Integration of Enterprise Resource Planning and Advanced Data Analytics for Cost Optimization and Supply Chain Performance Improvement in Saudi Cement Manufacturing.

Abstract

Saudi cement manufacturing operates at the intersection of energy-intensive production, geographically dispersed distribution, capital-intensive assets and fluctuating construction demand. Although enterprise resource planning (ERP) systems consolidate transactional records, the economic value of those records depends on their integration with process measurements and analytical decision routines. This critical integrative review examines how ERP-linked advanced analytics could reduce cost-to-serve and improve supply chain reliability across procurement, kiln operations, inventory, maintenance and outbound logistics. Thirty peer-reviewed publications were selected for their contributions to ERP integration, analytics capabilities, cement process optimisation, supply chain modelling and the Saudi industrial context. Evidence was compared through an explicit mechanism–outcome matrix rather than pooled into a causal estimate. The synthesis identifies three necessary connections: reliable reconciliation of plant and commercial data; optimisation models that respect process and service constraints; and organisational routines that convert model outputs into accountable actions. A proposed architecture and measurement protocol are evaluated through illustrative, fully disclosed cost scenarios. The framework distinguishes verified operational benefits from assumptions and treats energy prices, clinker quality, transport capacity and demand uncertainty as binding constraints. Findings indicate that joint visibility, rather than analytics sophistication alone, is the likely prerequisite for sustained cost and delivery improvements. The review offers testable propositions and a phased assessment strategy for Saudi cement enterprises, while highlighting the shortage of longitudinal, plant-level evidence.

Keywords: Cement manufacturing; Enterprise resource planning; Advanced data analytics; Cost optimisation; Supply chain performance; Saudi Arabia; Industrial digital transformation

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1. Introduction

Cement is an unusually demanding setting for enterprise-wide analytics. The principal material flows are massive, continuous and costly to interrupt; the commercial outputs are comparatively standardised; and product value is highly sensitive to fuel, electricity, transport and production reliability. Managers therefore require a picture that connects the quarry, raw mill, kiln, cement grinding, storage silos, sales orders and dispatch activity with the financial consequences of each operational decision. An ERP system contains many of the required commercial records but is seldom a complete account of what is occurring inside the plant. Equipment instrumentation, laboratory results and transport systems are commonly managed through different applications. The central research question is not whether more data could be collected, but whether these sources can be combined into decisions whose outcomes are technically feasible, financially measurable and operationally defensible (Kusiak, 2018; Tao et al., 2018).

Saudi Arabia makes this question commercially salient. Industrial diversification and infrastructure development place continuing demands on domestic construction-material supply chains, yet cement producers also face costs associated with fuel choice, electricity, maintenance and transport. An assessment

of Saudi construction-material firms demonstrates that technology and fuel-switching economics depend substantially on policy and capital assumptions; the least-cost alternative cannot be identified independently of the operating context (Matar et al., 2025). In the Saudi industrial sector, ERP–business intelligence integration has been associated with more effective decision processes when infrastructure readiness, data quality, access control and employee capabilities are considered together (Jaradat et al., 2024). These findings support investigation but do not establish the size of any financial return specifically attributable to analytics in Saudi cement plants.

The present article develops a tightly bounded argument around that unresolved attribution problem. Its unit of analysis is the joined decision system consisting of ERP transactions, industrial-process signals, analytics models and decision owners. The focus is not an isolated forecasting algorithm, generic cloud migration, or standalone emissions assessment. Instead, the paper examines when integration can change cost per saleable tonne, procurement cycle behaviour, stock availability, order fulfilment and decision timeliness. This emphasis separates the article from wider digital-transformation accounts that describe technology adoption without mapping the route from information to operational value (Vial, 2019; Aldossari et al., 2025).

1.1 Aim, objectives and research questions

The aim is to critically evaluate the pathways through which integrated ERP and advanced data analytics may improve cost control and supply chain performance in Saudi cement manufacturing, and to construct a framework that could subsequently be tested with plant-level evidence. Four objectives structure the enquiry: identify the operational data interfaces necessary for reliable analysis; assess the evidence for cost-relevant applications in energy, maintenance, procurement and distribution; distinguish managerial and technical enablers from implementation risks; and define measures and comparison strategies appropriate to a Saudi cement setting. Unlike an empirical evaluation, the study does not claim that an integration project was implemented or that numerical savings were directly measured.

Three questions operationalise this aim. RQ1 asks which ERP-to-plant and ERP-to-supply-chain information links are required to generate reliable cost and service measures. RQ2 asks how predictive and prescriptive methods could alter procurement, maintenance, energy and dispatch decisions without jeopardising product quality or supply continuity. RQ3 asks under which organisational, market and technical conditions projected improvements are likely to materialise and remain auditable. Addressing these questions together prevents the common substitution of technical predictive accuracy for a demonstrated business outcome; a good forecast is not necessarily a better decision, and a better decision is not automatically a positive net investment (Akter et al., 2016; Mikalef et al., 2020).

