Operations Research for Cement Distribution Planning: A Literature-Based Review

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***Abstract*— Although a single tonne of cement is relatively cheap, it is a heavy product, and thus distribution from works to depots, dealers, and finally to worksites is among the largest expenditures for cement producers. This paper undertakes a survey of operations research (OR) applications to cement distribution planning: from 20 articles retrieved between 1999 and 2025 in Asia, Africa, Europe, and Latin America, the case study literature on cement distribution is dominated by classical transportation and transshipment models solved with tableau, Excel Solver, LINGO, or QM for Windows, with 5% to 37% of travel cost reductions over the firm's practice reported, including a Rp49,6 billion cost saved by a Java Bali cement producer. Integer programming and metaheuristic approaches are used when allocating distribution hubs, designing vehicle routes, or scheduling ships; on a real-world distribution task, an exactly solved integer programming model reduced the average day of delivery by 15 20%. The paper develops a generic cement transshipment model, evaluates the solution software used in the literature, resolves five transportation examples from the articles to check the correctness of their results, and discusses the frequent oversights in cement distribution planning models.**

***Index Terms*— operations research; transportation problem; transshipment; vehicle routing; facility location; cement distribution**

I. INTRODUCTION

Operations Research (OR) utilizes mathematical models to make choices when limited resources have to be apportioned among conflicting needs. Its oldest and richest application area concerns transportation: given sources of supply and destinations with demand, how many units should be shipped from where to where so that supplies are not exceeded, demands are met, and transportation costs are minimized? Since costs, capacities, and demands all enter the objective function and constraints linearly, the problem reduces to a linear program (LP) and can be solved exactly.

Cement is an example of a product that fits this framework almost perfectly. Plants are located near limestone deposits, and the demand is spread throughout thousands of dealers and construction sites. The product is low-value and high-bulk, meaning that it is the freight that sets the landed price. In India freight accounts for about 17% of the cost of production, and a plant's competitive radius rarely extends beyond 300 km [12]. As for an Indonesian producer that services Java and Bali, distribution reached nearly 14% of the principal expenses, or Rp 2.19 trillion, as of 2018 [13]. Thus, a cement company that is used to apportioning its plants to markets by habit is leaving real money on the table. The decisions by habit are leaving real money on the table. The decisions involved come in many layers. Where to open depots or packing plants is a problem of facility location. How many tonnes to move along each link is a transportation or transshipment problem. Which truck serves which customer and in what order is a vehicle routing problem and when ships and silos are involved stock levels must be planned together with routes. Each layer has its own OR model and the literature uses almost all of them.

This paper has two objectives: summarizing how 20 studies formulated and solved cement distribution problems and extracting a common model, comparing solution approaches, and reflecting critically on the field's strengths and weaknesses

II. REVIEW SCOPE AND APPROACH

This is a descriptive review, not a systematic one. The pool of sources was made up of the papers located by the project scoping group, plus six others found in ScienceDirect, Springer, Wiley, Nature and the IEOM proceedings, after searching by keywords. All entries were checked against the article's publisher page or DOI before having been added to the list. Four entries were excluded for being unverifiable – DOIs provided for Fahim and Wibowo (2021) and Wang and Zhang (2023) led to different papers, and those for Al-Shiha and Rahman (2020) and Tavana et al. (2021) are nonexistent. Two duplicated entries (Daniel et al. and Hertz et al.)

Were Counted as One.

Out of the 20 studies retained for further consideration, 15 were read in their entirety. The other five could be accessed only up to the level of abstract or repository record ([1], [3], [11], [16], [19]), and are cited here only to the extent that the records or their abstracts report. If a paper does not report something, the review does not claim that it does. The review focuses on four issues: (1) the framing of the problem; (2) the solution methods and tools used and how results are validated; (3) comparisons of exact and heuristic approaches; and (4) limitations and research opportunities identified in the work. Table I classifies the sources according to seven literature streams, and Appendix A records, for each study, the items that the project guidelines ask for.

