The National Disaster-Warning Case Study on heain-core

PM2.5 in Chiang Mai and Bangkok, the 2026 Season
Replaying a Five-Month Chronic Hazard on a 37-Node Simulation:
Community Sensors, Standards and Burn Quotas, with Core C8

Jakkrit Boonma (จักรกฤษ บุญมา)
Independent Researcher · ORCID: 0009-0000-7165-3787 · jaggid.boonma@yahoo.co.th

Date: 29 October 2026
Implementation: heain-core 3329b2f (Go 1.26), HP Z840
Repository: github.com/JakkritB/heain-core (casestudies/disaster/, e4.sh)

Abstract

PM2.5 differs from the hazards of earlier volumes: it is chronic, lasts months, returns every year, and often comes from outside the area it harms. In the 2026 season Chiang Mai had 11,023 hotspots and 53 days above 37.5 μg/m³ [8]; Bangkok used Cell Broadcast to warn people entering red zones on 14–15 January 2026 [9]; and the clean-air bill, which gives provinces a larger role, is not yet law [11]. This Volume 6 of the case study [1] reports the replay of this season (event series E4).

The author replayed 1 January–31 May 2026 at 1 day = 1 minute on a 37-node layout adding Chiang Mai province, Mueang district (an official station and 30 synthetic community sensors) and Chiang Dao district (a fire watch and burn permits), in two runs: "as it happened" and "with HEAIN". Requirements R31–R40 test cheap sensors, national and provincial standards, a chronic hazard, sources outside the area, burn quotas, school closures, case evidence, health data and months of readings.

The first run on core C7 found the two expected gaps: a province could set a standard looser than the nation's (60), and P5 approved permits one at a time without counting, so 41 went over the quota. Core C8 (3329b2f) added p5.threshold_direction, which lets a lower tier only tighten, and p5.quota, which counts approvals per Zone per period. After the fix the HEAIN run passed 28 of 28 checks with no gap. Warnings and school closures on cheap sensors alone fell to zero (from 9 and 8); messages to Mueang Chiang Mai changed from 62 new Alerts to 5 Alerts, 51 Updates and 5 Cancels; permits on bad-air days and over the quota fell to zero (from 33 and 41); and all 75 case records were kept. All figures come from a simulation on one machine.

Keywords: *HEAIN Framework, heain-core, PM2.5, Chiang Mai, Bangkok, Chronic Hazard, Low-cost Sensors, Corroboration, Decentralisation, Threshold Direction, P5 Quota, Burn Permits, Alert Fatigue*

1. Introduction

1.1 Background

Volume 1 of this series showed that heain-core, the implementation of the HEAIN Framework [3], supports the four-tier national disaster-warning design in 26 designed scenarios [1]. Volumes 4, 5 and 7 replayed real hazards with a clear start and end: the Bangkok flood of 2026, the Hat Yai flood of 2025 and the earthquake of 28 March 2025 [2]. PM2.5 is not like that. It lasts months, returns every year, and the smoke that harms a city often comes from elsewhere: forests in outlying districts, farmland around Bangkok, and neighbouring countries [10][11].

What is tested is therefore different from earlier volumes: warning every day without people growing used to it; rules set at both national and provincial level; data from many cheap sensors that is detailed but not trustworthy on its own; enforcement against burning with evidence that can be checked; and data that must be kept with care over many months.

1.2 Why the 2026 season

Table 1 summarizes the figures that make this season a good test. It has a sharp rise (hotspots up 134%), a reported change of standard, and a draft law that would change how authority is shared between the centre and the provinces.

Figure	Meaning	Source
11,023 hotspots	Hotspots in Chiang Mai, 1 Jan–31 May 2026; 4,644 over target, up 134% on the year before	[8]
1,532 / 1,173 / 1,095	Hotspots in Chiang Dao, Hot and Mae Chaem districts	[8]
1,468,289 rai	Area burned, Jan–Apr	[8]
53 days	Days PM2.5 exceeded 37.5 µg/m³ in Chiang Mai, 7 fewer than the year before	[8]
245 cases / 262 people	Enforcement of the burning-control order (allegations)	[8]
58.1–58.5 µg/m³	Bangkok-wide average, 14–15 Jan 2026, when red-zone warnings began	[9]
352 schools	Schools Bangkok closed on 24 Jan 2025 in 67 red zones	[10]
50 → 37.5 µg/m³	The reported change to the daily PM2.5 standard	[12]
15 May 2026	Parliament voted to take up the clean-air bill again; not yet law	[11]

Table 1 — Key figures of the 2026 PM2.5 season

1.3 Status of this volume

This deployment is the author's hypothetical design, not a project of any agency, and no agency has reviewed it. The clean-air bill is not yet law. The 37.5 µg/m³ standard is the reported value, and its change in the simulation is a P5 step on a synthetic date (1 February). Hourly readings, community sensors, permit applicants, cases and people at risk are all synthetic. Burning cases appear only as allegations at the enforcement stage. No real person is named, and the difference between the two runs is not a criticism of the people who did the work.

1.4 Research questions

- **RQ1 Many sensors.** Can readings from many cheap community sensors help without causing warnings or school closures from untrustworthy data alone?
- **RQ2 National and provincial standards.** Is a national standard changed through P5 inherited by every province, and can a province set a stricter value but not a looser one?
- **RQ3 A chronic hazard.** Can the system warn for five months with no day over the standard left without a warning, and without sending new Alerts again and again until people tune out?
- **RQ4 Quotas and enforcement.** Are burn permits counted against a quota per area per day and against the forecast, and is case evidence kept in full?
- **RQ5 Sensitive and long-lived data.** Is health data separated, kept only with consent and destroyed at the end of the season, and do months of readings leave the disk unfilled?

1.5 Contributions

1. A summary of the real season and how it differs from sudden hazards, with requirements R31–R40 (Sections 2 and 3).
2. The 37-node e4 layout, three new apps, and predictions before running (Section 4).
3. The first run on core C7 and its two gaps, traced to their causes in the code (Section 5).
4. Core round C8: threshold direction and P5 quotas, with the reruns (Section 6).
5. Final results, lessons, and proposals for Chiang Mai and Bangkok (Sections 7 to 10).

