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Reducing Material Overordering in UK Construction Projects: A NetLogo Study of Procurement Under Schedule Uncertainty

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Abstract: Ordering more material than a job needs (material overordering) can protect installation work from shortages, but it can also leave costly stock at handover. This study examines how that trade-off changes when a construction buyer revises purchase orders against a shifting work schedule. A NetLogo 7.0.4 agent-based model represents a buyer, a supplier, two installation crews, 24 work packages and an order pipeline. A fully crossed BehaviorSpace experiment compares padded bulk buying, two standard rolling order rules and a rolling policy that caps its target at remaining demand. The 12,800 runs reuse 200 matched seeds across 64 combinations of policy, schedule uncertainty, supplier lead-time uncertainty, pack size and lookahead. With 10-unit packs and a five-day lookahead, mean gross surplus was 16.10% of demand for padded bulk buying and 0.94% for capped rolling buying. Under high schedule and lead-time uncertainty, 70.0% of capped rolling runs still had at least one material stoppage, although mean additional completion time was only 0.30 working days. Extending the lookahead to eight days eliminated observed stoppages in that scenario but raised mean peak stock from 127 to 215 units. The cap's surplus result follows from known demand and pack rounding; it is not a measured industry saving. The study supports testing procurement rules against both material and service outcomes and identifies the project records needed to validate the model in practice. For engineering project management, it frames waste prevention under SDG 12 as a measurable procurement decision rather than a downstream recycling outcome.

Keywords: *Construction Procurement; Material Overordering; Engineering Project Management; Schedule Uncertainty; Agent-Based Modelling; Netlogo; Waste Prevention; SDG 12.*

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I. INTRODUCTION

The last unopened pack on a construction site is not necessarily evidence of careless buying. It may be what allowed the team to start on time when a promised delivery moved, or it may have been added to an order without checking what was already on site. These two explanations suggest different responses. One calls for a credible buffer and better supply information; the other for tighter stock reconciliation and order control. Research on construction materials procurement identifies accurate quantity take-off, delivery management, supplier flexibility and prevention of overordering as important, but that evidence does not specify how procurement policies perform when work dates and delivery times vary together (Ajayi et al., 2017a; Ajayi & Oyedele, 2018).

The scale of the wider waste problem explains why upstream prevention merits attention, not how much a buyer can save. Defra's September 2026 release provisionally puts England's 2024 construction, demolition and excavation (CD&E) waste at 118.2 million tonnes, including dredging, or about 66% of the country's total waste generation. In a separate series excluding excavation, England generated an estimated 63.3 million tonnes of non-hazardous construction and demolition (C&D) waste and recovered 60.3 million tonnes, a 95.3% recovery rate. For England this recovery estimate is calculated as generation minus landfill; neither series measures unused stock attributable to overordering, and the 2024 figures are not UK totals (Defra, 2026).

The engineering project management question is whether a different order rule can reduce surplus without making the installation plan less reliable. The study takes the UK as its practice and policy context, with England explicitly identified where statistics and policy are England-specific. The simulation itself represents a fictional installation phase rather than any named site, client or material. It holds

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installed demand fixed so that an order policy cannot gain an apparent material benefit by completing less work. It does not assume that every unit of unused stock enters a waste stream.

➢ *Aim, Research Questions and Contribution*

The aim is to compare transparent procurement policies for a single, exchangeable, pack-sized material under timing uncertainty. RQ1 asks how much each policy changes unused purchased material at settlement. RQ2 asks how schedule and supplier regimes change crew interruptions and the completion lag relative to the same project with unlimited stock. RQ3 asks how pack size and buyer lookahead alter those trade-offs. The contribution is a reproducible work-package experiment joining a material ledger to a schedule-service measure, rather than an estimate of how much UK construction waste is caused by overordering.

The study anticipated three mechanisms. First, a target capped at the total quantity still to install should leave no surplus beyond pack rounding when demand is exact and material cannot be lost. Second, a buffer can protect some crews against longer delivery times, although it need not protect the finish milestone. Third, a longer lookahead should reduce exposure to long lead times at the cost of more inventory on site. These are mechanisms to examine within the model, not pre-registered claims about actual contractors.

II. LITERATURE REVIEW AND RESEARCH RATIONALE

➢ *Why Procurement, Rather than Construction Waste as a Whole?*

Waste prevention starts before the skip. Design decisions and design changes may produce offcuts or make previously specified stock redundant; poor handling and storage can damage otherwise usable material. Ordering decisions produce a different exposure: the site may take ownership of more valid, usable material than it needs to install. Research on architects' perspectives shows why waste should be designed out upstream, while procurement research highlights purchasing, supplier practices, delivery and bills of quantities as distinct points of intervention (Osmani et al., 2008; Ajayi et al., 2017a; Ajayi et al., 2017b).

A quantity surveyor's allowance is not intrinsically overordering. A bill of quantities or checked take-off may include a legitimate allowance for cutting, breakage or tolerances. Here, "15%" is an assumed contingency on top of exact simulated installation demand; it is not an industry norm or a recommendation. The distinction matters: if material losses are real but omitted from the demand basis, a cap calculated on installation quantities alone can understate the requirement. A field model would separate justified consumption allowances from uncertainty buffers and track product disposition after closeout.

Procurement connects information, product and cash flows between organisations, rather than simply transferring material to site. Construction supply-chain research treats the supply-chain/site interface as a problem in its own right; Donyavi and colleagues' qualitative work with three firms and observations across 19 projects in South East England identifies difficulties with planning, tracking stock and synchronising supply with site needs. Those studies justify the modelling of these mechanisms but provide no probability distribution for the hypothetical project in this paper (Vrijhoef & Koskela, 2000; Donyavi et al., 2024).

➢ *Why Introduce Schedule Uncertainty?*

Project controls bring together scope, time, cost, risk, change and information. A baseline programme is needed for comparison, but procurement needs a current forecast of work release and remaining material. A critical-path model is appropriate for assessing an integrated network; it does not on its own say when an individual buyer should place an order or whether two crews can draw on the same stock on the same day (Association for Project Management, n.d.-a; Association for Project Management, n.d.-b).