Table I. Literature streams covered in this review

Stream	Studies	Purpose
Classical transportation models	[5], [6], [7], [12], [14], [16]	Plant-to-market allocation at minimum cost
Transshipment and multi-echelon networks	[2], [10], [13]	Flows through packing plants and depots
Facility location and network design	[1], [9], [11]	Where to open depots and distribution centres
Uncertainty and multiple objectives	[19], [20]	Fuzzy, robust and bi-objective planning
Exact vehicle routing	[8]	Daily truck assignment and routes
Routing heuristics and metaheuristics	[3], [15], [17], [18]	Fast routes for dealers and agents
Maritime inventory routing	[4]	Ship routes and silo stock together

III. LITERATURE REVIEW

A. Classical transportation models

The bulk of the articles gathered are concerned with applications of the textbook transportation model to a real company. Oba [14] transports cement from the construction company Julius Berger from three depots to three flyover sites in Port Harcourt, Nigeria, measuring supplies and demands in the number of 900-bag truck trips. The initial solutions worked out by North-West Corner, Least Cost and Vogel methods cost US$2,273, US$2,309 and US$2,291; two stepping-stone iterations then reached the optimum of US$2,259 according to Excel Solver. However, the abstract states that the Least Cost method provided the best starting solution, while the results presented in the paper and its conclusion point to the North-West Corner method.

Daniel et al. [5] take up Ebonyi State, Nigeria, in which there was no information on reliable freight rates. Instead of the cost matrix, they use the distance matrix, assuming that the cost is proportional to the distance, and then apply the Vogel's method in TORA to allocate 401,000 bags from Dangote, Ibeto and Unicem plants to four distribution centres. According to the solution that they provide, the total transportation plan involves 57,074,000 bag-km of distance, but it ships 258,000 bags from one of Dangote plants that can supply only 240,000 bags.

Flores Tapia and Flores Cevallos [7] model Holcim Ecuador's shipments of GU cement from its Latacunga and Guayaquil plants to six Disensa distribution cities, 175,950 sacks in total, and solve the LP in Excel Solver. They report a minimum cost of US$240,365 for 2019 and US$191,205 under projected 2020 freight rates, with the same allocation in both years.

Devani et al. [6] study PT SP Dumai in mainland Riau, Indonesia: Vogel's method gives an initial plan of Rp 833.5 million, and the multiplier (MODI) method improves it to Rp 695.7 million, 36.82% below the cost the authors attribute to the company's actual routing.

More and Sharma [12], both from NMIMS, survey about 100 channel partners in Jaipur and build a balanced 4 × 4 model in which factories, warehouses, dealers and retailers ship to warehouses, dealers, retailers and end in customers. He finds that direct shipment from plant or warehouse to site is the most viable option but at a much higher price of Rs 72,050 per bag for 3,000 bags. On the other hand, M. Vogel's method yields Rs 37,987,500 for 1.6 million bags per month in an average of Rs 23.74 per bag and the authors conclude that direct delivery from plant or warehouse to site is the most viable channel. Polat [16] solves a transportation model for seven Turkish regions and then introduces goal programming in WinQSB such that both cost and supply–demand matching are considered as separate goals; both were satisfied.

B. Transshipment and multi-echelon networks

Nooranda and Vanany [13] develop the model further to a complete network of 2 plants, 5 packing plants, 6 virtual distribution centres and 128 districts in Java and Bali, where bag and bulk cement are transported by ship and truck. The objective function includes fixed, production, sea-shipping, truck and administration costs, and a 0/1 variable indicates whether each packing plant is operated. Solved in LINGO with 2,467 variables, the model reduces supply chain cost from Rp 954.4 billion to Rp 904.8 billion (saving 5.2%), with a 31.5% decrease in sea shipping cost. It also reveals that one packing plant was operated at only 21% of its capacity; closing it reduces cost by a further Rp 4.25 billion.

Atristyanti [2] investigates whether PT Semen Gresik should construct packing plants in Kalimantan instead of transporting bagged cement from Tuban to 16 destinations. Four scenarios are compared using a transshipment LP in QM for Windows, where each packing plant unit costs Rp 120.2 billion to produce 300,000 tonnes per year. The lowest total cost of Rp 850.4 billion per year is achieved with plants at Banjarmasin and Pontianak, compared to Rp 1,002.4 billion without a packing plant. Kurniawan and Rusdiansyah [10] construct an LP for a producer which has just acquired a competitor in Java, consisting of 3 factories, 3 packing plants, a grinding plant and 103 sales areas. They maximise operating income subject to market-share bounds in OpenSolver, reporting scenarios generating 32.51% and 34.20% above the expected income.

C. Facility location and network design

Lwin [11] formulates a capacitated location-allocation MILP for cement company "X" in Myanmar, with 3 plants, 6 candidate distribution centres and 6 market regions. Across three scenarios the profit-maximising design always opened just two centres, at Mandalay and Meikhtila. Khan and Sinha [9] decide how many distribution and retail centres to open in Srinagar, India, and where. A real-coded genetic algorithm in MATLAB selects 3 distribution centres (Sonwar, Batamaloo and Badamwari) with 3 retail centres each, and an emissions constraint caps output at 90 truckloads a day. At the other end of the scale, Abt and Tisera [1] build a MILP for a multinational trader distributing slag and other cementitious materials worldwide. Reallocating existing volumes was projected to raise contribution margin by 11%, while a 20% rise in transport cost would cut it by 51%.