2. Conceptual foundations

ERP is most useful here as a system of commercial commitments and verified transactions. It can record purchase requisitions, contracts, receipts, batch costing, inventory balances, sales orders and invoiced deliveries. It cannot, by itself, explain why a kiln experienced thermal instability or why a specific shipment missed its promised window. Analytics adds estimation, comparison and optimisation to the transaction layer; process-control systems add high-frequency evidence about actual physical behaviour. Their combined value depends on consistent identifiers, timing and units. A saleable tonne cannot be equated indiscriminately with a tonne of clinker, a tonne of raw meal or a tonne despatched. Likewise, the financial value of a delayed order depends on service commitments, alternative supply and the marginal economics of fulfilment.

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The resource-based and dynamic-capability perspectives offer a useful distinction between owning a tool and knowing how to use it. Analytics capability is formed through data accessibility, managerial interpretation, skilled analysts and routines that reconfigure action, not through software purchase alone. Firm-level studies have linked analytics capability and strategic alignment to performance, but also indicate that dynamic and operational capabilities mediate this relationship (Akter et al., 2016; Wamba et al., 2017; Mikalef et al., 2019). In manufacturing, different combinations of connected equipment, planning tools and analytical infrastructure produce different implementation patterns rather than one universal path (Frank et al., 2019). Consequently, the proposed framework treats ERP as an enabling platform and explicitly locates the sources of performance change in decision rules, process redesign and coordinated execution.

The available literature also cautions against collapsing distinct outcomes into a single notion of efficiency. A plant may reduce specific fuel consumption while increasing maintenance expenditure; an inventory policy may reduce working capital while heightening missed-order risk; a transport algorithm may minimise kilometres while increasing customer waiting time. Optimisation must therefore recognise several objectives simultaneously. Operations analytics research emphasises the joint importance of model design, uncertainty and managerial implementation (Choi et al., 2018), while studies of supply-chain digital information highlight difficulties of interoperability, data interpretation and inter-organisational coordination (Kache and Seuring, 2017). The practical criterion is an improvement in total constrained performance, not the optimisation of a convenient dashboard measure.

3. Review methodology

A critical integrative review was selected because the topic joins several evidence streams that cannot reasonably be reduced to one pooled effect size: ERP integration studies, organisational analytics research, cement-process engineering, energy economics and supply-chain optimisation. The review uses a deliberately bounded corpus of 30 peer-reviewed studies published from 2015 to 2025. Literature was identified through targeted searches for combinations of “enterprise resource planning”, “business intelligence”, “cement kiln”, “analytics”, “energy optimisation”, “supply chain resilience”, “maintenance”, “Saudi Arabia”, and “cost”. Candidate sources were prioritised where a publisher or reliable bibliographic record provided a title, date and DOI. The three supplied background documents informed the initial problem framing; two carry 2026 dates and were excluded from the eligible reference period.

Eligibility required relevance to at least one specified causal link: data or system integration, the formation of analytical capability, a cement-manufacturing decision mechanism, supply-chain cost or service, or the Saudi industrial context. The inclusion of adjacent sectors is deliberate but conditional: findings from concrete manufacturing or construction logistics are discussed as transferable propositions, not as proven cement-plant effects. Reviews and modelling papers contribute conceptual mechanisms, whereas empirical studies contribute observations from their actual study settings. For each source, the synthesis records context, research design, mechanism, endpoint and external-validity limitation. This is a transparent purposive evidence synthesis, not a claim that every relevant record in all databases was retrieved.

The analytical procedure had four stages. First, recurring processes were mapped against the cement value chain. Second, each mechanism was connected to a financially interpretable or service-relevant endpoint, such as thermal cost per tonne, inventory days, vehicle turnaround or on-time-in-full delivery. Third, potential countervailing effects and confounding factors were identified: product mix, fuel prices, quarry chemistry, demand cycles, plant utilisation and seasonal logistics constraints. Finally, a conceptual architecture and illustrative cost model were constructed to demonstrate how future research could evaluate effects. The numerical examples are assumptions, not estimates extracted from Saudi enterprises.

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The review accordingly reports no fictional sample size, significance levels or effect magnitudes (Snyder, 2019).

4. Empirical and theoretical evidence

Research on Saudi industrial digitalisation is informative but uneven in direct applicability. Jaradat et al. (2024) examined ERP and business intelligence within Saudi industrial firms, reporting favourable relationships between integration and decision-making alongside the importance of data quality and user preparedness. Aldossari et al. (2025), studying Saudi manufacturing small and medium-sized enterprises, identify technological, organisational and environmental drivers of big-data-analytics adoption. These studies establish that Saudi organisational conditions are relevant to the mechanism; neither isolates the incremental cost impact of ERP-linked analytics in cement operations. Cross-national evidence of enterprise integration likewise stresses that the conditions for business impact extend beyond technical connectivity (Chang, 2025). Their combined relevance is stronger for feasibility and adoption than for a numerical savings forecast.

Evidence from cement processes is more concrete about particular operational decisions. Pan et al. (2024) linked a neural-network model with a genetic algorithm to optimise clinker-line operating settings using plant measurements. Manis et al. (2024) describe an adjustable objective function for cement mills and kilns with data-driven predictions and operator-defined constraints. Zhao et al. (2024) demonstrate the technical interest of multisource information fusion for estimating free lime during clinker burning. These analyses indicate that useful physical predictions can be constructed, but their results depend on the instrument quality, range of operating conditions and plant configuration. An ERP layer should not be credited with improvements produced solely by closed-loop process control; its distinctive contribution is linking those improvements with financial, material and dispatch decisions.