Lean construction gives a complementary explanation. Lookahead planning makes assignments ready by removing constraints before commitments are made. The Parade Game illustrates how variable work and dependencies can reduce throughput even when average production seems adequate. This study borrows the ideas of a visible readiness horizon and a resource buffer; it does not implement a full Last Planner System or a precedence network. Work packages may be postponed and, once released, share a limited stock pool. A procurement decision can therefore delay a crew even when overall installation demand is unchanged (Ballard, 2000; Tommelein et al., 1999).

➢ *Why SDG 12, and what May Legitimately be Claimed?*

Target 12.2 concerns efficient use and sustainable management of natural resources; its indicators cover material footprint and domestic material consumption. Target 12.5 addresses prevention, reduction, recycling and reuse; its official indicator is the national recycling rate and tonnes of material recycled. The model measures gross unused purchased units, not a national footprint, recycling rate or waste tonnage. Its strongest SDG link is to the prevention intent of Target 12.5: if equivalent work can be delivered without ordering a unit, that unit need not enter the project stock account. Any avoided disposal, virgin extraction or carbon emissions would require further evidence (United Nations Statistics Division, n.d.; UK SDG Data, n.d.).

Target 12.7 is relevant when public clients set sustainable procurement requirements. The Construction Playbook encourages early supply-chain involvement and takes a "comply or explain" approach for central government departments and arm's-length bodies; it is not imposed universally on all UK private projects. England's waste prevention programme and Defra's waste-hierarchy guidance support a prevention-first interpretation. Neither a supplier take-back clause nor the transfer of surplus to another site should be reported as prevented purchasing at the original site. The original order, the product's destination and its waste classification should therefore be recorded separately (Cabinet Office, 2022; Defra, 2023; Defra, 2011).

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Table 1 How the Evidence Narrowed the Topic from Construction Waste to Procurement Under Schedule Uncertainty.

Question in topic selection	Decision and consequence
What is controllable?	Focus on purchase quantity and timing, not aggregate sector waste. Keep paid-for excess separate from damage, offcuts and disposal. (Ajayi & Oyedele, 2018)
What uncertainty is tractable?	Separate when work is ready from how long supply takes. Keep quantities fixed in each paired comparison; do not silently treat rescheduling as a scope change. (Association for Project Management, n.d.-b; Tommelein et al., 1999)
What prevents a false improvement?	Report material stoppages, completion delay and peak inventory alongside surplus and order workload. The policy must deliver the identical installation scope.
What is the environmental claim?	Report an upstream project-level proxy aligned with prevention under SDG 12.5, not performance against UN indicator 12.5.1. (United Nations Statistics Division, n.d.)

➢ *Why Agent-Based Modelling, and Why NetLogo?*

Agent-based modelling (ABM) explains a system by specifying how its individual entities behave and interact. The buyer acts on known dates, inventory and purchase commitments; crews act on actual release and available stock; the supplier dispatches commitments with variable lead time. Their interaction determines which work is delayed and when the backlog clears. An aggregate stock equation is a useful check, but it cannot identify the crew whose ready job was blocked. A discrete-event model could implement all of these rules and would be a credible alternative, especially with more detailed logistics timestamps. In a different operational setting, Keshi et al. (2025) used discrete-event simulation to examine patient behaviour, patient flow and staff allocation at a vaccination centre. ABM is chosen here for explicit local information, independent state and a direct path to multiple buyers or suppliers in future work, not because this small problem is impossible to solve another way (Bonabeau, 2002).

Construction applications are not new. Min and Bjornsson used agent-based simulation to study real-time construction supply-chain information sharing; Knoeri and colleagues used NetLogo 5.0 to study demand for recycled construction materials in a Swiss market with empirically informed agent decisions. Li and colleagues used NetLogo 6.2.0 for enterprise adoption of greener practices. More recently, Kahalimoghadam and Thompson used NetLogo to assess the financial viability of construction and demolition waste recycling among government, contractors, demolition firms and recyclers. Those studies provide precedent for explicit decisions and material flows, but address different outcomes, geographies or scales. None of these particular comparisons directly tests a remaining-demand cap on project purchase orders under a changing release schedule (Min & Bjornsson, 2008; Knoeri et al., 2014; Li et al., 2022; Kahalimoghadam & Thompson, 2026).

NetLogo provides agent breeds, an observer, programmable widgets and plots, and the bundled BehaviorSpace experiment runner. The model was implemented and run in NetLogo 7.0.4, the current release at the time of writing, using both the Desktop application and the headless engine. The interface captures in Appendix A are taken from the running Desktop model. Python was used only to audit the exported data, summarise results and render figures, not to generate the runs. The literature search was targeted and narrative rather than systematic: it prioritised peer-reviewed construction and simulation studies, official UK and UN sources, and version-specific NetLogo documentation. Searches combined construction procurement and overordering, lead time and work readiness, and construction ABM and NetLogo; cross-references were used to distinguish application precedents from empirical parameter evidence (Wilensky, 1999; NetLogo, 2026a; NetLogo, 2026b).

III. METHODS

➢ *Overview, Entities and Boundary*

The model follows the Overview, Design concepts and Details (ODD) protocol. One tick is one abstract working day. One synthetic project phase contains 24 single-day jobs split equally over two crews and one common material stock. Quantities are dimensionless integer material units; a pack is an ordering multiple, not a job and not a tonne. The buyer sees the exact take-off, site stock, open purchase orders, and baseline job dates updated by the schedule signal. The buyer does not have access to future delivery shocks or to unrevealed readiness dates. The simulation omits financial optimisation, design change, breakage, expiry, returns, transport emissions, storage limits, supplier capacity constraints and shortages upstream. Packages and shipment agents carry state; the buyer, supplier and crews act on it (Grimm et al., 2020).