D. Uncertainty and multiple objectives

Shih [19] plans cement transport in Taiwan after a ban on limestone mining in the west forced production to move east of the Central Ridge. Three fuzzy LP approaches are compared with a crisp LP to set transport volumes and the capacity of new facilities, under port, demand-fulfilment, trans-shipping and traffic-congestion constraints. Tirkolaee et al. [20] configure a three-echelon network of suppliers, a three-stage plant, distribution centres and markets as a bi-objective MILP that maximises profit and minimises dust. Demand, costs and emission rates are trapezoidal fuzzy numbers, a carbon cap limits emissions and part of the electricity comes from a local microgrid. Solved in GAMS with CPLEX in under two seconds, the compromise plan earns US$815,468 with 270,981 kg of dust, although the data are illustrative values taken from the literature.

E. Vehicle routing with exact methods

Hertz et al. [8] tackle the daily delivery plan of a cement supplier with a mixed truck fleet, a central

depot and 14 rail-fed local depots. Most orders exceed one truckload, so customers are visited several times, which makes this a split delivery vehicle routing problem. Their two-phase method first assigns deliveries to trucks and then sequences each route, both as integer programs; a one-phase model combines them. On ten real days solved with CPLEX, the plans cut delivery time by 14.8% (two-phase) and 19.8% (one-phase) on average compared with the plans the company actually ran, and used up to five fewer trucks.

F. Routing heuristics and metaheuristics

At the dealer level, simpler heuristics dominate. Rahmawati et al. [17] apply the saving matrix to eight customer regions served from the Tuban plant in East Java, merging eight shipping routes into four and cutting distance from 3,146.6 km to 1,970.6 km. Rusindiyanto et al. [18] use ant colony optimisation in MATLAB to route 40 kg cement to nine agents of PT SBI Tuban, splitting 15.6 tonnes across two trucks with routes of 151.7 km and 61.7 km. Azad and Hasin [3] use a genetic algorithm to cluster resellers and sequence deliveries for a Bangladeshi cement company. Pham and Nguyen [15] combine the sine cosine algorithm with the grey wolf optimiser and other operators; for a dealer with 30 customers and five 90-bag trucks, the best route set was 701.16 distance units, 14.7% to 37.5% shorter than the best results of four rival algorithms.

G. Maritime inventory routing

Christiansen et al. [4] plan the coastal fleet of Norcem, Norway's main cement producer: five ships carrying ten non-mixable grades from two factories to silos in 28 ports, with upper and lower stock limits at every silo. A construction heuristic, tuned by a genetic algorithm, builds a 14-day plan in 0.71 seconds. The company judged the plans better than its manual ones, although the paper gives no formal algebraic model.

IV. MATHEMATICAL FORMULATION

A. Type of problem

At its core, cement distribution planning is a transportation problem, and when cement passes through depots, packing plants or distribution centres it becomes a transshipment problem. Adding a yes/no decision on whether each intermediate facility is open turns the LP into a mixed-integer linear program (MILP), the facility location case [9], [11], [13]. Routing studies sit one level lower: once tonnes are allocated, the order of visits is a travelling salesman or vehicle routing problem, which is NP-hard and therefore often solved heuristically [3], [15], [17], [18]. The common network core of the reviewed models is set out below, with notation in Table II.

B. Sets, parameters and decision variables

Table II. Notation

Symbol	Meaning
I, K, J	Plants (sources); depots, packing plants or DCs; demand points
S_i, D_j	Supply of plant i; demand of point j (tonnes, bags or trips)
Q_k, f_k	Capacity and fixed (annualised) cost of facility k
c_{ij}, c_{ik}, c_{kj}	Unit cost or distance on each link
x_{ij}, x_{ik}, x_{kj}	Decision: quantity shipped on each link
y_k	Decision: 1 if facility k is open, 0 otherwise
x_{ijs}, y_{is}	Routing decisions: vehicle s drives i to j; vehicle s serves customer i
g_i, q_s, u_i	Customer demand; vehicle capacity; position of stop i on a route

C. Objective function

The most common objective minimises total cost: shipping on every link plus the fixed cost of the facilities that are opened:

$$\min Z = \sum_i \sum_j c_{ij} x_{ij} + \sum_i \sum_k c_{ik} x_{ik} + \sum_k \sum_j c_{kj} x_{kj} + \sum_k f_k y_k$$

When the network has no intermediate layer and no fixed costs, only the first term remains and the model is the classical transportation problem used in [5], [6], [7], [12] and [14]. The reviewed studies use several variants of the cost. Daniel et al. [5] replace cost with distance, Nooranda and Vanany [13] add production and administration costs, Kurniawan and Rusdiansyah [10] maximise operating income instead, and Tirkolaee et al. [20] maximise profit while minimising dust.