The cost frontier of cement production is also shaped by investments outside conventional ERP boundaries. Poggianti et al. (2024) model waste-heat recovery from a precalciner kiln and report a representative recovery potential of approximately 4 MW under their analysed conditions. Kukreja et al. (2023) discuss operational and financial trade-offs of alternative-fuel use in an Indian cement context. Georgiopoulou and Lyberatos (2018) compare alternative-fuel scenarios through life-cycle analysis, demonstrating that environmental ranking depends on the chosen fuel portfolio and assessment assumptions. Chew et al. (2024) model a coupled energy and decarbonisation system and explicitly optimise cost subject to emissions-related decisions. These results concern different plants and system boundaries; they should not be averaged, nor should their numerical outputs be inserted into a Saudi budget without recalibration.

The supply-chain evidence adds another qualification. Chen et al. (2024) show, in construction supply-chain modelling, that sourcing redundancy, inventory buffers and backorders create trade-offs among cost and risk under uncertain demand. Ivanov et al. (2019) argue that digital technology can support the analysis of disruption propagation, but better visibility does not abolish physical dependencies. Cement manufacturers are exposed to quarry, grinding, transport and customer-site bottlenecks that require coordinated planning. Buer et al. (2018) similarly distinguish digital connectivity from lean operational redesign, while Dalenogare et al. (2018) find that the expected benefits of Industry 4.0 technologies vary by deployment. Transfer to Saudi cement production is a plausible hypothesis whose accuracy must be tested against road networks, contractual terms and plant-level inventory practices.

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Table 1. Selected numerical findings from different published study settings (not pooled effect sizes).

Study	Study context / design	Reported quantitative element	Transferability boundary
Aldossari et al. (2025)	Saudi manufacturing SME survey	384 valid responses	Adoption and decision-making; not cement cost
Chang (2025)	Enterprise ERP/BI integration	289 enterprise responses	Organisational mechanism; non-Saudi
Pan et al. (2024)	Clinker-line optimisation	615 operating records	Equipment-specific optimisation
Poggianti et al. (2024)	Precalciner kiln energy model	~4 MW recoverable power	Plant design and heat assumptions
Georgiopoulou & Lyberatos (2018)	Kiln fuel life-cycle assessment	7 fuel-mix scenarios	Environmental boundary, not local tariff

4.1 Evidence quality and boundary conditions

There are three recurring evidence limitations. First, many enterprise studies use cross-sectional manager perceptions as dependent measures; these assess perceived integration quality more directly than objective tonne-level cost. Second, cement engineering papers may optimise a single unit operation under carefully specified assumptions while leaving procurement, order acceptance and distribution unchanged. Third, resilience and forecasting models often rely on simulated demand or controlled experimental data, which can conceal implementation friction. A rigorous synthesis therefore distinguishes evidence that an algorithm predicts well, evidence that a manager acts on the result, and evidence that the resulting action improves an operational or financial outcome. Conflating the three produces unjustified claims about return on investment.

The distinction matters especially in energy-intensive sectors. A model may find a lower instantaneous fuel set point, but this change could alter clinker quality, emissions, kiln stability or maintenance risk. Financial optimisation requires constraints reflecting laboratory acceptance, equipment safety and contractual availability. Pan et al. (2024) and Zhao et al. (2024) address physically defined kiln indicators, whereas cost-oriented scenarios in Matar et al. (2025) remind researchers that energy prices and capital incentives can reverse economic rankings. A transferable research contribution must therefore integrate process feasibility with accounting outcomes rather than treating electricity, fuel and logistics as independent optimisation exercises.

5. Integrated decision architecture

Figure 1 proposes four logically distinct but connected layers. The transaction layer contains ERP events such as purchases, receipting, sales bookings, production declarations and costing entries. The operations layer captures control-system tags, sensor measurements, quality laboratory records and fleet or weighbridge activity. A governed integration layer reconciles item codes, equipment IDs, site definitions, calendars and measurement units, while preserving an audit trail to source transactions. The analytics layer then calculates forecasts, anomaly scores, constrained production plans, stock policies and dispatch alternatives. Outputs return to ERP as controlled planning recommendations or authorised actions rather than untraceable changes to operational records. This bidirectional design closes the gap between information visibility and accountable execution.

A foundational requirement is temporal alignment. Laboratory assays may arrive hours after a clinker lot was produced, while PLC or distributed-control-system measurements are registered in seconds and financial records are posted after approval. Analytic tables must preserve event time, recording time and

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approval time; otherwise, a supposedly predictive model might unknowingly use information unavailable when the decision was made. Material provenance needs similar care. Cost per cement tonne depends on clinker-to-cement ratios, additives, yield loss and inventory movements. Linking production campaigns to general-ledger periods with explicit allocation rules is essential for interpreting apparent efficiency gains without double-counting transfers.

Governance also determines analytical credibility. Master data should identify supplier, material grade, production line, vehicle, customer destination and cost centre consistently. Rules should test missingness, duplication, negative quantities, unit conversion and abnormal timestamps before scores are exposed to planners. Exceptions should create review tasks with named owners; unauthorised correction of source transactions would undermine the very auditability that ERP is intended to provide. Research on analytics capability emphasises management of data and complementary skills (Gupta and George, 2016), and evidence from Saudi ERP–BI integration highlights the role of security, skills and access control (Jaradat et al., 2024).