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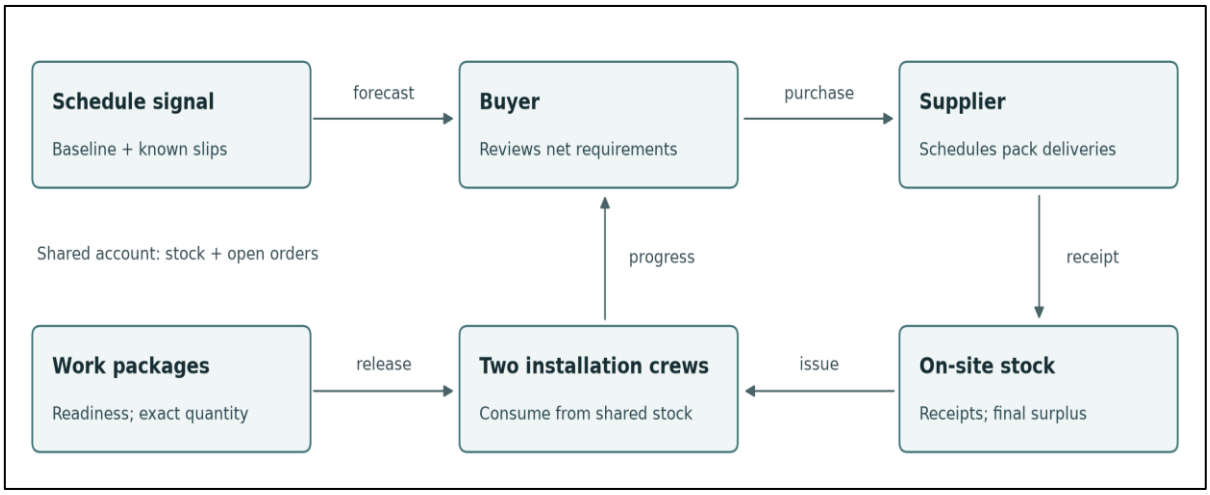


Fig 1 Agent-Based Model Structure. The Schedule Signal Updates the Buyer's Forecast; Jobs Release to Crews; Supplier Receipts Replenish the Shared Stock; Completed Work Feeds Back to the Next Order Calculation. The Buyer Also Reads Site Stock and Open Purchase Commitments Through the Shared Material Account. The Diagram is Schematic Rather than a Logistics Map.

Table 2 Agent Entities and Local Rules.

Entity	State and operating rule
Buyer (1)	Uses the chosen order-up-to rule after daily installation attempts. Nets on-site stock and all open purchase orders against the target. May submit at most one positive order per day.
Supplier (1)	Accepts each positive order in full. Records a discrete lead time by dispatch day; shipment lots can arrive out of sequence and are never cancelled.
Installation crews (2)	Each attempts at most one job from its own lane per day, choosing earliest actual release, then lowest package identifier. Crew 1 moves first; no partial issue or same-day substitution after a failed attempt.
Work packages (24)	Carry lane, baseline date, schedule information date, actual ready date, exact material quantity and installed flag. No cross-lane precedence; released work can be resequenced within a lane.
Shipments (variable)	Store issue day, due day and quantity. They move visually along a schematic track; on the due day they transfer the entire lot into shared stock and leave the simulation.
Observer and patches	The observer schedules processes and maintains the ledger. Patches display the world; distance and position have no effect on procurement, travel or productivity.

➢ *Time Sequence, Quantities and Information*

At the beginning of day t, due lots are received and the model records pre-installation inventory for the peak-stock measure. Each crew then attempts its highest-priority released job. If the full job quantity is unavailable, that attempt is blocked and the job stays open. The model records both affected days and affected crew attempts. The buyer then reviews replenishment using the updated ledger and the schedule information available that day. End-of-day stock is added to the stock-days measure, the material balances are checked, and the simulation clock advances. Installation completion is the day on which the last job is installed. The run ends only after all commitments have arrived; the settlement tick count can differ from the zero-based completion-day index.

For each seed, the model draws 24 quantities, plus the two uniform schedule values per job used for deciding whether and how long it slips. It then draws a lead time for each possible dispatch day. These draws occur at Setup, before decisions. A policy that happens to place fewer orders does not consume fewer lead draws and thereby change the supply environment faced by the next policy. The same hypothetical lot issued on the same day faces the same lead time within a matched environment. The nominal programme starts on day 8: baseline day = 8 + 2 × position within lane + lane index, where positions range from 0 to 11 and lane indices are 0 and 1. For each job, the actual date becomes known to the buyer two days before its baseline date. A postponed job remains known at its revised date; there is no second revision.

Table 3 Experimental Factors and Assumptions.

Input	Implementation and level
Work package quantity	Independent uniform integer 12–28 units; quantities identical for a given seed across all settings. Synthetic material, not a field-fitted distribution.
Schedule uncertainty	Low: each job has a 15% chance of slipping uniformly by 1–3 working days. High: 55% chance of a uniform 2–10 day slip. All remaining jobs release on baseline; no early releases.
Supplier lead-time uncertainty	Low: uniform 3–4 days. High: uniform 3–8 days. The high regime changes both the mean and dispersion; it does not identify a pure variance effect.

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Pack size	10 or 25 material units; every positive order rounds up to a full pack. This is not a separate minimum freight or minimum invoice constraint.
Lookahead	5 or 8 working days, inclusive of the endpoint. Open overdue work is included. Applied to rolling policies; crossed for the bulk comparator but not used in its rule.
Stock and starting conditions	Zero opening stock and pipeline; all jobs incomplete. The bulk order is placed on day 0, before the start of installation.
Random seeds and design	Integers 1001–1200 explicitly crossed with 64 cells. One run per seed and cell, not 200 repeats of a single seed.

➢ *Procurement Rules and Accounting*

Let U_t denote total uninstalled demand after the day's crew attempts and F_t the part forecast to be needed no later than $t + H$, where H is lookahead. Inventory position I_t is on-site stock plus the quantity in all outstanding orders; it does not weight a delivery by whether it is due in time. For target T_t and pack size P, the placed quantity is $Q_t = P\lceil \max(0, T_t - I_t)/P \rceil$. Rolling policies do not order when there is no near-term work. None of the policies orders after installation completion.

Table 4 Tested Procurement Rules for Limiting Material Overordering.

Policy	Target and timing	Why include it?
Bulk +15%	Day 0 only: round the target 1.15 × total demand up to integer units, then to the next pack.	Represents early bulk coverage with an assumed blanket allowance.
Rolling +15%	Daily review: round 1.15 × near-term demand up to integer units, then round the net requirement to packs.	Separates rescheduling and netting from the decision to retain a percentage buffer.
Rolling 0%	Daily review: target equals near-term demand before pack rounding.	Tests whether the purchasing buffer protects installation without changing the attainable final material total.
Capped +15%	Daily review: target is the smaller of remaining project demand and the rounded 115% near-term target.	Retains coverage for near-term uncertainty but disallows a deliberate buffer beyond the remaining take-off. Full-pack rounding still applies.

