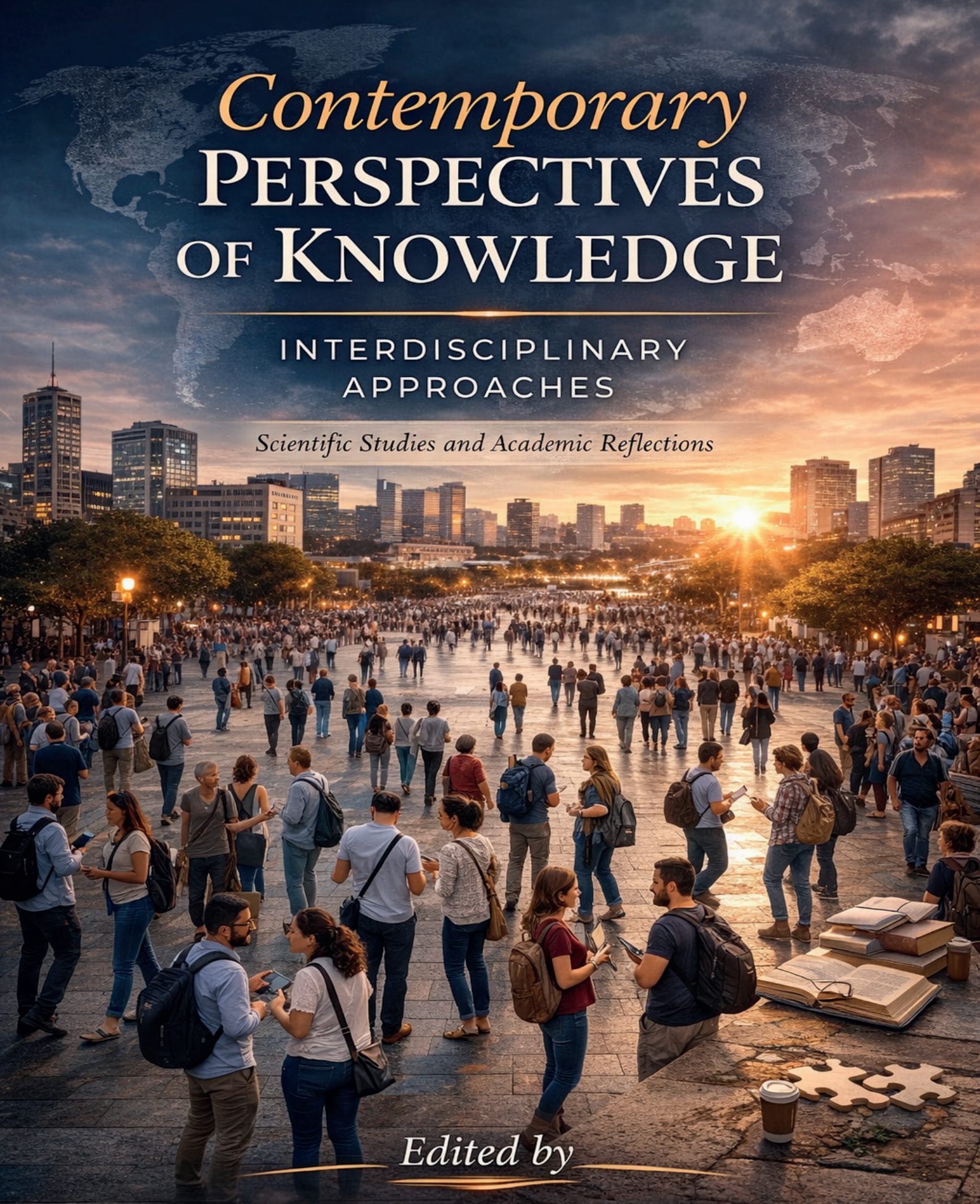
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Scientific Studies and Academic Reflections



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Chapter 36

BID LEVELING AS A MANAGEMENT CONTROL: A CONCEPTUAL MODEL AND SIMULATION-BASED ASSESSMENT LINKING PROCUREMENT SCHEDULES TO LOOKAHEAD PLANNING IN SUBCONTRACTOR-INTENSIVE INDUSTRIAL PROJECTS



BID LEVELING AS A MANAGEMENT CONTROL: A CONCEPTUAL MODEL AND SIMULATION-BASED ASSESSMENT LINKING PROCUREMENT SCHEDULES TO LOOKAHEAD PLANNING IN SUBCONTRACTOR-INTENSIVE INDUSTRIAL PROJECTS

Luiz Graccho Bicudo[1]

Abstract: In industrial projects delivered through fragmented subcontractor supply chains, bid leveling is usually treated as an administrative price-selection step, disconnected from production planning. This paper proposes and assesses a model that repositions bid leveling as a management control mechanism for schedule. The model combines two instruments, the Extended Bid Comparison Map (EBCM) and the Procurement Tracker (PT), and replaces the fixed lookahead horizon with a variable horizon defined by each package's lead time. Drawing on management control theory, the model shifts control from outcomes (delivery) to actions (the purchasing decision) and uses the weekly coordination meeting as an interactive control. The model is positioned against the Last Planner System, Advanced Work Packaging and the subcontractor selection literature, and six propositions specifying mechanisms and boundary conditions are developed. Four are examined through Monte Carlo simulation. Results reveal a threshold effect: for packages with lead times below roughly half the lookahead horizon, both triggering logics are equivalent; above it, the conventional logic reduces on-time-for-production delivery to below 20% when lead time equals the horizon, whereas the proposed model keeps it above 70%. Design indefinition moderates the effect, safety margins must be proportional to lead time, and the absolute benefit grows with the number of subcontracted packages. The paper integrates production planning and control

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research with management control theory and offers a lean model suited to small and mid-sized contractors.

