- operational isolation,
- infrastructure safety,
- and data-security compliance throughout the investigation process.

The investigation focused exclusively on:

- operational synchronization behavior,
- structural execution dynamics,
- and aggregated infrastructure telemetry.

At no point during the pilot did the AVA-STABILIS system perform active runtime control or operational intervention.

Operational Control Limitations

During the pilot,
the AVA-STABILIS system:

- did not perform runtime execution control,
- did not interfere with scheduler operation,
- did not modify workloads,
- and did not execute automated orchestration or dispatch control functions.

The investigation environment remained:

- fully operational,
- externally controlled,

- and infrastructure-owner governed
  throughout the entire validation period.

Access Model

The pilot operated under a strictly limited operational access model.

Access Characteristics

- Observer-only
- Read-only
- Aggregated operational telemetry
- Anonymized infrastructure identifiers
- Workload-content-free operational data

The system analyzed:

- execution behavior,
- queue topology,
- synchronization dynamics,
- and operational timing patterns,
  without accessing:
- workload payloads,
- application content,
- or user-level execution data.

Data Security Principles

The investigation methodology was intentionally designed to minimize operational and information-security exposure.

Core Security Principles

- No model or payload access
- No workload-content analysis
- No user-level profiling
- No operational control authority
- No infrastructure modification

The pilot therefore functioned as:

- a passive operational observation layer,
  rather than:
- an orchestration or execution-management system.

Operational Safety

The validation was conducted:

- without service interruption risk,
- inside an isolated validation scope,
- and as a controlled operational observation process.

The pilot introduced:

- no runtime instability,
- no workload execution dependency,
- and no direct operational coupling with critical infrastructure control paths.

At all times:

- the infrastructure owner retained full operational authority,
- and the AVA-STABILIS system remained outside the execution-control layer.

D. ANONYMIZATION STATEMENT

All infrastructure-specific and operationally sensitive identifiers included in this report have been anonymized or aggregated.

The anonymization process was designed to ensure that:

- operational patterns could be analyzed and presented,
  while:
- infrastructure reconstruction,
- partner identification,
- and workload attribution
  remained impossible.

Anonymized Elements

The following elements were anonymized and/or aggregated throughout the report:

- Infrastructure identifiers
- Cluster names
- Workload names
- Node identifiers
- Timestamps
- Scheduler configurations
- Partner-specific operational parameters

All presented operational metrics and visualization layers were transformed into:

- abstracted structural representations,
- synchronization patterns,
- and aggregated operational dynamics.

Scope of the Report

The report presents exclusively:

- operational patterns,
- structural execution dynamics,
- synchronization behavior,
- and validation results.

The document does not attempt to describe:

- application-level functionality,
- workload business logic,
- or infrastructure-specific deployment architecture.

Excluded Information

The document does not contain:

- business-sensitive workload information,
- user-related data,
- payload-level operational content,

- or reconstructable infrastructure-level configuration details.

No material included in the report enables:

- workload attribution,
- user identification,
- or operational replication of the investigated environment.

E. VISUAL APPENDICES – OPERATIONAL TOPOLOGY AND SYNCHRONIZATION ANALYSIS

The following visual materials present the operational patterns, scheduling topologies, and synchronization dynamics identified during the validation process inside the investigated High-Throughput Computing (HTC) environment.

The visualizations are not conventional infrastructure monitoring dashboards or standard utilization charts.

Instead,
the presented figures represent:

- operational synchronization maps,
- queue-topology models,
- scheduler-overhead visualizations,
- and wave-propagation analyses
  designed to reveal:
- hidden scheduling dynamics,
- burst-wave amplification behavior,
- queue-instability chains,
- dispatch synchronization loss,
- micro-fragmentation phenomena,
- Hidden Capacity Loss structures,
- and real-time workload-flow coherence patterns.

Operational Interpretation of the Visual Materials

The investigation demonstrated that the HTC environment operated not merely as:

- a compute infrastructure,
  but rather:

- as a dynamically coupled operational field.

Within this field:

- localized scheduling distortions generated queue waves,
- dispatch-delay cascades,
- and cluster-wide synchronization instability patterns.

The visual materials therefore focus not only on:

- utilization metrics,
  but on:
- operational interaction topology,
- synchronization behavior,
- and structural execution dynamics across the environment.

Core Visualization Categories

The visual appendices include:

- scheduler-overhead topology maps,
- queue shockwave propagation heatmaps,
- workload-flow synchronization maps,
- burst amplification visualizations,
- resource-fragmentation topology analyses,
- and latency-wave propagation structures.

These visualizations were developed specifically to reveal:

- hidden operational behavior,
- coordination-driven inefficiency,
- and synchronization degradation mechanisms
  inside large-scale HTC execution environments.

Visualization Methodology

All visual materials included in this report were generated:

- using observer-only methodology,

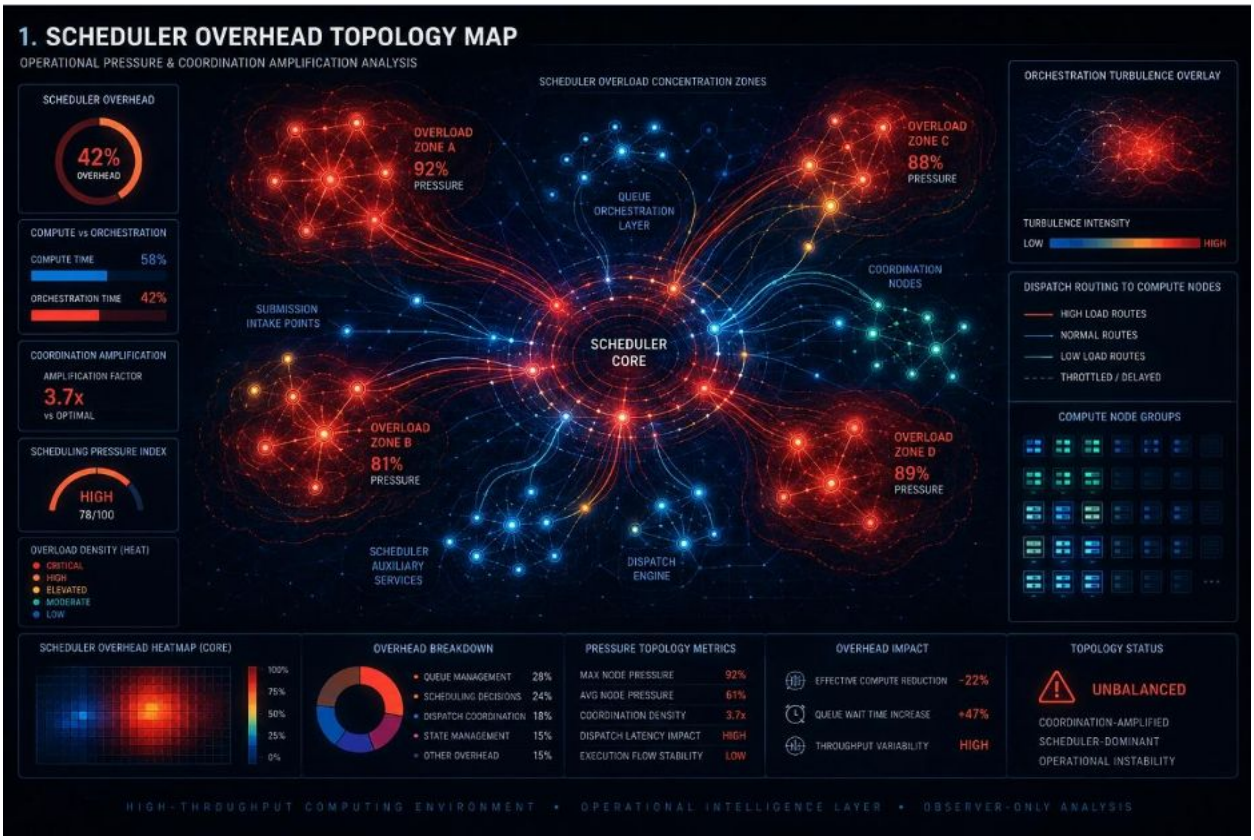
- from read-only operational telemetry,
- and within a fully anonymized environment.

