CHAPTER 19

SUPPLY CHAIN, LOGISTICS, AND INVENTORY MANAGEMENT

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ABSTRACT

A supply chain is not simply the movement of purchased goods between independent firms. It is a governed network of physical, informational and financial commitments whose performance emerges from coordination across organizational and territorial boundaries. This chapter critically develops supply chain, logistics and inventory management through twelve interdependent domains, encompassing network design, demand amplification, inventory economics, warehousing, transport, trade facilitation, resilience, relational integration, information systems, performance measurement, circular logistics and emerging technologies. A targeted, transparent synthesis connects foundational operations research and interorganizational theory with peer-reviewed resilience and sustainability scholarship, professional standards and dated Rwandan institutional evidence. Rwanda's 2024 Integrated Business Enterprise Survey and 2025 Northern Corridor measurements contextualize the distinctive conditions of small enterprises and landlocked regional trade, without implying firm-level causal effects. A fully hypothetical Kigali distribution case demonstrates economic order quantity, safety stock, reorder points, expected shortages, cash exposure and a quantified border-disruption response. An end-to-end network model, decision matrices, a metric dictionary and an accompanying formula-based inventory workbook make the analysis inspectable. The argument is that supply chain effectiveness cannot be inferred from lowest freight cost, high asset utilization or minimum inventory alone: it requires conditional alignment among service reliability, total cost, liquidity, adaptability, informational credibility and legitimate stakeholder interests. The proposed integration is a pedagogical and analytical synthesis, not an empirically validated causal model.

Keywords: supply chain management; logistics network design; demand amplification; inventory control; economic order quantity; trade corridors; supply chain resilience; traceability; circular logistics; Rwanda.

LEARNING OUTCOMES AND CONCEPTUAL ROADMAP

By the end of this chapter, readers should be able to: **LO1** distinguish supply chain, logistics, procurement and operations and map a multi-tier network with material, information and financial flows; **LO2** critically evaluate supply chain integration, bullwhip, network-design, global-value-chain and resilience perspectives; **LO3** calculate and qualify economic order quantities, replenishment points, safety stocks, service levels and working-capital exposure; **LO4** design defensible warehouse, transport and cross-border distribution decisions subject to physical and institutional constraints; **LO5** diagnose disruptions and quantify continuity alternatives using scenario analysis and explicit assumptions; **LO6** define, compute and critically audit inventory, reliability, cost, carbon and traceability indicators; **LO7** compare documented Rwandan corridor and enterprise conditions with international

evidence without presuming transferability; and **LO8** defend a cross-functional logistics improvement plan addressing economic viability, technical feasibility, environmental responsibility and human dignity.

The twelve approved domains progress from network scope (19.1), coordination (19.2), inventory policy (19.3), storage (19.4), transportation (19.5), and border interfaces (19.6) to disruption management (19.7), collaboration (19.8), data infrastructure (19.9), metrics (19.10), sustainability (19.11) and future systems (19.12). A Rwandan scenario, comparative analysis, research synthesis, terminology, assessments and full references complete the chapter. Chapter 17 established internal operations, while Chapter 18 explained acquisition and sourcing governance. This chapter takes responsibility for the physical and informational flows between supply, storage, production and delivery. Specialist supplier award decisions belong to Chapter 18, quality assurance to Chapter 20, accounting for full product costs to Chapter 23, trade-policy analysis to Chapter 30 and enterprise-wide crisis governance to Chapter 32.

19.0 INTRODUCTION: THE VALUE OF A PROMISE DEPENDS ON THE NETWORK

Imagine a Rwandan producer that sells shelf-stable foods to clinics, small retailers and institutional buyers. Its production manager reports sufficient installed capacity, procurement has negotiated a favorable price for imported packaging, and the sales team promises delivery within seven days. The packaging has not cleared the border, however, and the warehouse's digital balance fails to record damaged stock. A truck is available but cannot be dispatched before quality release. The customer may receive the order late even though production, buying and transport managers each appear to have met their local performance targets. This is an explicitly constructed teaching scenario, not an allegation about an identifiable business.

Supply chain management concerns the design, governance and coordination of interdependent organizations, facilities, activities and relationships involved in obtaining inputs, transforming them, and making products or services available to users, including the return or recovery of materials. Logistics is the specialized planning and control of goods and associated information in movement and storage. Inventory management decides what stock should be held, where, in what condition, under which replenishment rules and with what financial and service consequences. Procurement creates governed external acquisition commitments (Chapter 18); operations transform resources (Chapter 17); logistics and inventory make timely exchange physically achievable. The three terms should not be collapsed, although one person may perform all three functions in a small enterprise.

The intellectual question is how decentralized actors can achieve coordinated outcomes when information is imperfect, incentives differ, uncertainty changes through time and risk cannot be eliminated. A stock reduction might release cash yet increase emergency transport, spoilage, missed health-service deliveries or upstream pressure on suppliers. More inventory might improve local availability while masking inaccurate records or consuming funds needed for wages. Thus the defensible object of optimization is a declared system and set of constraints, not an isolated stock-keeping unit, warehouse, department or quarterly margin. Fisher (1997) linked supply chain design to heterogeneous demand and product characteristics; Lee et al. (1997) explained endogenous amplification of orders; Christopher and Peck (2004) and Ivanov and Dolgui (2020) expanded the analysis of vulnerability from efficient chains to resilient and viable networks. Each is indispensable but incomplete.

19.0.1 Evidence design, source hierarchy and analytic boundaries

The chapter uses a critical, purposive synthesis of published literature, professional standards and official secondary documentation available by 2 November 2026. It combines landmark articles establishing distinct mechanisms, selected empirical and conceptual studies challenging managerial prescriptions, and primary institutional sources for Rwanda and international rules. Particular searches verified the original publication records for Lee et al. (1997), Christopher and Peck (2004), Hendricks and Singhal (2005), Tang (2006), Seuring and Müller (2008), Ivanov and Dolgui (2020), and the respective standard-setting bodies. Institutional source selection included the National Institute of Statistics of Rwanda (NISR), the East African Community (EAC), the

Northern Corridor Transport Observatory (NCTO), Rwanda Revenue Authority (RRA), the WTO, ICC, ISO and the World Bank. Selection is targeted rather than exhaustive: it entails no preregistered systematic search, PRISMA screening totals, meta-analysis, interviews, original survey, or new causal estimation.

Four categories of warrant remain distinct throughout: mathematical identities and optimization results hold subject to stated assumptions; peer-reviewed studies describe findings in their actual study designs; institutional statistics refer to documented measurement populations and observation windows; and all enterprise-level numerical values in the Kigali case are hypothetical. A formal standard establishes a published specification, not automatically a legal duty or evidence of certification. Neither LPI scores nor corridor travel-time averages measure the delivery reliability of the illustrative enterprise. Causal claims cannot be inferred from descriptive differences between corridors, years or firms. The methodology privileges traceable definitions, dated and sourced indicators, units, sensitivity and transparent limits over artificially precise comparisons.

19.0.2 Intellectual genealogy and the competing explanatory traditions

Operations research gave supply chain analysis a rigorous treatment of stock replenishment, transportation, flows and capacity allocation. The classical economic order quantity model identifies a cost-minimizing lot size when annual demand, ordering and holding costs are known, supply is available and the relevant cost structure is stationary (Harris, 1913). Its deductive result is analytically exact inside its assumptions and potentially misleading when lead-time tail risks, quantity discounts, product expiry or variable transport costs dominate. Network optimization extends the calculation by assigning facilities, flows and capacities, often expressing total cost as a constrained mathematical programme. Those models make opportunity costs explicit but cannot themselves establish trustworthy data or fair allocation of shortages.