2. The Real Season

This section summarizes the 2026 PM2.5 season from the reports cited. Some figures come from a single source; the author cites every one and has not checked them against agency data. Figure 1 shows the key events of the season as reported, alongside what happened in the HEAIN run.

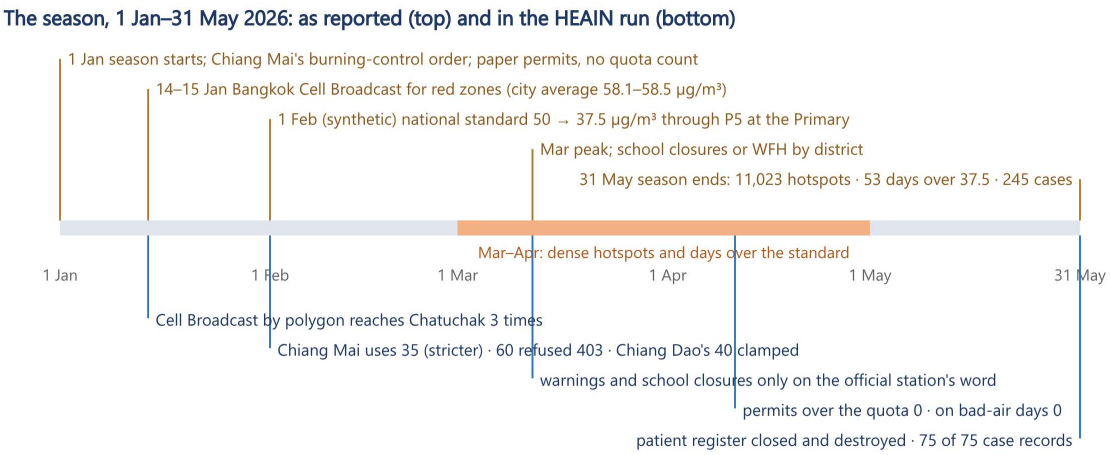


Figure 1 — The 2026 PM2.5 season as reported (top) and what the system did in the HEAIN run (bottom)

2.1 Chiang Mai

Over the season, 1 Jan–31 May 2026, Chiang Mai had 11,023 hotspots, 4,644 over target and 134% more than in 2025, mostly in forest. The districts with the most were Chiang Dao (1,532), Hot (1,173) and Mae Chaem (1,095). The area burned from January to April was 1,468,289 rai, and PM2.5 exceeded 37.5 µg/m³ on 53 days, 7 fewer than the year before [8]. The two figures together suggest that days over the standard do not depend on the number of fires in the province alone; weather and smoke from outside the province play a part as well.

Enforcement of the burning-control order produced 245 cases against 262 people [8]. Command lay with the provincial committee on forest fires and PM2.5, chaired by a deputy governor with the district chiefs as members [8]. The province is thus at once the one who warns, the one who permits burning, and the one who enforces the law.

2.2 Bangkok

On 24 January 2025 Bangkok closed 352 schools in 67 red zones, and the city's administration named burning in the surrounding areas, such as rice stubble in Nakhon Nayok, as the main cause [10]. In the 2026 season, on 14–15 January, Bangkok and DDPM used Cell Broadcast to warn people automatically as they entered red zones (Bang Rak, Pathum Wan, Sathon and Chatuchak), while the city-wide average stood at 58.1–58.5 µg/m³ [9]. Warning by location in this way is what the system in this volume must do at the level of a Zone.

2.3 Sources outside the area

Smoke comes both from within the country and across borders. Reports cite smoke from Myanmar, Laos and Cambodia [11], and one news report cited 573 hotspots in the country in a single day [13]. The hazard is thus like the water that crossed the Hok Wa canal in Volume 4: the data that gives early warning lies outside the warner's area. The system must carry hotspots in forest districts or neighbouring provinces as evidence to the areas that will be affected.

2.4 Law and standards

The clean-air bill passed the House of Representatives in October 2025 and then stalled in the Senate; the House was dissolved in December 2025, and on 15 May 2026 Parliament voted to take up the bill again. It is not yet law. Its reported substance includes a right to clean air, the polluter-pays principle, decentralisation to the provinces, and tracing pollution back to its source [11]. The daily PM2.5 standard is reported to have changed from 50 to 37.5 μg/m³ [12], matching the standard Chiang Mai uses to count days over. Two requirements of this volume (R32 and R36) therefore come from the direction of the bill, not from law already in force.

2.5 What differs from sudden hazards

1. **A chronic hazard.** It lasts months each year and recurs; warnings must last without people growing used to them.
2. **Sources outside the area.** Smoke comes from forest districts, neighbouring provinces and across borders.
3. **Data from many cheap sensors** that gives a detailed picture but is not trustworthy on its own.
4. **Rules at two levels.** A national standard, and decentralisation that lets provinces be stricter.
5. **Enforcement.** Burn permits under a quota, and cases that need evidence.

3. Requirements

The five characteristics become ten requirements (R31–R40) [6], following R1–R30 of the earlier events. Table 2 shows each requirement and the prediction before running against core C7.