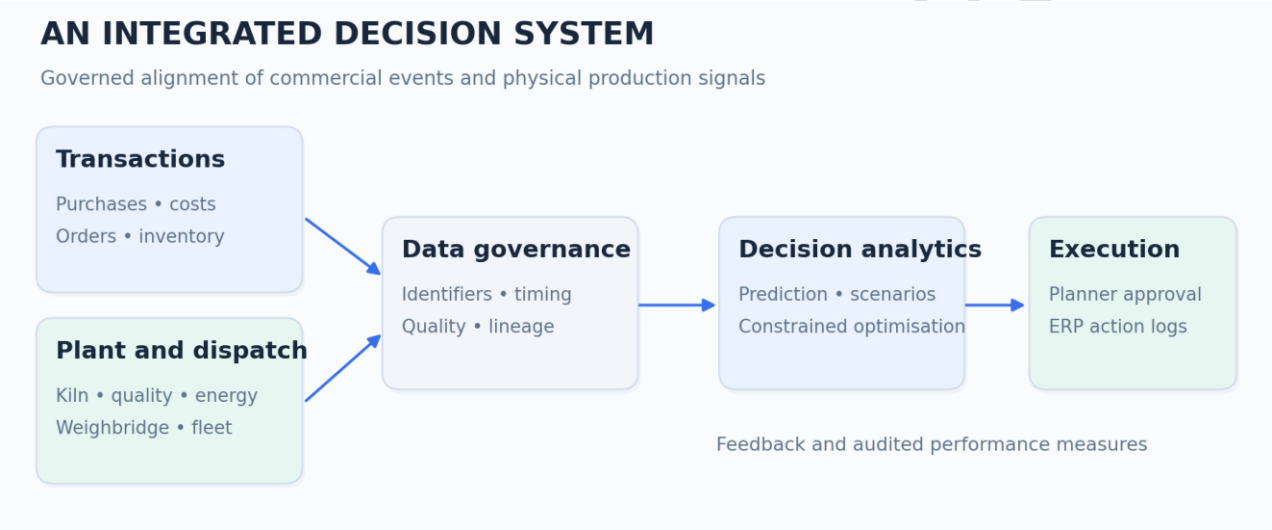


Figure 1. Proposed ERP–operations–analytics architecture with governed, auditable decision feedback (original conceptual diagram).

5.1 Analytics choices by decision frequency

Descriptive analysis should establish common definitions before predictive models are commissioned. Operational and finance teams must agree, for example, whether transport cost refers to invoiced freight, loaded-kilometre expenditure or fully allocated delivery cost. Forecasting then addresses uncertainties over appropriate horizons: hours for energy demand and kiln abnormalities, days for dispatch and replenishment, and weeks or months for material contracts and cash requirements. Prescriptive models convert forecasts into choices while respecting constraints. A demand forecast that leaves insufficient loading slots cannot improve fulfilment; an inventory target that ignores quarry disruption can generate preventable shutdowns. The ambition should be right-time decisions, not indiscriminate real-time automation.

Model governance follows the same logic. Validation should be time-ordered, preferably with entire later months reserved for testing and exceptional high-demand intervals retained as separate stress tests. Accuracy must be compared with a defensible simple baseline and reported by product, route and demand regime rather than as a single pooled percentage. Managers need to know whether an algorithm is wrong

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precisely when action is most consequential. Model drift should trigger review when fuel quality, additive selection, equipment condition or customer mix changes. As Carvalho et al. (2019) note in predictive-maintenance scholarship, maintenance value requires attention to failure definitions and operational usability, not only classification success.

Table 2. Proposed integration and measurement specification for a future Saudi cement-plant pilot.

Source / data family	Illustrative cadence	Core join key	Pilot quality gate
ERP sales and dispatch	At each transaction	Order and shipment ID	≥99% orders joined
ERP purchasing / stocks	At each transaction	Item, lot and location	≤1% unreconciled lines
Kiln DCS measurements	1-minute aggregates	Line and event timestamp	≥98% valid intervals
Laboratory results	4-hour / batch record	Production lot	≥95% lots matched
Weighbridge / telematics	1-minute event stream	Truck and consignment	≤2% missing events
Management accounting	Daily cost ledger close	Cost centre and period	100% balanced totals

5.2 Reconciliation of commercial and physical inventories

Inventory accuracy is often discussed as an ERP data-quality problem, but cement production introduces a deeper measurement problem. Raw material received is not necessarily available for immediate conversion; stored clinker can move between silos, grinding lines and delivery modes; and sales postings may lag despatch. Analytical reports must distinguish physical stock, released stock, quality-hold stock, stock in transit and goods invoiced but not yet accepted. Periodic reconciliation should connect weighbridge quantities, silo estimates, laboratory release records and inventory adjustments through an approved material-balance method. Small persistent losses or conversion errors can materially distort tonne-level cost allocation when multiplied across large volumes. A practical pilot can calculate reconciliation variance separately for raw meal, clinker and finished cement, then examine whether variance decreases after identifier standardisation. This is more informative than reporting the volume of data integrated. Analytics-led maintenance and process studies provide evidence of technical potential, but they do not remove the necessity of basic physical accounting (Carvalho et al., 2019; Tao et al., 2018).