Interorganizational perspectives question the assumption that firms are simply points on a physical network. Information sharing can be strategically distorted; long-term commitments can create both joint capabilities and dependence; outsourcing may transfer assets without transferring accountability. Lee et al. (1997) demonstrate how individually understandable ordering rules can generate collectively excessive variation. Collaboration scholarship identifies trust, incompatible incentives and organizational culture as substantive constraints rather than obstacles that software alone can remove (Barratt, 2004; Fawcett et al., 2008). Fisher's (1997) distinction between functional products and innovative products offers a useful contingency lens: predictable, price-sensitive items more readily justify efficient chains, whereas demand-uncertain items may require responsiveness. Binary product classifications nevertheless oversimplify enterprises with hybrid portfolios, seasonal shifts and combined service requirements.

Resilience scholarship challenges purely expected-cost designs because rare but consequential disruptions can collapse the feasibility of an ostensibly optimal network. Christopher and Peck (2004) associate vulnerability with tightly coupled, globally extended networks; Chopra and Sodhi (2004) classify different supply risks and emphasize tailored mitigation; Ivanov and Dolgui (2020) conceptualize viability as sustaining essential provision across intertwined networks. Empirical work by Hendricks and Singhal (2005) reports adverse performance associations for firms announcing supply chain glitches, but announcement-based samples and observational controls do not establish the causal return on a particular buffer for every enterprise. Sustainable-supply-chain scholarship further argues that cost, service and resilience scores can conceal environmental degradation or exploitation borne outside the focal firm's accounting boundary (Seuring & Müller, 2008; Carter & Rogers, 2008). The integrated position advanced here is contingent pluralism: different decision mechanisms illuminate different aspects of performance, and proposed remedies must be evaluated jointly against measurable economic, social and ecological constraints.

These traditions also imply different conceptions of what constitutes a supply chain. The optimization perspective treats the chain as a set of measurable flows subject to constraints; the relational perspective views it as an arrangement of contracts, expectations and power; the institutional perspective emphasizes the lawful permissions

and informal practices through which exchange becomes possible; and the resilience perspective treats it as a temporally evolving system exposed to common shocks. None has an exclusive claim to explanatory adequacy. A model identifying an optimal shipment quantity can be valid within its assumptions while failing as an account of why a supplier conceals a delay or why emergency relief should take precedence over a commercial order. The appropriate ontology is consequently neither a purely physical pipeline nor an abstract network of contracts, but an interconnected socio-technical and institutional system whose boundaries must be specified for the question being investigated.

A related epistemological problem concerns the difference between observing a transaction and knowing its underlying state. Warehouse balances, customs timestamps, advertised lead times and supplier declarations are records produced by fallible actors and technical systems. Their apparent precision does not certify their completeness, comparability or independence. Managers need reasons to trust observations, and researchers need an inferential design appropriate to the claims drawn from them. This is especially important where digital data are abundant but physical verification is infrequent. Finally, supply chain choice is normatively irreducible to cost minimization: a resource allocation may be mathematically efficient under an assigned objective and still be unjust if it externalizes occupational risk, conceals unsafe substitutions or denies indispensable goods to a vulnerable user. Ethical constraints are not a decorative addition to optimization but part of defining what choices are admissible.

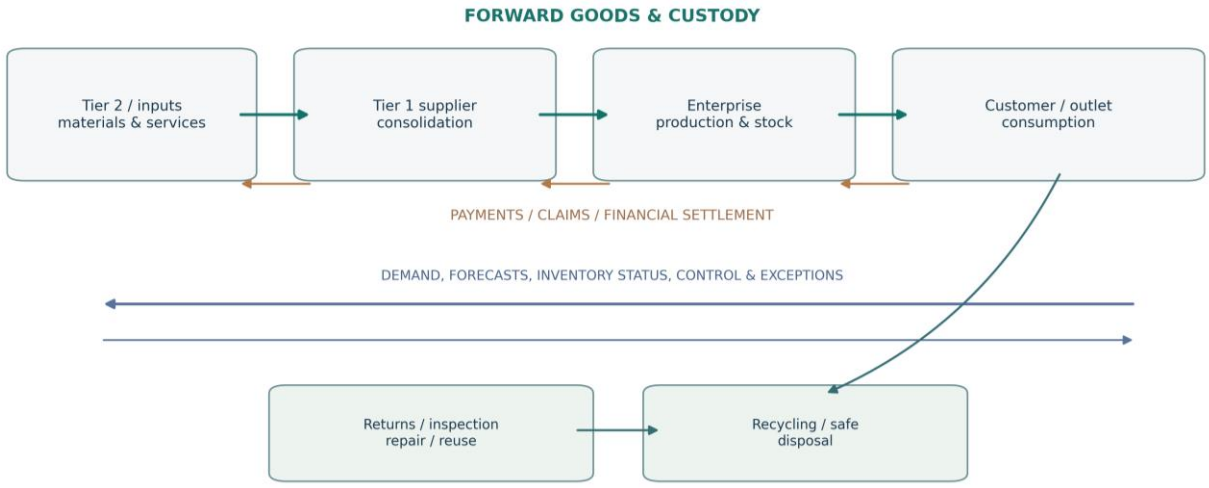
19.1 SUPPLY CHAIN SYSTEMS AND NETWORK DESIGN

19.1.1 Boundaries, actors, tiers and the three-flow system

The supply network is best represented as a directed, multi-tier structure. Nodes include raw-material producers, processing plants, suppliers, subcontractors, consolidation centres, ports, customs agencies, warehouses, retailers, service providers, customers, recyclers and waste processors. Arcs represent permitted flows among nodes, while inventory at a node is a state variable, not itself a shipment.

Figure 19.1

End-to-end enterprise supply network and reciprocal flow architecture.



Note. Original conceptual visualization. Material flows toward customers, financial settlement and information have distinct directions, and returns feed recovery. Informed by the ASCM SCOR Digital Standard and Christopher and Peck (2004); not an empirical map of a named firm.

Upstream connections refer to successive sources of inputs and capability; downstream connections refer to customer-facing transformations, distributors and eventual users. A tier-one supplier contracts directly with the focal enterprise; tier-two and deeper suppliers supply preceding tiers. Mapping beyond the contractual first tier

matters when different apparent suppliers depend on one port, origin, subcontractor, energy source or digital service.

Physical flows include raw inputs, work-in-process, finished goods, reusable containers, returns and by-products. Information flows include orders, demand signals, availability, shipment milestones, forecasts, compliance documents, product identifiers and exceptions. Financial flows include customer payments, supplier settlements, credit, duties, insurance and claims. They need not travel in the same direction or at the same speed. The goods may move from a supplier toward a buyer, payment in the reverse direction, and inventory-record corrections in either direction. Ownership, control and liability also change at contractually specified points. The frequently repeated expression that supply chains are simply 'linear' is particularly misleading once reverse logistics, shared transport, subcontracting and alternative suppliers are represented.

19.1.2 Configuration, facility location and operational decisions

Network design has at least three decision horizons. Strategic decisions determine markets served, facility locations, capacities, redundancy, major transport links and whether to own or contract for warehousing. Tactical decisions allocate inventories, carrier capacity, territories and replenishment rules across periods. Operational decisions release orders, pick shipments, assign trucks and resolve exceptions. The boundaries blur because a poor daily workaround can become an enduring network dependency. Decision rights should therefore specify which deviations require finance, safety or commercial approval.

A general capacitated network model selects nonnegative shipment flows x_{ij} from node i to node j, optional facility openings y_j, and potentially inventory positions I_j. One simplified objective minimizes $\Sigma c_{ij} x_{ij} + \Sigma f_j y_j + \Sigma h_j I_j$ + penalty for unmet demand, subject to origin supply, destination demand, warehouse capacity, balance equations and service constraints. Costs c_{ij} and f_j must use compatible periods and currency; binary opening variables y_j are constrained to zero or one. This formal expression is a decision aid, not an automatic recommendation, because social access, emergency service, border risk and environmental burdens may be invisible to a narrowly specified objective. A least-cost central warehouse can be undesirable when a regional service failure is socially unacceptable or local access matters.