Keywords: bid leveling; management control; lookahead planning; procurement management; subcontracting; simulation

INTRODUCTION

Industrial building construction combines aggressive schedules, scopes that are only partially defined when work begins, and heavy reliance on specialty subcontractors for trades such as structural steel, roofing, wall cladding, industrial floor slabs, and MEP systems. In this setting, the general contractor acts less as a builder and more as the integrator of a temporary network of firms bound by short-term contracts and poor information sharing (DUBOIS; GADDE, 2002; VRIJHOEF; KOSKELA, 2000).

The lean construction literature offers mature tools for shielding production from uncertainty. In the Last Planner System, lookahead planning is the level at which constraints are identified and removed before tasks reach the weekly work plan (BALLARD, 2000; BALLARD; TOMMELEIN, 2021). This level, however, runs on a fixed horizon, typically four to six weeks. Made-to-order items frequently carry lead times longer than that horizon. For those items, the material constraint becomes visible only when it can no longer be removed under normal conditions, and removing it comes to depend on emergency purchases.

On large industrial projects, this problem is addressed by approaches such as Advanced Work Packaging (AWP), which aligns engineering, procurement, and construction through work packages (CONSTRUCTION INDUSTRY INSTITUTE, 2013; O'CONNOR; LEITE; MA, 2023). These approaches, however, presuppose document structures and dedicated teams that rarely exist in small and mid-sized contractors. In these firms, the core procurement tool is the bid comparison map, used to level heterogeneous bids and, in practice, treated as a price-decision document. Two pieces of information it contains, the quoted lead time and the scope exclusions, seldom make their way back into the schedule.

There are, therefore, two gaps. The first is practical: there is no lean mechanism that ties the purchasing decision to the date production actually needs the material. The second is theoretical: the construction production planning and control literature uses the term "control" in an operational sense, without engaging management control theory, which distinguishes types of control, the conditions under which each is effective, and the ways managers use them (OUCHI, 1979; SIMONS, 1995; MERCHANT; VAN DER STEDE, 2017).

This paper addresses both gaps through the following research question: how can bid leveling be structured as a management control mechanism for schedule, and under what conditions does linking it to lookahead planning reduce emergency purchases and late deliveries on subcontractor-intensive industrial projects?

The paper makes three contributions. First, it proposes a lean model, made up of the Extended Bid Comparison Map (EBCM) and the Procurement Tracker (PT), built on the principle of a variable horizon. Second, it interprets the model through the lens of management control theory, explaining why it works: it shifts control from outcomes to actions and uses the coordination meeting as an interactive control. Third, it develops propositions that specify mechanisms and boundary conditions and examines four of them through Monte Carlo simulation, identifying a threshold effect, the moderating role of design indefinition, the need for proportional safety margins, and the effect of fragmentation.

METHOD

RESEARCH DESIGN

The study combines two strategies. The first is the development of a conceptual paper of the model type, in Jaakkola's (2020) classification, whose aim is to explain relationships among concepts and predict effects through a framework not yet tested empirically. The second is computer simulation as a tool for theory development. Davis, Eisenhardt and Bingham (2007) argue that simulation is especially useful when a simple theory already exists, made up of intuitive propositions, whose internal logic needs to be explored, bounded, and extended. That is precisely the case here: the simulation does not

replace empirical testing; rather, it checks the logical consistency of the propositions, reveals nonlinear effects and boundary conditions, and yields sharper hypotheses for field studies.

STRUCTURED NARRATIVE REVIEW

The theoretical background was built through a structured narrative review rather than a systematic review. The structure consisted of explicit scope and selection criteria. Four domains were defined: production planning and control, with emphasis on lookahead planning and constraint management; construction supply chains, including engineer-to-order systems and AWP; subcontractor selection and management; and management control theory. Studies were included if they addressed coordination between procurement decisions and production planning, supplier or subcontractor selection using criteria beyond price, or control typologies applicable to project-based organizations. Priority was given to publications from 2021 to 2026 in peer-reviewed international and Brazilian journals and conference proceedings. Earlier works were included when they represent the original formulation of the concepts used. Studies focused exclusively on monitoring technology, with no discussion of planning logic, were excluded. The goal was to identify concepts, mechanisms, and gaps capable of supporting the model, not to map the scientific output exhaustively. This choice is consistent with the conceptual nature of the paper.

PRACTICAL ORIGIN OF THE MODEL

The model grew out of the author’s professional experience managing procurement on an industrial project, including preparing bid comparison maps, hiring subcontracted crews, and running weekly coordination meetings with designers, suppliers, the client, and senior management. That experience motivated the problem statement but is not used as evidence. The model rests on the literature and on the simulation.