Material conservation is checked during every run: cumulative ordered equals cumulative received plus outstanding; received equals installed plus site stock; and total take-off equals installed plus the quantity on incomplete packages. With no losses, returns or opening stock and with every run settled, surplus is $\max(0, \text{ordered} - \text{demand})$, which equals closing stock. The paper reports both surplus units and surplus divided by total installation demand. It does not subtract stock sent to another project or equate stock with waste.

The model has a useful analytic property. At any order event for either capped or zero-buffer rolling buying, the order target is at most the entire remaining quantity. Since inventory position equals previously purchased minus installed, the net requirement is no more than total demand minus previously purchased. Cumulative purchases, being pack multiples, cannot exceed the smallest pack multiple covering total demand. As all work is later completed, that multiple is also necessary. Thus closing surplus is exactly $P\lceil D/P \rceil - D$ for these rules, where D is exact installation demand. No number of replications changes that structural result. Replication is needed for the timing, stock and order-workload outcomes and for comparators without the cap.

➢ *Experimental Design and Performance Measures*

The factorial crosses four policies, two schedule regimes, two lead-time regimes, two pack sizes and two lookaheads. Each cell has 200 runs, yielding 12,800 terminal observations. The main comparison uses a 10-unit pack and five-day lookahead; pack and horizon sensitivity is discussed separately. Low/high labels indicate designed contrasts, not estimates of how frequently those conditions occur in UK construction. The hypothetical phase is a terminating system; there is no warm-up period. An unfinished run at the 180-day guard raises an error rather than being accepted as a low-surplus outcome.

Table 5 Outcome Definitions.

Measure	Measurement rule and practical meaning
Gross surplus, units and %	Paid-for quantity minus net installed demand after settlement, divided by net demand for the percentage. This is the primary material outcome.
Any stoppage / blocked days	Share of runs with a material-blocked work attempt; blocked days count a calendar tick once even if both crews are affected. Two failed crew attempts on one day mean one blocked day and two blocked events.
Material completion lag	Actual finish minus an unlimited-stock reference finish under the same release dates and one-job-per-crew daily capacity. This is an installation-phase measure, not critical-path delay for a whole project.
Peak site stock / stock-days	Largest inventory immediately after daily receipts and before issues; sum of end-of-day site inventory. Both expose the holding implications of earlier delivery.

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Purchase orders	Count of positive orders, one delivery lot each in this model. A purchasing workload proxy, not a freight cost, actual truck count or carbon metric.

Reported means describe synthetic project paths. Within a condition, the primary contrast is the seed-by-seed difference between capped and uncapped rolling +15%, which isolates the cap more directly than the bulk comparison. An approximate 95% paired t interval uses the mean of the 200 seed-level differences and its standard error with 199 degrees of freedom. These are Monte Carlo intervals conditional on the model, not inference about construction firms, and are not multiplicity adjusted. Zero observed stoppages is a simulation observation, not a field reliability guarantee. The paired comparisons are not pooled as though the same 200 seeds were independent across factor combinations.

➢ *Verification, Reproducibility and Field Validity*

Verification asks whether the implementation obeys its own rules; validation asks whether those rules represent the intended real system sufficiently for use. Verification here included daily runtime conservation checks, terminal checks across all runs, analytic checks on sizing, seed-matching checks and a repeated full experiment with a different thread count. At settlement all 12,800 runs installed their full demand, all orders had arrived and no negative material delay was reported. Bulk purchases matched the analytic rounding formula and never blocked a crew. The two bounded rolling policies ended below one full pack of surplus in every case. Terminal metrics agreed exactly on repeat when joined by the scenario and seed keys, regardless of file row order (Sargent, 2013).

The seed 1037 high/high example makes the arithmetic inspectable. Net demand is 510 units. Bulk's 115% target rounds up to 587 units, then to 590 in full packs, leaving 80. The capped rule purchases 510 in 18 orders and finishes on day 35 despite three material-blocked days. Rolling without a buffer also purchases 510, but has seven blocked days and finishes on day 37. All three complete identical installation scope. This is a worked consistency check under a particular trace, not evidence of external validity.

Field validation was not undertaken. Interviews with a buyer and planner could challenge the information and ordering assumptions before data collection; buyer logs and numeric fit alone cannot establish operational validity if the actual work-selection rule differs. A field programme is set out after the results. Exact reproducibility for this executable does not establish realism or universal transferability.

IV. RESULTS

➢ *Surplus and Installation Service*

In the reference configuration, early padded bulk ordering was the largest purchaser: 16.10% mean surplus, about 77.64 units, with no blocked work. Its apparent service advantage is built into the scenario: an order issued on day 0 in this experiment can arrive by day 8, the earliest possible installation day, and receipts occur before work. Capped buying and rolling 0% both left 0.94% mean surplus, about 4.49 units, in all four risk combinations. Their equality follows from the pack arithmetic, not from equal installation service.

Table 6 Main Outcomes: 10-Unit Packs, Five-Day Lookahead; $n = 200$ Per row.

Schedule / supply	Policy	Surplus (% of demand)	Any stoppage (%)	Blocked days	Finish lag (days)	Orders
Low / Low	Bulk +15%	16.10	0.0	0.00	0.00	1.00
Low / Low	Rolling +15%	4.31	0.0	0.00	0.00	23.93
Low / Low	Rolling 0%	0.94	0.0	0.00	0.00	24.00
Low / Low	Capped +15%	0.94	0.0	0.00	0.00	23.37
Low / High	Bulk +15%	16.10	0.0	0.00	0.00	1.00
Low / High	Rolling +15%	4.51	99.0	5.51	0.57	23.92
Low / High	Rolling 0%	0.94	100.0	9.12	1.21	24.00
Low / High	Capped +15%	0.94	99.5	5.68	0.71	23.29
High / Low	Bulk +15%	16.10	0.0	0.00	0.00	1.00
High / Low	Rolling +15%	3.81	0.0	0.00	0.00	19.63
High / Low	Rolling 0%	0.94	0.0	0.00	0.00	20.51
High / Low	Capped +15%	0.94	0.0	0.00	0.00	19.18
High / High	Bulk +15%	16.10	0.0	0.00	0.00	1.00
High / High	Rolling +15%	3.84	69.0	1.70	0.27	19.60
High / High	Rolling 0%	0.94	95.5	4.17	0.84	20.51
High / High	Capped +15%	0.94	70.0	1.74	0.30	19.16

Table note: All continuous summaries are means; "any stoppage" is the percentage of runs with at least one blocked day. Values are rounded from unrounded run data. Rounded differences need not equal the paired difference reported below.