6. Cost optimisation across the cement value chain

Procurement analytics begins with a distinction between expenditure reduction and supply protection. ERP history identifies ordered quantities, supplier lead times, contract prices and invoice exceptions; forecasts add probable consumption and delivery variability. A constrained reorder policy can reduce slow-moving stores while protecting critical spares and fuels. However, minimising purchase price may increase stockout costs, financing charges or maintenance-related production losses. Total landed cost should include quality rejection, freight, import or handling charges and the expected disruption penalty. Cement's continuous production regime makes small-price gains potentially insignificant compared with one lost production campaign. Accordingly, supplier evaluation should combine cost, quality conformity, lead-time reliability and criticality rather than use nominal unit price alone.

Energy cost demands explicit operational boundaries. Specific thermal consumption is generally connected to clinker production, while electrical intensity may be reported per tonne of cement or by process stage. Both metrics should be reconciled with operating hours and product mix. A model that improves energy per tonne at a low utilisation rate could still increase total plant expenditure. An integrated calculation should therefore consider power demand, tariff structures, fuel mix, emissions obligations, output volume and maintenance impacts simultaneously. The studies of kiln process optimisation and energy recovery provide

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technically credible examples of why unit operation design matters (Pan et al., 2024; Poggianti et al., 2024). Their findings do not establish the savings available to an arbitrary Saudi facility.

Maintenance analytics creates value only when the probability and consequence of failure are linked to scheduling constraints. If vibration, motor current and temperature readings predict risk, the enterprise needs to determine whether maintenance should be brought forward, whether a spare is available and whether a temporary throughput adjustment can avoid loss. Alshboul et al. (2024) demonstrate the relevance of machine learning to reliability in related construction-material production; Bokrantz et al. (2020) emphasise the wider organisational conception of smart maintenance. The correct commercial metric is avoided unplanned downtime net of false-alarm interventions, extra spare usage and planned maintenance costs. A high-recall alerting algorithm can be economically harmful if it repeatedly shuts down healthy equipment.

Outbound distribution links the cement plant to its commercial promise. Despatch planners choose loading sequences, vehicle assignments and route consolidation under capacity limits, customer delivery windows and maintenance restrictions. ERP order status alone cannot reveal gate queues or vehicle availability; weighbridge, telematics and order-management integration can supply missing states. Vehicle routing should optimise cost per fulfilled order and on-time-in-full service jointly. For distant markets, buffer stocks or strategically positioned depots may raise holding costs but reduce delivery variability. The interpretation of supply-chain performance therefore involves explicit service–cost trade-offs, rather than a presumption that the shortest kilometre route or smallest inventory always produces the best economic result (Chen et al., 2024; Ivanov et al., 2019).

6.1 From departmental targets to total cost-to-serve

A fragmented organisation rewards individual optimisation. Procurement seeks the cheapest supplier, production seeks maximum utilisation, sales seeks prompt acceptance of orders and logistics seeks full truckloads. These choices can conflict. An integrated data model permits the enterprise to express decisions in terms of a delivered-order contribution margin: sales revenue less variable materials, thermal and electrical inputs, conversion cost, freight, likely service penalties and appropriately allocated capacity costs. Certain expenditures, notably installed capacity and depreciation, cannot be treated as freely avoidable over every scheduling horizon. The decision model should therefore distinguish marginal, committed and sunk costs. This distinction avoids creating fictitious savings when accounting allocations change without physical resource use changing.

Table 3 illustrates such a reconciliation using a hypothetical SAR-per-tonne cost baseline. The example is an arithmetic teaching case, not a measured Saudi plant. Its categories cover materials, thermal energy, electricity, maintenance, outbound logistics and inventory-related charges; each has a recorded baseline, target and implied change. The reduction is deliberately modest enough to demonstrate that multiple small improvements could matter without suggesting an industry benchmark. Actual managers would substitute audited chart-of-account transactions, metered fuel and power, tonne balances, freight invoices and agreed working-capital methods. A correct evaluation should also recognise investment and recurring costs of analytics operation, data integration and user training.

Table 3. Illustrative annualised cost-per-tonne construction, SAR per saleable tonne.

Cost category	Baseline	Integrated	Saving	Change (%)
Materials	78	75	3	3.8
Thermal energy	58	54	4	6.9

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Cost category	Baseline	Integrated	Saving	Change (%)
Electricity	40	36	4	10.0
Maintenance	22	20	2	9.1
Transport	42	37	5	11.9
Inventory charges	20	18	2	10.0
TOTAL	260	240	20	7.7