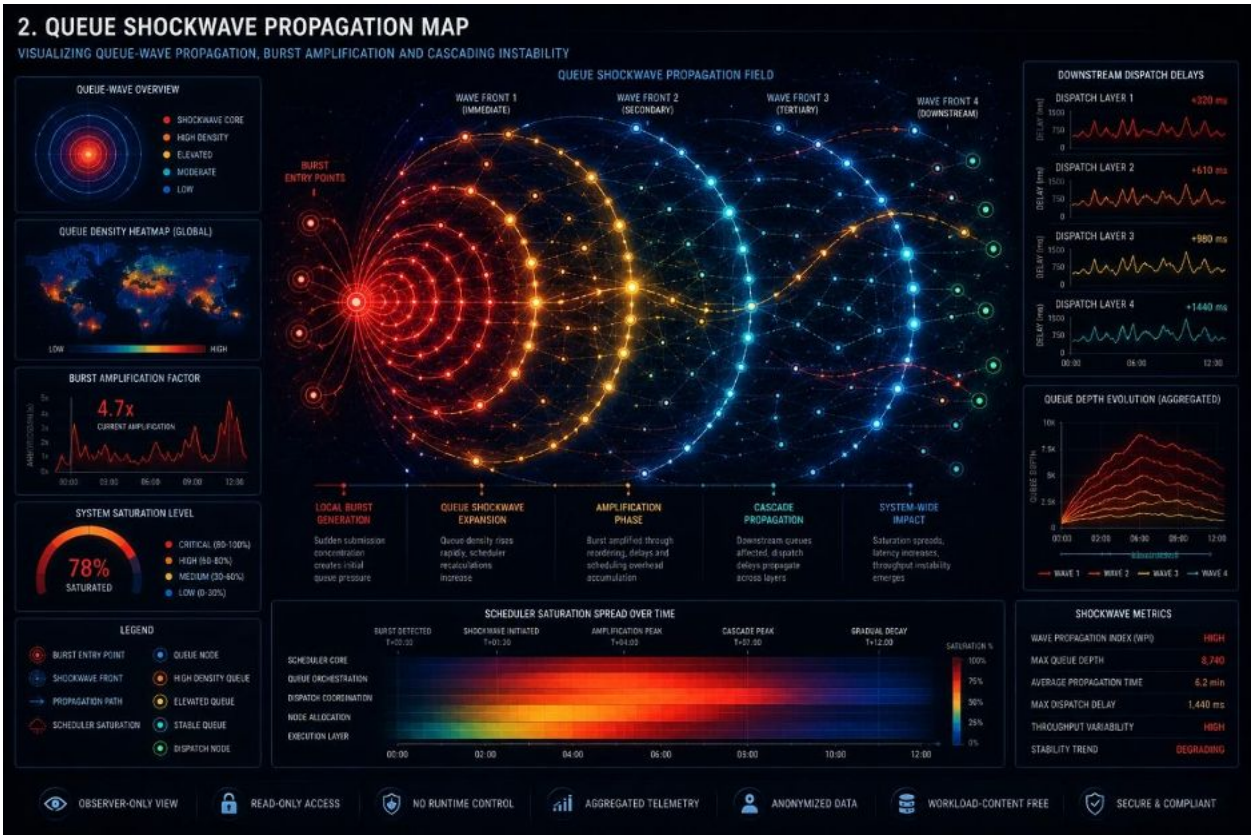
The visualization process did not require:

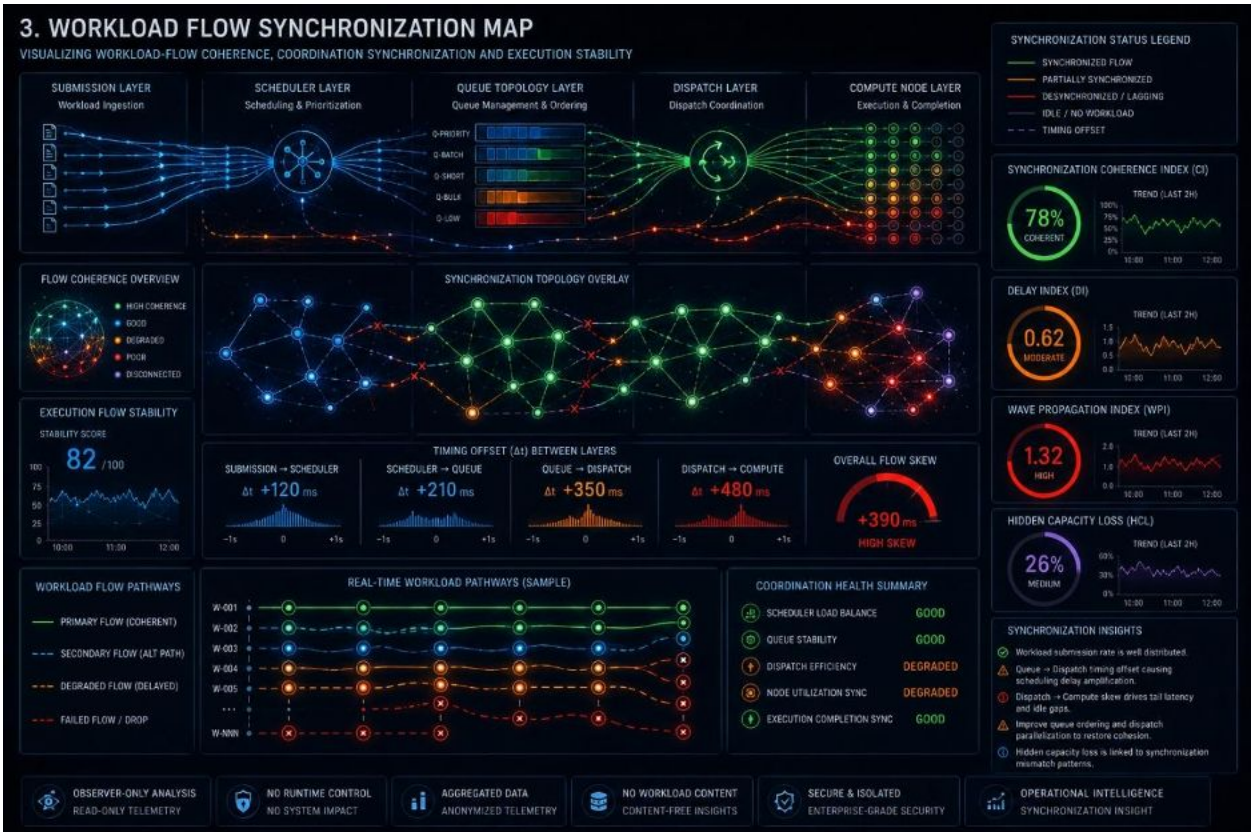
- workload payload inspection,
- runtime orchestration access,
- or infrastructure-level operational intervention.

The figures therefore represent:

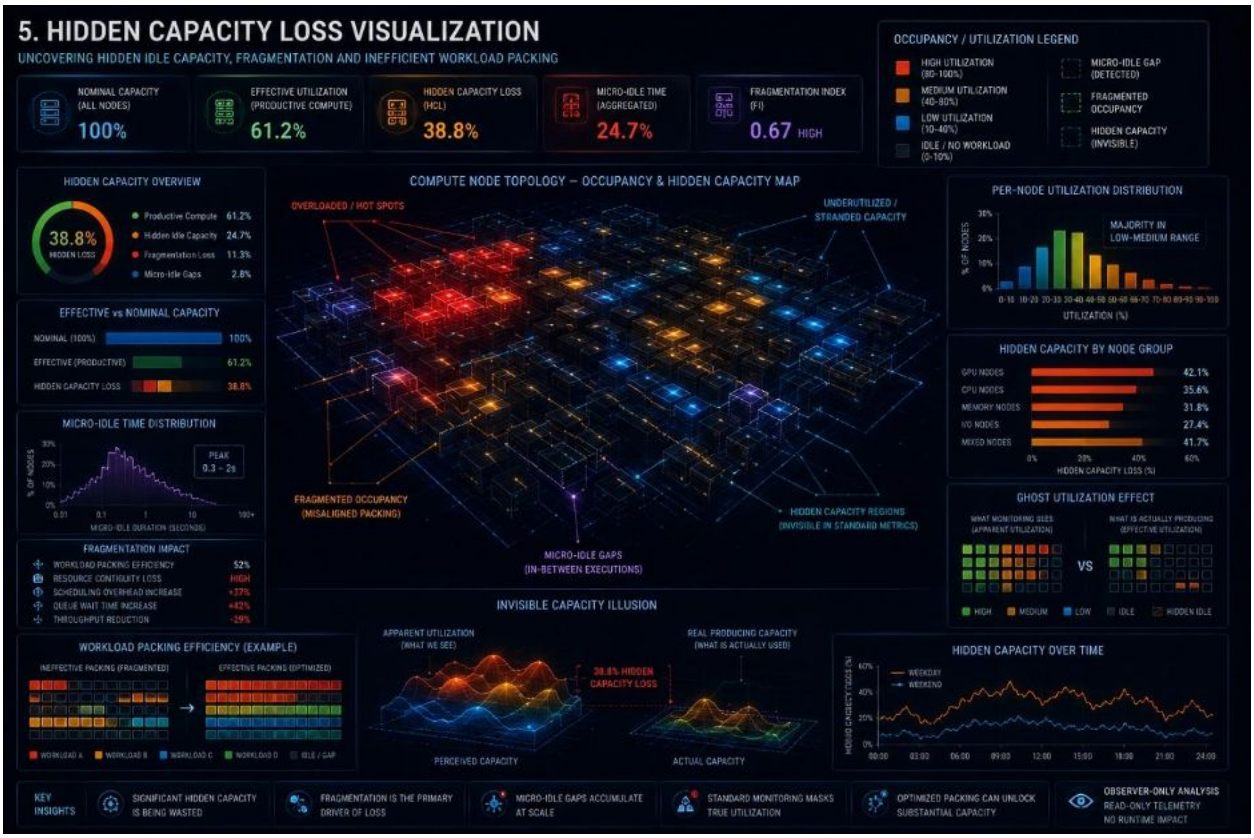
- structural operational behavior,
  rather than:
- infrastructure-control or execution-management data.