In practice, managers should first map actual flows and customer promises, then identify the relevant network boundary and counterfactual choices. A two-warehouse proposal should compare fixed space and supervision costs with changes in route length, inventory pooling, promised lead time and service during interruption. Inventory pooling can reduce safety stock when geographically separated demand streams are imperfectly correlated; it does not necessarily lower total cost if the centralized warehouse lengthens delivery or concentrates catastrophe exposure. Decision quality therefore depends on the distribution of demand, not simply its mean, and on the credibility of emergency alternatives. The diagram must also record data ownership and who can correct erroneous shipment status.

A more rigorous design distinguishes decisions that can be reversed cheaply from those that create durable commitments. A temporary cross-dock can be trialled over one demand season, whereas a long-term lease, dedicated cold store or exclusive transport agreement may lock the enterprise into a particular demand geography. Let F represent annual fixed facility cost, V the annual variable handling and transport cost, K the annual economic cost of additional stock, and P expected penalties for unmet service. The decision compares $F + V + K + P$ for each feasible alternative, while preserving legally required and ethically justified minimum-service constraints. An option with a lower expected total can still be unacceptable if plausible extreme delays prevent the delivery of critical supplies. The relevant recommendation should consequently report the feasible frontier between cost, reliability and worst-case continuity rather than conceal these dimensions in one unexamined score.

Network pooling deserves equal caution. If two markets exhibit imperfectly correlated demand, a centralized reserve may reduce aggregate safety-stock requirements, but only when replenishment from that node is

dependable and the inventory is genuinely substitutable. Shared forecasting errors, common floods and border closure can make nominally independent markets fail together. A location model should therefore record correlations, service windows, operating-day calendars and the option value of a second route. For microenterprises, geographical consolidation through a cooperative may have lower fixed cost than wholly owned depots, but governance of access, custody, liability and payment becomes an additional network-design variable.

19.1.3 Network governance and business-function interfaces

The board and strategy team determine risk appetite and market scope; procurement governs supplier commitments; operations controls transformation and release; logistics schedules movement and storage; finance funds inventory and credit; marketing defines customer service promises; information systems maintain shared records. A logistics manager can control dispatch but cannot ethically alter a patient's product requirement, waive statutory inspection or promise supplier payment without authority. Interface rules must therefore answer which event transfers custody, which evidence confirms condition, who bears shortage costs and which decision rights enable rapid yet accountable recovery.

For small Rwandan enterprises, the economically relevant network may rely on a handful of people, mobile telephones, owner-managed vans and cash or mobile-money settlements. Such organizations do not require the same software architecture as a multinational, but they still require functional clarity: consistent stock identifiers, dated stock balances, customer delivery promises, and a written escalation procedure for border or vehicle disruptions. The 2024 Integrated Business Enterprise Survey estimates 278,060 businesses and reports extensive informality; this describes a sampling frame and macro-level structure, not proof of any particular firm's logistics competence (NISR, 2025). A context-sensitive model therefore begins with low-cost record integrity and decision accountability before prescribing sophisticated optimization software.

19.2 DEMAND AND SUPPLY COORDINATION

19.2.1 Demand is not the same as orders or sales

Demand represents the quantities customers would seek under specified prices, service conditions, periods and availability. Recorded sales equal fulfilled transactions, not necessarily true demand: stock-outs censor observations, promotions shift purchase timing, and institutional tenders concentrate orders. The distinction matters when projecting the number of trucks, purchase orders or storage locations required. A forecast should state its time horizon, stock-keeping-unit definition, customer segment, loss function and intervention assumptions. Aggregating demand can improve signal-to-noise ratios but may conceal the particular item or location whose failure would damage a critical service.

A sales and operations planning (S&OP) cycle reconciles commercially expected demand, production and procurement capabilities, constrained supply, inventory availability and financial resources at a common cadence. Its intellectual value is not that a forecast eventually becomes exact, but that assumptions become visible and incompatible commitments are resolved before money or capacity is spent. Sales may favor availability, operations stable utilization, procurement large purchasing batches and finance low inventory. A disciplined monthly decision records the consensus baseline, authorized alternatives, constraints, responsible managers and leading indicators for revising the plan. Exception-led weekly reviews are appropriate where demand and transit times change faster than the monthly cadence.

19.2.2 The bullwhip effect and its measurement

The bullwhip effect describes amplification of upstream order variability relative to downstream consumer demand. Lee et al. (1997) identify demand-signal processing, order batching, price variation and rationing/shortage gaming as mechanisms. An enterprise responding to one large retailer order may infer durable demand, order a full

truck to save freight cost, and trigger additional supplier capacity adjustments. If each tier sees only its immediate buyer's order, not final consumption and genuine inventory, plausible local responses can create network-wide excess and subsequent shortage.

A descriptive indicator is B = Var(Q_upstream) / Var(D_downstream), using the same observation frequency and appropriately aligned time window. For a hypothetical 52-week observation window in which weekly retailer demand has standard deviation 20 units and wholesale orders have standard deviation 35 units, $B = 35^2 / 20^2 = 3.0625$. The statistic indicates variance amplification for those measured series; it neither proves the cause nor implies that each upstream actor behaved irrationally. A variance ratio below one may arise from smoothing or constrained replenishment; it is not sufficient evidence of a healthy chain. The time aggregation, stock-out censoring, price promotions and nonstationarity must be disclosed.

Coordination instruments include sharing point-of-sale quantities instead of only downstream orders, shorter and more consistent replenishment cycles, stable pricing, explicit treatment of promotions, credible allocation during shortages, vendor-managed inventory and collaborative forecasting, planning and replenishment (CPFR). Their benefits are conditional. Sharing data can expose commercially sensitive information or reveal identifiable customers; lower batch sizes can increase transport emissions or border transactions unless consolidated; collaborative planning can entrench an unequal dominant buyer. Where customer information is incomplete, managers should compare forecast errors by item and horizon rather than promising 'real-time visibility' from inaccurate source records.

19.2.3 A coordination diagnostic

A practical demand–supply diagnostic records the consumer demand series, orders to each tier, forecast release dates, replenishment rules, batch constraints, promotion calendars, stock-outs, lead-time variation and financial approval delays. The decisive analytical step is to distinguish forecast disagreement from operational inability to implement a shared forecast. An inaccurate common forecast may synchronize all firms into the same mistake; independent local information can sometimes create beneficial diversity. Consequently, information sharing is valuable when it changes decision quality and incentives, not merely when dashboards become identical (Lee et al., 1997; Barratt, 2004).

Coordination also requires an explicit forecast-quality protocol. A comparable baseline may use seasonal naive demand, with more elaborate models judged through holdout periods matching procurement or dispatch decisions. Mean absolute error is the average absolute difference between forecast and realized demand; a scale-adjusted error permits comparisons across products, but ratio-based percentage errors become unstable near zero consumption. Bias should be monitored separately from error magnitude because persistent underforecasting can systematically disadvantage low-volume customers even when average accuracy appears strong. A decision-oriented review should test whether the forecast improvement changes replenishment choices, avoidable inventory, stock-outs or service loss. Forecast accuracy alone is not the business outcome, and sales suppressed by stock-outs should not be treated as an uncensored measure of demand.

In institutional settings, the timing of budgets and authorizations is itself a source of demand amplification. Quarterly purchasing ceilings can create end-of-period order clusters unrelated to final consumption. A defensible S&OP process therefore reconciles not only physical capacity but also procurement lead times, funds release, client acceptance dates and the information available to decision makers. It records dissenting forecasts where uncertainty is material instead of manufacturing false agreement around a single point estimate.