Note. Hypothetical cost-allocation example for methodological demonstration

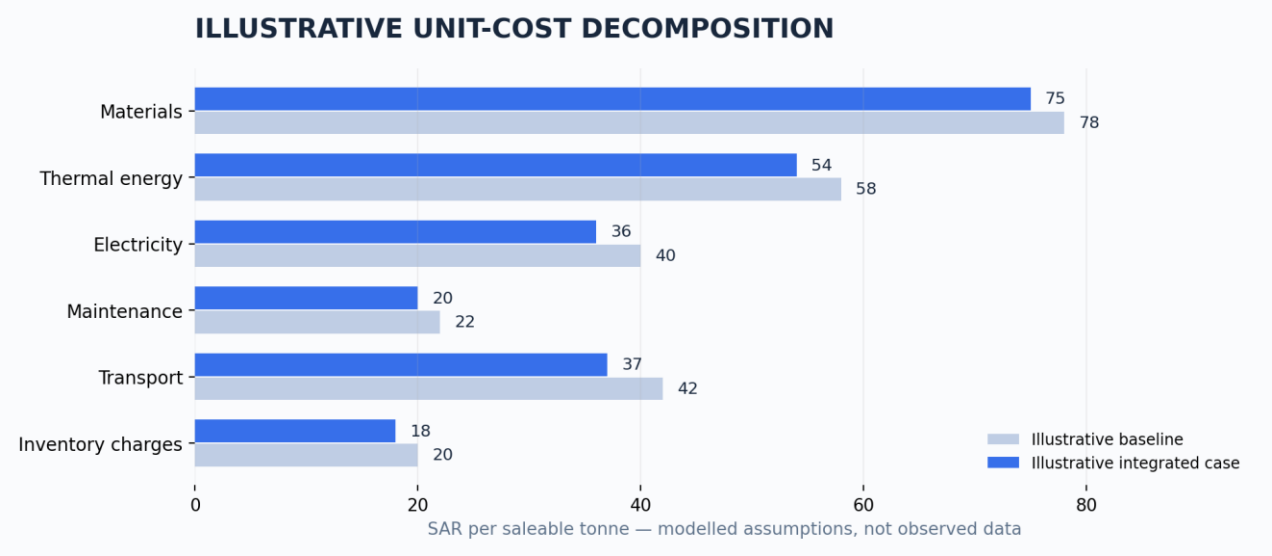


Figure 2. Decomposition of an illustrative cost-to-serve change; original arithmetic, not empirical results.

6.2 Environmental constraints in economic decisions

Cost minimisation must operate inside emission, process-safety and product-specification limits. Lower-cost fuel may require handling upgrades, alter combustion behaviour or increase quality-control expenditure. Clinker-factor reduction may lower embodied carbon yet affect the mix of additives, grinding energy and customer qualification requirements. Consequently, the optimisation function should contain explicit feasible ranges and penalty terms rather than assume unrestricted substitutability. Chew et al. (2024) make the cost and decarbonisation interface explicit at the energy-system level, while Georgiopoulou and Lyberatos (2018) show that different alternatives cannot be judged by a single environmental indicator. A defensible enterprise model could report a frontier of cost and environmental scenarios for management review, with assumptions published alongside each scenario. This gives finance visibility over the economic consequences of the environmental constraint without treating compliance as a discretionary target.

7. Supply chain performance measurement

Cost metrics are insufficient because a plant can improve its apparent expenditure through rationing deliveries or shifting work to customers. A balanced scorecard should measure order-acceptance lead time, promised-versus-actual delivery, order completeness, stock availability, vessel or truck turnaround, forecast error and supply continuity. Each indicator needs a numerator, denominator, unit and clear event timestamp. On-time-in-full, for example, requires rules for partial shipments, customer-requested deferrals and changes to the promised date. Without an agreed measurement protocol, integration may simply produce a faster disagreement between sales, finance and logistics. In practice, useful visibility means that all parties inspect the same order and physical shipment events.

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Leading and lagging indicators should be paired. Demand-forecast error, supplier delay probability, stockout risk and kiln variability are early signals; delivery reliability, demurrage, write-offs and invoice disputes are realised outcomes. The analytical model must demonstrate that intervening on a leading signal changes a lagging result. A planner who receives repeated forecasts but does not alter vehicle dispatch has not created an operational feedback loop. Supply-chain research identifies integration, flexibility and resilience as channels by which analytical capability might translate into performance, and the wider manufacturing literature shows that digitalisation works through complementary changes in organisation and process (Kache and Seuring, 2017; Buer et al., 2018).

7.1 Scenario and sensitivity analysis

Table 4 defines three hypothetical implementation cases using one million saleable tonnes annually. The conservative, central and ambitious cases differ only in gross unit savings; the same annual analytics operating cost and initial investment apply across the cases. This transparent design highlights nonlinearity in investment attractiveness: an apparent improvement in specific unit cost does not necessarily produce acceptable financial payback after continuing expense is recognised. The simple-payback indicator used here divides initial capital expenditure by annual net cash benefit. It does not replace discounted-cash-flow analysis and should not be interpreted as a forecast. Figure 3 translates these arithmetic scenarios into their year-one cash implications.

Sensitivity analysis should extend beyond savings assumptions. A real cement producer would vary demand volumes, energy prices, transport rates, foreign-exchange exposure for equipment, downtime frequency and the timing of project deployment. Interactions are central: lower demand may worsen fixed-cost absorption even where variable energy consumption improves, and a fuel substitution that raises laboratory rejection rates can offset energy-price savings. Two-way scenarios around plant utilisation and fuel cost could reveal whether integration remains favourable in weak construction markets. If estimated benefits disappear under plausible variation, the appropriate conclusion is not necessarily to reject analytics but to narrow the pilot to the decision problems with the clearest controllable cash flow.