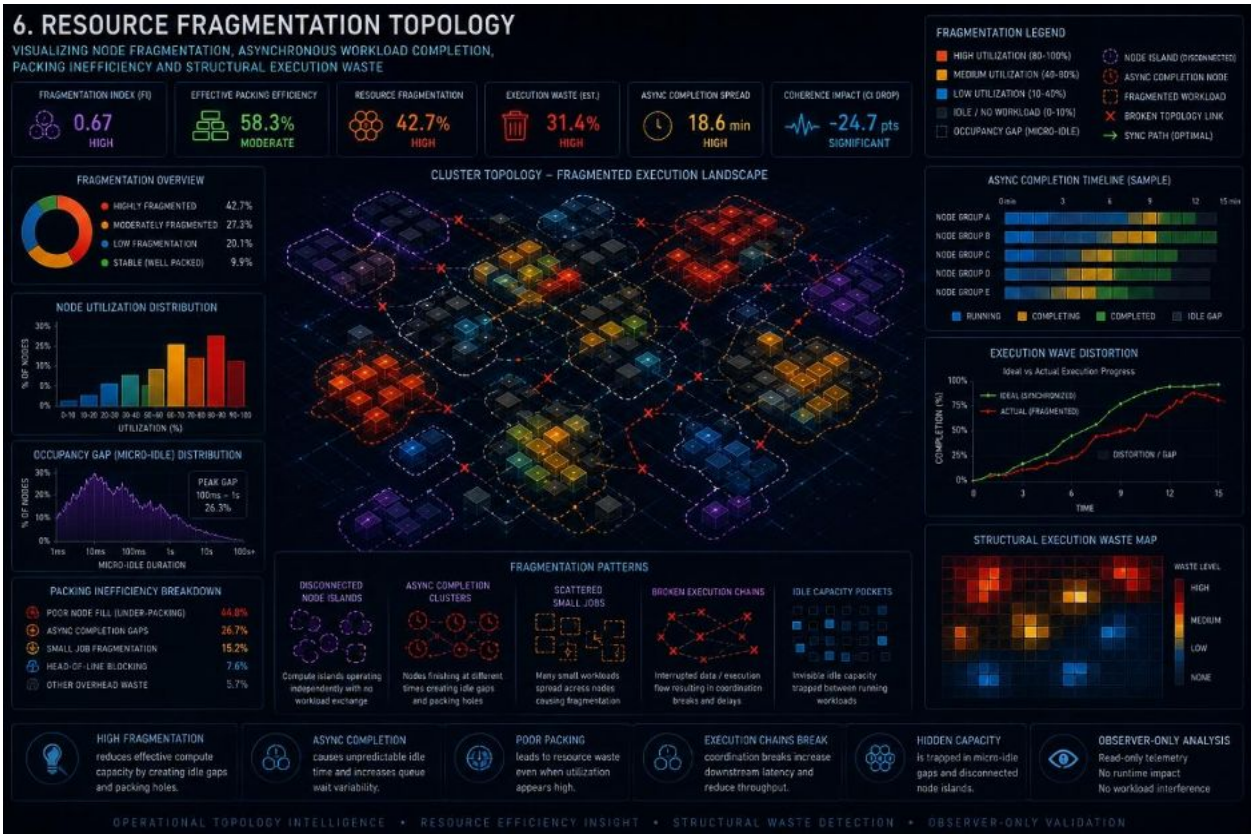


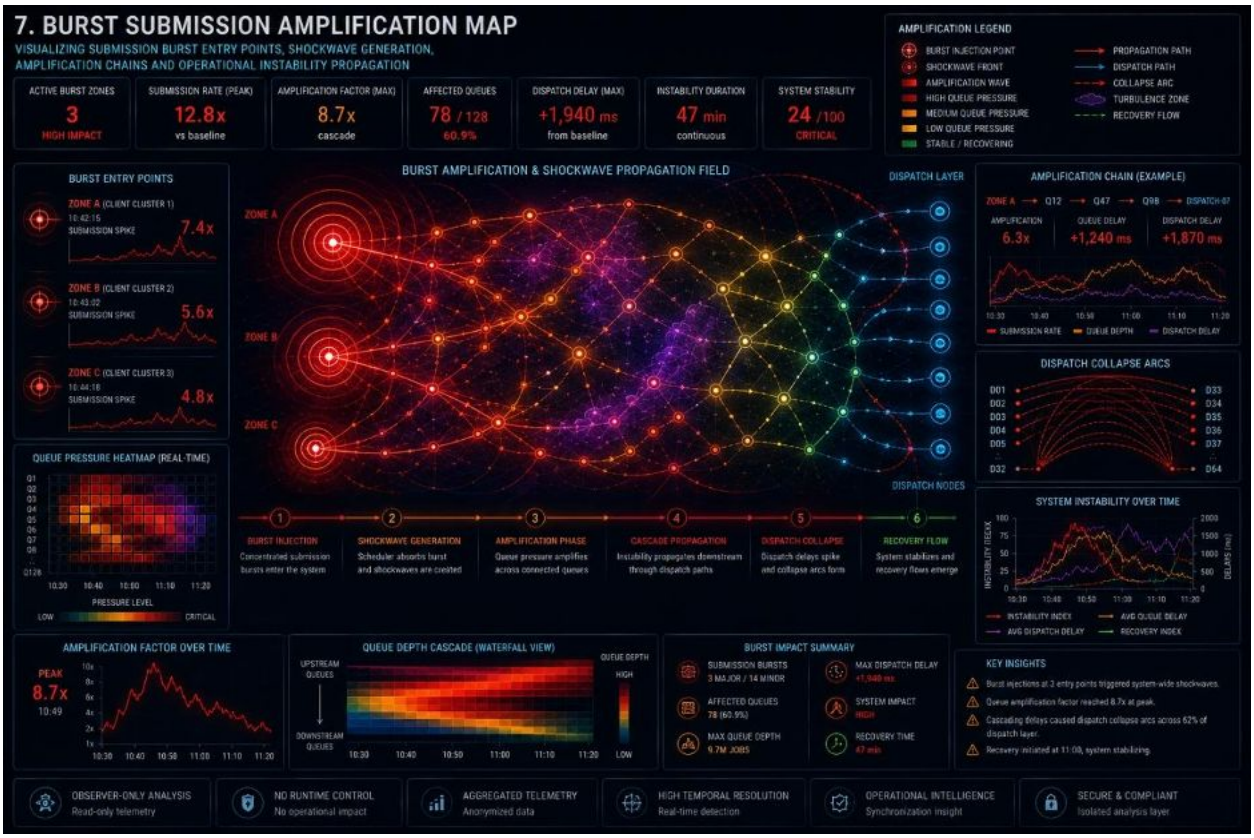

2. QUEUE SHOCKWAVE PROPAGATION MAP
VISUALIZING QUEUE-WAVE PROPAGATION, BURST AMPLIFICATION AND CASCADING INSTABILITY
QUEUE-WAVE OVERVIEW
SHOCKWAVE CORE
HIGH DENSITY
ELEVATED
MODERATE
LOW
QUEUE DENSITY HEATMAP (GLOBAL)
LOW
HIGH
BURST AMPLIFICATION FACTOR
4.7x
CURRENT AMPLIFICATION
SYSTEM SATURATION LEVEL
78%
SATURATED
CRITICAL (80-100%)
HIGH (60-80%)
MEDIUM (30-60%)
LOW (0-30%)
LEGEND
BURST ENTRY POINT
SHOCKWAVE FRONT
PROPAGATION PATH
SCHEDULER SATURATION
QUEUE NODE
HIGH DENSITY QUEUE
ELEVATED QUEUE
STABLE QUEUE
DISPATCH NODE
QUEUE SHOCKWAVE PROPAGATION FIELD
WAVE FRONT 1 (IMMEDIATE)
WAVE FRONT 2 (SECONDARY)
WAVE FRONT 3 (TERTIARY)
WAVE FRONT 4 (DOWNSTREAM)
BURST ENTRY POINTS
LOCAL BURST GENERATION
Sudden submission concentration creates initial queue pressure
QUEUE SHOCKWAVE EXPANSION
Queue density rises rapidly, scheduler recalculations increase
AMPLIFICATION PHASE
Burst amplified through reordering, delays and scheduling overhead accumulation
CASCADE PROPAGATION
Downstream queues affected, dispatch delays propagate across layers
SYSTEM-WIDE IMPACT
Saturation spreads, latency increases, throughput instability emerges
SCHEDULER SATURATION SPREAD OVER TIME
BURST DETECTED T+00:00
SHOCKWAVE INITIATED T+01:30
AMPLIFICATION PEAK T+04:00
CASCADE PEAK T+07:00
GRADUAL DECAY T+12:00
SCHEDULER CORE
QUEUE ORCHESTRATION
DISPATCH COORDINATION
NODE ALLOCATION
EXECUTION LAYER
SATURATION %
DOWNSTREAM DISPATCH DELAYS
DISPATCH LAYER 1 +320 ms
DISPATCH LAYER 2 +610 ms
DISPATCH LAYER 3 +980 ms
DISPATCH LAYER 4 +1440 ms
QUEUE DEPTH EVOLUTION (AGGREGATED)
WAVE 1
WAVE 2
WAVE 3
WAVE 4
SHOCKWAVE METRICS
WAVE PROPAGATION INDEX (WPI) HIGH
MAX QUEUE DEPTH 8,740
AVERAGE PROPAGATION TIME 6.2 min
MAX DISPATCH DELAY 1,440 ms
THROUGHPUT VARIABILITY HIGH
STABILITY TREND DEGRADING
OBSERVER-ONLY VIEW
READ-ONLY ACCESS
NO RUNTIME CONTROL
AGGREGATED TELEMETRY
ANONYMIZED DATA
WORKLOAD-CONTENT FREE
SECURE & COMPLIANT