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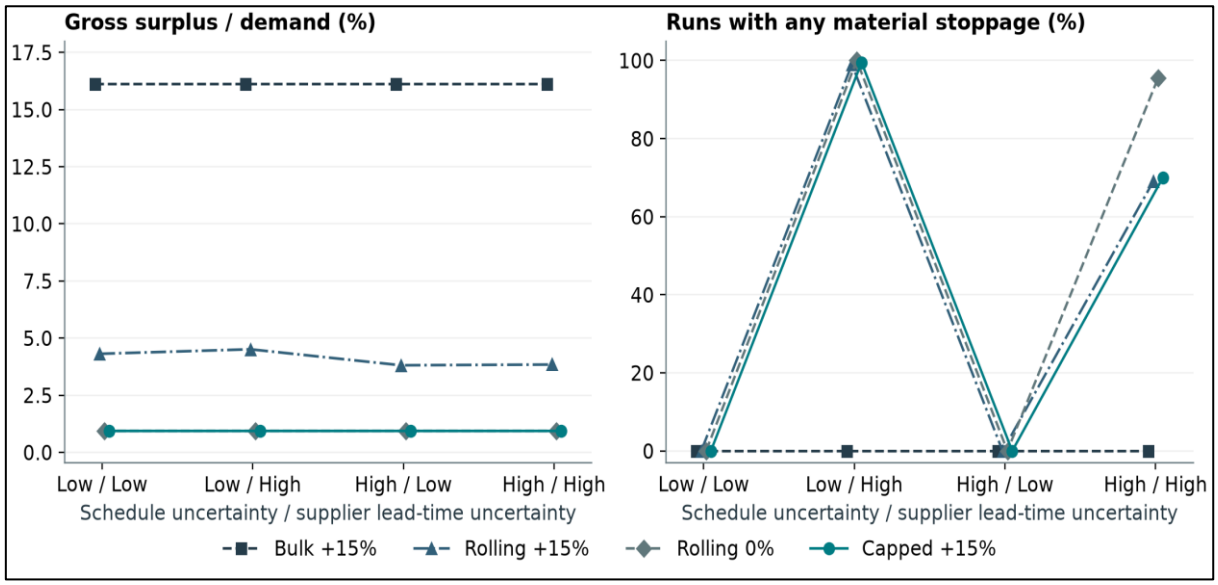


Fig 2 Surplus and the Incidence of Crew Stoppage Tell Different Stories. Full Project Demand was Installed in Every Run. Capped and zero-buffer rolling surplus coincide at the 10-unit Pack Floor; that Overlap is a Model Property, not Missing Data. Percentages are descriptive cell summaries; environments are categorical.

With high schedule and high lead-time uncertainty, the demand cap reduced surplus by 2.91 percentage points versus uncapped rolling +15% (95% paired interval 2.67–3.14 points lower). It added a mean of 0.04 material-blocked days (0.01–0.07) and 0.025 days of completion lag (0.003–0.047). Compared with rolling 0%, the cap retained the same material surplus but avoided a mean of 2.44 blocked days (2.21–2.66 fewer) and 0.55 days of completion lag (0.41–0.69 fewer). The contrast with padded bulk was larger on materials: 15.17 percentage points less surplus (15.04–15.30 points less), but the capped rule increased service exposure relative to bulk. In 10 of the 200 capped runs, the completion lag was three working days, despite a mean of just 0.30 days.

In the low-schedule/high-supply condition, nearly all capped runs had a stoppage, compared with 70.0% under high/high. That is not evidence that schedule disruption benefits a real project. Modelled slips only postpone releases, so they can give incoming stock more time to arrive and create installation gaps where a crew can recover. They also shift the reference finish and can bunch jobs. The result depends on the model's timing and should not be generalised to schedule acceleration, design revisions or correlated disruption.

➢ *What Changed with Lookahead and Pack Size?*

With 10-unit packs under high/high risk, increasing lookahead from five to eight days moved capped purchasing from 1.74 blocked days on average to none observed. This changed neither the rounding floor nor the installation requirement, but raised mean peak site stock from 127.24 to 215.37 units and stock exposure from approximately 1,406 to 3,447 unit-days. An eight-day horizon covers the longest modelled lead; the result is conditional on complete deliveries, no early releases and the tested environment. It does not establish eight days as an optimum.

Table 7 High Schedule and High Supply Uncertainty: Inventory and Service Sensitivity, $n = 200$ Per row.

Policy	Pack / lookahead	Surplus (%)	Any stoppage (%)	Peak stock (units)	Stock-days (unit-days)	Orders
Bulk +15%	10 / 5	16.10	0.0	559.85	11,053	1.00
Rolling 0%	10 / 5	0.94	95.5	106.84	996	20.51
Rolling +15%	10 / 5	3.84	69.0	127.81	1,464	19.60
Capped +15%	10 / 5	0.94	70.0	127.24	1,406	19.16
Capped +15%	10 / 8	0.94	0.0	215.37	3,447	20.24
Rolling 0%	10 / 8	0.94	0.0	184.22	2,840	21.74
Rolling +15%	10 / 8	7.49	0.0	218.05	3,748	21.38
Capped +15%	25 / 5	2.47	60.0	134.38	1,611	15.64
Capped +15%	25 / 8	2.47	0.0	225.19	3,699	16.66

At five days, moving the cap from 10-unit to 25-unit packs increased mean surplus from 4.49 to 11.91 units but reduced both order workload and the incidence of stoppage. Pack rounding created extra cover. At eight days and 10-unit packs, rolling 0% and capped rolling had the same surplus and no observed stoppage. Rolling 0% used less site stock, while the capped policy placed fewer orders. The experiment therefore does not crown a single winner; the choice depends on the site's storage, ordering and schedule-service constraints.