19.3 INVENTORY POLICIES AND ECONOMICS

19.3.1 Inventory as a buffer, asset and liability

Inventory comprises raw materials, work-in-process, finished products, spare parts and goods in transit; items may additionally be cycle, seasonal, anticipatory, safety, decoupling or obsolete stock, depending on why they are held. The operational classification and the accounting classification need not coincide. Pipeline stock covers material in transit, while safety stock protects against uncertainty in demand or lead time. Decoupling stock limits the propagation of variability between activities. Seasonal inventory anticipates predictable timing; speculative inventory is held in anticipation of prices or supply restrictions. Hazardous, perishable and regulated goods also impose storage, traceability and disposal obligations.

A stock decision exchanges distinct economic exposures. Ordering too frequently generates administration, handling or setup costs. Ordering too much consumes working capital, storage capacity, insurance and deterioration, and may lower flexibility when preferences change. Insufficient inventory creates backorders, lost contribution, emergency freight, breach of contract, disruption of production or harm to service users. These consequences differ fundamentally across business settings. A hospital supply chain should not price a critical medicine stock-out only at the item's sales margin; a seasonal fashion retailer may rationally tolerate some lost demand to avoid severe markdowns. Neither lowest inventory nor maximum availability is an unconditional managerial objective.

19.3.2 EOQ, assumptions and full derivation

The standard economic order quantity (EOQ) balances annual fixed ordering cost and annual proportional holding cost. Let D be annual demand in units per year, S be fixed cost per replenishment order in RWF/order, H be annual holding cost per unit in RWF/unit/year and Q be the lot size in units. When demand is stationary, replenishment is instantaneous, stock-outs are excluded and purchase price is unchanged with Q, the variable annual cost is $C(Q) = (D/Q)S + (Q/2)H$. Differentiating gives $dC/dQ = -DS/Q^2 + H/2 = 0$; hence $Q^* = \sqrt{(2DS/H)}$. The second derivative $2DS/Q^3$ is positive for positive values, establishing a minimum of this defined cost function. Purchase expenditure D×unit price is constant and therefore excluded from the lot-size optimization, but must be included in full cash planning.

Worked example 19.1 (entirely hypothetical). A Kigali packaged-food distributor forecasts annual demand D = 24,000 cartons, pays S = RWF 18,000 per standard replenishment order, and estimates annual holding cost H = RWF 1,200 per carton. Then EOQ = $\sqrt{(2\times24{,}000\times18{,}000/1{,}200)} = \sqrt{720{,}000} =$ **848.53**, or approximately **849 cartons** per order, subject to packaging multiples and truck constraints. The resulting annual order frequency is 24,000/848.53 = 28.28 orders; expected cycle inventory averages 424.26 cartons. Annual ordering cost and annual cycle-stock holding cost are each approximately **RWF 509,117**; their sum is **RWF 1,018,234**. At an illustrative purchase price of RWF 4,000 per carton, the annual purchase expenditure is RWF 96 million, and the average cycle-stock purchase value is approximately RWF 1.697 million. The latter is inventory capital at one point in the cycle, not an additional expense on top of the annual procurement bill. All values exclude taxes, duties, financing details and extraordinary disruption losses.

The assumptions matter more than cosmetic decimal precision. If orders must be in cases of 25, the manager compares costs at 825 and 850, rather than mechanically ordering 849. If a truckload discount changes unit purchase price, the candidate total cost must include purchase costs and freight. If cartons perish, an expiry constraint may cap Q. If a supplier accepts orders only weekly, an optimal continuous-review Q may be infeasible. A sensitivity result, $Q^* \propto 1/\sqrt{H}$, means that doubling the holding rate reduces the theoretical EOQ by about 29.3%, not by half. The accompanying spreadsheet is structured so readers can change the assumptions without mistaking hypothetical quantities for surveyed data.

19.3.3 Reorder points, demand variability and service definitions

An EOQ answers how much to order, not when. Under a continuous-review fixed lead time L in operating days and deterministic daily demand d, the reorder point is ROP = dL, defined in the same units as inventory position. When demand during replenishment is variable, a conventional normal-approximation policy sets ROP = dL + zσ_LT, where σ_LT is the standard deviation of demand over lead time and z is a quantile for a declared cycle-service probability. When daily independent demand has standard deviation σ_d and lead time is fixed at L days, σ_LT = σ_d√L. If lead time L also varies independently of daily demand, a common approximation is σ_LT = √(L̄σ_d² + d²σ_L²), where L̄ and σ_L are the mean and standard deviation of lead time. Dependence, serial correlation and extreme events invalidate casual use of these formulas.

In the hypothetical firm, 24,000 cartons are demanded during 300 operating days, so d = 80 cartons/day. Assume σ_d = 20 cartons/day, mean lead time = 8 days, lead-time standard deviation = 2 days, and independence for the illustration. Then σ_LT = √(8×20² + 80²×2²) = √28,800 = **169.71 cartons**. For a nominal 95% cycle-service target, z ≈ 1.645, giving safety stock 279.17 cartons and ROP ≈ 919.17 cartons. Under the model, the firm orders when inventory position, defined as available stock plus open orders minus committed backorders, falls to approximately **920 cartons**. Reorder triggers based on physical on-hand stock alone can lead to double ordering when deliveries are already in transit. Policy units, lead-time conventions and stock validity must be written down before deployment.

Cycle-service level is the probability of no stock-out during one replenishment cycle; item fill rate is the share of demand quantity satisfied immediately from available stock. They are not equivalent. With normally approximated lead-time demand, expected shortage per cycle is σ_LT[φ(z) − z(1 − Φ(z))], where φ and Φ are standard-normal density and distribution functions. At z = 1.645, the expected shortage is approximately 3.54 cartons per cycle; dividing by Q ≈ 848.53 gives a model-based fill rate near **99.58%**. That figure is conditional on the stated distribution, lost-sales/backorder conventions and fixed-order policy; it cannot be interpreted as the actual customer's observed experience. Delivery timeliness and product condition are separate requirements.

19.3.4 Working capital, stock segmentation and policy choice

At a hypothetical unit purchase cost of RWF 4,000, the safety reserve of 279.17 cartons ties up roughly RWF 1.117 million in addition to cycle stock; the total mean on-site inventory under the simple model is approximately 703.43 cartons, valued at RWF 2.814 million. This capital is economically consequential to an enterprise with limited access to short-term credit. In a stress case where transit lead time increases from eight to twelve days with the same variable demand assumptions, mean lead-time demand rises from 640 to 960 cartons. A reorder point calibrated for the old mean and uncertainty cannot be assumed adequate. Whether additional stock is justified depends on disruption frequency, available emergency supply, product margins, replenishment lead-time distribution and the social cost of unfilled orders.

ABC classification ranks items by chosen importance, conventionally annual consumption value D×unit cost. It should not be confused with clinical or operational criticality: low-price spare parts can shut down a high-value line. XYZ analysis classifies demand predictability or variability, but definitions vary and must be specified. A defensible segmentation combines value, criticality, shelf life, demand uncertainty, lead-time variability, substitution and recovery options. Continuous review is preferable for critical or expensive stock when reliable transaction records are available; periodic review may be efficient for many low-value items or suppliers with fixed delivery calendars. Two-bin visual replenishment can suit microenterprises when its bin quantities are calibrated and its exceptions logged. Newsvendor models are more appropriate for single-period perishable demand; material requirements planning links component needs to a bill of materials and production schedule. Selection follows the economic structure of the problem rather than fashion.

Table 19.1

Comparison of inventory decision rules and limits.