#	Requirement	Prediction against core C7
R31	Cheap community sensors (untrusted) need an official station (trusted) to confirm before a red warning or a school closure	pass (two-source corroboration, C1)
R32	The national standard changes (50 → 37.5) through P5 at the Primary and is inherited by every province; a province may be stricter but not looser	probable gap: inheritance and locks exist, but no rule that a lower tier may only tighten
R33	A chronic hazard: a cap on messages per area per day, with Update and Cancel, so people do not tune out	pass (cap app from E2)
R34	Warning by location on entering a red zone: the system sends the polygon and level to the gateway	pass
R35	Satellite hotspots and burning in neighbouring provinces or across borders are evidence for Bangkok or Chiang Mai	pass (evidence at the Primary; evidence.reach from C5)
R36	Burn permits under a quota per area per day and the forecast; requests over the quota or on bad-air days wait for an approver	probable gap: P5 decides one request at a time, with no count per area per period

#	Requirement	Prediction against core C7
R37	School closures or WFH by district on one rule for the whole province; who ordered it, on what data, can be traced	pass (P5 lane 2, corroboration, audit)
R38	Enforcement: photos and coordinates of fires as evidence, time-stamped, with a chain of custody	pass (TSA, custody, legal hold)
R39	Health data (COPD patients, masks handed out) separate from environmental data, kept locally and used by consent	pass, but never tested
R40	Months of readings from every sensor: retention, roll-ups, a Micro Node's disk not filling up	pass, but never tested over months

Table 2 — Requirements from the PM2.5 season and predictions before running

The author decided that R32 and R36 would run as expected gaps, so the gaps were recorded before being fixed, as in Volume 5, and that new apps would be built for R36 and R39 [6].

4. Simulation Design

4.1 Layout e4

Layout e4 is the 29-node base layout of Volume 1 plus 8 nodes (Figure 2). Chiang Mai province (sec-cm) stands for the provincial committee. Mueang district is where people breathe the smoke, with an official station and a gateway for 30 community sensors. Chiang Dao district has the most hotspots, with a fire watch and the burn-permit register. Bangkok uses its existing Zones: Chatuchak for the red zone, and Khlong Sam Wa, where smoke comes from farmland outside the city.

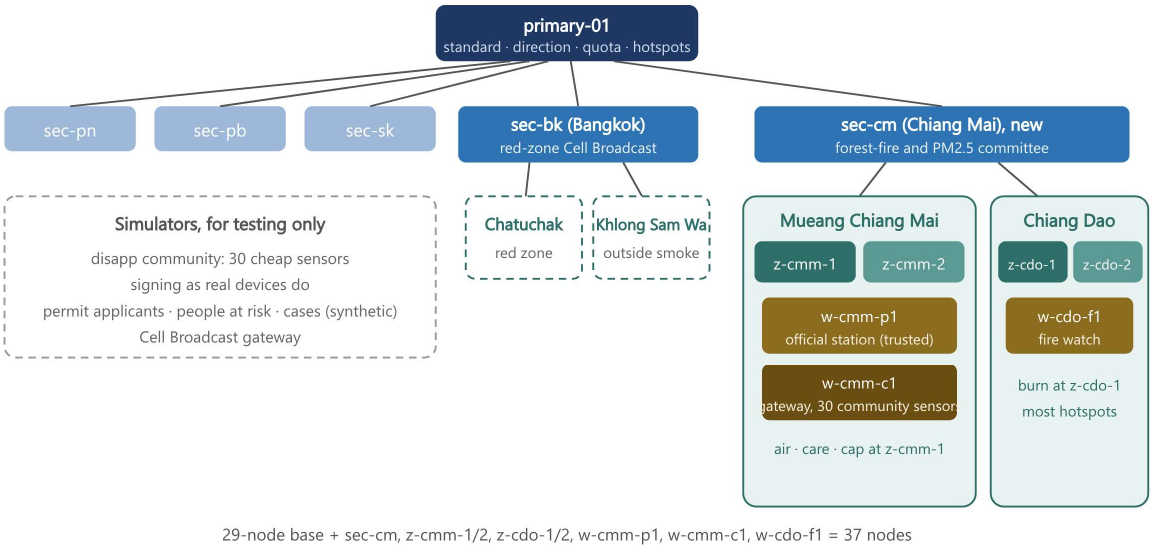


Figure 2 — The 37-node e4 layout: Chiang Mai and Bangkok

Node	Role	Real-world counterpart
sec-cm	New province under the Primary: the province's approvers, witness and thresholds	Chiang Mai's forest-fire and PM2.5 committee
z-cmm-1, z-cmm-2	Zone office and standby	Mueang Chiang Mai district
z-cdo-1, z-cdo-2	Zone office and standby	Chiang Dao district (1,532 hotspots)
w-cmm-p1	Official-station Micro Node (trusted)	Air-quality monitoring station in the city
w-cmm-c1	Micro Node gateway for 30 community sensors (untrusted)	Community network of cheap sensors
w-cdo-f1	Fire-watch Micro Node	The district's forest-fire control point
sec-bk, Chatuchak and Khlong Sam Wa Zones (existing)	Bangkok and the Zones that receive location-based warnings	Red zone and city edge
primary-01 (existing)	National standard, threshold direction, quotas and satellite hotspots	Central agencies

Table 3 — Nodes added in layout e4 and existing nodes with a role in the season

4.2 Timeline

The season, 1 Jan–31 May 2026, runs at 1 day = 1 minute, with readings as hourly averages, 24 per minute of the run. A full run takes about 2.5 hours; a trial uses 15 seconds per day. Table 4 shows the key dates on the same clock.

Real date	Simulated minute	Event
1 Jan 2026	0	Season starts on the national standard of 50 µg/m³; Chiang Dao sets its own warning threshold at 40
14–15 Jan	13–14	Bangkok warns red zones by Cell Broadcast
1 Feb (synthetic)	31	National standard changes to 37.5 through P5 at the Primary
Feb	31–58	Chiang Mai proposes thresholds of 35 and 60 through the province's P5
Mar–Apr	59–119	Peak: dense hotspots, most burn requests, school closures or WFH by district
Whole season	0–150	375 burn-permit requests, 75 burning cases, 40 people at risk
31 May	150	Season ends: case records checked, patient register closed through P5, disk and reading retention checked

Table 4 — Real dates and simulated minutes of the season

4.3 The event's apps

- **disapp cap** CAP 1.2 templates [5] for PM2.5 (orange watch, red warning, school closure), with a cap per Zone per day and polygons sent to the gateway; the same app as in E2.
- **disapp feed** The official station, satellite hotspots and the fire watch's reports in one app with three capabilities (hotspot.report, air.station, fire.watch), because core accepts one manifest per app per version.
- **heain-sensor** takes the readings of the 30 community sensors at w-cmm-c1 and labels them untrusted.
- **disapp air (new)** The community register at the Mueang Chiang Mai office. It reads heain-sensor as one of its readers and labels air.community an untrusted_source, so the data helps show the picture, but P5 approves a warning or a school closure only with a report from the official station.
- **disapp burn (new)** Burn permits as P5 proposals of type burn.permit with a Zone and a date, checked against the forecast. The app can count the quota but cannot enforce it. Burning cases form a chain of custody at every step under a legal hold. The register runs at the Chiang Dao office (z-cdo-1).
- **disapp care (new)** People at risk, sealed under their own Zone key and kept only with consent; counts per district leave through P7, and the register is destroyed at the end of the season through P5.
- **Simulators for testing only** disapp community (30 cheap sensors signing as devices do), permit applicants, and the Cell Broadcast gateway.

