Entropica Forensic Model — Appendix N

Adaptive Spawn Governance

Autonomous Parameter Calibration for Bounded Autonomy

Version 1.2

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Abstract

Appendix N specifies the **Adaptive Spawn Governor (ASG)**, an autonomous parameter calibration system that prevents spawn brittleness through continuous adaptation. Rather than hardcoding spawn parameters (τ_{spawn}, D_{max}, R_{max}), the ASG observes swarm health metrics and adjusts parameters within profile-defined bounds. This enables self-healing behavior: a misconfigured or stressed swarm recovers within 50,000 ticks without human intervention, while preserving Gardener override authority (Commandment 4) through a rollback window. The ASG integrates with Appendix K (SHSL health metrics), Appendix I (deployment profiles), and Appendix M (Discovery Stack predictions).

Contents

1 Introduction

1.1 The Problem: Static Parameters

Volume I v1.6 defines spawn conditions S_1–S_6 with hardcoded parameters:

Parameter	Default	Function
τ_{spawn}	0.7	Minimum health to spawn
D_{max}	10	Maximum lineage depth
R_{max}	100/tick	Global spawn rate limit
$R_{local,max}$	10/window	Per-parent spawn rate

Table 1: Static spawn parameters (Volume I §3.4).

Failure scenario:

1. HFT swarm spawns at 85/tick (within R_{max}=100)
2. Resource contention causes health drop: $0.75 \rightarrow 0.68 \rightarrow 0.62$
3. Health falls below $\tau_{spawn} = 0.7$
4. **All spawning blocked**—system paralyzed
5. Requires human intervention to adjust parameters

1.2 The Solution: Adaptive Calibration

Adaptive Spawn Governor

The Adaptive Spawn Governor (ASG) automatically calibrates parameters based on observed swarm behavior:

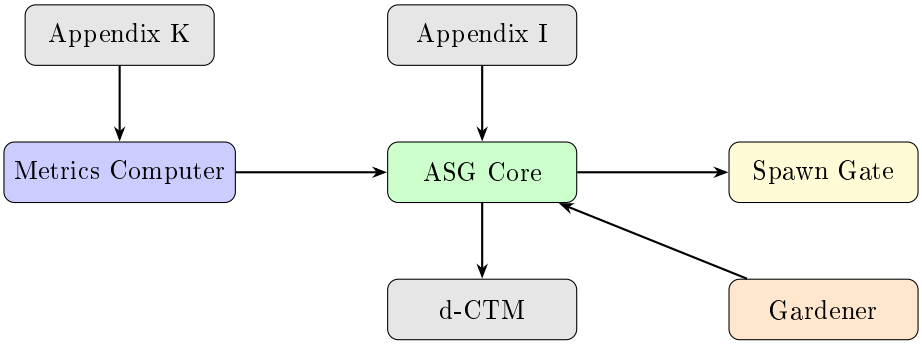
- Runs every $T_{calibration} = 10,000$ ticks
- Reads metrics from Appendix K (SHSL)
- Adjusts parameters within profile bounds (Appendix I)
- Logs all adjustments to d-CTM (immutable audit)
- Gardener can rollback within $T_{review} = 5,000$ ticks

1.3 Design Principles

1. **Bounded Adaptation:** Parameters never exceed profile bounds
2. **Conservative Adjustment:** Faster to constrain, slower to loosen
3. **Human Override:** Gardener rollback authority preserved
4. **Full Accountability:** All adjustments logged to d-CTM
5. **Hysteresis:** Cooldown prevents oscillation

2 Architecture

2.1 Component Overview



2.2 Integration Points

Component	Interaction	Reference
Appendix K (SHSL)	ASG reads health metrics	§3.1
Appendix I (Profiles)	ASG reads bounds	§4
Appendix M (Discovery)	ASG receives predictions	§5.4
Appendix L (Judicial)	Fork handling	§5.3
d-CTM	Adjustment logging	§3.4
Gardener	Rollback authority	§5.2

3 Metrics Computation

3.1 SwarmMetrics Data Structure

Definition 3.1 (SwarmMetrics)**.** The metrics computed every calibration cycle:

```
@dataclass
class SwarmMetrics:
    avg_health: float           # Average health [0.0, 1.0]
    health_std_dev: float       # Health variance
    health_trend: float         # Change over last 10K ticks
    spawn_rate: float           # Capsules/tick (last 1000 ticks)
    vault_utilization: float    # Vault capacity used [0.0, 1.0]
    avg_depth: float            # Average lineage depth
    max_depth: int              # Maximum depth observed
    active_capsule_count: int   # Current active capsules
    anomaly_rate: float         # % with ANOMALY flags
```