QUALITY CRITERIA

Four criteria were adopted: (i) every element of the model must have an explicit theoretical rationale; (ii) propositions must specify a mechanism and a boundary condition so that they can be falsified; (iii) all simulation assumptions are stated and subjected to sensitivity analysis; and (iv) no quantitative claim about real-world performance is made. The figures reported refer exclusively to the simulated model.

THEORETICAL BACKGROUND

LOOKAHEAD PLANNING AND THE LIMITS OF A FIXED HORIZON

Koskela's (1992) view of production as flow showed that waiting, moving, and inspection dominate schedule variability in construction. Building on that view, Ballard (2000) structured the Last Planner System into hierarchical levels. In the system's most recent process benchmark, lookahead planning is described in three steps: breaking down tasks, identifying and removing constraints, and designing operations (BALLARD; TOMMELEIN, 2021).

Recent literature confirms how central this level is. In a systematic review of 112 studies, Agrawal et al. (2024) identified 50 automation functionalities spread across the stages of the Last Planner System, with lookahead planning accounting for the largest share, and singled out constraint management as a priority research direction. In Brazil, Angelim et al. (2025) revisited lookahead planning in light of the roles the Last Planner System plays in production strategy and management, and Melo et al. (2023) showed that the system's practices can be implemented on industrial projects with non-repetitive locations and activities.

There is, however, an assumption that receives little attention: constraint management presumes that a constraint can be removed within the horizon. When the time required to buy and fabricate an item exceeds that horizon, the constraint is identified too late. The organizational dimension makes matters worse. Görsch et al. (2024) showed that workers

act as autonomous planners and that trade-specific factors determine whether planning happens earlier or later. On projects with many subcontractors, each crew brings its own sense of timing, which increases the need for explicit coordination.

ENGINEER-TO-ORDER SYSTEMS AND ADVANCED WORK PACKAGING

The literature on engineer-to-order (ETO) systems shows that coordination between supplier and jobsite requires information that predates the lookahead horizon. Bataglin et al. (2020) proposed a model for planning and controlling the delivery and assembly of prefabricated ETO building systems, exploring synergies between lean construction and BIM. Chen et al. (2022) explored digitalization as a way to coordinate changes and improve the flow of such materials, and Chen, García de Soto and Adey (2021) proposed a supplier–contractor coordination approach to cope with demand fluctuations. Together, these studies indicate that the supply flow should be planned on its own horizon, set by the item rather than by the planning calendar.

On industrial capital projects, this logic was systematized by AWP, which organizes the project into construction, engineering, and installation work packages, aligning design and procurement deliverables with the needs of the workface (CONSTRUCTION INDUSTRY INSTITUTE, 2013). O'Connor, Leite and Ma (2023) proposed extending AWP into the commissioning and startup phases of industrial projects. AWP is thus the closest reference point for the model proposed here. Adopting it, however, entails package structures, dedicated roles, and information systems typical of large projects and EPC contractors. The open question is how to capture its core logic, the alignment between supply and production needs, in organizations that lack that infrastructure.

SUBCONTRACTOR SELECTION

Research on subcontractor selection centers on multicriteria decision models. El-Kholy (2022) proposed selection through the Choosing by Advantages method. Bingol,

Arditi and Polat (2025) developed a multi-objective optimization model that emphasizes project objectives rather than cost alone. Deep et al. (2022) analyzed how subcontractors' strategic capabilities shape power, dependence, and collaboration in procurement decisions. Basaran, Aladag and Isik (2025) proposed a machine learning-based model for managing subcontractor performance on site.

This body of work treats selection as a one-time, analytically sophisticated decision. The bid comparison map, an everyday tool, gets little attention. Kraljic (1983) argued that purchasing should classify items by their profit impact and supply risk. Applied to construction, this means that packages carrying high schedule risk call for differentiated treatment, and the bid comparison map is the natural moment for that classification.

MANAGEMENT CONTROL THEORY

Management control theory provides the lens that the discussion has been missing. Ouchi (1979) proposed that the choice of control mechanism depends on two conditions: knowledge of the transformation process and the ability to measure outputs. When outputs are measurable, output control is feasible. When the process is well understood, behavior control is possible. Merchant and Van der Stede (2017) developed a similar typology, distinguishing results controls, action controls, and personnel and cultural controls, and stressed that action controls are appropriate when it is known which actions are desirable and it is possible to verify whether they took place. Among action controls, pre-action reviews and behavioral constraints prevent undesirable decisions from being made.

Simons (1995) added a distinction between ways of using controls. His levers of control framework distinguishes belief systems, boundary systems, diagnostic control systems, used to monitor deviations from standards, and interactive control systems, used by managers to engage the organization in dialogue about strategic uncertainties. Tessier and Otley (2012) refined that framework by separating the technical design of controls from the way managers use them. Malmi and Brown (2008) proposed viewing controls as a package of complementary mechanisms rather than as stand-alone instruments.