4.4 The as-it-happened run

Warnings go out by hand with generic text and no cap; every day over the standard is a new Alert. Permits are paper, with no quota count and no look at the forecast. Cheap-sensor readings are read as if official, so some warnings or school closures come from the sensors alone. Standards are set province by province by changing local values, and cases have no chain of custody, so their records are pruned with ordinary audit retention.

4.5 The HEAIN run

Red warnings and school closures rest on confirmation from the official station (Figure 3). Community readings still help, by showing where the smoke is in the city, but cannot approve a warning themselves. On days when readings stay over the threshold, messages are Updates under the cap. Hotspots are evidence that reaches the affected Zones. Standards change through P5; burn permits go through P5; cases have custody; health data stays in the Zone with consent; and readings are pruned by retention.

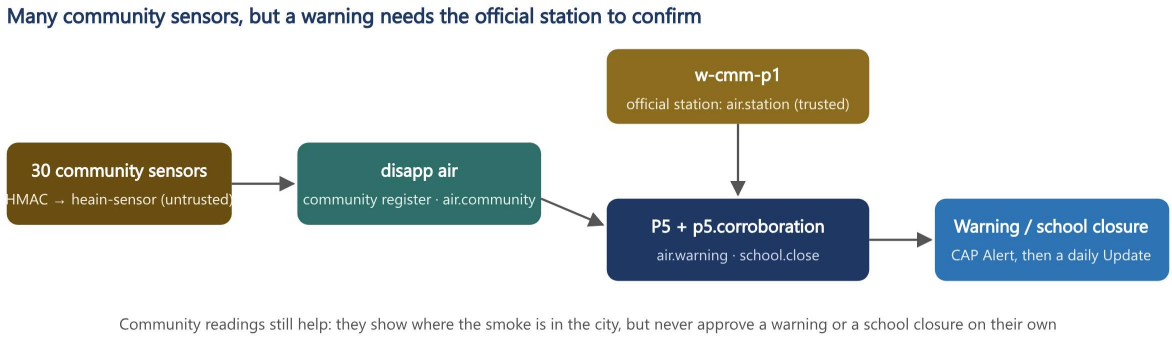


Figure 3 — Community sensors and the official station in the HEAIN run

4.6 Procedure and pass criteria

The step script first runs regressions: rounds 0–5b on the base layout and the trials of Hat Yai (E1), Bangkok (E2) and the earthquake (E3). It then runs the trials and the full runs of both modes, and commits only when every run has zero failed checks. Expected gaps do not count as failures but are recorded in the results as GAP (expected). Before building the image, the script starts disapp in every mode once to catch start-up errors. Every check uses evidence the system records itself: the audit chain of every node, the simulated gateway's log, the apps' databases, and each run's metrics.json.

5. First Run (core C7)

5.1 What the runs before the commit found

The step script ran five times before it passed. Every problem lay in the case study, not in core: main.go declared the -window flag twice, so disapp crashed at start-up (renamed -lookback, and every mode is now started before the image is built); lib.sh had no port for sec-cm; two official apps

at the Primary used different manifests and collided (app_id_conflict), so they were merged into the single disapp feed; and the R32 check read config through a function that printed Python syntax instead of JSON.

5.2 Full-run results

The full run on core C7 (cb86f51; e4 commit 2d85b63) passed 12 of 12 checks as it happened, and 24 of 24 with HEAIN, with the two expected gaps (R32, R36). The trials at 15 seconds per day gave the same results. Every regression passed: rounds 0–5b (25, 53, 31, 56, 39, 26, 34) and the trials of Hat Yai (22 and 34), Bangkok (11 and 26) and the earthquake (13 and 26). Table 5 shows the first run.

Measure	As it happened	With HEAIN
Days the Mueang Chiang Mai official station was at or over the standard	53	56 (on the stricter 35)
Warnings on cheap sensors alone	9	0
Days over the standard without a warning	0	0
Messages to Mueang Chiang Mai: all / new Alerts / Updates / Cancels	62 / 62 / 0 / 0	61 / 5 / 51 / 5
Most messages in one day	1	1
School closures: all / on cheap sensors alone	39 / 8	31 / 0
Bangkok's Cell Broadcasts to Chatuchak	2	3
Burn permits at Chiang Dao: requested / granted	375 / 375	375 / 342
Permits granted on bad-air forecast days	33	0
Permits granted over the quota (10 a day)	41	41 (gap R36)
Burning-case records on 31 May	0 of 75	75 of 75 (legal hold)
Readings kept by one cheap sensor (30-day retention)	1,457	1,466 (bound 2,232)

Table 5 — First run on core C7: as it happened compared with HEAIN

Predicted to pass. R31, R33, R34, R35, R37 and R38 passed, and R39 and R40, predicted as "pass, but never tested", both passed too. R39: the register kept 37 people who consented; 3 who did not were refused (403) and nothing of theirs was kept; counts reached the Primary through P7 with small groups suppressed; and on 31 May the register was closed through P5 and the Zone key destroyed (410). R40: heain-sensor's hourly sweep deleted about 65,000 readings past retention, and one sensor kept about 1,460 readings, below the calculated bound.