Policy	Decision logic	Suitable conditions	Material limitations
EOQ with continuous review	Fixed Q; reorder at inventory-position threshold	Recurrent, stable demand; known ordering and holding costs	Misspecifies discounts, expiry and long-tail lead-time risk
Periodic review/order-up-to	Inspect every T days; order up to target S	Scheduled supplier routes; many low-cost stock items	Protects review period plus lead time; may require more buffer
Newsvendor/single-period	Trade expected shortage and leftover costs	Seasonal/perishable one-shot purchase	Depends heavily on demand distribution and salvage value
Materials requirements planning	Explode scheduled output through bill of materials	Interdependent components and reliable production records	Planning errors and nervousness propagate without controls
Criticality-weighted buffer	Extra protection for high-consequence shortages	Health, safety and continuity-critical items	Governance required to define consequences and funding

Note. Original synthesis of standard inventory control logic. Policy boundaries must be checked against the enterprise's actual constraints; the row descriptions are not universal prescriptions.

A periodic-review policy makes the review interval part of the protection period. If inventory is reviewed every T days and replenishment takes L days, the order-up-to target covers demand over approximately T + L days, not L alone; under suitable independence and distribution assumptions, a buffer may be based on the variability of demand over that combined horizon. Thus two firms facing identical daily demand and lead time can require different reserves because one orders continuously and the other only on scheduled market days. Similarly, single-period inventory with uncertain demand is better represented by the newsvendor problem. With underage cost Cu for one unit of unmet demand and overage cost Co for one unused unit, the continuous-demand optimum satisfies $F(Q^*) = Cu/(Cu + Co)$, provided the stated demand distribution F and linear marginal costs are justified. Salvage proceeds, expiry, substitution and social consequences change these costs. Neither model should be presented as a universal prescription for all stock.

Inventory arithmetic should also distinguish the unit used for ordering from the unit used for financial valuation and physical picking. A carton, case, kilogram and pallet may coexist in one enterprise; unit conversion errors can overwhelm optimization gains. A minimal stock master identifies each stock-keeping unit, base measurement, packaging multiple, usable shelf life, lead-time clock, approved supplier, cost basis and criticality. An inventory policy is operationally credible only when staff can execute the rule with available data, transport schedules and authorization rights. The finance function should monitor the cash conversion cycle and supplier settlement terms alongside days on hand, because a reserve financed by overdue supplier payments may merely displace fragility upstream.

19.4 WAREHOUSING AND STORAGE

19.4.1 Storage as a controlled transformation, not an idle location

A warehouse is simultaneously a physical location, a custody regime, a data system and a point of operational transformation. Receiving confirms identity, quantity, condition and entitlement; put-away allocates a safe and traceable location; storage protects quality; picking and packing assemble customer orders; dispatch establishes transfer evidence; returns processing determines re-entry, quarantine, repair, recycling or disposal. Cross-docking minimizes dwell by directing eligible inbound loads toward outbound dispatch, but only when item, destination,

timing and quality information are dependable. A warehouse cannot compensate indefinitely for incoherent upstream forecasts or unapproved order changes.

Layout decisions reconcile accessibility, travel distance, handling safety, product compatibility and security. Fast-moving items are often placed near dispatch, but velocity-based slotting should be qualified by weight, fragility, packaging dimensions and risk. Food and medicines require appropriate temperature and hygiene controls; hazardous materials require verified compatibility, labeling, ventilation and worker safeguards. FIFO allocates oldest receipt first and FEFO prioritizes earliest expiry where relevant. Neither solves a stock ledger whose batches are not recorded correctly. Cycle counts can target high-value or error-prone locations rather than waiting for one annual inventory closure.

Storage becomes especially consequential when condition deteriorates with time, temperature, humidity or handling. For a cold-chain product, a recorded arrival temperature is insufficient evidence of continuous protection during transport and storage. The system needs specified permissible ranges, calibrated monitoring, excursion records, segregated quarantine, authorized disposition and traceable batch linkage to the customer. Where power reliability is uncertain, backup supply and a documented holdover response must be appraised against realistic failure duration rather than assumed adequate. The required controls vary with the product and applicable standards; this general framework neither certifies a facility nor substitutes for technical, pharmaceutical or food-safety requirements.

Warehouse flow also creates capacity queues. A receiving dock that can process deliveries rapidly in a typical hour may nevertheless generate substantial delay when several inbound vehicles arrive together. Managers should therefore measure arrival variability, unloading and inspection time, put-away capacity and release constraints, rather than interpret floor space alone as effective warehouse capacity. Cross-docking can reduce inventory and dwell time, but concentrating arrival and dispatch schedules too tightly may reduce the margin for recovery when quality release or border clearance runs late.

19.4.2 Accuracy, shrinkage and human safety

Book-to-physical accuracy must distinguish several indicators: count-line accuracy is the share of counted lines whose recorded quantity lies within a defined tolerance; quantity variance measures the absolute or signed unit discrepancy; value accuracy weights by unit cost; and location accuracy asks whether a physically present item is where the system says it is. A firm could report 98% line accuracy and still have critical expired product in one uncorrected location. Variances arise from receiving errors, unrecorded damages, unconfirmed transfers, theft, unit-of-measure confusion and deliberate manipulation. An accountable process isolates each discrepancy, reconstructs transaction history, corrects records under authorization and examines root causes. Simply resetting the balance conceals failure.

Worker safety and productivity are joint design variables. High racks without appropriate loading and handling controls, congested aisles, excessive manual lifting, unsafe pedestrian–vehicle interactions and long shifts can produce injury risk even when the dispatch dashboard improves. The choice between manual shelves, forklifts, barcodes and automated sorting should therefore be evaluated against throughput, error rates, training, maintenance, energy, capital availability and contingency when power or connectivity fails. Warehouse-management-system integration can reduce duplicate transactions but creates new failure modes if stock is not updated at the event of physical movement. An employee's ability to report and isolate unsafe or damaged goods without retaliation is an essential quality and governance mechanism.

An auditable count procedure begins with a frozen transaction timestamp, independent or blind count for selected items, documented discrepancies, recount thresholds and controlled ledger adjustment. Sampling must not systematically exclude inconvenient locations; high-consequence stock deserves greater attention even when its accounting value is low. Root-cause findings should distinguish process error from theft or misconduct to avoid

punitive responses based only on variance. Pick accuracy, receipt-to-available time, stock ageing, preventable damage and worker injuries should be examined jointly, since maximizing picks per hour can conceal growing rework or unsafe handling. The economic test of an automation investment must include human training, integration, maintenance, power interruptions and the possibility of continuing manual operations during failure.

19.5 TRANSPORT AND DISTRIBUTION

19.5.1 Mode selection as a multi-objective decision

Transport creates time and place utility by connecting supply and demand, but its performance depends on much more than distance. Modes include road, rail, air, inland water and maritime transport, combined in intermodal services where infrastructure and handling interfaces permit. Road affords relative flexibility and final-mile reach, though road freight is exposed to traffic, fuel prices, vehicle breakdown, pavement and security conditions. Rail can move heavy consolidated loads efficiently where routes, terminals and service schedules fit the shipment; air prioritizes speed or high-value urgency at generally higher cost and different environmental implications. Shipping containers improve interchangeability across modes but do not eliminate customs procedures, terminal congestion or last-mile constraints. In Rwanda, the immediate feasibility of modes differs from that in a coastal port city. A nominally cheap overseas ocean freight rate cannot be evaluated without the inland corridor, border handling, insurance and inventory implications.