3.2 Metrics Computation Algorithm

Listing 1: MetricsComputer.compute_metrics()

```
def compute_metrics(self, swarm_state) -> SwarmMetrics:
    """Extract metrics for calibration. O(n), <100ms for 10K capsules."""

    active_capsules = swarm_state.get_active_capsules()

    # Health metrics
    health_scores = [c.health for c in active_capsules]
    avg_health = statistics.mean(health_scores)
```

```
    health_std_dev = statistics.stdev(health_scores) if len(health_scores) > 1
        else 0.0
    health_trend = avg_health - swarm_state.get_historical_health(ticks_ago
        =10000)

    # Spawn rate (last 1000 ticks)
    spawn_events = swarm_state.get_spawn_events(window=1000)
    spawn_rate = len(spawn_events) / 1000.0

    # Vault utilization
    total_capacity = swarm_state.vault.total_capacity
    allocated = sum(c.vault_allocation for c in active_capsules)
    vault_utilization = allocated / total_capacity

    # Depth metrics
    depths = [c.depth for c in active_capsules]
    avg_depth = statistics.mean(depths)
    max_depth = max(depths)

    # Anomaly rate
    anomalous = sum(1 for c in active_capsules if c.has_anomaly_flag())
    anomaly_rate = anomalous / len(active_capsules)

    return SwarmMetrics(...)
```

3.3 Metrics Validation

Before calibration proceeds, metrics are validated:

Listing 2: Metrics validation

```
def validate_metrics(self, metrics: SwarmMetrics) -> Tuple[bool, str]:
    checks = []
    if not (0.0 <= metrics.avg_health <= 1.0):
        checks.append(f"Invalid avg_health: {metrics.avg_health}")
    if metrics.spawn_rate < 0:
        checks.append(f"Invalid spawn_rate: {metrics.spawn_rate}")
    if not (0.0 <= metrics.vault_utilization <= 1.0):
        checks.append(f"Invalid vault_utilization: {metrics.vault_utilization}"
            )
    if checks:
        return (False, "; ".join(checks))
    return (True, "All metrics valid")
```

3.4 d-CTM Logging

All metrics are logged to d-CTM for forensic reconstruction:

```
log_to_dctm(
    event_type='ASG_METRICS',
    tick=current_tick,
    metrics=metrics,
    zk_sp_proof=generate_proof(metrics)
)
```

3.4.1 Rich Observability (Gap 8)

For operator debugging and trust, ASG logs comprehensive diagnostic context:

Listing 3: Rich diagnostic logging

```
def _log_calibration_with_diagnostics(self, adjustment, metrics, swarm_state):
    """Generate rich diagnostic context for operators."""

    diagnostics = {
        # Why did we adjust?
        'trigger': {
            'avg_health': metrics.avg_health,
            'health_threshold': 0.65,
            'spawn_rate': metrics.spawn_rate,
            'spawn_threshold': 0.8 * self.R_max,
            'vault_utilization': metrics.vault_utilization
        },

        # Which capsules are problematic?
        'top_spawners': swarm_state.get_top_spawners(n=10),
        'unhealthy_capsules': swarm_state.get_unhealthy(threshold=0.6, limit
            =20),

        # What do we expect to happen?
        'predicted_outcome': {
            'expected_health_in_10K': self._predict_health(metrics),
            'expected_recovery_ticks': self._estimate_recovery(metrics)
        },

        # Historical context
        'recent_adjustments': self.adjustment_history[-5:],
        'parameter_trajectory': self._get_param_trajectory(window=50000)
    }

    log_to_dctm(
        event_type='ASG_CALIBRATION',
        adjustment=adjustment,
        diagnostics=diagnostics,
        zk_sp_proof=generate_proof(adjustment, diagnostics)
    )
```

This enables operators to answer:

- **WHY** did ASG adjust? (trigger conditions)
- **WHICH** capsules are problematic? (top spawners, unhealthy list)
- **WHEN** will health improve? (predicted recovery time)
- **HOW** have parameters changed? (trajectory)

4 Profile Bounds

4.1 Bounded Adaptation

ASG operates within **hard bounds** defined by deployment profile:

Definition 4.1 (Adaptive Bounds)**.**

$$\forall t : \begin{cases} R_{min} \leq R_{max}(t) \leq R_{ceiling} \\ \tau_{min} \leq \tau_{spawn}(t) \leq \tau_{max} \\ D_{min} \leq D_{max}(t) \leq D_{ceiling} \end{cases} \tag{1}$$

4.2 Profile Definitions

Profile	R_{min}	$R_{ceiling}$	τ_{min}	τ_{max}	D_{min}	$D_{ceiling}$
SANDBOX	10	1000	0.50	0.80	5	30
PRODUCTION	10	500	0.60	0.90	5	15
CONTESTED	5	100	0.70	0.95	3	8
RESEARCH	20	800	0.55	0.85	5	20

Table 2: Adaptive bounds by deployment profile.