D. Constraints

The hard constraints common to nearly every reviewed model are:

$$\sum_j x_{ij} + \sum_k x_{ik} \le S_i \quad \forall i \tag{1}$$

$$\sum_i x_{ij} + \sum_k x_{kj} \ge D_j \quad \forall j \tag{2}$$

$$\sum_i x_{ik} = \sum_j x_{kj} \quad \forall k \tag{3}$$

$$\sum_i x_{ik} \le Q_k\, y_k \quad \forall k \tag{4}$$

$$x \ge 0, \quad y_k \in \{0, 1\} \tag{5}$$

Constraint (1) keeps each plant within its supply, (2) guarantees each demand point at least its demand, and (3) says that a depot or packing plant passes on exactly what it receives, so no stock is held. Constraint (4) links flow to the open/close decision: if $y_k = 0$ nothing can pass through facility k, and if $y_k = 1$ the flow is capped by its capacity. Constraint (5) keeps flows non-negative and the location decisions binary.

Individual studies extend this core with their own rules: market-share bounds [10]; an emissions cap [9], [20]; restricted routes priced at a very large cost M [12], [13]; truck availability, depot access and union overtime limits [8]; sub-tour elimination for routes [8], [15]; and stock limits at every silo [4].

E. Illustrative example

The small example of Oba [14] illustrates the model. Three depots supply 7, 5 and 3 truckloads, and three sites need 4, 6 and 5, so that supply equals demand, and the problem is balanced (Table III). The contents of each cell give the cost in US dollars of one 900-bag trip, between the two places denoted by the row and column respectively.

Table III. Worked example from Oba [14]: cost per trip (US$), optimal trips in brackets

Depot (supply)	Site X (4)	Site Y (6)	Site Z (5)
A (7 trips)	131 [4]	145 [1]	135 [2]
B (5 trips)	138	144 [5]	141
C (3 trips)	213	222	200 [3]

Starting from the North-West Corner solution (US$2,273), the stepping-stone method evaluates each empty cell. Shipping along A→Z has a net cost change of −7, so flow is moved into it; after the second iteration every empty cell has a non-negative net change and the plan is optimal at US$2,259. The optimal plan entails making 4, 1 and 2 trips from depot A, 5 from B to site Y and 3 from C to site Z. The saving over the starting plan is small here, only US$14, also indicating how good a careful initial solution can be on a 3 × 3 problem.

F. Extension to vehicle routing

Once tonnes are allocated, the routing studies decide how trucks visit the demand points. The capacitated vehicle routing problem used by Pham and Nguyen [15] adds a binary x_{ijs} (vehicle s drives from i to j) and a binary y_{is} (customer i is served by vehicle s), with customer demand g_i, vehicle capacity q_s and k vehicles based at depot 0:

$$\min \; D = \sum_{i=0}^{h} \sum_{j=0}^{h} \sum_{s=1}^{k} c_{ij}\, x_{ijs}$$

$$\sum_i x_{ijs} = y_{js} \quad \forall j, s \tag{6}$$

$$\sum_j x_{ijs} = y_{is} \quad \forall i, s \tag{7}$$

$$\sum_i g_i\, y_{is} \le q_s \quad \forall s \tag{8}$$

$$\sum_s y_{is} = 1 \;\; (i \ge 1), \quad \sum_s y_{0s} = k \tag{9}$$

$$u_i - u_j + h\, x_{ijs} \le h - 1 \quad \forall i \ne j \ge 1 \tag{10}$$

Constraints (6) and (7) let a vehicle enter and leave a customer only if that customer is on its route, (8) keeps each load within capacity, and (9) gives every customer exactly one vehicle while all k vehicles start at the depot. Constraint (10) removes sub-tours, loops that never return to the depot, by giving each stop a position u_i; Hertz et al. [8] use this form, while the version printed in [15] omits it. Hertz et al. also replace the single visit in (9) with an integer number of trips per order, which is what allows split deliveries.