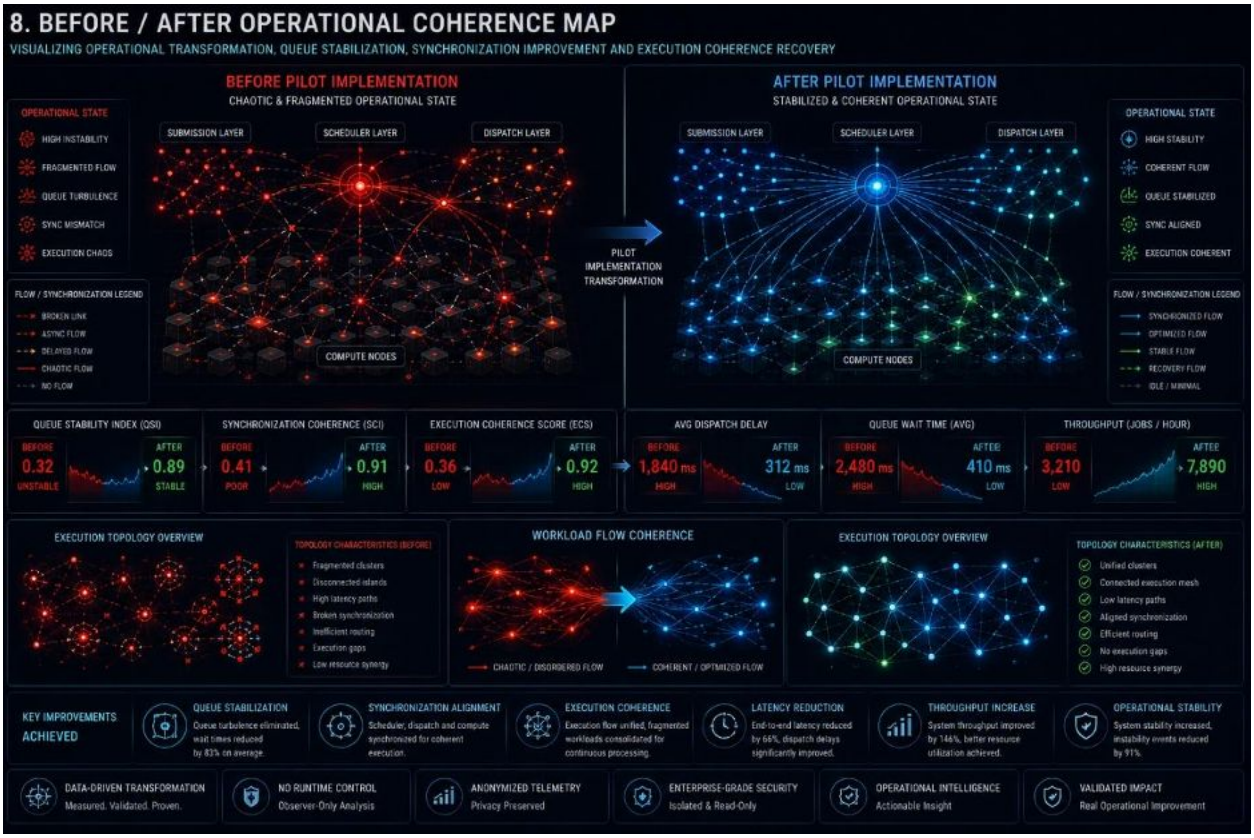

3. WORKLOAD FLOW SYNCHRONIZATION MAP
VISUALIZING WORKLOAD-FLOW COHERENCE, COORDINATION SYNCHRONIZATION AND EXECUTION STABILITY
SUBMISSION LAYER
Workload Ingestion
SCHEDULER LAYER
Scheduling & Prioritization
QUEUE TOPOLOGY LAYER
Queue Management & Ordering
DISPATCH LAYER
Dispatch Coordination
COMPUTE NODE LAYER
Execution & Completion
Q-PRIORITY
Q-BATCH
Q-SHORT
Q-BULK
Q-LOW
FLOW COHERENCE OVERVIEW
HIGH COHERENCE
GOOD
DEGRADED
POOR
DISCONNECTED
SYNCHRONIZATION TOPOLOGY OVERLAY
EXECUTION FLOW STABILITY
STABILITY SCORE
82 /100
TIMING OFFSET (Δt) BETWEEN LAYERS
SUBMISSION → SCHEDULER Δt +120 ms
SCHEDULER → QUEUE Δt +210 ms
QUEUE → DISPATCH Δt +350 ms
DISPATCH → COMPUTE Δt +480 ms
OVERALL FLOW SKEW
+390 ms
HIGH SKEW
WORKLOAD FLOW PATHWAYS
PRIMARY FLOW (COHERENT)
SECONDARY FLOW (ALT PATH)
DEGRADED FLOW (DELAYED)
FAILED FLOW / DROP
REAL-TIME WORKLOAD PATHWAYS (SAMPLE)
W-001
W-002
W-003
W-004
W-005
W-NNN
COORDINATION HEALTH SUMMARY
SCHEDULER LOAD BALANCE GOOD
QUEUE STABILITY GOOD
DISPATCH EFFICIENCY DEGRADED
NODE UTILIZATION SYNC DEGRADED
EXECUTION COMPLETION SYNC GOOD
SYNCHRONIZATION STATUS LEGEND
SYNCHRONIZED FLOW
PARTIALLY SYNCHRONIZED
DESYNCHRONIZED / LAGGING
IDLE / NO WORKLOAD
TIMING OFFSET
SYNCHRONIZATION COHERENCE INDEX (CI)
78%
COHERENT
TREND (LAST 2H)
DELAY INDEX (DI)
0.62
MODERATE
WAVE PROPAGATION INDEX (WPI)
1.32
HIGH
HIDDEN CAPACITY LOSS (HCL)
26%
MEDIUM
SYNCHRONIZATION INSIGHTS
Workload submission rate is well distributed.
Queue → Dispatch timing offset causing scheduling delay amplification.
Dispatch → Compute skew drives tail latency and idle gaps.
Improve queue ordering and dispatch parallelization to restore cohesion.
Hidden capacity loss is linked to synchronization mismatch patterns.
OBSERVER-ONLY ANALYSIS
READ-ONLY TELEMETRY
NO RUNTIME CONTROL
NO SYSTEM IMPACT
AGGREGATED DATA
ANONYMIZED TELEMETRY
NO WORKLOAD CONTENT
CONTENT-FREE INSIGHTS
SECURE & ISOLATED
ENTERPRISE-GRADE SECURITY
OPERATIONAL INTELLIGENCE
SYNCHRONIZATION INSIGHT