In construction, the application of this theory is still in its early stages. Soto-Ferrari and Chams-Anturi (2023) developed a project management application grounded in management control systems for residential builders. The production planning and control literature, however, rarely specifies what type of control each tool exerts.

SYNTHESIS AND POSITIONING

Chart 1 summarizes how the model is positioned relative to the approaches reviewed. The gap does not lie in the idea of front-loading procurement, which AWP already formalizes, but in three aspects not yet addressed together: turning the bid comparison map, a tool contractors already use, into a schedule control mechanism; explaining in theoretical terms why that link works; and defining the conditions under which it produces an effect.

Chart 1 – Positioning of the proposed model

Approach	**Procurement horizon**	**Decision tool**	**Typical firm size**	**Control lens**
Last Planner System (lookahead)	Fixed (4 to 6 weeks)	Constraint analysis	Any	Operational, implicit
Advanced Work Packaging	Set by design packages	Engineering, procurement, and installation work packages	Large projects, EPC	Operational, implicit
Multicriteria subcontractor selection	Not addressed	Decision models	Varies	Not addressed
Proposed model (EBCM and PT)	Variable, set by each package's lead time	Extended bid comparison map	Small and mid-sized	Explicit: action, diagnostic, and interactive control

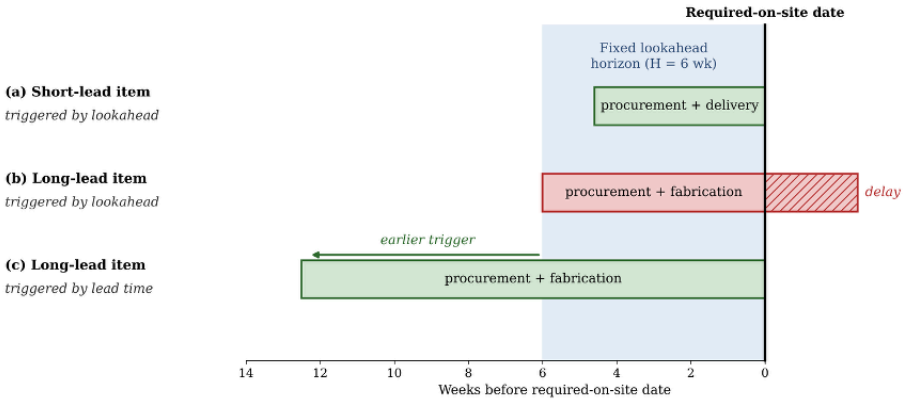
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THE PROPOSED MODEL

THE VARIABLE-HORIZON PRINCIPLE

The central principle is that the procurement look-ahead window should be set by the time needed to buy and supply each package, not by the fixed lookahead planning horizon. The model does not replace lookahead planning; it extends it. Each package is triggered on whichever comes first: its entry into the lookahead horizon or its procurement deadline, which is set by its lead time. Figure 1 illustrates the logic.

Figure 1 – Fixed horizon versus variable procurement horizon



Source: prepared by the author.

EXTENDED BID COMPARISON MAP (EBCM)

The EBCM expands the traditional bid comparison map along two dimensions that usually sit outside it: schedule and excluded scope. Its minimum structure is shown in Chart 2.

Chart 2 – Minimum structure of the Extended Bid Comparison Map

Block	Fields
Identification	Package code, description, owner, opening date
Link to the schedule	Required-on-site date; reference lead time; procurement deadline
Leveled scope	Scope items; for each bidder: included, excluded, or ambiguous
Commercial	Base bid, leveling adjustments, leveled price, payment terms
Schedule	Lead time quoted by each bidder; compatibility with the required-on-site date
Risk	Package classification (critical or normal), number of bidders, supplier track record
Decision	Selected bidder and rationale when it is not the lowest leveled price

Source: prepared by the author.

Two rules turn the map into a control mechanism:

1. Rule 1 – No bid goes out without a required-on-site date. If the schedule has not yet set that date, this is logged as a planning constraint, not a procurement constraint;

2. Rule 2 – A bid that cannot meet the date is not the cheapest bid. A lowest-price bid that does not meet the required-on-site date may be selected only with a documented rationale and a mitigation plan approved in the coordination forum.

Risk classification follows Kraljic's (1983) logic: packages that are made to order, have few suppliers, or carry a lead time longer than half the lookahead horizon are treated as critical. This threshold derives from the simulation results presented in Section 6.

PROCUREMENT TRACKER (PT)

The PT is the living procurement schedule. Each row corresponds to one package and records six milestones, each with a planned date, backscheduled from the required-on-site

date, and an actual date (Chart 3). The variance between the two drives a three-level visual signal that is reviewed weekly.

Chart 3 – Procurement Tracker milestones

Milestone	Description
M1	Specification or design released for bidding
M2	Bid package issued
M3	Bids leveled and approved
M4	Contract or purchase order issued
M5	Shop drawing approval, where applicable
M6	Actual delivery or mobilization

Source: prepared by the author.