In the as-it-happened run, all 75 case records were gone by 31 May, pruned with ordinary retention along with 1,925 other records. In the HEAIN run the legal hold kept every case record, while 1,614 other records were still pruned as usual. Keeping evidence did not mean keeping everything forever.

5.3 Gaps

Code	What was seen	Cause in the code
R32	37.5 passed P5 at the Primary and every province took it. Chiang Mai could set a stricter 35, but when it proposed a looser 60, the province's approver approved it and sec-cm took that value	A lower tier inherits the higher tier's value as a default and may override it through its own P5. The only limit is config.locked_keys, which forbids both looser and stricter values, and a lower tier's p5.thresholds replaces the whole map
R36	No permits on bad-air days, because p5.thresholds released them only when the forecast was at most 50; but on good-air days 41 permits on 9 days were approved over the quota of 10 a day	P5's rules look at one proposal at a time: type, value and allowlist. Nothing counts what has already been approved. A counter in the app is no control, because the app is the one asking

Table 6 — Gaps from the first run

One subtlety concerns "stricter". For a protective action, such as air.warning and school.close, stricter means a wider automatic range: warning from a lower level. For a permissive action, such as burn.permit, stricter means a narrower range: fewer permits that pass without a person. The rule must therefore know each type's direction. Locking the key alone does not work, because it would stop provinces from tightening too.

6. Core Round C8 (3329b2f)

The author decided the four questions as recommended: fix at once as core round C8; make R32 a per-type direction on p5.thresholds; make R36's period a fixed window from an anchor; and have a request at the quota wait for an approver instead of being refused [6].

6.1 R32: p5.threshold_direction

1. **The new key.** p5.threshold_direction maps each action type to protective or permissive. It changes only through P5. It is inherited and accumulates downwards: a lower tier may add a rule for a type the higher tier left out, but cannot remove or flip an inherited direction.
2. **The rule.** For a protective type, the lower tier's range must contain the inherited range. For a permissive type, it must lie inside it.
3. **Where it is checked.** When proposed (Check), a value breaking the rule is refused with 403 looser_than_parent and both ranges, so no one is asked to approve what core will not apply. When applied (planLocked) it is checked again, because the inherited value may have changed while waiting.
4. **When the higher tier moves later.** If a province's value becomes looser, the effective range for that type is the inherited range (clamped); other types are unchanged, and core records config.override_clamped once per entry.

5. **Missing types.** For a type with a direction, a lower tier's map that leaves the type out gets the inherited range instead of no rule at all.

In code the rule lives in config.Field.Guard, config.ThresholdGuard and config.DirectionMapField. Figure 4 shows the rule's effect on the warning thresholds in the run.

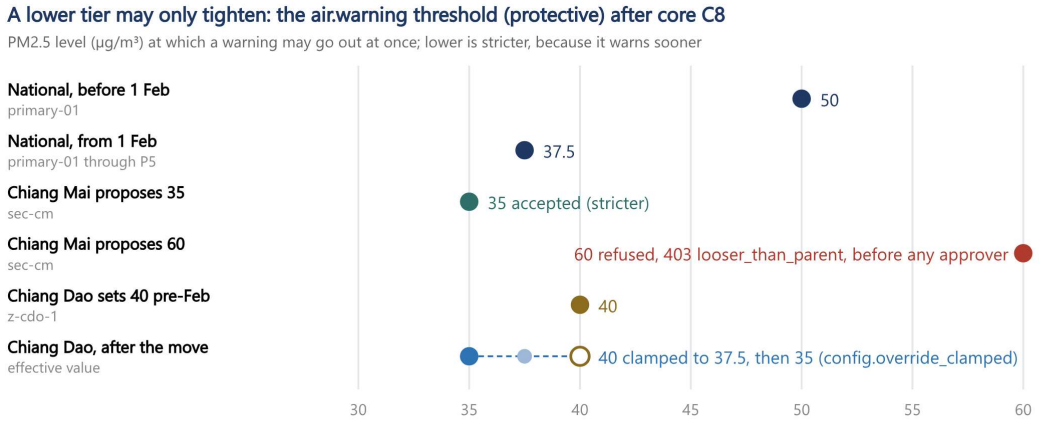


Figure 4 — Threshold direction after C8: stricter accepted, looser refused, and a value that became looser clamped

6.2 R36: p5.quota

1. **The new key.** p5.quota maps each type to max, period and anchor, counted per zone_id. Periods are fixed windows [anchor + k·period, anchor + (k+1)·period) on the node's clock; an anchor at midnight Thai time makes them calendar days. The app cannot shift the window, because the day a request counts in belongs to core.
2. **The check.** A proposal a rule would approve at once (threshold, allowlist or corroboration) passes at once only while the Zone's count for the period is below max. At the quota it waits for an approver, with quota_reached in its audit details, which the app cannot set. An approver may still approve it, and that decision is recorded with a name.
3. **What counts.** Every approval of the type in the Zone in the period: automatic, by corroboration, or by an approver. The count lives in P5's store (bbolt bucket p5_quota), so it survives a restart. The check and the count are one step under a lock, so two simultaneous requests cannot both take the tenth place, and old periods are deleted.
4. **Unchanged.** Types without a quota behave as before, and a quota never lets through a request that would otherwise wait.

Known limit. P5's store is per node and not replicated. A standby that takes over a Zone office counts from its own store and starts from zero for the rest of the period. E4 did not test this case, and this volume proposes fixing it before real use (Section 9).

6.3 The C8 runs

In e4.sh the Primary sets p5.threshold_direction (air.warning and school.close protective, burn.permit permissive) and p5.quota for burn.permit (max 10, a period of one day of the run, anchored when the rule is set), and T0 is placed on a period boundary. Chiang Dao sets its own warning threshold at 40 before 1 February to test the clamp.