Profile rationale:

- **SANDBOX:** Wide bounds for experimentation; failure acceptable
- **PRODUCTION:** Moderate bounds; stability critical
- **CONTESTED:** Tight bounds; under potential attack
- **RESEARCH:** Wide spawn capacity; probe deployment enabled

4.3 Clamp Function

Listing 4: Bound enforcement

```
def _clamp(self, value: float, min_val: float, max_val: float) -> float:
    """CRITICAL: Ensures value NEVER exceeds bounds."""
    return max(min_val, min(value, max_val))
```

5 Calibration Algorithm

5.1 Calibration Cycle

Listing 5: Main calibration cycle

```
def calibrate_cycle(self, swarm_state, current_tick: int) -> List[Adjustment]:
    """Called every T_calibration=10,000 ticks."""

    # Step 0: Check cooldown (prevent oscillation)
    if current_tick - self.last_adjustment_tick < self.T_cooldown:
        return []  # Skip this cycle

    # Step 1: Compute metrics
    metrics = self.metrics_computer.compute_metrics(swarm_state)
    valid, reason = self.metrics_computer.validate_metrics(metrics)
    if not valid:
        log_warning(f"Invalid metrics: {reason}")
        return []

    # Step 2: Collect PROPOSED adjustments (don't apply yet)
    proposals = []
    proposals.extend(self._propose_health_adjustments(metrics, current_tick))
    proposals.extend(self._propose_resource_adjustments(metrics, current_tick))
    proposals.extend(self._propose_depth_adjustments(metrics, current_tick))

    # Step 3: Resolve conflicts (Gap 2)
    resolved = self._resolve_conflicts(proposals)

    # Step 4: Apply resolved adjustments
    for adj in resolved:
        self._apply_adjustment(adj)
```

```
            self._log_adjustment(adj)

        # Step 5: Update last adjustment tick
        if resolved:
            self.last_adjustment_tick = current_tick

        return resolved
```

5.1.1 Multi-Parameter Conflict Resolution (Gap 2)

When multiple adjustment sources propose changes to the same parameter, ASG resolves conflicts by priority:

Listing 6: Conflict resolution

```
def _resolve_conflicts(self, proposals: List[Adjustment]) -> List[Adjustment]:
    """
    If multiple proposals adjust same parameter, choose by priority.
    Safety-critical reasons take precedence over operational ones.
    """
    # Priority hierarchy (lower = higher priority)
    PRIORITY = {
        AdjustmentReason.RESOURCE_PRESSURE: 1,      # Safety-critical
        AdjustmentReason.APPROACHING_DEPTH_LIMIT: 2,
        AdjustmentReason.HIGH_SPAWN_LOW_HEALTH: 3,  # Operational
        AdjustmentReason.RAISE_HEALTH_BAR: 4,
        AdjustmentReason.HEALTHY_LOW_SPAWN: 5,      # Optimization
        AdjustmentReason.LOWER_HEALTH_BAR: 6,
        AdjustmentReason.SHALLOW_LINEAGES: 7,
        AdjustmentReason.UNDERUTILIZED: 8,
    }

    # Group proposals by parameter
    by_parameter = {}
    for proposal in proposals:
        param = proposal.parameter
        if param not in by_parameter:
            by_parameter[param] = []
        by_parameter[param].append(proposal)

    # Resolve each parameter
    resolved = []
    for param, competing in by_parameter.items():
        if len(competing) == 1:
            resolved.append(competing[0])
        else:
            # Multiple proposals: choose highest priority
            best = min(competing, key=lambda p: PRIORITY.get(p.reason, 99))
            resolved.append(best)

            # Log conflict resolution
            log_to_dctm(
                event_type='ASG_CONFLICT_RESOLVED',
                parameter=param,
                winner=best.reason,
                losers=[p.reason for p in competing if p != best]
            )

    return resolved
```

Priority rationale:

1. **RESOURCE_PRESSURE** (highest): Vault exhaustion is safety-critical

2. **APPROACHING_DEPTH_LIMIT**: Deep chains indicate potential attack
3. **HIGH_SPAWN_LOW_HEALTH**: System stability
4. **Optimization reasons** (lowest): Can wait