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V. DISCUSSIONS

➢ *What the Results Establish, and what They do Not*

The large difference versus bulk should not be read as a generic benefit of staged ordering over every bulk policy. A useful analytic comparator, not a fifth simulated policy, is a day-zero bulk order without padding. With exact known demand it would buy the same minimal over-pack quantity as capped rolling, yet would have no shortages under the study's day-zero lead-time bounds. In the reference pack size it would place an average of about 487 units on site at first receipt, versus a peak of about 127 for capped rolling in the high/high, five-day case. The advantage of staged buying here is primarily in holding stock later and in smaller quantities; the control on total purchasing derives from the cap or removing the blanket allowance.

The same distinction explains why the uncapped rolling buffer left more surplus at an eight-day than a five-day horizon in the high/high case. A longer horizon exposes a larger work volume to padding; with no cancellation or return rule, the buyer cannot unwind surplus once purchased. In contrast, a cap distinguishes a temporary availability buffer from a permanent increase in eventual project commitments. When quantities are uncertain or products are not interchangeable, the cap must be driven by an approved, updated forecast rather than by a fixed take-off. An unreconciled cap risks moving problems from material waste to logistics and production.

Days with blocked work should not be replaced with a simple completion statistic. A crew can lose productive time and recover the end date if work is released at a later point, if it can catch up within unused capacity, or if the other lane determines the final finish. This model captures that distinction, but it does not estimate labour or preliminaries costs. An interrupted day is not necessarily eight lost hours, a missed handover, or a delay for the overall project. Equally, order count is not the count of vehicle trips; transport consolidation could alter that relationship. No cash or carbon saving is estimated.

➢ *Limitations*

Several limitations bound these findings. First, all inputs are synthetic: the quantity, slip and lead-time distributions are designed contrasts rather than distributions fitted to UK project records, so the magnitudes reported describe the model, not the industry. Second, the model represents a single interchangeable material with exact, known demand and no breakage, offcuts, expiry or returns; under these conditions the cap's surplus result follows analytically, and with uncertain take-offs a cap could under-buy. Third, the high lead-time regime raises both the mean and the spread of delivery times, so a pure variability effect cannot be isolated. Fourth, inventory position counts every open order regardless of its due date, crews follow a fixed priority with one-job daily capacity, and schedule slips only postpone work; date-aware netting, alternative dispatch rules, accelerations or correlated disruptions could change the service results. Fifth, no labour, holding, ordering or carbon costs are estimated, so trade-offs are reported in physical units only. Finally, the model has been verified against its own rules but has not been validated against field data.

➢ *Implications for Engineering Project Management*

- Establish a quantity baseline: Use a versioned, approved take-off. Separate the expected net installation quantity, allowance for technically justified consumption losses, and the temporary buffer used to manage uncertainty. Reconcile stock on site, open orders and material already issued before placing a call-off.
- Make readiness visible: Give the planner ownership of work-package release dates and constraints. Link material requirements to the live lookahead, and have the buyer and site logistics team review shortages alongside overdue, outstanding and newly released risks.
- Set a lead-time-aware order horizon: Use actual supplier service data and the dates on which forecasts become credible. Consider promised due dates explicitly rather than counting every open order as equally useful. Agree a service threshold and test its implications for storage and cash; do not copy the study's eight-day horizon into a contract.
- Negotiate the buying rules: Ask the supplier for smaller pack options, staggered call-offs, agreed windows for amendments, order consolidation and return terms for compatible stock. The cap and changes in pack size are modelled here; the commercial effect of returns, consolidation and amendments is not.
- Close the material loop: Reconcile paid-for quantities with installed quantities and remaining stock. Record unopened return, redeployment, damage, recycling and disposal separately, with a consistent cutoff date. Check public-client reporting requirements rather than treating a site proxy as an SDG indicator (Cabinet Office, 2022; United Nations Statistics Division, n.d.).

➢ *Field Validation and Extension*

The next study should choose one frequently ordered, genuinely interchangeable material specification on an installation package, for example one size and grade of packaged bracket. Unlike SKUs should not be pooled into a common unit. A quantity surveyor should reconcile frozen and revised take-offs; a planner should supply dated schedule snapshots and actual readiness; and stores or logistics should supply goods receipts and issue records. Records should be linked by SKU, package, order line and project rather than through month-end stock totals, and the study would require pseudonymised project and supplier identifiers, restricted access to commercial data and written organisational permission. This manuscript used no project or participant data.

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Table 8 Data to Collect before Using the Model to Set Procurement Policy.

Record	Key fields and why they matter
Work and take-off	Version, planned and revised start, release timestamp and reason, exact SKU quantity, job start/finish, installed quantity. Reconstruct forecasting information available on each historical review day.
Purchase order and delivery	Order and amendment timestamps, ordered quantity, pack size, promised/actual receipt, partial delivery, outstanding balance, cancellation. Estimate lead-time distributions conditional on product, supplier and order size.
Stock and disposition	Opening stock, receipt, issue, adjustment, damage, closing stock, transfer/return confirmation and waste tickets where applicable. Validate the material ledger and separate stock from waste.
Service and costs	Blocked trade, duration and verified material cause, expedite events, order admin and delivery charges, storage constraints or charges. Distinguish stockouts from other readiness constraints and make an implementable decision.

The incumbent policy should first be replayed on historical data with a time-stamped “as known then” freeze, not the final programme decisions loaded retrospectively. Empirical distributions should then be fitted on a designated calibration sample and checked for correlated release and supply delays, before surplus, lead times, stock profiles and material stoppages are compared on a held-out project or phase. Interruptions should be reason-coded, and distribution tails examined as well as means. It should also be tested separately whether the assumed one-job daily capacity and fixed crew priority produce recognisable results with planners. After validation, a monitored shadow trial with escalation rules and agreed stoppage thresholds should precede any live change. A stronger field evaluation would compare matched packages or staggered deployments while tracking differences in SKU mix, planned scope and contractor practice (Sargent, 2013).