G. Assumptions

The reviewed models share several assumptions. Demand, supply and costs are known and fixed for the planning period; costs are linear in the quantity shipped, with no volume discounts; the period is a single month or year; and trucks or ships are always available. Several models also assume that what enters a depot leaves it in the same period, so no inventory is held [13], [20]. Only Shih [19] and Tirkolaee et al. [20] relax the certainty assumption, and only Christiansen et al. [4] plan stock levels over time.

V. SOLUTION METHODOLOGY

Tableau methods. Small balanced transportation problems are solved in two steps. An initial basic feasible solution with m + n − 1 allocations are built

by the North-West Corner, Least Cost or Vogel's approximation method; Vogel's method, which allocates first where the penalty for missing the cheapest route is largest, usually starts closest to the optimum. The stepping-stone or MODI (multiplier) method then tests each empty cell and moves flow until no cell can lower the cost. Four studies follow this route [5], [6], [12], [14].

Exact LP and MILP. Larger models are solved by the simplex method or, when binary variables are present, by branch-and-bound: the solver relaxes the binaries, solves the LP, and branches on any fractional value until an integer solution is proven optimal. This is how LINGO [13], CPLEX [8] and GAMS [20] reach proven optima. Hertz et al. [8] show the limit of the approach: their one-phase model could not prove optimality within six hours, so they split the problem into two smaller integer programs that solved within minutes.

Heuristics and meta-heuristics. As routing and location problems grow exponentially to sizes too large for exact methods to handle, many researchers are turning to search methods that find good, although not optimal, solutions with a provable worst-case performance bound. The saving matrix method merges together routes in a greedy way [17]; the ant colony optimisation builds routes out of simulated pheromone trails [18]; genetic algorithms allow evolution of candidate solutions through selection, crossover and mutation [3], [4], [9]; and hybrid swarm algorithms combine wide-ranging exploration with exploitation of promising regions [15].

Software. The software used in the papers are listed in Table IV. Spreadsheet solvers and teaching packages are used in the transportation case studies, while the routing and network papers use commercial solvers or their own code.

Table IV. Software and solvers used in the reviewed studies

Tool	Type	Used in
Excel Solver / OpenSolver	Spreadsheet LP solver	[7], [10], [14]
QM for Windows, TORA, WinQSB	Teaching OR packages	[2], [5], [6], [16]
LINGO	Commercial LP/MILP solver	[13]
IBM CPLEX	Commercial MILP solver	[8], [20]
GAMS	Algebraic modelling language	[20]
MATLAB	Numerical computing (GA, ACO)	[9], [18]
Java, C++	Custom heuristic code	[4], [15]
Not reported	—	[1], [3], [11], [17], [19]

Validation. The studies validate results in four ways. The strongest compares the model with what the company actually did [6], [8], [13], [17]. Others compare methods or algorithms on the same data [14], [15], test scenarios and sensitivity [1], [2], [10], [20], or only confirm that the solver output satisfies the constraints [5], [12]. To check the smaller studies, this review re-solved the five transportation instances whose full data are published, using the open-source HiGHS LP solver in Python (Table VI). Three reported optima were confirmed exactly. Two were not: the plans printed in [5] and [7] break their own supply or demand constraints, and the feasible optimum for [7] is about 21% cheaper than the reported one.

Table VI. Re-solving published instances (HiGHS LP solver)

Study	Reported / re-solved optimum	Finding
Oba [14]	US$2,259 / US$2,259	Confirmed
More & Sharma [12]	Rs 37,987,500 / Rs 37,987,500	Confirmed
Devani et al. [6]	Rp 695,672,000 / Rp 695,672,000	Confirmed
Daniel et al. [5]	57,074,000 / 57,346,000 bag-km	Printed plan exceeds Dangote supply by 18,000 bags
Flores Tapia [7]	US$240,365 / US$188,765 (2019)	Printed plan leaves 29,700 sacks undelivered

VI. COMPARATIVE RESULTS

Table V summarises all 20 reviewed studies. Three patterns emerge from it.

First, the classical transportation model is the workhorse of practice. Ten of the 20 studies use a

transportation or transshipment LP, and the reported gains against company practice are large: 5.2% on a Rp 954 billion network [13], about 15% with new packing plants in Kalimantan [2] and 36.82% in Riau [6]. These are the easiest gains to capture, because the data are usually already in the company's books.