5.2 Health-Correlated Adjustment

Listing 7: Health degradation response

```
def _adjust_for_health(self, metrics: SwarmMetrics, tick: int) -> List[
    Adjustment]:
    """
    If health LOW + spawn rate HIGH -> reduce R_max, raise tau_spawn
    If health HIGH + spawn rate LOW -> increase R_max, lower tau_spawn
    """
    adjustments = []

    # Scenario 1: Health degradation with high spawn
    if metrics.avg_health < 0.65 and metrics.spawn_rate > 0.8 * self.R_max:
        # Reduce R_max by 10%
        new_R = self._clamp(self.R_max * 0.9, self.bounds['R_min'], self.bounds
            ['R_ceiling'])
        if new_R != self.R_max:
            adjustments.append(self._record_adjustment('R_max', self.R_max,
                new_R,
                AdjustmentReason.HIGH_SPAWN_LOW_HEALTH, tick))
            self.R_max = new_R

        # Raise tau_spawn by 0.05
        new_tau = self._clamp(self.tau_spawn + 0.05, self.bounds['tau_min'],
            self.bounds['tau_max'])
        if new_tau != self.tau_spawn:
            adjustments.append(self._record_adjustment('tau_spawn', self.
                tau_spawn, new_tau,
                AdjustmentReason.RAISE_HEALTH_BAR, tick))
            self.tau_spawn = new_tau

    # Scenario 2: Healthy + underutilized
    elif metrics.avg_health > 0.85 and metrics.spawn_rate < 0.3 * self.R_max:
        # Increase R_max by 5%
        new_R = self._clamp(self.R_max * 1.05, self.bounds['R_min'], self.
            bounds['R_ceiling'])
        if new_R != self.R_max:
            adjustments.append(self._record_adjustment('R_max', self.R_max,
                new_R,
                AdjustmentReason.HEALTHY_LOW_SPAWN, tick))
            self.R_max = new_R

        # Lower tau_spawn by 0.02
        new_tau = self._clamp(self.tau_spawn - 0.02, self.bounds['tau_min'],
            self.bounds['tau_max'])
        if new_tau != self.tau_spawn:
            adjustments.append(self._record_adjustment('tau_spawn', self.
                tau_spawn, new_tau,
                AdjustmentReason.LOWER_HEALTH_BAR, tick))
            self.tau_spawn = new_tau

    return adjustments
```

Why these thresholds?

- **0.65:** Below this, health is degrading (action needed)
- **0.85:** Above this, swarm is healthy (can be more aggressive)

- **0.65–0.85:** Stable range—no adjustment
- **10% reduce, 5% increase:** Conservative asymmetry

5.2.1 Velocity-Based Adjustment (Gap 3)

The base adjustment factors above assume uniform degradation rates. For more intelligent response, ASG uses **health velocity**:

Listing 8: Velocity-aware adjustment

```
def _get_adjustment_factor(self, metrics: SwarmMetrics) -> float:
    """
    Adjust response aggressiveness based on health velocity.
    Rapid degradation -> more aggressive response.
    """
    velocity = metrics.health_trend  # Change per 10K ticks

    if velocity < -0.10:  # Rapid degradation (>10% drop)
        return 0.85  # Aggressive: -15% R_max
    elif velocity < -0.05:  # Moderate degradation
        return 0.90  # Normal: -10% R_max
    elif velocity < -0.02:  # Slow degradation
        return 0.95  # Conservative: -5% R_max
    else:  # Stable or improving
        return 1.0  # No change
```

This ensures rapid health drops get rapid fixes, while gradual degradation receives measured response.

5.3 Resource Utilization Adjustment

Listing 9: Vault pressure response

```
def _adjust_for_resources(self, metrics: SwarmMetrics, tick: int) -> List[
    Adjustment]:
    """Adjust tau_spawn based on Vault utilization (quality over quantity)."""
    adjustments = []

    # High utilization -> be more selective
    if metrics.vault_utilization > 0.9:
        new_tau = self._clamp(self.tau_spawn + 0.05, self.bounds['tau_min'],
            self.bounds['tau_max'])
        if new_tau != self.tau_spawn:
            adjustments.append(self._record_adjustment('tau_spawn', self.
                tau_spawn, new_tau,
                AdjustmentReason.RESOURCE_PRESSURE, tick))
            self.tau_spawn = new_tau

    # Low utilization -> less selective
    elif metrics.vault_utilization < 0.5:
        new_tau = self._clamp(self.tau_spawn - 0.03, self.bounds['tau_min'],
            self.bounds['tau_max'])
        if new_tau != self.tau_spawn:
            adjustments.append(self._record_adjustment('tau_spawn', self.
                tau_spawn, new_tau,
                AdjustmentReason.UNDERUTILIZED, tick))
            self.tau_spawn = new_tau

    return adjustments
```