The most important structural extensions are uncertain or changing take-offs; date-aware netting against confirmed and unreliable deliveries; alternative priorities between crews; storage limits; and loss, return or transfer pathways. Supplier capacity, correlated disruptions, minimum invoice value, multiple SKUs and interdependent work should be added only with data and a clearly stated use case. Higher complexity does not compensate for missing input evidence. A second model built as a discrete-event simulation could check whether major findings depend on daily aggregation or scheduling order.

VI. CONCLUSION

The reproducible NetLogo experiment separates two procurement problems: buying too many units over the life of the package, and having too few units available on the day work is ready. A remaining-demand cap addresses the former directly. In the tested design it left only pack-rounding surplus, matching zero-buffer buying while reducing blockage in the stressed five-day case. It did not protect crews from late deliveries by itself. The longer horizon removed observed stoppages under the model’s lead-time bounds but raised inventory exposure, and the cap was not superior to all alternatives.

For UK practice, the most defensible next step is to test the rule against real take-offs, order and goods-receipt records, live work release dates and verified interruption events before it governs live orders. For SDG 12, the contribution is to make a prevention-oriented decision measurable without claiming that unused stock is automatically waste or that synthetic trials establish a national saving.

➢ *Manuscript Declarations*

- *Data and Code Availability:*

All simulation inputs are generated by the model source code. The NetLogo model (UK-Construction-Procurement.nlogox), the full BehaviorSpace results file, the analysis script and a run guide are available from the author on reasonable request.

- *Ethics Statement:*

Not applicable. This is a synthetic computational study; no human participants, personal data or commercial project records were used.

- *Funding:*

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

- *Competing Interests:*

The author declares no competing interests.

- *Author Contribution (CRediT):*

Prince Keshi is the sole author and was responsible for conceptualisation, methodology, software, formal analysis, visualisation, and writing (original draft, review and editing).

- *Declaration of Generative AI Use:*

During the preparation of this work the author used ChatGPT (OpenAI) to assist with formatting the manuscript, and Claude (Anthropic) for language editing, including condensing the abstract, consolidating the stated limitations into a single section and drafting standard declaration wording. After using these tools, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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APPENDIX

➢ *Appendix A. Live NetLogo Captures and Reproduction*

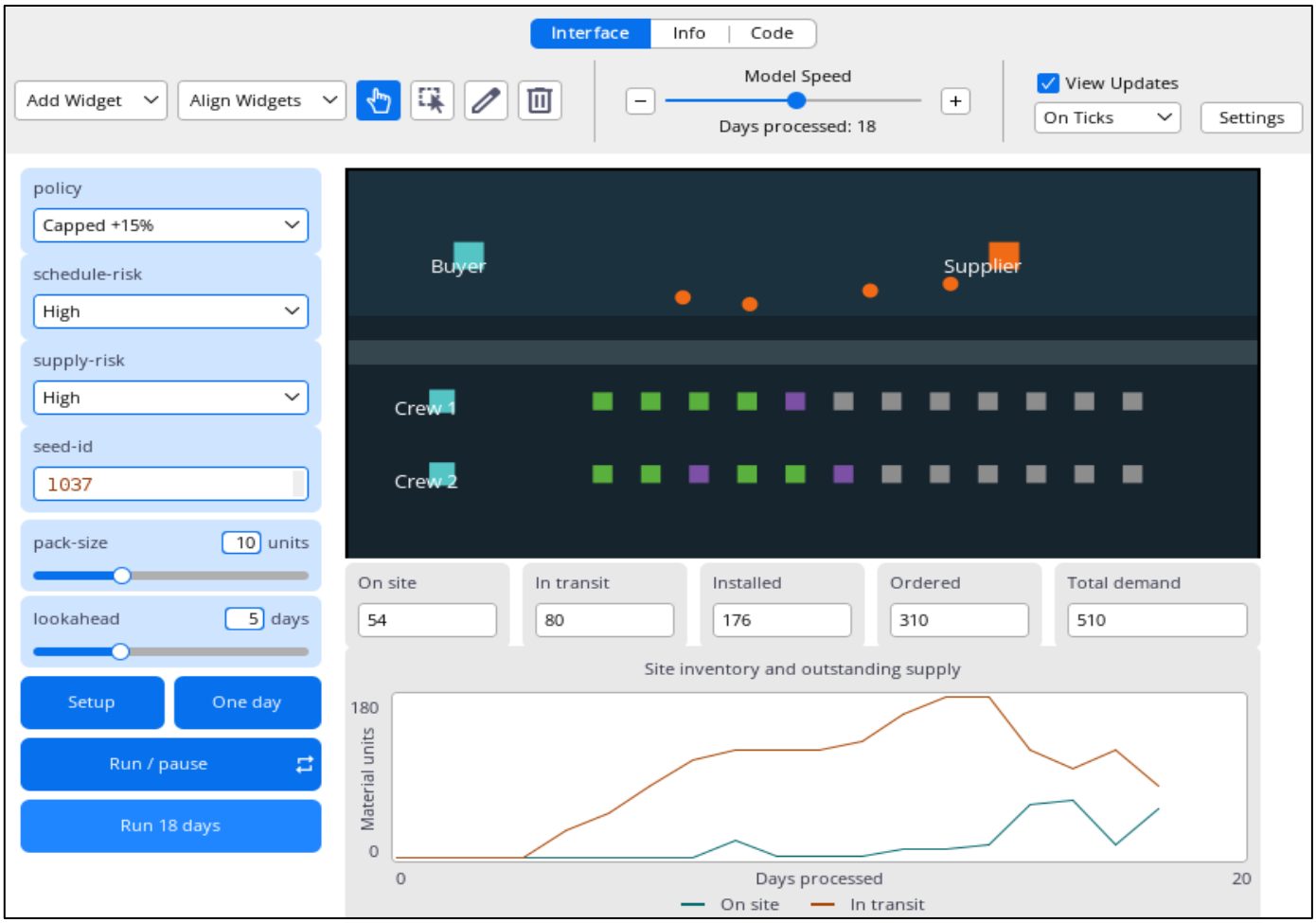


Fig 3 NetLogo Desktop 7.0.4: live run after 18 working days processed. Seed 1037, Capped +15%, high/high, 10-unit pack, five-day lookahead. Of 310 units ordered, 176 are installed, 54 are on site and 80 are in transit. Green squares show installed jobs; yellow denotes any released but incomplete jobs, violet a disclosed postponement, and grey unreleased work. Orange dots represent open shipment lots; their positions are indicators, not physical travel.