Table 4. Transparent, illustrative simple-payback sensitivity at 1.0 million tonnes/year.

Case	Gross saving (SAR/t)	Gross/yr (SAR m)	Net/yr (SAR m)	Payback (years)
Conservative	5	5	2	6.00
Central	12	12	9	1.33
Ambitious	20	20	17	0.71

Note. Each case assumes SAR 12 million initial investment and SAR 3 million annual recurring analytics cost. Net annual benefit = volume × gross saving − annual operating cost; simple payback = initial investment ÷ annual net benefit. Taxes, financing and discounting excluded.

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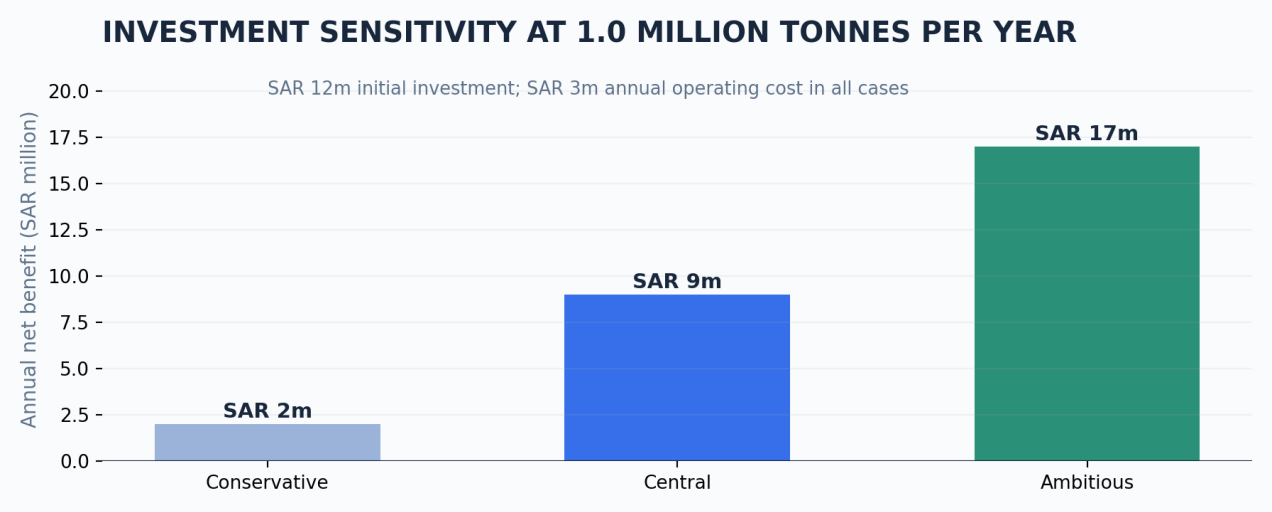


Figure 3. Illustrative sensitivity of annual net benefit to gross unit-cost improvement (original scenario calculation).

7.2 Attributing benefits and avoiding double counting

Financial attribution requires a disciplined counterfactual. Suppose the production team reports lower thermal energy per clinker tonne and purchasing reports a lower fuel spend. Unless the accounting boundary is carefully defined, these may represent the same benefit twice. Savings should be classified as quantity effects, price effects, product-mix effects and one-off accounting adjustments, with only incremental cash-relevant changes included in the investment case. The same concern arises when faster procurement reduces both purchasing staff time and allocated departmental overhead: saved hours are not necessarily cash savings unless capacity or expenditure changes. Audited savings are therefore best signed off jointly by operational owners and finance. Enterprise studies connect analytics with performance but also show the importance of organisational moderators (Dubey et al., 2020; Mikalef et al., 2019). In this application, benefit realisation is an observable decision process, not a line of projected percentages in a business case.

8. Organisational implementation and governance

The proposed adoption sequence is organised around demonstrable managerial decisions. A preliminary diagnostic should map ERP records, control-system data, laboratory datasets, fuel measurement and dispatch events into common material and order identifiers. The first pilot should target a bounded question—such as clinker energy variance by production campaign or route-specific late-delivery cost—for which a historical baseline is available. Only after reconciling operational definitions should the firm undertake model selection. A parallel-run period lets planners compare recommendations with current practice without exposing the plant to poorly understood automation. The implementation plan should specify who can overrule a model, how an override is recorded and who examines recurring divergences.

A cross-functional steering group is essential because a single department cannot legitimately define the trade-offs. Process engineers can establish kiln safety constraints; quality managers can determine acceptable product variation; finance must validate avoidable costs; supply-chain managers understand external lead times; and information-security staff govern access. Analytics output should be accompanied by a confidence assessment and explanation of the constraints that shaped the result. Independent review of data transformations and parameter changes is especially important where financial recommendations affect supplier selection or customer allocation. Chang (2025) and Jaradat et al. (2024) provide support for

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treating integration success as simultaneously technological and organisational, rather than as a standalone dashboard procurement exercise.