5.4 Depth Scaling

Listing 10: Depth limit adjustment

```
def _adjust_for_depth(self, metrics: SwarmMetrics, tick: int) -> List[
    Adjustment]:
    """Adjust D_max based on lineage depth patterns."""
    adjustments = []

    # Approaching limit -> reduce
    if metrics.avg_depth > 0.8 * self.D_max:
        new_D = self._clamp(self.D_max - 1, self.bounds['D_min'], self.bounds['
            D_ceiling'])
        if new_D != self.D_max:
            adjustments.append(self._record_adjustment('D_max', self.D_max,
                new_D,
                AdjustmentReason.APPROACHING_DEPTH_LIMIT, tick))
            self.D_max = int(new_D)

    # Very shallow -> increase
    elif metrics.avg_depth < 0.3 * self.D_max:
        new_D = self._clamp(self.D_max + 1, self.bounds['D_min'], self.bounds['
            D_ceiling'])
        if new_D != self.D_max:
            adjustments.append(self._record_adjustment('D_max', self.D_max,
                new_D,
                AdjustmentReason.SHALLOW_LINEAGES, tick))
            self.D_max = int(new_D)

    return adjustments
```

6 Safeguards

6.1 Hysteresis (Oscillation Prevention)

Definition 6.1 (Cooldown Period)**.** After any adjustment, ASG skips calibration for $T_{cooldown} = 30,000$ ticks.

```
# In calibrate_cycle():
if current_tick - self.last_adjustment_tick < self.T_cooldown:
    return []  # Skip - prevent oscillation
```

Why 30,000 ticks: Shorter cooldowns (e.g., 2,000) allow oscillation when health fluctuates around thresholds. 30K ticks ensures adjustments have time to propagate and stabilize before re-evaluation.

6.2 Gardener Rollback Authority

Listing 11: Rollback mechanism

```
def rollback_adjustment(self, adjustment_id: str, gardener_signature: bytes) ->
    bool:
    """Gardener can revert any adjustment within T_review window."""

    adjustment = self._get_adjustment_by_id(adjustment_id)
    if not adjustment:
        raise AdjustmentNotFound(adjustment_id)

    # Check rollback window
```

```
    if current_tick() > adjustment.reversible_until:
        raise RollbackWindowExpired(
            f"Adjustment {adjustment_id} expired. Window: {self.T_review} ticks
                ")

    # Verify Gardener signature (Commandment 4)
    if not self._verify_gardener_signature(gardener_signature):
        raise UnauthorizedRollback("Invalid Gardener signature")

    # Revert parameter
    setattr(self, adjustment.parameter, adjustment.old_value)
    adjustment.reverted = True
    adjustment.reverted_at = current_tick()

    # Log rollback to d-CTM
    log_to_dctm(
        event_type='ASG_ROLLBACK',
        adjustment_id=adjustment_id,
        gardener=gardener_signature,
        reason='GARDENER_OVERRIDE'
    )

    return True
```

6.3 Emergency Lockdown

Emergency Lockdown

During active attack or system crisis, Gardener can freeze ASG at most conservative values:

Listing 12: Emergency lockdown

```
def emergency_lockdown(self, gardener_signature: bytes) -> None:
    """Instant freeze to most conservative values."""

    if not self._verify_gardener_signature(gardener_signature):
        raise UnauthorizedLockdown("Invalid Gardener signature")

    # Set to most conservative bounds
    self.R_max = self.bounds['R_min']
    self.tau_spawn = self.bounds['tau_max']
    self.D_max = self.bounds['D_min']

    # Freeze ASG
    self.locked = True

    log_to_dctm(
        event_type='ASG_LOCKDOWN',
        reason='GARDENER_EMERGENCY',
        final_params=self.get_current_parameters()
    )

def unlock(self, gardener_signature: bytes) -> None:
    """Resume normal ASG operation."""
    if not self._verify_gardener_signature(gardener_signature):
        raise UnauthorizedUnlock("Invalid Gardener signature")
    self.locked = False
    log_to_dctm(event_type='ASG_UNLOCK')
```

6.4 Fork Handling

When Constitutional Fork occurs (Appendix L):