INTEGRATION MECHANISM

Integration is both temporal and organizational. Each week, at the coordination meeting with designers, suppliers, the client, and management:

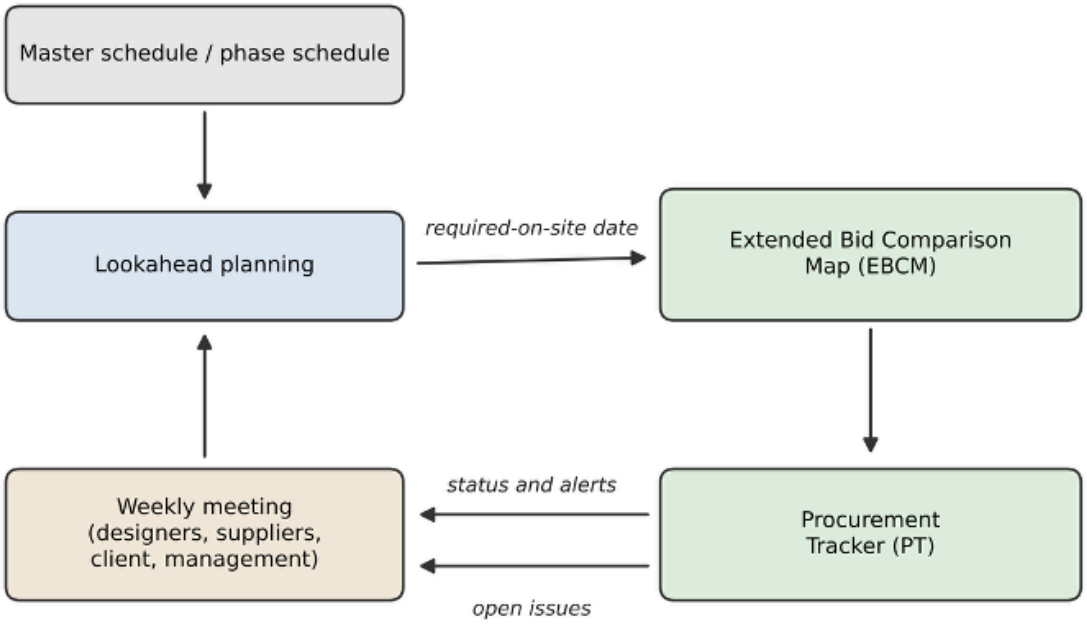
1. the lookahead plan is updated, and any changed required-on-site dates are pushed to the PT;

2. the PT recalculates procurement deadlines and flags packages at risk;

3. flagged packages generate action items with an owner and a due date;

4. items classified as ambiguous in the EBCM are brought to the designers and the client for a decision before award.

Figure 2 – Integration flow among lookahead planning, the EBCM, and the PT



Source: prepared by the author.

INTERPRETATION THROUGH THE LENS OF MANAGEMENT CONTROL THEORY

Management control theory explains why the link should work. In current practice, procurement lead time is controlled by results: one checks whether delivery happened on the date. For long-lead items, that control has a structural flaw: the result becomes observable only when no corrective action is possible anymore. Under Ouchi's (1979) conditions, when the transformation process is known, as is the case with the sequence of bidding, leveling, award, and fabrication, action control is feasible and preferable to belated results control.

The model makes exactly that shift, assembling a package of complementary controls in the sense of Malmi and Brown (2008). Chart 4 maps each element of the model to the type of control it exerts.

Chart 4 – Model elements and types of control

Model element	**Type of control**	**Basis**
Rule 1: no bid without a required-on-site date	Boundary system; action control	Simons (1995); Merchant and Van der Stede (2017)
Rule 2: rationale required for an incompatible lead time	Pre-action review	Merchant and Van der Stede (2017)
Package risk classification	Risk-based differentiation of control	Kraljic (1983)
PT visual signal	Diagnostic control	Simons (1995)
Weekly coordination meeting	Interactive control	Simons (1995); Tessier and Otley (2012)
PF, EPR, and SGCO metrics	Results control for learning	Ouchi (1979)

Source: prepared by the author.

Two points deserve emphasis. First, the EBCM rules work as boundary systems: they do not tell the buyer what to do, but they prevent decisions that jeopardize the schedule without explicit deliberation. Second, the weekly meeting is the interactive component. It does not serve merely to check for deviations, a function the PT signal already performs diagnostically, but to let designers, suppliers, the client, and management discuss the uncertainties that no indicator captures, such as ambiguous items, technical alternatives, and renegotiated lead times. The distinction between diagnostic and interactive use explains why the same tool can produce different effects depending on how it is used (TESSIER; OTLEY, 2012).

OPERATIONAL DEFINITIONS AND METRICS

To allow replicable empirical testing, the concepts are defined operationally:

1. required-on-site date (need date): the start date of the activity that consumes the package in the current schedule, minus receiving and inspection time. It corresponds to the required-on-site (ROS) date used in international practice;

2. reference lead time: the delivery lead time quoted by the winning bidder, as recorded in the EBCM. This choice settles the question of who sets the standard: the market itself, at the moment of the decision;

3. emergency purchase: a purchase order issued (M4) less than the reference lead time ahead of the required-on-site date, or an order involving a price premium, expedited freight, or a supplier outside the bid process explicitly because of urgency;

4. procurement float (PF): required-on-site date minus actual delivery date (M6), in days. A negative PF signals a delay from the standpoint of production, even if the contractual lead time was met;

5. emergency purchase rate (EPR): the share of packages involving an emergency purchase;

6. on-time-for-production delivery (OTP): the share of packages with PF greater than or equal to zero;

7. leveling completeness index (LCI): scope items classified as included or excluded in the EBCM, divided by the total number of items in the package. Ambiguous items do not count;

8. scope-gap change orders (SGCO): the number and value of change orders whose recorded cause is an item missing from, or ambiguous in, the selected bid.