Run 1. Every regression passed: gofmt, the apps, the SDK, notify and sensor, cross-builds for 7 targets, vet, unit tests (including seven new ones such as TestThresholdGuard, TestQuota and TestQuotaStore), conformance, live tests 51 and 37, the 19 live regressions with test_cert_last_known and test_license, the southern border rounds 0–5b, CineNexus rounds 1, 2, 3, 6 and 7, this case's rounds 0–5b, and the trials of E1 (22 and 34), E2 (11 and 26) and E3 (13 and 26). E4's as-it-happened trial passed 12 of 12. The HEAIN trial passed both R32 checks but stopped at R36: 19 of 41 held, and 31 over the quota. The cause lay in the run, not in core. At 15 seconds per day, a busy day's requests, sent one at a time from 0.72 of the day, spilled past the period's boundary, so the end of one day was counted in the next day's period.

Run 2. Core was byte for byte the same as in run 1 (checked by hash 3d602f8d3da41436), so run 1's regressions stand. e4.sh now sends each day's requests from 0.20 of the day and records the time taken. The result: 12 of 12 as it happened, 28 of 28 with HEAIN and no gap, with the same results in the trials (Figure 5). The next day both trials passed again as regressions of core C10 (9d09746).

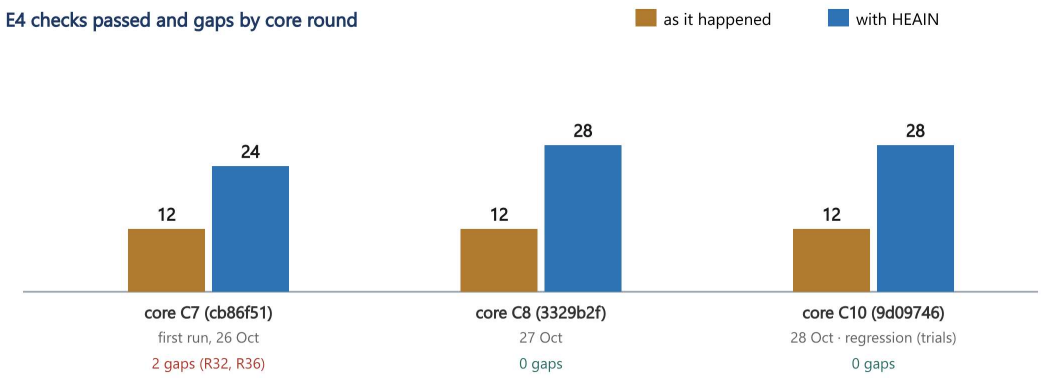


Figure 5 — E4 checks passed and gaps by core round

7. Final Results

7.1 As it happened versus with HEAIN

After C8 the as-it-happened run passed 12 of 12 checks and the HEAIN run 28 of 28, with no gap. Table 7 shows the final results, Figure 6 the warnings at Mueang Chiang Mai, and Figure 7 the burn permits at Chiang Dao in the three runs.

Measure	As it happened	With HEAIN (C8)
Days the Mueang Chiang Mai official station was at or over the threshold	53	56 (threshold 35)
Warnings on cheap sensors alone	9	0
Days over the threshold without a warning	0	0
Messages to Mueang Chiang Mai: all / new Alerts / Updates / Cancels	62 / 62 / 0 / 0	61 / 5 / 51 / 5
School closures: all / on cheap sensors alone	39 / 8	31 / 0
Bangkok's Cell Broadcasts to Chatuchak	2	3
Burn permits: requested / granted	375 / 375	375 / 301
Permits on bad-air forecast days	33	0
Permits over the quota / held for an approver at the quota	41 / –	0 / 41
Provincial standard looser than the nation's (Chiang Mai 60)	not tested	refused 403 before any approver
Chiang Dao's value that became looser when the nation moved	not tested	clamped 40 → 37.5 → 35 and recorded
Burning-case records on 31 May / other records pruned by retention	0 of 75 / 1,923	75 of 75 / 1,671
Readings kept by one cheap sensor (30-day retention)	1,457	1,495 (bound 2,232)
Checks passed / gaps	12 / 0	28 / 0

Table 7 — Final E4 results on core C8: as it happened compared with HEAIN

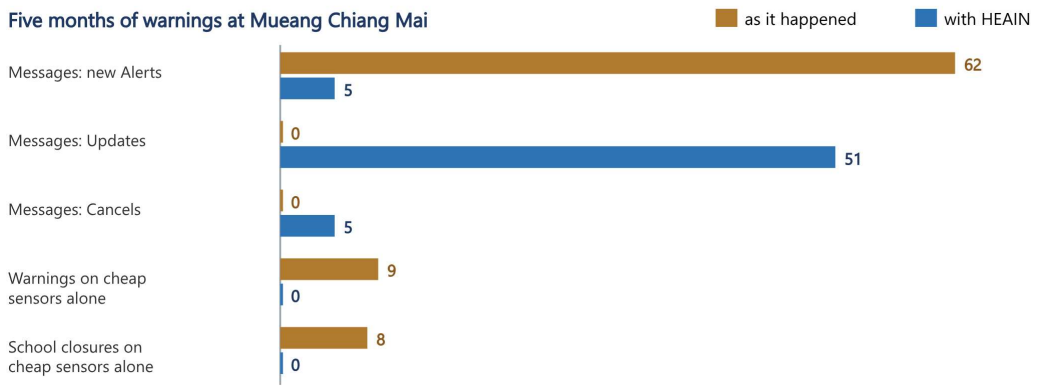


Figure 6 — Five months of warnings at Mueang Chiang Mai in the two runs

The total number of messages is almost the same (62 and 61), but their meaning differs greatly. As it happened, every day over the threshold was a new Alert, so people received a "new event" 62 times in five months. With HEAIN there were new Alerts only when an episode began (5), Updates on the

days it continued (51), and Cancels when it passed (5). No day had more than one message in either run. The HEAIN run counts more days over the threshold at the official station (56 against 53) because Chiang Mai uses a threshold of 35, stricter than the national standard, which is exactly what decentralisation is meant to allow.