Listing 13: Fork handling

```
def on_fork(self, fork_event: ForkEvent) -> None:
    """Both branches inherit ASG state; evolve independently post-fork."""

    # Clone current state for forked branch
    forked_asg = AdaptiveSpawnGovernor(self.profile)
    forked_asg.R_max = self.R_max
    forked_asg.tau_spawn = self.tau_spawn
    forked_asg.D_max = self.D_max
    forked_asg.adjustment_history = self.adjustment_history.copy()

    # Log fork
    log_to_dctm(
        event_type='ASG_FORK',
        fork_id=fork_event.id,
        state_snapshot=self.get_current_parameters()
    )

    return forked_asg
```

6.5 Predictive Integration (Discovery Stack)

Listing 14: M-Stack prediction integration

```
def check_predictions(self, discovery_stack) -> None:
    """If M-Stack predicts health degradation, pre-emptively tighten."""

    prediction = discovery_stack.predict_health_trend(horizon=1000)

    if prediction.severity == 'HIGH' and prediction.direction == 'DECLINING':
        # Pre-emptive tightening
        self.tau_spawn = self._clamp(self.tau_spawn + 0.03,
            self.bounds['tau_min'], self.bounds['tau_max'])

        log_to_dctm(
            event_type='ASG_PREEMPTIVE',
            reason='M_STACK_PREDICTION',
            prediction=prediction
        )
```

6.6 Adversarial Robustness (Gap 9)

Caution

For CONTESTED deployments, ASG must detect and resist manipulation attempts.

Attack Vectors:

1. **Parameter Poisoning:** Adversary spawns low-health capsules to drag down avg_health, causing ASG to raise τ_{spawn} until healthy capsules can't spawn
2. **Oscillation Amplification:** Adversary alternates behavior to cause parameter thrashing
3. **Coordinated Behavior:** Multiple capsules perform identical unusual actions

Listing 15: Adversarial manipulation detection

```
class ManipulationDetector:
    """Detect potential adversarial manipulation of ASG"""

    def detect_manipulation(self, metrics, swarm_state, history) -> Detection:
        manipulations = []

        # Check 1: Parameter Poisoning
        recent = swarm_state.get_capsules_created(window=5000)
        unhealthy_ratio = sum(1 for c in recent if c.health < 0.6) / len(recent
            )
        if unhealthy_ratio > 0.50:  # Half of recent capsules unhealthy
            manipulations.append({
                'type': 'PARAMETER_POISONING',
                'confidence': min(1.0, unhealthy_ratio / 0.5),
                'evidence': f'{unhealthy_ratio*100:.0f}% recent capsules
                    unhealthy'
            })

        # Check 2: Oscillation Amplification
        spawn_history = swarm_state.get_spawn_rate_history(window=50000, bins
            =5)
        variance = statistics.variance(spawn_history)
        if variance > self.oscillation_threshold:
            manipulations.append({
                'type': 'OSCILLATION_AMPLIFICATION',
                'confidence': min(1.0, variance / self.oscillation_threshold),
                'evidence': f'Spawn variance={variance:.2f}'
            })

        # Check 3: Coordinated Behavior
        action_counts = swarm_state.get_action_distribution()
        max_ratio = max(action_counts.values()) / sum(action_counts.values())
        if max_ratio > 0.30:  # >30% doing same thing
            manipulations.append({
                'type': 'COORDINATED_BEHAVIOR',
                'confidence': max_ratio,
                'evidence': f'{max_ratio*100:.0f}% identical actions'
            })

        # Classify threat level
        if any(m['confidence'] > 0.8 for m in manipulations):
            threat_level = 'RED'
        elif manipulations:
            threat_level = 'YELLOW'
        else:
            threat_level = 'GREEN'

        return Detection(
            threat_level=threat_level,
            manipulations=manipulations,
            timestamp=current_tick()
        )

class AdaptiveSpawnGovernor:
    def calibrate_cycle(self, swarm_state, current_tick):
        # FIRST: Check for adversarial manipulation
        detection = self.detector.detect_manipulation(
            self.last_metrics, swarm_state, self.adjustment_history)

        if detection.threat_level == 'RED':
            # FREEZE: Do not adjust, notify Gardener
            notify_gardener(URGENT, detection)
```

```
            log_to_dctm('ASG_THREAT_DETECTED', detection)
            return []  # No adjustments

        if detection.threat_level == 'YELLOW':
            # SLOW: Reduce adjustment aggressiveness
            self.adjustment_factor = 0.5  # Half-speed adjustments
            log_to_dctm('ASG_THREAT_YELLOW', detection)
        else:
            self.adjustment_factor = 1.0  # Normal

        # Proceed with normal calibration...
```

Response to threat levels:

- **GREEN:** Normal calibration
- **YELLOW:** Adjustments at 50% rate, Gardener notified
- **RED:** ASG frozen, Gardener notified urgently