Open the model file UK-Construction-Procurement.nlogox in NetLogo Desktop 7.0.4. In the Interface tab, keep the supplied defaults and press Setup, then Run 18 days for Figure 3. For Figure 4, use Run / pause and let the model settle. Press Setup again after changing inputs. The Info tab explains the display; the Code tab contains the full implementation with no extensions. The sanity experiment provides four single-seed reference runs, and factorial performs the full design (NetLogo, 2026b).

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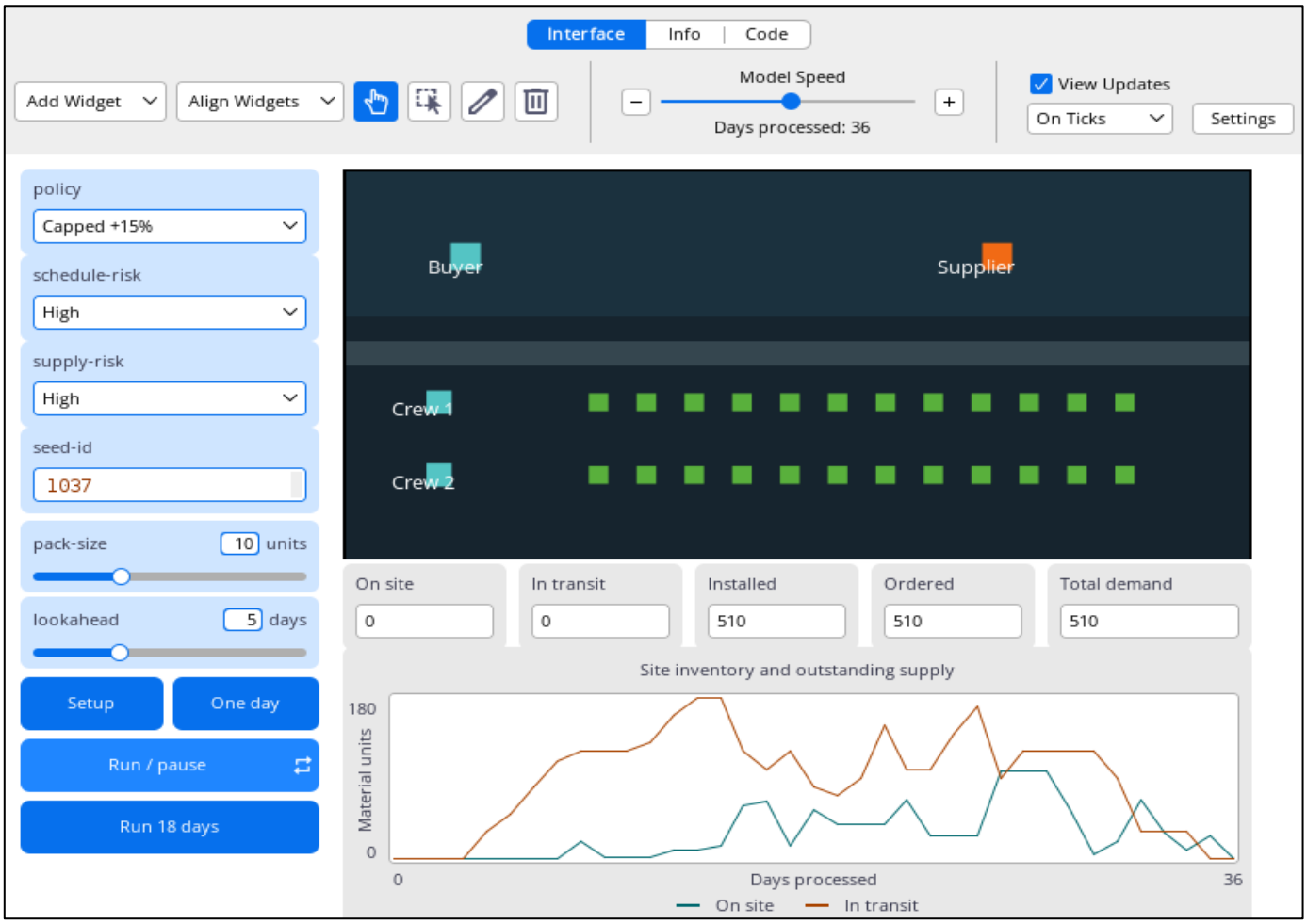


Fig 4 The same Desktop run at settlement. The completed package balances at 510 units ordered and installed, zero remaining on site and zero in transit. The display shows 36 days processed, corresponding to the close of zero-based day 35.

From the NetLogo 7.0.4 installation directory on Linux, use the following command (substitute an absolute path to the model). The experiment is embedded in the model, so no separate setup XML is needed. Choose Table output when using the GUI. Row order can differ when parallel threads are used (NetLogo, 2026b).

./NetLogo_Console --headless \

--model /path/to/UK-Construction-Procurement.nlogox \

--experiment factorial --threads 4 \

--table NetLogo-BehaviorSpace-Results.csv

The reproducibility materials, available from the author on request, comprise the .nlogox model, full terminal results CSV, analysis script, screenshots and a run guide. The CSV includes the six-line BehaviorSpace preamble before the column header. Each result row is uniquely located by policy, schedule-risk, supply-risk, pack-size, lookahead and seed-id; the execution row number is not the pairing key. Run python analyse_results.py in that folder to audit balances, reproduce reported summaries and generate the plots.

For code review, start with setup for seed and synthetic input generation, go for the daily event sequence, place-order for the policy branches and pack ceiling, and check-balances for the invariant checks. The reporters readiness-finish and order-delay implement the material-unconstrained date and the difference from it. The buyer and supplier are distinct turtle breeds; their procedures share an observer-level ledger. The code processes crews in a fixed sorted order, rather than relying on the order of an unrestricted ask crews. This makes priority explicit and keeps the experiment interpretable when both crews are simultaneously ready.