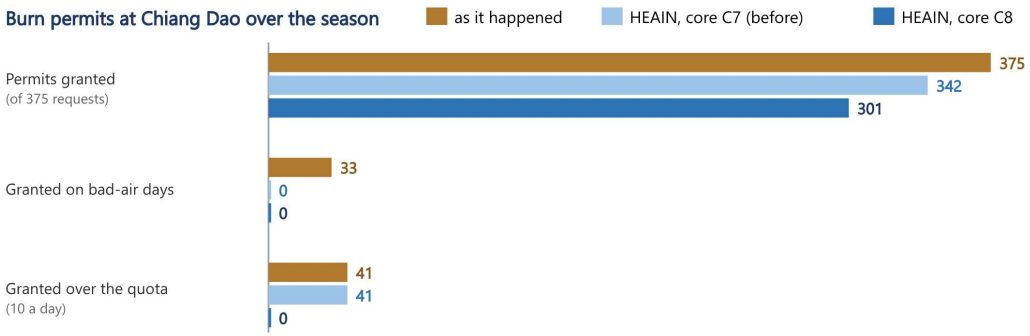


Figure 7 — Burn permits at Chiang Dao in the three runs

The 41 requests over the quota on good-air days waited for an approver with quota_reached and were refused by the district at the end of the day, so permits granted fell from 342 to 301. Waiting for an approver rather than refusing automatically has a reason: a genuine need, such as a controlled burn to make a firebreak, still has a way for a person to decide and answer for it by name, but nothing slips through silently.

7.2 Results by requirement

#	Result	Evidence
R31	passed	Warnings and school closures on cheap sensors alone: 0 (instead of 9 and 8)
R32	passed (C8)	37.5 through P5 at the Primary; Chiang Mai's 35 accepted; 60 refused 403; Chiang Dao's 40 clamped and recorded
R33	passed	5 new Alerts, 51 Updates, 5 Cancels; at most one message a day; no day over the threshold without a warning
R34	passed	Cell Broadcast by polygon reached Chatuchak 3 times
R35	passed	Hotspots were evidence at the Primary and reached the affected Zones under evidence.reach
R36	passed (C8)	Over the quota: 0 (instead of 41); bad-air days: 0; requests at the quota waited for an approver with quota_reached
R37	passed	31 school closures on one rule for the whole province, each with the official station's evidence in the audit
R38	passed	75 of 75 case records, TSA time-stamped [14], with custody under a legal hold
R39	passed	37 who consented kept; 3 who did not refused; counts through P7; register destroyed (410)

#	Result	Evidence
R40	passed	About 65,000 readings past retention deleted; one sensor kept 1,495, below the bound of 2,232

Table 8 — Final results by requirement

8. Discussion

8.1 Answers to the research questions

RQ1. Community sensors were used to show where the smoke was, but warnings and school closures happened only when the official station confirmed, so warnings on cheap sensors alone were zero. **RQ2.** After C8 the national standard is a floor: provinces may be stricter, a looser value is refused before reaching an approver, and a value that becomes looser when the nation moves is clamped and recorded. **RQ3.** Five months used 5 new Alerts and 51 Updates instead of 62 new Alerts, and no day over the standard went without a warning. **RQ4.** After C8, permits over the quota and on bad-air days were zero, and every case record was kept. **RQ5.** Health data was kept only with consent, counts left through P7, and the register was destroyed at the end of the season; months of readings were pruned by retention without filling the disk.

8.2 Lessons

- **Decentralisation needs a direction.** Locking a key forbids both looser and stricter values; not locking allows both. The decentralisation the clean-air bill intends needs a third way: a lower tier may move in one direction only, and "one direction" differs between protective and permissive actions. The principle extends Role Ceiling in the theory of structural immunities [4], where a lower tier gets no more authority than the tier above sets.
- **A counter in the app is no control.** The app asking for permits cannot do the counting. The quota must sit with the one who decides, and the time window must belong to core, not to a value the requester sends.
- **Cheap sensors are valuable in the right place.** Community readings give the local detail an official station cannot, but letting them approve warnings themselves produced 9 warnings and 8 school closures with no official confirmation.
- **A chronic hazard needs Updates, not Alerts.** The same number of messages has very different effects. A new Alert every day tells people there is something new every day; an Update says the same event continues and how it has changed. This matches the principle of Escalation Saturation that prevents Alert Storms [4].
- **Window boundaries are real.** The first C8 run stopped because a busy day's requests spilled across the day's boundary. In real use, a request at midnight will likewise count in the new day. A rule that states clearly when a day begins matters as much as the size of the quota.

- **Evidence must be separate from ordinary retention.** As it happened, every case record vanished with the ordinary records. A legal hold keeps only what must be kept and lets the rest be pruned as usual.

8.3 What HEAIN did not fix

HEAIN does not reduce burning, does not stop smoke from across borders, and does not bring the clean-air bill into force. The system makes existing rules work consistently and traceably, and makes the decentralisation the bill intends technically enforceable once the law arrives. Health data remains subject to the PDPA [15], and using data to care for people at risk needs a legal basis or consent. Whether warnings change people's behaviour, the simulation does not measure.

8.4 Threats to validity

Internal. Hourly readings, community sensors, requests and bad-air days were generated at a scale close to what was reported, but are not the season's real data. **External.** One machine and a virtual network; and the trial at 15 seconds per day showed that window boundaries are sensitive to compressed time. **Measurement.** One full run per mode, with the trials giving the same results. **Context.** The two added rules (direction and quota) rest on the substance of a bill not yet in force, and the 37.5 standard is the reported value, not checked against the actual notification.

9. Proposals for Chiang Mai and Bangkok

These proposals come from the results of this volume, together with the design's pilot plan [7], and still need to be discussed with the agencies concerned.