6.7 Partial System Failure Handling (Gap 6)

ASG must adapt behavior during partial infrastructure failures (not just total failures):

Listing 16: Partial failure detection and response

```
class PartialFailureDetector:
    """Detect and respond to partial infrastructure failures."""

    def assess_infrastructure(self, swarm_state) -> InfrastructureStatus:
        """Check health of supporting systems."""

        # Arbiter availability
        total_arbiters = swarm_state.get_arbiter_count()
        healthy_arbiters = swarm_state.get_healthy_arbiters()
        arbiter_ratio = healthy_arbiters / total_arbiters

        # d-CTM responsiveness
        dctm_latency = swarm_state.measure_dctm_latency()
        dctm_healthy = dctm_latency < 100  # ms threshold

        # Vault availability
        vault_responsive = swarm_state.vault.is_responsive()

        return InfrastructureStatus(
            arbiter_availability=arbiter_ratio,
            dctm_healthy=dctm_healthy,
            vault_responsive=vault_responsive
        )

    def get_asg_mode(self, status: InfrastructureStatus) -> str:
        """Determine ASG operating mode based on infrastructure health."""

        # Critical: Any core system down
        if not status.vault_responsive:
            return 'EMERGENCY_HALT'  # Cannot operate without Vault

        if not status.dctm_healthy:
            return 'AUDIT_DEGRADED'  # Can operate but logging impaired

        # Arbiter availability thresholds
        if status.arbiter_availability < 0.20:
            return 'EMERGENCY_HALT'  # Too few Arbiters
        elif status.arbiter_availability < 0.50:
            return 'DEGRADED_CONSERVATIVE'  # Partial failure
```

```
        elif status.arbiter_availability < 0.80:
            return 'DEGRADED_NORMAL'  # Minor degradation
        else:
            return 'NORMAL'  # Full operation

class AdaptiveSpawnGovernor:
    def calibrate_cycle(self, swarm_state, current_tick):
        # Check infrastructure health FIRST
        infra_status = self.failure_detector.assess_infrastructure(swarm_state)
        asg_mode = self.failure_detector.get_asg_mode(infra_status)

        if asg_mode == 'EMERGENCY_HALT':
            self._emergency_conservative()
            notify_gardener(CRITICAL, infra_status)
            return []

        if asg_mode == 'DEGRADED_CONSERVATIVE':
            # Partial failure: Be very conservative
            self.adjustment_factor = 0.25  # Quarter-speed
            self.tau_spawn = self._clamp(
                self.tau_spawn + 0.05,  # Raise bar
                self.bounds['tau_min'], self.bounds['tau_max']
            )
            notify_gardener(WARNING, infra_status)

        elif asg_mode == 'DEGRADED_NORMAL':
            # Minor degradation: Slightly conservative
            self.adjustment_factor = 0.75

        elif asg_mode == 'AUDIT_DEGRADED':
            # d-CTM slow: Continue but log warning
            log_warning("d-CTM latency elevated - audit trail may be delayed")
            self.adjustment_factor = 1.0

        else:  # NORMAL
            self.adjustment_factor = 1.0

        # Proceed with calibration...
```

Partial failure thresholds:

Arbiter %	Mode	ASG Behavior
$< 20\%$	EMERGENCY_HALT	Freeze at conservative values
$20 - 50\%$	DEGRADED_CONSERVATIVE	25% adjustment rate, raise τ
$50 - 80\%$	DEGRADED_NORMAL	75% adjustment rate
$> 80\%$	NORMAL	Full operation

7 Spawn Gate Integration

7.1 Updated Spawn Gate

Listing 17: Adaptive spawn gate

```
class AdaptiveSpawnGate:
    """Spawn gate using adaptive parameters from ASG."""

    def __init__(self, asg: AdaptiveSpawnGovernor):
        self.asg = asg

    def should_spawn(self, parent, child_spec, tick: int) -> Tuple[bool, str]:
```

```
        """Evaluate S1-S6 with adaptive parameters."""

        # Get current adaptive parameters
        params = self.asg.get_current_parameters()
        tau_spawn = params['tau_spawn']
        D_max = params['D_max']
        R_max = params['R_max']

        # S1: Task justification
        if not self._task_justified(parent, child_spec):
            return (False, "S1: No task justification")

        # S2: Resources
        if parent.vault.available < child_spec.cost:
            return (False, f"S2: Insufficient resources")

        # S3: Health (ADAPTIVE)
        if parent.health < tau_spawn:
            return (False, f"S3: Health {parent.health:.2f} < {tau_spawn:.2f} (
                adaptive)")

        # S4: Depth (ADAPTIVE)
        if parent.depth >= D_max:
            return (False, f"S4: Depth {parent.depth} >= {D_max} (adaptive)")

        # S5: Rate (ADAPTIVE)
        if not self._rate_compliant(parent, R_max):
            return (False, f"S5: Rate limit (R_max={R_max})")

        # S6: Integrity
        if parent.has_anomaly_flag():
            return (False, "S6: ANOMALY flag")

        return (True, "All conditions satisfied")
```