Second, the method shifts with the decision. Allocation problems are solved exactly in seconds; routing and location problems move to integer programming when they are small enough [8], [11] and to metaheuristics when they are not [3], [9], [15], [18]. The only paper that compares an exact plan with a company's real plan on the same days, Hertz et al. [8], also produced the most convincing operational result.

Third, results are rarely comparable across studies. Each measure against its own baseline, in its own unit (US dollars, rupees, rupiah, kilometres, bag-kilometres or abstract distance units), and several baselines are not explained. The 36.82% saving in [6], for instance, is measured against a "real condition" cost whose calculation the paper does not show; against the Vogel starting solution the gain is about 17%.

Table V. Comparative summary of the 20 reviewed studies (newest first)

Ref.	Study	Setting	Model / method	Key result
[20]	Tirkolaee et al. (2025)	Illustrative 3-echelon network	Bi-objective robust fuzzy MILP; GAMS, CPLEX	Profit US$815,468, dust 270,981 kg; solved in under 2 s
[12]	More & Sharma (2025)	Channel partners, Jaipur, India	Transportation LP; Vogel's method	Rs 37.99 million for 1.6 million bags (Rs 23.74 a bag)
[14]	Oba (2023)	Julius Berger, Port Harcourt, Nigeria	Transportation LP; stepping stone; Excel	Optimum US$2,259 for 15 truck trips
[15]	Pham & Nguyen (2023)	Cement dealer, 30 customers	CVRP; hybrid sine cosine algorithm; Java	701.16 units; 14.7% to 37.5% below rival algorithms
[18]	Rusindiyanto et al. (2023)	PT SBI Tuban, Indonesia	TSP; ant colony optimisation; MATLAB	Two truck routes of 151.7 km and 61.7 km
[6]	Devani et al. (2022)	PT SP Dumai, Riau, Indonesia	Transportation LP; Vogel + MODI; QM	Rp 695.7 million, 36.82% below reported practice
[9]	Khan & Sinha (2022)	Srinagar, India	Two-level location; real-coded GA; MATLAB	3 DCs with 3 retail centres each; at most 90 trucks a day
[13]	Nooranda & Vanany (2021)	Java and Bali, Indonesia	Transshipment MILP; LINGO	Cost down 5.2% (Rp 49.6 bn); close one packing plant
[5]	Daniel et al. (2021)	Ebonyi State, Nigeria	Transportation model on distances; Vogel; TORA	57.07 million bag-km (printed plan infeasible)
[7]	Flores Tapia & Flores Cevallos (2021)	Holcim, Ecuador	Transportation LP; Excel Solver	US$240,365 reported; feasible optimum US$188,765
[17]	Rahmawati et al. (2021)	PT XYZ Tuban, East Java	CVRP; saving matrix	8 routes to 4; 1,176 km shorter (37%)
[10]	Kurniawan & Rusdiansyah (2020)	Java, after an acquisition	LP location-allocation; OpenSolver	Operating income 32.5% to 34.2% above expected
[3]	Azad & Hasin (2019)	Cement company, Bangladesh	CVRP; genetic algorithm	Minimum-distance reseller routes
[1]	Abt & Tisera (2018)	Global slag trader	MILP; scenario planning	Margin +11%; freight +20% cuts margin 51%
[16]	Polat (2018)	Seven regions, Turkey	Transportation model + goal programming; WinQSB	Cost and supply–demand goals both met
[2]	Atristyanti (2015)	Semen Gresik, Kalimantan	Transshipment LP; QM for Windows	Two new packing plant sites cut total cost about 15%
[11]	Lwin (2015)	Company “X”, Myanmar	Location-allocation MILP	Open 2 of 6 candidate DCs

[8]	Hertz et al. (2012)	Cement supplier, 15 depots	Split delivery VRP; ILP; CPLEX	Delivery time 15% to 20% lower; up to 5 fewer trucks
[4]	Christiansen et al. (2011)	Norcem, Norway	Maritime inventory routing; heuristic + GA	14-day plan in 0.71 s; better than manual plans
[19]	Shih (1999)	Taiwan, east–west shift	Fuzzy LP vs crisp LP	Transport volumes and new facility capacities

VII. CRITICAL ANALYSIS AND IMPLICATIONS

A. Strengths

Proven optimality where it matters. An LP or MILP solver either finds the cheapest plan or proves that the rules can't be all satisfied. For the allocation layer, on which the largest part of the money is spent, this is hardly a problem: the instances in [12] and [14] are solved by hand or Excel, while [13] has 2,467 variables in LINGO.