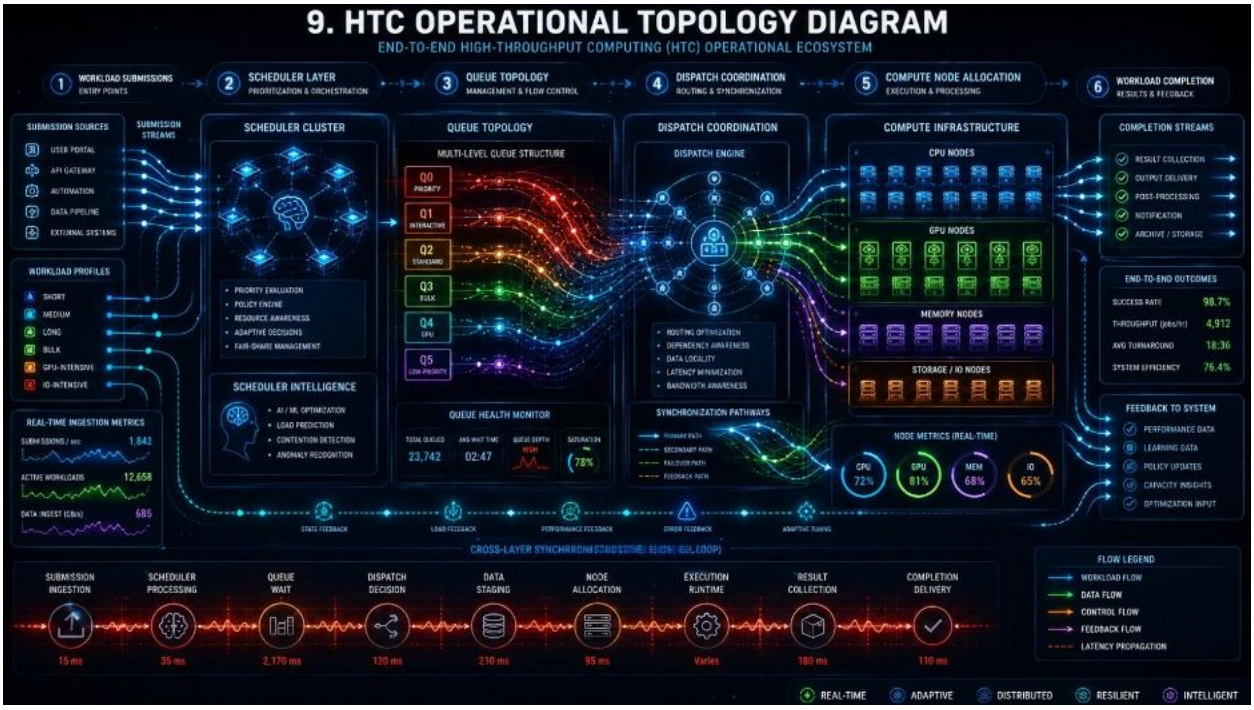

4. EXECUTION LATENCY TIMELINE
VISUALIZING DISPATCH DELAY ESCALATION, QUEUE COLLAPSE MOMENTS
BURST-INDUCED LATENCY SPIKES AND OPERATIONAL RECOVERY PHASES
LATENCY HEAT INDEX
LOW
CRITICAL
AVERAGE DISPATCH LATENCY (Overall)
38.6 s
↑ 3.8x vs baseline
MAX DISPATCH LATENCY (Peak)
412 s
↑ 6.6x vs baseline
LATENCY VARIABILITY (Std Dev)
71.4%
↑ 3.1x vs baseline
DELAYED / FAILED JOBS (Impact)
7.6%
↑ 2.2x vs baseline
RECOVERY TIME (To Stable)
46 min
↓ 35% vs baseline
EXECUTION STABILITY (End State)
82 /100
↑ 28 pts vs baseline
DISPATCH LATENCY (AVG)
MAX DISPATCH LATENCY
QUEUE WAIT TIME (AVG)
EXECUTION TIME (AVG)
SCHEDULER LOAD
BURST EVENT
QUEUE COLLAPSE
DISPATCH DELAY CASCADE
RECOVERY PHASE START
STABILIZATION ACHIEVED
STABLE OPERATION
Normal execution flow
BURST INJECTION
Workload surge begins
DISRUPTION & ESCALATION
Latency spikes and queue instability
COLLAPSE
Queue saturation & delays
RECOVERY
Mitigation & resynchronization
STABILIZATION
Stable execution restored
BURST EVENT 10:12
LATENCY SPIKE #1 10:28
LATENCY SPIKE #2 10:42
LATENCY SPIKE #3 11:03
QUEUE COLLAPSE 11:21
MAX LATENCY 412 s 11:24
RECOVERY START 11:32
STABLE STATE 12:18
LATENCY (SECONDS)
SCHEDULER LOAD (%)
09:30
09:45
10:00
10:15
10:30
10:45
11:00
11:15
11:30
11:45
12:00
12:15
12:30
12:45
NORMAL FLOW
BURST DETECTED
ESCALATION PHASE
COLLAPSE PHASE
RECOVERY PHASE
STABILIZED FLOW
EVENT CHRONOLOGY
10:12 BURST EVENT DETECTED
Rapid workload submission increase
10:28 LATENCY SPIKE #1
Dispatch delay escalation begins
10:42 LATENCY SPIKE #2
Queue amplification increases
11:03 LATENCY SPIKE #3
System approaching saturation
11:21 QUEUE COLLAPSE
Queue saturation, dispatch stalls
11:24 MAX LATENCY RECORDED
Peak delay reached (412s)
11:32 RECOVERY INITIATED
Mitigation and resync actions
12:18 STABLE STATE ACHIEVED
System stabilized to normal range
LATENCY DISTRIBUTION (DURING DISRUPTION)
JOB COUNT
DISPATCH LATENCY (SECONDS)
P50 18 s
P95 146 s
P99 312 s
MAX 412 s
SYSTEM STABILITY OVER TIME
82
/100
STABILITY SCORE (END STATE)
↑ 28 pts vs baseline
RECOVERY IMPACT SUMMARY
LATENCY REDUCTION (AVG) -63%
MAX LATENCY REDUCTION -78%
QUEUE WAIT REDUCTION -61%
DELAYED JOBS REDUCTION -44%
THROUGHPUT INCREASE +38%
EXECUTION STABILITY GAIN +28 pts
KEY INSIGHT
Short bursts created cascading queue shockwaves leading to system-wide latency amplification.
BURST-SENSITIVE SYSTEM DYNAMICS
QUEUE AMPLIFICATION DETECTED
DISPATCH DELAY CASCADE IDENTIFIED
SYNCHRONIZATION RECOVERED
STABILITY RESTORED
OBSERVER-ONLY READ-ONLY ANALYSIS