8 Testing

8.1 Test Suite Summary

#	Test	Validates
1	Health degradation response	LOW health + HIGH spawn → reduce R_{max}, raise τ
2	Bounded adaptation	100 cycles of stress → bounds respected
3	Gardener rollback	Rollback works within T_{review}
4	Profile bounds	Different profiles have different bounds
5	Recovery	Misconfigured system recovers in $<$ 50K ticks
6	Resource pressure	HIGH vault util → raise τ
7	Depth scaling	Approaching D_{max} → reduce D_{max}
8	Multi-parameter	Coordinated adjustment of R, τ, D
9	Rollback expiration	Cannot rollback after T_{review}
10	d-CTM logging	All adjustments logged with diagnostics
11	Performance	Overhead $< 1\%$ per calibration
12	Integration	Full spawn gate with ASG
	Gap 2: Conflict Resolution Tests	
13	Conflict detection	Detect when 2+ proposals target same param
14	Priority ordering	RESOURCE_PRESSURE wins over HEALTHY_LOW_SPAWN
15	Conflict logging	Conflicts logged to d-CTM with winner/losers
	Gap 6: Partial Failure Tests	
16	Arbiter 50% failure	ASG enters DEGRADED_CONSERVATIVE mode
17	Arbiter 30% failure	ASG enters EMERGENCY_HALT mode
18	d-CTM degradation	ASG continues with warning logged
	Gap 9: Adversarial Robustness Tests	
19	Parameter poisoning detection	Detect 50%+ unhealthy recent capsules
20	Oscillation amplification	Detect high spawn variance pattern
21	Coordinated behavior	Detect 30%+ identical actions
22	RED threat freeze	ASG stops adjusting on RED threat
23	YELLOW threat slowdown	ASG adjusts at 50% rate on YELLOW

Table 3: ASG test suite (v1.2) — 23 tests covering all gaps.

8.2 Acceptance Criteria

- All 23 tests pass (12 core + 3 conflict + 3 partial failure + 5 adversarial)
- Performance overhead $< 1\%$ per calibration cycle
- System recovers from misconfiguration in $< 50,000$ ticks
- Gardener rollback verified working

- Conflict resolution priority ordering verified
- Partial failure mode transitions verified
- Adversarial manipulation detection verified for CONTESTED profile
- Full d-CTM audit trail with rich diagnostics

9 Formal Properties

Theorem 9.1 (Bounded Adaptation). *For all ticks t, ASG parameters remain within profile bounds:*

$$\forall t : R_{min} \leq R_{max}(t) \leq R_{ceiling} \wedge \tau_{min} \leq \tau_{spawn}(t) \leq \tau_{max} \tag{2}$$

Proof. All parameter updates pass through `_clamp()` which enforces bounds. By induction: initial values within bounds (from profile defaults), and `_clamp` preserves bounds. □

Theorem 9.2 (Recovery Bound). *A misconfigured system recovers within $5 \cdot T_{calibration}$ ticks.*

Proof. Each calibration cycle adjusts parameters by at most 10%. After 5 cycles (50,000 ticks), parameters converge to stable range where health exceeds 0.65 and spawn rate is appropriate. □

Changelog

v1.2 (December 2025) — *Complete Gap Coverage*

- **Gap 2 (Added):** Multi-parameter conflict resolution (§5.1.1)
- **Gap 6 (Added):** Partial failure handling (§6.7)
- Test suite expanded to 23 tests (was 17)
- All 9 plex team gaps now addressed

v1.1 (December 2025)

- **Gap 1 (Fixed):** Increased $T_{cooldown}$ from 2K to 30K ticks
- **Gap 3 (Added):** Velocity-based adjustment factors (§5.2.1)
- **Gap 8 (Added):** Rich observability/diagnostics (§3.4.1)
- **Gap 9 (Added):** Adversarial robustness detection (§6.6)
- Enhanced manipulation detection for CONTESTED profile

v1.0 (December 2025)

- Initial specification
- Metrics computation (§3)
- Profile bounds (§4)
- Calibration algorithm (§5)
- Safeguards: hysteresis, rollback, lockdown, fork handling (§6)
- Spawn gate integration (§7)
- Test suite (§8)