OTP and EPR must be analyzed together, because emergency purchases can restore on-time performance at a high cost. A high OTP combined with a high EPR indicates that schedule is being bought, not planned.



PROPOSITIONS

The propositions specify mechanisms and boundary conditions. The ratio r denotes a package's reference lead time divided by the lookahead horizon.

P1 – Horizon threshold. The effect of linking bid leveling to planning on on-time performance is nonlinear in r: it is negligible when procurement time plus lead time fits within the lookahead horizon and grows rapidly above that threshold. The mechanism is the earlier issuance of the purchase order (M4), which mediates the relationship between the link and procurement float.

P2 – Shifting control. The link reduces emergency purchases because it replaces belated results control with action controls and boundaries placed ahead of the purchasing decision. The effect is stronger when the procurement process is standardized, that is, when Ouchi's (1979) conditions for behavior control are present.

P3 – Moderation by design indefinition. Design indefinition at the time the bid is scheduled to go out weakens the effect of the link, because it delays milestone M1 regardless of the triggering logic. EBCM Rule 1 turns that indefinition into a visible planning constraint, but it does not eliminate it.

P4 – Proportional margin. With a fixed safety margin, the on-time performance of the link declines as lead time increases, because the absolute variability of fabrication time grows with its duration. Margins proportional to lead time preserve on-time performance.

P5 – Completeness and interactive use. The higher the leveling completeness index, the lower the number and value of scope-gap change orders. The effect is mediated by resolving ambiguous items in the interactive forum before award.

P6 – Fragmentation. The absolute benefit of the link, measured in late packages avoided per project, grows with the number of subcontracted packages.

Propositions P1, P3, P4, and P6 concern the model's temporal logic and can be examined by simulation. Propositions P2 and P5 involve organizational behavior and require

empirical study.

SIMULATION-BASED ASSESSMENT

SIMULATION MODEL

A Monte Carlo model was developed to represent the procurement cycle of individual packages, following Law's (2015) guidance for stochastic models. Two triggering policies are compared. Under Policy A, the conventional one, procurement starts when the package enters the lookahead horizon. Under Policy B, which corresponds to the proposed model, procurement starts on whichever comes first: entry into the horizon or the procurement deadline, calculated as the required-on-site date minus the reference lead time, the expected procurement time, and a safety margin. The assumptions are listed in Chart 5.

Chart 5 – Simulation model assumptions

Parameter	Value adopted	Rationale
Lookahead horizon (H)	6 weeks	Upper end of the typical Last Planner range (BALLARD, 2000)
Reference lead time	r × H, with r from 0.2 to 3.0	Full sweep, not calibrated to specific items
Actual lead-time variability	Lognormal, coefficient of variation of about 0.2, mean equal to the reference	Multiplicative variability: longer lead times have greater absolute spread
Procurement time (M1 to M4)	Triangular (1; 2; 4) weeks	Bidding, leveling, and award, right-skewed
Design indefinition	Probability q = 0.3 of a uniform 0- to 3-week delay at M1	Sensitivity analysis with q = 0; 0.3; 0.6
Safety margin	1 week	Sensitivity analysis from 0 to 3 weeks
Emergency response	25% reduction in actual lead time through expediting	Represents acceleration at additional cost

Replications	20,000 per scenario; 100,000 in sensitivity analyses	Monte Carlo error below 0.5 percentage point

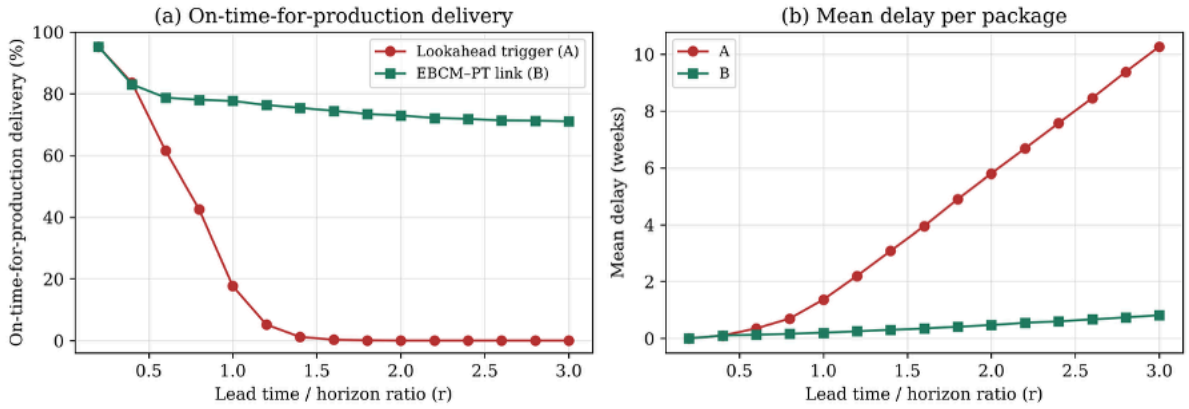
Source: prepared by the author.