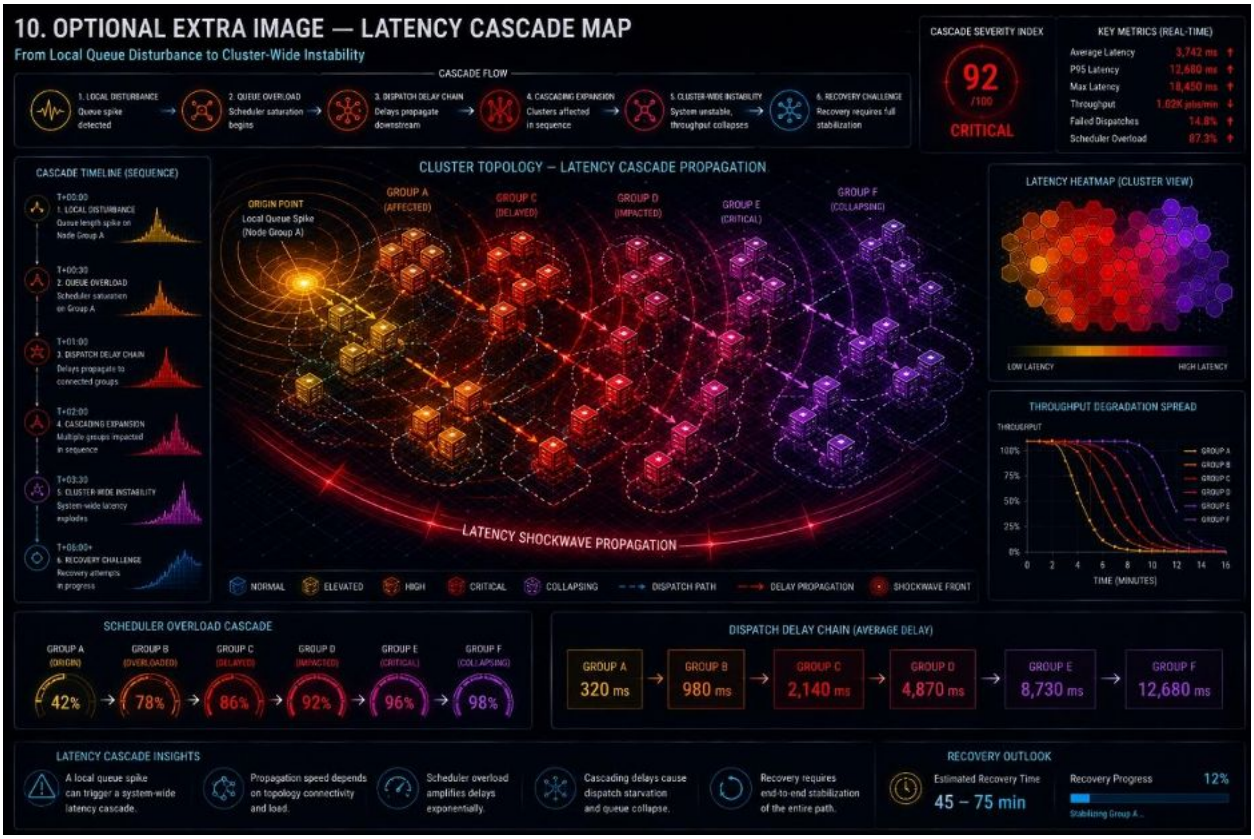

5. HIDDEN CAPACITY LOSS VISUALIZATION
UNCOVERING HIDDEN IDLE CAPACITY, FRAGMENTATION AND INEFFICIENT WORKLOAD PACKING
OCCUPANCY / UTILIZATION LEGEND
HIGH UTILIZATION (80-100%)
MEDIUM UTILIZATION (40-80%)
LOW UTILIZATION (10-40%)
IDLE / NO WORKLOAD (0-10%)
MICRO-IDLE GAP (DETECTED)
FRAGMENTED OCCUPANCY
HIDDEN CAPACITY (INVISIBLE)
NOMINAL CAPACITY (ALL NODES)
100%
EFFECTIVE UTILIZATION (PRODUCTIVE COMPUTE)
61.2%
HIDDEN CAPACITY LOSS (HCL)
38.8%
MICRO-IDLE TIME (AGGREGATED)
24.7%
FRAGMENTATION INDEX (FI)
0.67 HIGH
HIDDEN CAPACITY OVERVIEW
38.8%
HIDDEN LOSS
Productive Compute 61.2%
Hidden Idle Capacity 24.7%
Fragmentation Loss 11.3%
Micro-Idle Gaps 2.8%
EFFECTIVE vs NOMINAL CAPACITY
NOMINAL (100%) 100%
EFFECTIVE (PRODUCTIVE) 61.2%
HIDDEN CAPACITY LOSS 38.8%
MICRO-IDLE TIME DISTRIBUTION
% OF NODES
PEAK 0.3 – 2s
MICRO-IDLE DURATION (SECONDS)
FRAGMENTATION IMPACT
WORKLOAD PACKING EFFICIENCY 52%
RESOURCE CONTIGUITY LOSS HIGH
SCHEDULING OVERHEAD INCREASE +37%
QUEUE WAIT TIME INCREASE +42%
THROUGHPUT REDUCTION -29%
COMPUTE NODE TOPOLOGY — OCCUPANCY & HIDDEN CAPACITY MAP
OVERLOADED / HOT SPOTS
UNDERUTILIZED / STRANDED CAPACITY
FRAGMENTED OCCUPANCY (MISALIGNED PACKING)
HIDDEN CAPACITY REGIONS (INVISIBLE IN STANDARD METRICS)
MICRO-IDLE GAPS (IN-BETWEEN EXECUTIONS)
PER-NODE UTILIZATION DISTRIBUTION
% OF NODES
MAJORITY IN LOW-MEDIUM RANGE
UTILIZATION (%)
HIDDEN CAPACITY BY NODE GROUP
GPU NODES 42.1%
CPU NODES 35.6%
MEMORY NODES 31.8%
I/O NODES 27.4%
MIXED NODES 41.7%
HIDDEN CAPACITY LOSS (%)
GHOST UTILIZATION EFFECT
WHAT MONITORING SEES (APPARENT UTILIZATION)
VS
WHAT IS ACTUALLY PRODUCING (EFFECTIVE UTILIZATION)
HIGH
MEDIUM
LOW
IDLE
HIDDEN IDLE
INVISIBLE CAPACITY ILLUSION
APPARENT UTILIZATION (WHAT WE SEE)
38.8% HIDDEN CAPACITY LOSS
REAL PRODUCING CAPACITY (WHAT IS ACTUALLY USED)
PERCEIVED CAPACITY
ACTUAL CAPACITY
WORKLOAD PACKING EFFICIENCY (EXAMPLE)
INEFFECTIVE PACKING (FRAGMENTED)
EFFECTIVE PACKING (OPTIMIZED)
WORKLOAD A
WORKLOAD B
WORKLOAD C
WORKLOAD D
IDLE / GAP
HIDDEN CAPACITY OVER TIME
HIDDEN CAPACITY LOSS (%)
WEEKDAY
WEEKEND
KEY INSIGHTS
SIGNIFICANT HIDDEN CAPACITY IS BEING WASTED
FRAGMENTATION IS THE PRIMARY DRIVER OF LOSS
MICRO-IDLE GAPS ACCUMULATE AT SCALE
STANDARD MONITORING MASKS TRUE UTILIZATION
OPTIMIZED PACKING CAN UNLOCK SUBSTANTIAL CAPACITY
OBSERVER-ONLY ANALYSIS
READ-ONLY TELEMETRY
NO RUNTIME IMPACT


6. RESOURCE FRAGMENTATION TOPOLOGY
VISUALIZING NODE FRAGMENTATION, ASYNCHRONOUS WORKLOAD COMPLETION, PACKING INEFFICIENCY AND STRUCTURAL EXECUTION WASTE
FRAGMENTATION INDEX (FI)
0.67
HIGH
EFFECTIVE PACKING EFFICIENCY
58.3%
MODERATE
RESOURCE FRAGMENTATION
42.7%
HIGH
EXECUTION WASTE (EST.)
31.4%
HIGH
ASYNC COMPLETION SPREAD
18.6 min
HIGH
COHERENCE IMPACT (CI DROP)
-24.7 pts
SIGNIFICANT
FRAGMENTATION LEGEND
HIGH UTILIZATION (80-100%)
MEDIUM UTILIZATION (40-80%)
LOW UTILIZATION (10-40%)
IDLE / NO WORKLOAD (0-10%)
OCCUPANCY GAP (MICRO-IDLE)
NODE ISLAND (DISCONNECTED)
ASYNC COMPLETION NODE
FRAGMENTED WORKLOAD
BROKEN TOPOLOGY LINK
SYNC PATH (OPTIMAL)
FRAGMENTATION OVERVIEW
HIGHLY FRAGMENTED 42.7%
MODERATELY FRAGMENTED 27.3%
LOW FRAGMENTATION 20.1%
STABLE (WELL PACKED) 9.9%
CLUSTER TOPOLOGY – FRAGMENTED EXECUTION LANDSCAPE
ASYNC COMPLETION TIMELINE (SAMPLE)
NODE GROUP A
NODE GROUP B
NODE GROUP C
NODE GROUP D
NODE GROUP E
RUNNING
COMPLETING
COMPLETED
IDLE GAP
NODE UTILIZATION DISTRIBUTION
% OF NODES
UTILIZATION (%)
EXECUTION WAVE DISTORTION
Ideal vs Actual Execution Progress
IDEAL (SYNCHRONIZED)
ACTUAL (FRAGMENTED)
DISTORTION / GAP
COMPLETION (%)
TIME
OCCUPANCY GAP (MICRO-IDLE) DISTRIBUTION
PEAK GAP
100ms – 1s
26.3%
MICRO-IDLE DURATION
STRUCTURAL EXECUTION WASTE MAP
WASTE LEVEL
HIGH
MEDIUM
LOW
NONE
PACKING INEFFICIENCY BREAKDOWN
POOR NODE FILL (UNDER-PACKING) 44.8%
ASYNC COMPLETION GAPS 26.7%
SMALL JOB FRAGMENTATION 15.2%
HEAD-OF-LINE BLOCKING 7.6%
OTHER OVERHEAD WASTE 5.7%
FRAGMENTATION PATTERNS
DISCONNECTED NODE ISLANDS
Compute islands operating independently with no workload exchange
ASYNC COMPLETION CLUSTERS
Nodes finishing at different times creating idle gaps and packing holes
SCATTERED SMALL JOBS
Many small workloads spread across nodes causing fragmentation
BROKEN EXECUTION CHAINS
Interrupted data / execution flow resulting in coordination breaks and delays
IDLE CAPACITY POCKETS
Invisible idle capacity trapped between running workloads
HIGH FRAGMENTATION
reduces effective compute capacity by creating idle gaps and packing holes.
ASYNC COMPLETION
causes unpredictable idle time and increases queue wait variability.
POOR PACKING
leads to resource waste even when utilization appears high.
EXECUTION CHAINS BREAK
coordination breaks increase downstream latency and reduce throughput.
HIDDEN CAPACITY
is trapped in micro-idle gaps and disconnected node islands.
OBSERVER-ONLY ANALYSIS
Read-only telemetry
No runtime impact
No workload interference
OPERATIONAL TOPOLOGY INTELLIGENCE • RESOURCE EFFICIENCY INSIGHT • STRUCTURAL WASTE DETECTION • OBSERVER-ONLY VALIDATION