Transport mode choice can be formulated as a comparison of generalized landed and service costs. Let C_k denote quoted freight and terminal charges for alternative k, T_k expected delivery lead time, V the cargo value, r the relevant annual financing rate, and E_k expected service/disruption losses. One simplified comparison is G_k = C_k + V(rT_k/365) + E_k, with common currency and calendar days. Actual decision-making may additionally require taxes and duties, damages, perishability, carbon impacts, insurance, loading, labor, contractual penalties, security and credible tail-risk estimates. The expected monetary sum is not the full ethical decision when a late delivery could endanger people or violate a legal standard. For an illustrative cargo valued at RWF 12 million and financing cost 18% annually, an additional seven-day delay generates an approximate incremental carrying cost of 12,000,000×0.18×7/365 = RWF 41,425, before any lost sales or spoilage. This calculation clarifies the financial mechanism; it does not establish a typical Rwandan interest rate.

19.5.2 Routing, load consolidation and last-mile design

Vehicle routing is a constrained optimization problem with customers, delivery windows, capacities, road availability, driving-time rules, vehicle limits and return destinations. Its simplest distance-minimization variant differs from a realistic routing problem in which deliveries have time windows, refrigeration needs, loading priorities and client service guarantees. A feasible route must also accommodate driver rest, occupational safety, weight restrictions and proof of delivery. Repeated demand can support fixed milk-run routes, while highly variable orders may require dynamic dispatch. Combining smaller deliveries into well-planned routes can improve vehicle utilization but lengthen the wait for customers who would otherwise receive direct service.

Last-mile operations often experience high delivery cost per unit because shipments fragment, addresses or receiving arrangements are imprecise, and unsuccessful delivery requires costly repeat visits. In practice, a manager should compare consignment value, drop density, route time, first-attempt success and claims rather than simply average cost per kilometre. A motorcycle courier may outperform a large truck for small urgent urban deliveries without being suitable for bulk cargo, temperature-sensitive freight or unsafe load weights. Consolidation points, agreed delivery windows, pickup arrangements, verified phone confirmation and electronic proof of delivery can reduce avoidable trips. These improvements remain conditional on customer accessibility, digital inclusion and safe labor practices.

Route design additionally raises a distributional question: which customers should receive scarce vehicle capacity when deadlines conflict? A pure revenue-maximization model can deprioritize remote or low-margin users, while a strict first-come rule may ignore essential-service criticality. Enterprises should disclose the hierarchy of contractual due dates, product deterioration, safety urgency and equitable access before allocating shortages. A route plan then becomes an accountable decision, not just a shortest-path calculation. Comparing alternative routes requires consistent treatment of the return journey, partial loads, unsuccessful delivery attempts, vehicle maintenance, tolls and the hours worked by drivers. Scenario-based routing should include a contingency for flooding, congestion, fuel disruption and manual dispatch if the digital platform fails.

19.5.3 Freight allocation, ownership and claims

Freight arrangements distribute more than the price of a vehicle. Contracts should identify pickup and delivery locations, loading and unloading responsibilities, insurance, custody, temperature and security requirements, delay notification, demurrage exposure, proof of delivery, loss/damage claims and dispute handling. For international trade, Incoterms® 2020 contain eleven trade rules allocating selected tasks, costs and the point of risk transfer in sales of goods. The ICC explicitly cautions that they are not the entire sales contract; they do not by themselves determine ownership transfer, payment terms or all legal remedies (International Chamber of Commerce [ICC], 2020). A commercial contract stating “CIF Kigali” is especially problematic: CIF is limited to sea or inland-waterway carriage and uses a named port of destination, whereas Kigali is inland. A multimodal consignment may instead require careful consideration of CIP or another appropriate rule, with the named place, insurance and risk allocation expressly agreed (ICC, 2020). The competent logistics manager coordinates legal counsel, purchasing and finance before a shipping term is accepted.

The practical compliance question is which documentary event the contracting parties will accept as proof of each obligation. A consignment note, bill of lading, electronic proof of delivery, temperature record and insurance certificate evidence different facts; none alone establishes that goods were conforming, correctly valued and free from loss. Freight claims should record condition at collection, seal and packaging integrity, custody transfer, timely notice and the applicable liability limit or exclusion. A dispute often involves several contracts, including the sale, carriage, insurance and customs agency arrangements, so the parties must not infer title or insurance entitlement from an Incoterms designation alone. An ethical claims system should preserve evidence fairly, prevent opportunistic deductions from small carriers and authorize prompt correction where the enterprise itself caused damage.

19.6 CROSS-BORDER LOGISTICS AND TRADE FACILITATION

19.6.1 The institutional chain beyond the border gate

Cross-border logistics combines physical movement with regulatory authorization. Importers and exporters must verify applicable tariff classification, customs valuation, rules of origin, technical requirements, sanitary and phytosanitary controls where applicable, conformity documentation, transit arrangements and destination-specific permissions. A typical consignment may require a commercial invoice, packing list, transport document, origin evidence, insurance records, customs declaration and product-specific permits. This is a functional checklist, not a claim that every document is legally required for every Rwandan shipment. Procedures vary by product, origin, destination and the current legal instruments. Incorrect harmonized-system classification or unsupported declarations can create delay, penalties and unfair treatment of market participants.

The WTO Trade Facilitation Agreement (TFA) seeks more predictable, simplified and transparent border procedures. Article 10.4 requires members to *endeavour* to establish or maintain a single window, a deliberately qualified treaty formulation rather than an unconditional guarantee of one portal functioning perfectly (World Trade Organization [WTO], 2017). The World Customs Organization's Revised Kyoto Convention sets out

principles of transparency, simplified declarations, risk management, information technology and coordinated border interventions (World Customs Organization [WCO], n.d.). Trade facilitation does not mean abandoning legitimate health, security or revenue controls. Rather, properly designed risk assessment should allocate inspection effort toward relevant risk instead of imposing universal friction. Customs digitalization also cannot repair impassable roads, port congestion or incomplete supplier documentation upstream.

19.6.2 Rwanda as a landlocked economy dependent on external corridors

The EAC identifies the Northern Corridor from Mombasa and the Central Corridor from Dar es Salaam as principal regional transport routes, serving several interior countries including Rwanda (East African Community [EAC], n.d.). Their economic significance extends beyond geographic length. Port performance, border inspections, road closures, terminal transfer, trucking competition, fuel costs and political relations influence not only freight charges but the variance of replenishment lead times. When inventory crosses several borders, a small factory may face cash tied up in goods that have been invoiced but cannot yet be transformed or sold. Contracting, documentary quality, customs procedure and replenishment-buffer design thus form one problem. A comparative decision should assess credible alternative route costs and times for the actual commodity rather than assuming one corridor is universally superior.

The NCTO's *Northern Corridor Quarterly Performance Dashboard, July to September 2025* reported the Mombasa–Kigali route's average transit time as 168 hours (seven days) across July, August and September 2025, with the monthly values 168, 154 and 181 hours respectively and a listed route distance of 1,693 kilometres (Northern Corridor Transport Observatory [NCTO], 2025, Table 5, p. 13). These published values describe an operationally defined corridor indicator based on the underlying reporting system, not the distribution of all importers' delivery times. Averaging monthly figures hides extreme delays, and the route's reported 'average' is not a parcel-level service guarantee. The quarterly series offers context for a hypothetical eight-day planning lead time but does not validate that parameter for an actual distributor. A useful managerial response is to record shipment-by-shipment port, customs, border, carrier and warehouse timestamps to construct the relevant enterprise-level distribution.

RRA states that the Rwanda Electronic Single Window was launched in 2012 and supports a single declaration and information sharing among the trading community and relevant authorities (Rwanda Revenue Authority [RRA], n.d.). Its announced evolution toward a Single Transactions Portal is a stated institutional development rather than a verified prediction of future savings. The distinction between electronic submission and physically released, deliverable goods is crucial. Reconciled clearance status, carrier dispatch and receiving information should drive the inbound plan; mere confirmation that a form has been lodged does not mean goods are available to production. Firms must keep electronic records and exception procedures in place while maintaining compliant alternatives during network outages.