Transparency. Every rule is an explicit constraint which can be read, audited and modified by a logistics manager. The fixed-cost and capacity structure of [2] and [13] turns a debate about building or closing a packing plant into a comparison of costed scenarios.

Decision support beyond routine shipping. Scenario runs answer strategic questions, such as which packing plants to build [2], which plant to close [13], how sensitive margin is to freight rates [1], or how many trucks per day an emissions cap allows [9].

Accessible tooling. Excel Solver, OpenSolver and QM for Windows [6], [7], [10], [14] all put the method within reach of a distributor even without a commercial licence.

B. Limitations and assumptions

Deterministic, single-period inputs. All the models except [4], [19] and [20] consider demand and freight as known and most of them consider only a single period, even though the cement demand varies with the season and the progress of construction works: Devani et al. [6] formulate their planning on the basis of a single day.

Errors in published solutions. The re-solve in Table VI reveals that two of five small studies printed plans which violate their own constraints. Several others have contradictions between the abstract and results, for example 163.2 km against 162.3 km in [18], and the wrong best starting method in [14]. A reader should examine reported optima rather than blindly believe them.

Proxies for cost. Distance replaces cost in [5], [15], [17], and [18], and none of these studies cite the saving in terms of money, fuel, or time.

Weak validation in the heuristic stream. With the exception of [4], [8], and [15], the routing and location papers do not compare their results to an exact or alternative approach, making it difficult to evaluate the quality of their solutions. Khan and Sinha [9] show only convergence plots from their genetic algorithm, even though the solution space of 4,050 combinations was completely searchable.

Layers solved separately. There is no study in this category that links location, allocation and routing in a single model, so a depot selected in a study's model can result in routes that would be rejected by another.

C. Implications

For cement companies, the first stage examples suggest that initial opportunities arise from re-allocating plants to meet markets with a simple transportation LP; this only requires supply, demand and freight data that most firms should be able to capture. Facility decisions follow naturally from the same model (with the addition of fixed costs) as shown by the Java–Bali and Kalimantan cases. Gains from daily scheduling appear substantial, but these require improved truck data and careful consideration of timing and orders.

For an Indian context the same logic applies directly. Plants are concentrated in a few limestone-rich states, rail rakes and road compete over distances of a few hundred kilometres, and dealers in cities such as Jaipur expect 50-bag lots delivered to site [12]. A multi-modal transshipment model with depot decisions, solved for each state, would address exactly the questions the reviewed papers raise.

D. Possibilities for extension

Several extensions follow from the limitations above. Stochastic or robust models could plan for seasonal demand rather than a single forecast, building on the fuzzy methods in [19] and [20]. Multi-period models

with stock at depots would capture seasonal slowdowns such as the monsoon and the build-up before them. Mode choice between road, rail rakes and coastal shipping, with a carbon cost per tonne-km, would reflect India's freight mix. Location-routing models could decide depots and delivery routes together. Finally, studies should publish their data and compare with company plans, as [8] and [13] do, so that results can be checked and reused.

VIII. CONCLUSION

Cement distribution planning is one of the most typical examples of the transportation problem in daily life. In all 20 articles reviewed from different regions of the world, including Asia, Africa, Europe, and Latin America, the same scheme was used. Several plants with limited supply and demand points were given, intermediate depots could be selected, and a function was sought to minimize logistics and facility costs. The exact LP and MILP models were used to find the optimal solution for the allocation and facility problems, which were proved to provide sufficient profit from 5% to 37% compared to the companies' previous practice. Moreover, in the cases where a decision had to be made on which truck to choose, integer programming was used for moderate sizes, and metaheuristics – for larger.

The main limitation of the field is that its models are still deterministic, single-period and loosely validated, and some published solutions do not survive a re-solve. The next logical step is to retain the transparency of the classical model but add uncertainty, multiple transport modes and links between facility and routing decisions, so that optimisation moves from one-off case studies to routine planning in cement companies.

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Appendix A. Study-by-study extraction against the project guidelines

For each included study, the table reports the real-world problem and industry, the objective, the main constraints, the stated assumptions and the method by which the result was verified. Problem type, solution approach, software and key results are presented in Tables IV and V. "Abstract only" indicates that the full text of the study could not be accessed; n/r means that the item is not reported in the study.