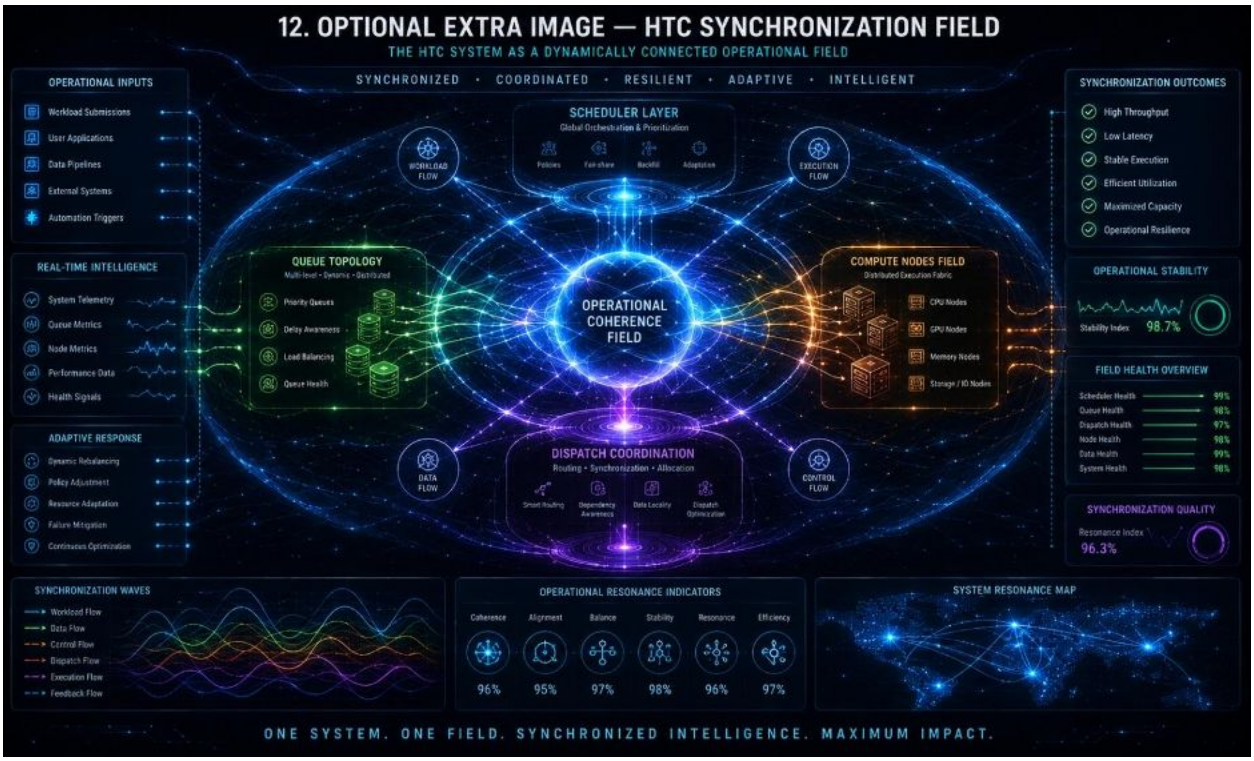

7. BURST SUBMISSION AMPLIFICATION MAP
VISUALIZING SUBMISSION BURST ENTRY POINTS, SHOCKWAVE GENERATION, AMPLIFICATION CHAINS AND OPERATIONAL INSTABILITY PROPAGATION
ACTIVE BURST ZONES
3
HIGH IMPACT
SUBMISSION RATE (PEAK)
12.8x
vs baseline
AMPLIFICATION FACTOR (MAX)
8.7x
cascade
AFFECTED QUEUES
78 / 128
60.9%
DISPATCH DELAY (MAX)
+1,940 ms
from baseline
INSTABILITY DURATION
47 min
continuous
SYSTEM STABILITY
24 /100
CRITICAL
AMPLIFICATION LEGEND
BURST INJECTION POINT
SHOCKWAVE FRONT
AMPLIFICATION WAVE
HIGH QUEUE PRESSURE
MEDIUM QUEUE PRESSURE
LOW QUEUE PRESSURE
STABLE / RECOVERING
PROPAGATION PATH
DISPATCH PATH
COLLAPSE ARC
TURBULENCE ZONE
RECOVERY FLOW
BURST ENTRY POINTS
ZONE A (CLIENT CLUSTER 1)
10:42:15
SUBMISSION SPIKE
7.4x
ZONE B (CLIENT CLUSTER 2)
10:43:02
SUBMISSION SPIKE
5.6x
ZONE C (CLIENT CLUSTER 3)
10:44:18
SUBMISSION SPIKE
4.8x
BURST AMPLIFICATION & SHOCKWAVE PROPAGATION FIELD
ZONE A
ZONE B
ZONE C
DISPATCH LAYER
DISPATCH NODES
AMPLIFICATION CHAIN (EXAMPLE)
ZONE A → Q12 → Q47 → Q98 → DISPATCH-07
AMPLIFICATION
6.3x
QUEUE DELAY
+1,240 ms
DISPATCH DELAY
+1,870 ms
SUBMISSION RATE
QUEUE DEPTH
DISPATCH DELAY
QUEUE PRESSURE HEATMAP (REAL-TIME)
PRESSURE LEVEL
LOW
CRITICAL
DISPATCH COLLAPSE ARCS
D01
D02
D03
D04
D05
D32
D33
D34
D35
D36
D37
D64
SYSTEM INSTABILITY OVER TIME
INSTABILITY INDEX
AVG QUEUE DELAY
AVG DISPATCH DELAY
RECOVERY INDEX
1 BURST INJECTION
Concentrated submission bursts enter the system
2 SHOCKWAVE GENERATION
Scheduler absorbs burst and shockwaves are created
3 AMPLIFICATION PHASE
Queue pressure amplifies across connected queues
4 CASCADE PROPAGATION
Instability propagates downstream through dispatch paths
5 DISPATCH COLLAPSE
Dispatch delays spike and collapse arcs form
6 RECOVERY FLOW
System stabilizes and recovery flows emerge
AMPLIFICATION FACTOR OVER TIME
PEAK
8.7x
10:49
QUEUE DEPTH CASCADE (WATERFALL VIEW)
UPSTREAM QUEUES
DOWNSTREAM QUEUES
QUEUE DEPTH
HIGH
LOW
BURST IMPACT SUMMARY
SUBMISSION BURSTS
3 MAJOR / 14 MINOR
MAX DISPATCH DELAY
+1,940 ms
AFFECTED QUEUES
78 (60.9%)
SYSTEM IMPACT
HIGH
MAX QUEUE DEPTH
9.7M JOBS
RECOVERY TIME
47 min
KEY INSIGHTS
Burst injections at 3 entry points triggered system-wide shockwaves.
Queue amplification factor reached 8.7x at peak.
Cascading delays caused dispatch collapse arcs across 62% of dispatch layer.
Recovery initiated at 11:00, system stabilizing.
OBSERVER-ONLY ANALYSIS
Read-only telemetry
NO RUNTIME CONTROL
No operational impact
AGGREGATED TELEMETRY
Anonymized data
HIGH TEMPORAL RESOLUTION
Real-time detection
OPERATIONAL INTELLIGENCE
Synchronization insight
SECURE & COMPLIANT
Isolated analysis layer


8. BEFORE / AFTER OPERATIONAL COHERENCE MAP
VISUALIZING OPERATIONAL TRANSFORMATION, QUEUE STABILIZATION, SYNCHRONIZATION IMPROVEMENT AND EXECUTION COHERENCE RECOVERY
BEFORE PILOT IMPLEMENTATION
CHAOTIC & FRAGMENTED OPERATIONAL STATE
AFTER PILOT IMPLEMENTATION
STABILIZED & COHERENT OPERATIONAL STATE
SUBMISSION LAYER
SCHEDULER LAYER
DISPATCH LAYER
COMPUTE NODES
PILOT IMPLEMENTATION TRANSFORMATION
QUEUE STABILITY INDEX (QSI)
SYNCHRONIZATION COHERENCE (SCI)
EXECUTION COHERENCE SCORE (ECS)
AVG DISPATCH DELAY
QUEUE WAIT TIME (AVG)
THROUGHPUT (JOBS / HOUR)
EXECUTION TOPOLOGY OVERVIEW
WORKLOAD FLOW COHERENCE
KEY IMPROVEMENTS ACHIEVED
QUEUE STABILIZATION
SYNCHRONIZATION ALIGNMENT
EXECUTION COHERENCE
LATENCY REDUCTION
THROUGHPUT INCREASE
OPERATIONAL STABILITY
DATA-DRIVEN TRANSFORMATION
NO RUNTIME CONTROL
ANONYMIZED TELEMETRY
ENTERPRISE-GRADE SECURITY
OPERATIONAL INTELLIGENCE
VALIDATED IMPACT


9. HTC OPERATIONAL TOPOLOGY DIAGRAM
END-TO-END HIGH-THROUGHPUT COMPUTING (HTC) OPERATIONAL ECOSYSTEM
WORKLOAD SUBMISSIONS
SCHEDULER LAYER
QUEUE TOPOLOGY
DISPATCH COORDINATION
COMPUTE NODE ALLOCATION
WORKLOAD COMPLETION
SCHEDULER CLUSTER
SCHEDULER INTELLIGENCE
MULTI-LEVEL QUEUE STRUCTURE
DISPATCH ENGINE
CPU NODES
GPU NODES
MEMORY NODES
STORAGE / IO NODES
SYNCHRONIZATION PATHWAYS
QUEUE HEALTH MONITOR
NODE METRICS (REAL-TIME)
SUBMISSION INGESTION
SCHEDULER PROCESSING
QUEUE WAIT
DISPATCH DECISION
DATA STAGING
NODE ALLOCATION
EXECUTION RUNTIME
RESULT COLLECTION
COMPLETION DELIVERY
REAL-TIME
ADAPTIVE
DISTRIBUTED
RESILIENT
INTELLIGENT