The measurement protocol for the quoted corridor series deserves precision. The NCTO table reports RRA-sourced average transit time for a defined route in July, August and September 2025, not a statistically identified probability distribution for all freight or an end-to-end import clearance time from the ship to usable warehouse stock. In particular, cargo may incur port dwell, inspection, unloading or quality-release time outside the clock represented by a given published indicator. For inventory policy the enterprise needs its own timestamps from authorized order release to physically usable stock, reconciled to invoices, carrier events and customs decisions. The regional source is useful precisely because it highlights the possibility of temporal variation without supplying the firm-specific parameters needed for a safety-stock calculation.

19.6.3 Trade integration, corridor diversification and affordability

Regional integration can reduce certain documentary or market-entry frictions, yet enterprises must not confuse accession to a regional trade arrangement with automatic eligibility for a duty preference or immediate border

clearance. Preferential treatment depends on applicable rules of origin and the specific agreement; product standards and national implementation remain consequential. A manufacturer considering the EAC or AfCFTA should separate market-access strategy (Chapter 30) from the logistics decision: how freight and inland handling will actually reach the consignee, who bears transit risk, and how return shipments and after-sales obligations are funded. A regional network expands potential demand, but can also expand exposure to currency, congestion, compliance and working-capital conditions.

Rwandan microenterprises and cooperatives may encounter scale disadvantages when moving small consignments over long corridors. Pooling loads through trusted consolidators or cooperative facilities can reduce unit freight cost, but adds handling, governance and distributional issues: which producer receives scarce vehicle space, who verifies quality and whose shipment is delayed when documentation fails? Policy analysis should identify genuine market failures and proportional institutional remedies rather than assuming either deregulation or digital platforms automatically solve the landlocked constraint. The relevant comparison is between achievable service systems with transparent costs and risks, not between idealized open markets and an undifferentiated description of 'African logistics'.

19.7 SUPPLY CHAIN RISK AND RESILIENCE

19.7.1 Disturbance, exposure, robustness, resilience and viability

Risk concerns uncertainty about outcomes relevant to an objective, with disturbances including demand shocks, supplier failure, vehicle breakdown, cyberattack, climate-related hazards, border closure, labor interruption, contamination and financial insolvency. Exposure is the extent to which a disruption can affect a network; robustness is the capacity to withstand disturbance without major structural change; resilience is the capacity to anticipate, respond, recover and adapt; viability concerns continued provision of essential functions under more profound system changes. These concepts intersect but are not synonyms. An enterprise may be robust to a one-day transport strike and unable to adapt to a sustained closure; it may restore internal throughput while its most vulnerable customers remain unserved.

Chopra and Sodhi (2004) argue that distinct risks require distinct mitigations. Christopher and Peck (2004) describe how complexity and reduced slack may increase vulnerability. Sheffi and Rice (2005) differentiate redundancy, such as reserved stock or spare capacity, from flexibility, such as the ability to switch a supplier or reallocate production. Ivanov and Dolgui's (2020) viability account broadens the system boundary to socially critical network provision. None implies that every firm should maximize redundancy: maintaining alternatives carries purchase, qualification, relationship, information, environmental and cash costs. The appropriate level of preparedness follows the severity, uncertainty, substitutability, lead time and distribution of consequences for each critical item.

19.7.2 Mapping concentration and hidden common-mode failures

A supplier list displaying three independent company names may conceal one shared regional port, subcontractor, data provider or origin of essential inputs. The relevant risk unit is not merely supplier count, but dependence across underlying components, facilities and geographic hazards. Managers can map critical tier-one and deeper suppliers, port/corridor dependence, alternative stock availability, qualification lead time and contract termination conditions. Concentration indicators such as a Herfindahl index of supplier expenditure shares can describe spend distribution but do not directly measure probability or impact of disruption. The analysis must include common-mode failures and the time needed to activate alternatives.

A structured risk register combines specific scenario, event pathway, earliest observables, probability evidence (when defensible), exposure, estimated consequence, mitigation owner and review trigger. An illustrative risk can be scored for screening, but multiplication of ordinal 1–5 'likelihood' and 'impact' scales is not cardinal expected

loss. Monetary expected loss is E[L] = Σp_s L_s only when probabilities p_s are meaningful, mutually exclusive and collectively exhaustive for the modeled cases. Stress testing is preferable where tail probabilities cannot be defensibly estimated. For perishables, tail events may dominate average cost even when frequent delivery is reliable. For essential clinical supplies, a social minimum-service constraint may be justified independent of the enterprise's immediate expected margin.

19.7.3 Border disruption and continuity economics: a transparent scenario

Consider the constructed distributor from Section 19.3 with d = 80 cartons/day. Suppose an unanticipated corridor interruption could extend replenishment lead time by six days. Without substitutes or an earlier shipment, **480 cartons** of additional demand arise during the extension, above the mean forecast for the original lead-time window. This is a deterministic incremental-exposure calculation, not a probability of shortage. Assume an emergency alternative can deliver the 480 cartons at an incremental premium of RWF 220 per carton plus RWF 45,000 dispatch/setup, for a total **RWF 150,600**. A second option is to finance and hold 480 additional cartons at an annual holding cost of RWF 1,200 each, i.e., **RWF 576,000 annually**, assuming continued maintenance of the incremental stock and ignoring initial stock value as an expense. The solutions are not directly comparable until disruption frequency, financial liquidity, supplier reliability, stock perishability and applicable decision horizon are stated.

For an explicitly hypothetical one-year case, suppose a disruption requiring the response has probability 0.30, occurs at most once, and the alternative supply is always available. Expected additional annual emergency cost is 0.30×150,600 = **RWF 45,180**, below RWF 576,000 in additional annual holding expense. Under these assumptions, permanent 480-carton buffering solely for this scenario is not cost-minimizing. However, this expectation changes if the emergency alternative disappears when the same corridor fails, if lost customer contribution is not recoverable, if delays last longer, or if the product has nonmonetary criticality. Holding a buffer could still be defensible for operational or ethical reasons. The calculation is intentionally simple: a real policy would optimize a distribution of lead times and correlated disruptions, with a feasible plan for simultaneously disrupted suppliers.

The emergency-versus-buffer comparison has an important decision-theoretic limitation. The emergency alternative is modeled as perfectly available whenever required, although a supplier drawing on the same port or corridor might fail in exactly the same event. This dependence is a common-mode risk, not an independent inconvenience that can be ignored after multiplying premium by probability. A realistic comparison would include the probability of alternative-supply failure conditional on the original disruption, the resulting forgone contribution or consequential harm, and the delay required to qualify substitute material. The expected-cost calculation is therefore a restricted benchmark, not proof that minimum inventories are universally superior. Where probabilities are highly unreliable, a stress-tested maximum acceptable service interruption may be more defensible than an apparently precise expected loss.

19.7.4 Continuity command and accountable recovery

Effective continuity preparation specifies signals and decision thresholds before a disruption. The procurement lead verifies alternate availability and specification equivalence; logistics confirms routing, carrier and border conditions; operations reschedules product mix; sales communicates revised delivery dates; finance authorizes emergency expenditure; quality verifies damaged or substituted inputs; and senior management protects legal and safety constraints. During an event, an auditable incident log records timestamps, stock, customer prioritization, workaround approvals, communication and remediation. Recovery review should compare planned and actual outcomes, identify avoidable harm, and update assumptions without converting a single dramatic event into an unsupported general law.

The recovery process should differentiate restoration of volume from restoration of legitimate service. A factory might resume production while a vulnerable customer group continues to experience shortages, a substitute product awaits conformity approval or suppliers are carrying uncompensated emergency costs. Managers should therefore define recovery time and recovery point objectives for critical records, together with minimum service quantities, safe substitution rules, decision authority and customer-notification thresholds. A post-incident review should preserve the chronology of warnings, rejected alternatives, emergency expenditures, physical inventory, quality holds and actual customer consequences. That record enables the organization to distinguish errors of foresight from errors of execution and to evaluate whether additional redundancy, greater flexibility or better institutional coordination would have produced a meaningfully different outcome.