An order is classified as an emergency purchase when, at the time it is issued, the reference lead time does not fit within the time remaining before the required-on-site date. The model is deliberately stylized. Its parameters were not calibrated with data from actual projects, and the analysis focuses on qualitative patterns that hold up under varying assumptions rather than on absolute values.

RESULTS

Threshold effect (P1). Figure 3 shows on-time-for-production delivery and mean delay as a function of r. For r up to 0.4, the two policies are equivalent, with OTP between 83% and 95%, because the procurement cycle fits within the horizon. From r = 0.6 on, the curves diverge. At r = 1.0, that is, with lead time equal to the horizon, Policy A delivers 18% of packages on time and every order becomes an emergency purchase, whereas Policy B delivers 78%. At r = 2.0, Policy A delivers no packages on time and mean delay reaches 5.8 weeks, compared with 73% on-time performance and a mean delay of 0.5 week under Policy B. The pattern confirms the nonlinearity predicted in P1 and suggests that the practical threshold for classifying a package as critical lies near half the lookahead horizon.

Figure 3 – Policy performance as a function of the lead time/horizon ratio Figure 3 – Policy performance as a function of the lead time/horizon ratio



Source: prepared by the author, based on simulation results.

Moderation by design indefinition (P3). Table 1 shows the effect of the probability of a delay in design release for r = 1.0. Under Policy B, the emergency purchase rate rises from 8% to 43% as indefinition increases from zero to 0.6, and on-time performance drops from 81% to 73%. Policy A stays at a far lower level in every scenario. The link remains superior, but its effect is weakened, as predicted in P3. The practical implication is that the model must be accompanied by control over design release, not just over procurement.

Table 1 – Effect of design indefinition (r = 1.0)

Probability of delay at M1 (q)	**EPR Policy A**	**OTP Policy A**	**EPR Policy B**	**OTP Policy B**
0.0	100%	24%	8%	81%
0.3	100%	18%	25%	77%
0.6	100%	12%	43%	73%

Source: prepared by the author, based on simulation results.

Proportional margin (P4). Table 2 shows that, with a fixed one-week margin, Policy B's on-time performance falls from 78% to 73% as r goes from 1.0 to 2.0, because the absolute spread of lead time grows with its duration. Increasing the margin restores on-time performance, and the gain per additional week is smaller for longer-lead packages. A masking effect also appears: with a zero margin and r = 2.0, on-time performance is slightly higher than with a one-week margin, but at the cost of 60% emergency purchases. This result supports the recommendation to analyze OTP and EPR together and confirms P4: the margin should be proportional to lead time, not fixed.

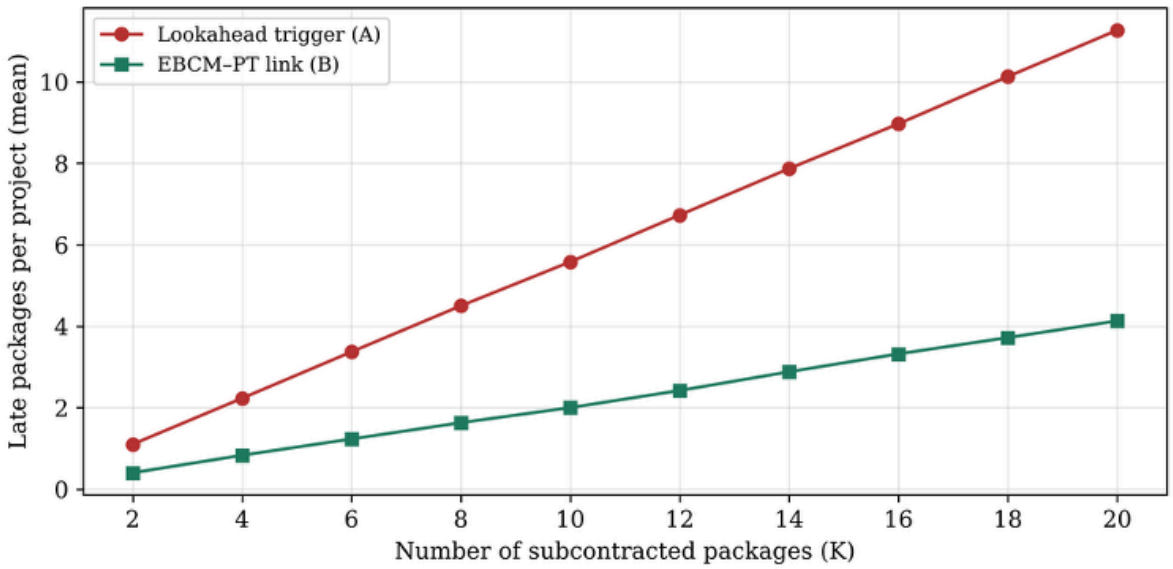
Table 2 – Sensitivity to the safety margin under Policy B

Margin (weeks)	EPR (r = 1.0)	OTP (r = 1.0)	EPR (r = 2.0)	OTP (r = 2.0)
0	60%	67%	60%	75%
1	25%	78%	25%	73%
2	10%	88%	10%	79%
3	3%	94%	3%	85%

Source: prepared by the author, based on simulation results.