Ref.	Real-life problem and industry	Objective	Main constraints	Stated assumptions	Validation
[1]	Global distribution of slag and other cementitious materials by a multinational trader (abstract only)	Max total contribution margin	n/r in abstract	n/r in abstract	Scenario planning on demand, supply and costs
[2]	PT Semen Gresik: ship bagged cement from Tuban to 16 Kalimantan destinations, or build packing plants there	Min distribution cost plus annualised investment	Supply of 935,715 t; demand at each destination; flow balance at packing plants	Demand grows 11.7% a year; Rp 120.2 bn per 300,000 t unit; 15-year life	Comparison of four scenarios; no sensitivity analysis
[3]	Order delivery for a cement company in Bangladesh: cluster resellers and sequence visits (abstract only)	Min total travel distance	Vehicle capacity; single central depot	n/r in abstract	n/r in abstract
[4]	Norcem, Norway: route five ships carrying ten cement grades to coastal silos	Min shortage and transport cost; reach target end	Silo stock limits; ship and compartment capacity; no mixing; draft; one ship per berth	Grade fixed per silo; forecasts given; ship stability ignored	Criteria compared; GA vs 500 random runs; judged better than manual plans by the company

		stock (stated in words)			
[5]	Cement supply from three plants to four distribution centres in Ebonyi State, Nigeria	Min total distance (bag-km)	Supply at each plant; demand at each centre	Cost proportional to distance	Agreement with an earlier study claimed, no figures
[6]	PT SP Dumai: ship cement from three sources to three regions of mainland Riau	Min transport cost	Supply; demand	One day's data	QM for Windows check; comparison with stated real cost
[7]	Holcim Ecuador: two plants supplying six distributor cities	Min shipping cost	Supply; demand; non-negativity	Unit costs fixed for the year	Re-run with projected 2020 costs
[8]	Daily cement delivery with a mixed truck fleet and 15 depots	Min trucks per customer, then trucks, then delivery time	Truck availability; demand; depot and customer limits; preloads; sub-tours	Unlimited depot stock; symmetric distances; one order per trip	Company plans; optimality gaps; test of θ from 0 to 1
[9]	Choosing distribution and retail centre sites for a cement plant serving Srinagar	Min set-up cost, area per centre and load factor; min transport cost per unit of coverage	Flow; capacity; GHG cap; 2–8 DCs and 2–6 RCs	Summer only; constant demand; 180-bag full truckloads; Rs 30 per km	GA convergence plots only
[10]	Indonesian producer allocating three factories, three packing plants and a grinding plant to 103 Java sales areas after an acquisition	Max operating income	Plant capacities; packing plant balance; market-share bounds	Transport and facility capacity unlimited; Java only	Comparison with expected income
[11]	Locating distribution centres for cement company “X” in Myanmar (abstract only)	Max profit	Plant and DC capacity; demand	n/r in abstract	Three scenarios
[12]	Channel-partner deliveries in Jaipur from factories, warehouses, dealers and retailers	Min transport cost	Supply; demand; balanced totals; restricted routes at cost M	Averages of the top 10 firms; loading charges excluded	$m + n - 1$ allocation check and optimality test; no baseline
[13]	Indonesian producer serving Java and Bali through packing plants and DCs	Min total supply chain cost	Plant and packing plant capacity; demand; transshipment balance; binary plant use	Peak-season capacity; no lead time, terrain or truck limits	Existing vs optimal cost
[14]	Julius Berger: cement from three depots to three flyover sites in Port Harcourt	Min shipping cost	Supply and demand in truck trips	Balanced problem; fixed cost per trip	Excel Solver cross-check
[15]	Cement dealer delivering to 30 customers with five trucks	Min total distance	Vehicle capacity; one visit per customer	One depot; known demand	Eight other algorithms; 20 runs each

[16]	Distribution from Turkish cement factories to seven regions (abstract only)	Min cost, then goals for cost and supply–demand match	Supply; demand	n/r in abstract	Goal attainment
[17]	Routes from a Tuban plant to eight East Java customer regions	Min distance	32-tonne truck capacity	Normal road conditions; one product per vehicle	Comparison with actual routes
[18]	PT SBI Tuban: delivering 40 kg cement to nine agents	Min distance	Truckloads of 8 t and 7.6 t	n/r	None reported
[19]	Taiwan: moving cement production east after a limestone mining ban (abstract only)	Min transport and facility cost	Port, demand, trans-shipping and traffic congestion limits	Imprecise (fuzzy) supply, schedules and goals	Three fuzzy LP methods compared with crisp LP
[20]	Configuring a supplier–plant–DC–market cement network partly powered by a microgrid	Max profit; min dust	Flow; capacity; demand; carbon cap; energy balance	No inventory or shortage; fuzzy costs, demand and emissions	Sensitivity analysis on five parameter groups

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