The Saudi setting adds contextual assessment rather than an assumption that one policy dictates every technology decision. Fuel-price exposure, local service coverage, workforce development, vendor interoperability and data-governance obligations should be checked against the organisation's actual contractual and regulatory position. Matar et al. (2025) show why fuel and technology choices must be evaluated against local prices and investment conditions. The broader Saudi analytics literature indicates that organisational capacity and environmental support matter for adoption (Aldossari et al., 2025). The review therefore recommends plant-specific due diligence rather than claiming that any generic platform is automatically compliant, economically optimal or aligned with every enterprise operating model.

8.1 Human interpretation and decision rights

There is a predictable failure mode in which an optimisation engine produces a technically elaborate recommendation that no accountable manager can safely authorise. For instance, a suggestion to reduce silo buffer may conflict with a salesperson's known but unentered tender pipeline; a proposal to alter firing conditions may rely on a sensor that operators already know is drifting. The right response is neither complete managerial discretion nor automatic machine execution. Decision rights should match reversibility and consequence: low-risk data exceptions may be auto-routed, routine dispatch options may be recommended to a scheduler, and kiln or high-value contract changes may require documented engineering and commercial approval. Overrides should include a reason code that becomes subsequent model-learning evidence rather than being dismissed as noncompliance. This approach converts organisational knowledge into a governed feedback asset and aligns with the broader understanding of analytics as a socio-technical capability (Gupta and George, 2016; Chang, 2025).

9. Testable propositions and future research

The synthesis yields three propositions suitable for empirical study. P1 states that the relationship between ERP–analytics integration and cost-to-serve improvement is mediated by cross-functional data consistency and the frequency with which recommendations are executed. P2 states that gains in energy optimisation will have a stronger positive association with enterprise margins when clinker quality, downtime and production volume are explicitly included in the objective function. P3 states that analytics-enabled logistics visibility improves on-time-in-full performance most where routing flexibility, buffer stock governance and dispatch authority are available. These are theoretically motivated propositions, not hypotheses already confirmed by this review.

A future evaluation should recruit Saudi cement plants with contrasting utilisation, age, geography and product portfolios, then establish at least twelve months of pre-implementation performance where records allow. A staggered rollout across depots, production lines or planning teams offers a stronger design than a single before–after comparison. Interrupted time-series or difference-in-differences analysis can isolate, subject to their assumptions, impacts from simultaneous fuel-price movements, plant overhauls and demand shifts. Outcomes should include audited total delivered cost, energy by product and production stage, order fulfilment, inventory days and unplanned downtime. The study should predefine exclusions for extraordinary shutdowns, document changes to customer promise rules and report missingness transparently.

Qualitative evidence remains necessary. Observations of planner meetings, override logs and maintenance scheduling can reveal whether analytic recommendations were actually adopted and why they failed.

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Without this process evidence, an observed change in delivery reliability could be misattributed to software when it was caused by added trucks or reduced demand. Research should report the project total cost of ownership and uncertainty in calculated benefits; technical performance in isolation is inadequate. Comparisons between cloud, hybrid and on-premises implementations should hold decision process and business scope as constant as possible. The resulting evidence could establish where data integration adds value, where human coordination dominates and where a simpler rule-based system performs equally well.

9.1 Research design for economic validity

The empirical design should keep intervention granularity aligned to the claimed benefit. If analytics changes weekly cement distribution, comparisons should be made at route, destination and week level, controlling for kilometres, customer order sizes, haulage capacity and weather interruptions. If the intervention changes kiln operating targets, production campaigns and product-quality results are the appropriate unit, with downtime and energy prices included. Exogenous events such as scheduled plant outages should be documented rather than mechanically attributed to technology. Researchers could triangulate fixed-effects estimates, event-study plots and interviews with the planners who accepted or rejected recommendations. Explicit registration of target outcomes before analysis would limit selective reporting. The result would be evidence not merely that the software was installed but that use of better-coordinated information changed observable operations and financial results.

10. Limitations

The manuscript's major limitation is the absence of a pooled Saudi cement-factory dataset linking ERP transactions to production telemetry and dispatch outcomes. The published evidence mixes different countries, industries, designs and financial boundaries. Some references concern cement engineering rather than enterprise systems; others examine general manufacturing analytics and are applicable only through reasoned transfer. The 30-study corpus is purposive and does not claim complete bibliographic coverage. A formal meta-analysis would be inappropriate given heterogeneous endpoints and largely incompatible reported effect measures. The numerical tables are either explicitly attributed to their original studies or labelled illustrative. No stated cost reduction, payback period or supply-chain improvement should be presented as an observed result for Fahd Aizaz or a Saudi cement producer.

11. Conclusion

ERP integration with advanced data analytics can be understood as a coordinated managerial capability rather than a technology purchase. In Saudi cement manufacturing, the most credible opportunities arise where the same materials, production and shipment events influence multiple costly decisions: procurement, kiln energy, maintenance, inventory and distribution. The reviewed evidence supports the feasibility of process optimisation and the relevance of data quality and organisational integration, but it does not prove a general Saudi cement-sector return on investment. The proposed architecture ties governed data to constrained recommendations, accountable approvals and audited outcomes; the numerical model makes assumptions and trade-offs explicit. Future longitudinal evaluations should test whether these mechanisms improve delivered cost and service simultaneously, accounting for fuel markets, plant utilisation, product quality and customer demand. The central implication is that actionable integration, not the volume or sophistication of analytics alone, is the precondition for durable improvement.

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