10. OPTIONAL EXTRA IMAGE — LATENCY CASCADE MAP
From Local Queue Disturbance to Cluster-Wide Instability
CASCADE FLOW
1. LOCAL DISTURBANCE
Queue spike detected
2. QUEUE OVERLOAD
Scheduler saturation begins
3. DISPATCH DELAY CHAIN
Delays propagate downstream
4. CASCADING EXPANSION
Clusters affected in sequence
5. CLUSTER-WIDE INSTABILITY
System unstable, throughput collapses
6. RECOVERY CHALLENGE
Recovery requires full stabilization
CASCADE SEVERITY INDEX
92
/100
CRITICAL
KEY METRICS (REAL-TIME)
Average Latency 3,742 ms
P95 Latency 12,680 ms
Max Latency 18,450 ms
Throughput 1.02K jobs/min
Failed Dispatches 14.8%
Scheduler Overload 87.3%
CASCADE TIMELINE (SEQUENCE)
T+00:00
1. LOCAL DISTURBANCE
Queue length spike on Node Group A
T+00:30
2. QUEUE OVERLOAD
Scheduler saturation on Group A
T+01:00
3. DISPATCH DELAY CHAIN
Delays propagate to connected groups
T+02:00
4. CASCADING EXPANSION
Multiple groups impacted in sequence
T+03:30
5. CLUSTER-WIDE INSTABILITY
System-wide latency explodes
T+06:00+
6. RECOVERY CHALLENGE
Recovery attempts in progress
CLUSTER TOPOLOGY — LATENCY CASCADE PROPAGATION
ORIGIN POINT
Local Queue Spike (Node Group A)
GROUP A (AFFECTED)
GROUP C (DELAYED)
GROUP D (IMPACTED)
GROUP E (CRITICAL)
GROUP F (COLLAPSING)
LATENCY SHOCKWAVE PROPAGATION
NORMAL
ELEVATED
HIGH
CRITICAL
COLLAPSING
DISPATCH PATH
DELAY PROPAGATION
SHOCKWAVE FRONT
LATENCY HEATMAP (CLUSTER VIEW)
LOW LATENCY
HIGH LATENCY
THROUGHPUT DEGRADATION SPREAD
THROUGHPUT
100%
75%
50%
25%
0%
0 2 4 6 8 10 12 14 16
TIME (MINUTES)
GROUP A
GROUP B
GROUP C
GROUP D
GROUP E
GROUP F
SCHEDULER OVERLOAD CASCADE
GROUP A (ORIGIN) 42%
GROUP B (OVERLOADED) 78%
GROUP C (DELAYED) 86%
GROUP D (IMPACTED) 92%
GROUP E (CRITICAL) 96%
GROUP F (COLLAPSING) 98%
DISPATCH DELAY CHAIN (AVERAGE DELAY)
GROUP A 320 ms
GROUP B 980 ms
GROUP C 2,140 ms
GROUP D 4,870 ms
GROUP E 8,730 ms
GROUP F 12,680 ms
LATENCY CASCADE INSIGHTS
A local queue spike can trigger a system-wide latency cascade.
Propagation speed depends on topology connectivity and load.
Scheduler overload amplifies delays exponentially.
Cascading delays cause dispatch starvation and queue collapse.
Recovery requires end-to-end stabilization of the entire path.
RECOVERY OUTLOOK
Estimated Recovery Time
45 – 75 min
Recovery Progress 12%
Stabilizing Group A...


11. OBSERVER-ONLY SECURITY MODEL
ISOLATED • READ-ONLY • NON-INVASIVE • SECURE BY DESIGN
OPERATIONAL INFRASTRUCTURE
PRODUCTION HPC ENVIRONMENT
WORKLOAD SUBMISSIONS
Users • Applications • Pipelines
SCHEDULER LAYER
Priority • Policies • Orchestration
QUEUE TOPOLOGY
Multi-level • Dynamic • Distributed
DISPATCH COORDINATION
Routing • Synchronization • Allocation
COMPUTE NODES
CPU • GPU • Memory • Storage
LIVE PRODUCTION OPERATIONS
OPERATIONAL DATA (INTERNAL)
Queue Events
Scheduler Metrics
Dispatch Events
Node Telemetry
Job Statistics
Performance Data
SECURE OBSERVER BOUNDARY
PHYSICAL & LOGICAL ISOLATION LAYER
NO CONTROL CHANNELS
NO WRITE ACCESS
NO CONFIG CHANGES
NO JOB INTERACTIONS
NO RUNTIME IMPACT
TELEMETRY MIRROR (READ-ONLY)
ONE-WAY DATA STREAMS
Queue Telemetry Stream
Scheduler Telemetry Stream
Dispatch Telemetry Stream
Node Telemetry Stream
Job Telemetry Stream
Performance Telemetry Stream
SECURITY ENFORCEMENT LAYER
FIREWALL ISOLATION
ONE-WAY DATA DIODES
ENCRYPTED CHANNELS
ACCESS CONTROL
AUDIT & INTEGRITY
OBSERVER-ONLY ENVIRONMENT
ISOLATED ANALYSIS PLATFORM
ANONYMIZED TELEMETRY
Data Anonymization & Aggregation
OPERATIONAL ANALYTICS
Read-Only • No Control • No Impact
SITUATIONAL AWARENESS
Health • Capacity • Efficiency • Risk
REPORTING & INSIGHTS
Dashboards • Reports • Alerts (Read-Only)
AUDIT & COMPLIANCE
Logs • Access • Integrity • Retention
ISOLATED OBSERVER ZONE
OBSERVER PRINCIPLES
WE OBSERVE. WE DO NOT INTERFERE.
READ-ONLY
Only read operations. No write access.
NON-INVASIVE
Zero impact on production workloads.
ANONYMIZED
All telemetry is anonymized & aggregated.
ISOLATED
Physically & logically separated environment.
SECURE
Enterprise-grade security controls.
AUDITABLE
All access & data streams are audited.
DATA FLOW GUARANTEE
PRODUCTION ENVIRONMENT
ONE-WAY ONLY
OBSERVER ENVIRONMENT
NO RETURN PATH • NO CONTROL • NO RISK
TRUSTED BY DESIGN
Zero Control
Zero Interference
Zero Runtime Impact
Complete Isolation
Maximum Security
Full Observability
MAXIMUM OBSERVABILITY. ZERO CONTROL. ABSOLUTE SECURITY.
OBSERVER-ONLY BY DESIGN. TRUSTED BY ARCHITECTURE.


12. OPTIONAL EXTRA IMAGE — HTC SYNCHRONIZATION FIELD
THE HTC SYSTEM AS A DYNAMICALLY CONNECTED OPERATIONAL FIELD
SYNCHRONIZED • COORDINATED • RESILIENT • ADAPTIVE • INTELLIGENT
OPERATIONAL INPUTS
Workload Submissions
User Applications
Data Pipelines
External Systems
Automation Triggers
REAL-TIME INTELLIGENCE
System Telemetry
Queue Metrics
Node Metrics
Performance Data
Health Signals
ADAPTIVE RESPONSE
Dynamic Rebalancing
Policy Adjustment
Resource Adaptation
Failure Mitigation
Continuous Optimization
SCHEDULER LAYER
Global Orchestration & Prioritization
Policies
Fair-share
Backfill
Adaptation
WORKLOAD FLOW
EXECUTION FLOW
QUEUE TOPOLOGY
Multi-level • Dynamic • Distributed
Priority Queues
Delay Awareness
Load Balancing
Queue Health
OPERATIONAL COHERENCE FIELD
COMPUTE NODES FIELD
Distributed Execution Fabric
CPU Nodes
GPU Nodes
Memory Nodes
Storage / IO Nodes
DATA FLOW
CONTROL FLOW
DISPATCH COORDINATION
Routing • Synchronization • Allocation
Smart Routing
Dependency Awareness
Data Locality
Dispatch Optimization
SYNCHRONIZATION OUTCOMES
High Throughput
Low Latency
Stable Execution
Efficient Utilization
Maximized Capacity
Operational Resilience
OPERATIONAL STABILITY
Stability Index 98.7%
FIELD HEALTH OVERVIEW
Scheduler Health 99%
Queue Health 98%
Dispatch Health 97%
Node Health 98%
Data Health 99%
System Health 98%
SYNCHRONIZATION QUALITY
Resonance Index 96.3%
SYNCHRONIZATION WAVES
Workload Flow
Data Flow
Control Flow
Dispatch Flow
Execution Flow
Feedback Flow
OPERATIONAL RESONANCE INDICATORS
Coherence 96%
Alignment 95%
Balance 97%
Stability 98%
Resonance 96%
Efficiency 97%
SYSTEM RESONANCE MAP
ONE SYSTEM. ONE FIELD. SYNCHRONIZED INTELLIGENCE. MAXIMUM IMPACT.