- **Threshold direction declared nationally.** p5.threshold_direction for PM2.5 warnings, school closures and burn permits, set together with the national standard, so provinces can always be stricter and never looser.
- **Burn-permit quotas in core.** p5.quota per district per day, anchored at midnight Thai time, with applicants told when the day begins.
- **Community sensors as supplementary data.** Registered through heain-sensor, labelled untrusted, with the official station as the one who confirms.
- **Cross-area evidence rules.** evidence.reach from forest districts to Mueang, and from neighbouring provinces to Bangkok.
- **Templates that favour Updates.** PM2.5 warnings use an Alert when an episode begins, daily Updates, and a Cancel when it passes.
- **Replicated quota counts.** Before real use, C8's limit must be fixed so a standby that takes over continues the existing count.

Indicator	Target
Warnings or school closures on cheap sensors alone	0
Days the official station is over the threshold with no warning in force	0
Provincial standards looser than the nation's in force	0
Permits over the quota without an approver	0
Case records lost before the case ends	0
Patient data left after the season ends	0 (confirmed by observers)
Ratio of Updates to new Alerts in a chronic hazard	tracked each season

Table 9 — Proposed indicators

10. Limitations

- **It is a simulation.** Every node runs on one machine, and the Cell Broadcast gateway is a simulator.
- **Synthetic data.** Readings, community sensors, permit requests, daily forecasts, cases and patients were generated.
- **A synthetic date.** The change of standard happens on 1 February in the simulation, not on the real date of the notification.
- **Law not in force.** R32 and R36 rest on the direction of the clean-air bill, which is not yet law.
- **Two districts.** Only Mueang Chiang Mai and Chiang Dao, and two Bangkok Zones, are simulated in detail; other northern provinces and cross-border smoke are not modelled as nodes.
- **Quota counts not replicated.** If a standby takes over, the count starts again from zero for the rest of the period.

11. Evidence and Reproducibility

The relevant commits are confirmed with git ls-remote: 2d85b63 (layout e4, apps and the first e4.sh run), 3329b2f (core C8; docs 4cb29df) and 9d09746 (core C10, against which the E4 trials passed as regressions). Each round's results are in the progress log and the project's plan and proposal documents [6].

To reproduce, check out heain-core commit 3329b2f, set DIS_LAYOUT=e4, run casestudies/disaster/sim.sh build and up, then run e4.sh in asis and heain modes with E4_SEC_PER_DAY=60 for a full run, or 15 for a trial. The test machine needs only Go and Docker.

File on the test machine	Contents
/mnt/xfs_nvme/heain-dis0/sim/e4-asis, e4-heain	metrics.json of each run, every node's log, and the audit chains
~/dis_e4*.out	Results of the first run and the trials
~/c8.out, ~/c8b.out	Results of core round C8 with regressions
casestudies/disaster/e4.sh, apps/	The event script and the air, burn, care and community apps
docs/progress-log.md	Each round's results with its commit

Table 10 — Evidence files for E4

12. Conclusion

Replaying the 2026 PM2.5 season shows that HEAIN handles a chronic hazard with the same mechanisms as sudden ones: rules agreed in advance, evidence that can be checked, and records that are kept in full. Community sensors were used without letting them approve warnings; five months of messages were mostly Updates rather than new Alerts; and health data was kept only with consent, then destroyed. The season exposed two gaps that bear directly on decentralisation: rules without a direction, and a P5 that did not count. Core C8 closed both. Provinces may be stricter than the nation but not looser, and permits over the quota fell to zero. After C8 every event series, E1–E4, runs with no gap. The remaining volumes (tsunami, landslides, southern storms and the Chiang Rai flood) need their real events replayed before they are written in the same form as this one.

References

[1] Boonma, J. "The National Disaster-Warning Case Study on heain-core, Volume 1: Overview." 27 October 2026 (companion paper).

[2] Boonma, J. Volume 4 (the Bangkok flood, 2026), Volume 5 (the Hat Yai flood, 2025) and Volume 7 (the earthquake of 28 March 2025) of this report series. 2026 (companion papers).

[3] Boonma, J. "HEAIN Framework: An Infinitely Scalable Fractal Intelligent Network Seamlessly Linking Cloud and Edge AI, Resilient to Failure and Multi-Dimensional Fraud." 2026 (companion paper).

[4] Boonma, J. "The Triad of Structural Immunities: A Theoretical Framework for Preventing Cascading Failures, Authority Creep, and Alert Storms in Fractal Edge AI." Zenodo, 2026. DOI: 10.5281/zenodo.23172868

[5] OASIS. "Common Alerting Protocol Version 1.2." OASIS Standard, 2010.

[6] Boonma, J. "docs/progress-log.md." heain-core repository, 2026; and the project documents claude/study-2026-10-17-disaster-three-events, claude/plan-2026-10-26-disaster-e4-pm25 and claude/proposal-2026-10-27-disaster-e4-core.

[7] Boonma, J. "HEAIN Disaster Summary v3: A National Disaster-Warning System on the HEAIN Framework." Author's design document, 15 October 2026 (in Thai).

[8] Chiang Mai News. Summary of the forest-fire and PM2.5 situation in Chiang Mai, 2026. 3 June 2026 (in Thai).

[9] Time Out Bangkok. Cell Broadcast red-zone PM2.5 warnings. 15 January 2026.

[10] PPTV. Bangkok closes 352 schools over PM2.5. 24 January 2025 (in Thai).

[11] Lowy Institute. "Hazy future: Thailand's clean air bill." The Interpreter, 26 May 2026.

[12] Thai PBS World. Report on the change of the PM2.5 standard to 37.5 µg/m³.

[13] The Nation. Report of 573 hotspots in the country. 2026.

[14] Adams, C., Cain, P., Pinkas, D., and Zuccherato, R. "Internet X.509 Public Key Infrastructure Time-Stamp Protocol (TSP)." RFC 3161, IETF, 2001.

[15] Personal Data Protection Act, B.E. 2562 (2019), Thailand.

Author and copyright holder: Mr. Jakkrit Boonma (Independent Researcher) | ORCID: 0009-0000-7165-3787 |

Email: jaggid.boonma@yahoo.co.th

© 2026 Jakkrit Boonma. All rights reserved. Ownership and copyright in this document belong to Mr. Jakkrit Boonma from the date of publication, under applicable copyright law.