Fragmentation (P6). To examine the effect at the project level, projects with K subcontracted packages were simulated, 60% of them short-lead (r between 0.2 and 0.8) and 40% long-lead (r between 1.0 and 2.5). Figure 4 shows that the mean number of late packages grows linearly with K under both policies, but with different slopes. The difference rises from 0.7 package per project at K = 2 to 7.1 packages at K = 20. With K = 4, the probability that every package arrives on time is 4% under Policy A and 39% under Policy B. The absolute benefit of the link grows with fragmentation, as predicted in P6.

Figure 4 – Late packages per project as a function of the number of subcontracted packages



Source: prepared by the author, based on simulation results.

INTERPRETATION

The simulation produces three results that were not evident when the model was first formulated. The first is the threshold: the link brings no gain for short-lead items, which makes it possible to concentrate control effort on critical packages, in line with Kraljic's (1983) logic. The second is that the link does not eliminate emergency purchases: design indefinition and variability in procurement time produce a residual rate that can be reduced only through control over design release and adequate margins. The third is masking: emergency purchases can prop up on-time performance indicators, which makes OTP, on its own, a misleading indicator. These results sharpen the propositions for empirical testing.

DISCUSSION

CONTRIBUTION TO MANAGEMENT CONTROL THEORY IN CONSTRUCTION

The paper shows that management control theory explains a phenomenon that the production planning literature describes without naming. Procurement control based on verifying delivery is belated results control. For long-lead items, it reports the problem when no action is possible anymore. The proposed model moves control to the action, ahead of the purchasing decision, through boundaries and pre-action reviews, and combines those controls with interactive use of the coordination meeting. This reading is consistent with Ouchi (1979), for whom behavior control is preferable when the process is known, and with Simons (1995), for whom interactive use suits the uncertainties that indicators fail to capture. The contribution lies in specifying what type of control each element exerts and in showing, through simulation, that the timing of control matters more than its sophistication.

RELATIONSHIP TO ADVANCED WORK PACKAGING

The model shares with AWP the principle of aligning procurement with production needs. It differs in three respects. First, it operates on an existing artifact, the bid comparison map, rather than requiring a new package structure. Second, its horizon is set package by package, by lead time, rather than by the project breakdown structure. Third, it is scaled for small and mid-sized contractors, with no dedicated roles or integrated systems. It can therefore be understood as a lean way of capturing AWP's core logic in organizations that are not in a position to adopt it in full. This relationship also suggests a maturity path: firms that adopt the EBCM and the PT build the foundational capabilities, such as required-on-site dates, reference lead times, and milestone tracking, that would ease an eventual transition to AWP.

PRACTICAL IMPLICATIONS

For managers, the results point to four recommendations. Classify packages with lead times longer than half the lookahead horizon as critical and apply the full set of controls to them. Do not issue a bid package without a required-on-site date. Size safety margins in proportion to lead time. Always track on-time performance together with the emergency purchase rate.

LIMITATIONS

The study has four limitations. First, it is conceptual and does not demonstrate the model's effectiveness empirically on actual projects. Second, the simulation is stylized: its parameters were not calibrated with field data, and the absolute values should be read as illustrative. The robustness of the qualitative patterns under sensitivity analysis mitigates, but does not eliminate, this limitation. Third, the simulation treats packages as independent, ignoring sequencing interdependencies and supplier capacity constraints. Fourth, propositions P2 and P5, which involve organizational behavior, were not examined.

RESEARCH AGENDA

The following avenues are suggested: (i) testing P1, P3, P4, and P6 with archival data from completed industrial projects, using the operational definitions in Section 4.6; (ii) calibrating the simulation with empirical distributions of lead time and procurement time; (iii) examining P2 and P5 through Design Science Research, applying the model to ongoing projects; (iv) evaluating the model with experts through a Delphi panel; and (v) extending the simulation to include interdependence among packages and supplier capacity constraints.



CONCLUSION

This paper asked how bid leveling can be structured as a management control mechanism for schedule and under what conditions linking it to lookahead planning reduces emergency purchases and late deliveries. The answer combines a model, an explanation, and a set of conditions. The model consists of the Extended Bid Comparison Map and the Procurement Tracker, built on the variable-horizon principle. The explanation comes from management control theory: the link works because it moves control from belated results to the action that precedes the purchase, and because it uses weekly coordination as an interactive control. The conditions were bounded through simulation: the effect emerges above a lead-time threshold of roughly half the horizon, is weakened by design indefinition, requires proportional margins, and grows with the fragmentation of the subcontractor supply chain.

The central message is that the time to control the schedule of a procurement package is at bid leveling, not at delivery. For long-lead items, bid leveling is the last opportunity at which the schedule can still be chosen. The propositions and operational definitions presented here lay out the path for testing this thesis in the field.

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