19.8 SUPPLIER AND CUSTOMER INTEGRATION

19.8.1 Coordination beyond transaction exchange

Supply chain integration joins internal decision-making with selected interorganizational processes without requiring full corporate ownership. Shared forecasts, vendor-managed replenishment, synchronized delivery schedules, common product identifiers, collaborative performance reviews and joint risk exercises can lower information latency and conflicting signals. CPFR provides a family of collaborative forecasting and replenishment practices rather than a single mandatory software product. Supplier relations are not universally cooperative, however: commercial parties have different margins, bargaining positions and incentives to reveal sensitive data. Integration is justified when there is a demonstrable cross-boundary interdependence that can be managed more effectively together than apart.

Barratt (2004) argues that collaboration depends on cultural, strategic and operational fit rather than technology adoption alone. Fawcett et al. (2008) identify process and social impediments that make high-profile collaboration hard to sustain. These arguments qualify a naive transaction-cost prescription to share all information with all partners. A producer may share aggregated forecasts while retaining customer identities, and may grant a logistics carrier shipment milestone access without disclosing purchase margins. Contracts should specify data minimization, timing, auditability, performance exceptions and allocation of adjustment costs. Buyer power can make data requests coercive when smaller suppliers have little capacity to refuse; procedural fairness and proportionate technology burdens consequently matter.

19.8.2 Governance instruments and failure conditions

A practical integration charter records the business problem, authorized participants, common item definitions, order cutoff times, forecast versions, revisions, exception response, system access, confidentiality, data retention and dispute resolution. It also identifies the indicators by which collaboration will be evaluated, rather than assuming meetings are valuable because they are frequent. Joint improvement should use a relevant baseline and account for simultaneous price or demand changes. If a pilot reduces visible backorders but increases emergency supplier labor, the network may have shifted rather than removed cost. Governance must include remedy for late payment, rejected conforming goods, inaccurate buyer forecasts and abrupt demand changes.

Customer integration should likewise respect differences among retail, institutional and vulnerable users. A hospital may require documented product traceability and minimum continuity stock; a small shop may need manageable pack sizes and reliable collection arrangements; a digital customer may demand accurate order visibility and reasonable return handling. The commercial relationship is made sustainable not by abstract 'customer centricity' alone but by a credible set of mutually understood commitments, including what happens when availability fails.

Incentive compatibility is central to collaboration. A retailer that frequently revises forecasts may benefit from rapid upstream replenishment while transferring all write-off costs to the producer. Conversely, a producer whose

incentives reward shipment rather than saleable delivery may overfill a retailer and report artificially attractive service levels. Governance can address these asymmetries through agreed forecast horizons, shared exception evidence, equitable allocation of obsolete stock and timely dispute procedures. Agreements should not grant the more powerful party unlimited access to smaller partners' customer or employee information. Success is better demonstrated by improvements in joint service and cost-to-serve, with adverse effects documented on both sides, than by the volume of data exchanged.

19.9 SUPPLY CHAIN INFORMATION SYSTEMS

19.9.1 Digital records as an operational control architecture

Enterprise resource planning (ERP) connects purchasing, stock, production, sales and accounting records; warehouse management systems (WMS) manage bin-level and task-level movements; transport management systems (TMS) support carrier selection, dispatch and tracking; application programming interfaces or electronic data interchange may transmit orders and shipment statuses between firms. Barcode or radio-frequency identification can improve identity capture, while telemetry and Internet-of-Things (IoT) devices can measure vehicle location or storage temperature. These systems answer different questions and depend on aligned item masters, units of measure, location codes, timestamps and approval responsibilities. Adding sensors to fundamentally incorrect inventory records can multiply rather than remove confusion.

The ASCM SCOR Digital Standard classifies supply chain activities across orchestrate, plan, order, source, transform, fulfill and return, enabling process comparison without implying that every organization should acquire a comprehensive enterprise suite (Association for Supply Chain Management [ASCM], n.d.). A useful minimum viable digital architecture for a small firm may be a controlled item register, transaction-level receipts/issues, regularly reconciled stock balances, a shipment milestone log and an escalation channel. Larger firms may require integrated batch genealogy and multiple warehouse systems. Decisions should reflect transactions per period, system uptime, training capacity, auditability, integration cost, network reliability and recovery procedures.

19.9.2 Traceability, cybersecurity and the limits of digitization

Traceability connects identifiers and events to establish the origin, movement, transformation and custody of a specified item or batch. A traceable production lot might require supplier lot identifier, production date, packaging batch, storage location, dispatch manifest and consignee record. Visibility is not equivalent to traceability: a vehicle location does not prove which sealed goods are inside, whether a temperature threshold was breached or whether the declared origin is true. Claims of provenance require verified event capture and controls against tampering. An immutable record of an untrue input remains untrue; technology cannot substitute for physical inspection, credible institutions or accountability.

Cybersecurity is a direct supply-risk category because ransomware, credential theft, unauthorized changes to master data and compromised third-party integrations can interrupt both planning and shipment authorization. ISO 28000:2022 supplies a published security-management-system reference relevant to supply chains, although the existence of a standard is not evidence of an enterprise's certification or legal obligation (International Organization for Standardization [ISO], 2022). Access should be role-based; high-risk changes need approval; critical records require backup and tested recovery; external integrations should be reviewed; and staff should know manual fallback procedures. The principle of least privilege may conflict with flexible exception handling during outages, so emergency access must be bounded, logged and retrospectively reviewed. Data protection matters when shipment histories reveal identifiable persons, household locations, employees or commercially sensitive customers. The balance to seek is sufficient information for a defined operational purpose, not unlimited visibility.

19.9.3 Evaluating the business case for a digital logistics intervention

A digital investment should specify its causal mechanism and a measurable counterfactual: improved barcode capture might reduce stock discrepancies, enabling fewer emergency orders and more dependable fill rates. Capital costs, subscriptions, scanners, network costs, training, transaction cleanup, operational disruption, cybersecurity, downtime recovery and vendor dependence all belong in the evaluation. A dashboard may show higher recorded accuracy because exceptions are automatically suppressed; independent stock counts and complaint audits are needed before interpreting this as improved physical control. Waller and Fawcett (2013) explain the research significance of data science in supply chains while acknowledging the importance of domain competence. This warrants serious experimentation, not the conclusion that algorithmic recommendations are superior merely because their data volume is large.

A proportionate evaluation may begin with a deliberately limited pilot: one warehouse zone or a selected group of stock-keeping units is assigned a barcode and controlled receipt procedure while a comparable zone retains current practice. Independent counts and archived transaction data establish baseline error, then observation periods cover normal and peak demand. Because pilots are rarely randomized and zones differ in throughput and staff, estimated differences require caution; a staggered implementation may provide stronger comparison if contamination and seasonality are addressed. Cost analysis must separate one-off data cleaning from recurring software fees and account for recovery time after power or connectivity failure. Employees should retain an intelligible process for challenging erroneous automated adjustments, with an authorized audit trail.

19.10 LOGISTICS AND INVENTORY METRICS

19.10.1 Valid metrics require numerators, denominators and clocks

Performance measurement must begin by deciding what event counts as the unit of service. Unit fill rate measures the share of eligible demand quantities satisfied immediately; order-line fill rate counts lines complete; order-complete rate counts whole orders fully supplied. They may differ sharply where a large institutional order consists of dozens of items. On-time-in-full (OTIF) normally requires both timeliness against an agreed delivery date and the ordered quantity, but organizations must disclose whether delivery is measured at carrier dispatch, customer receipt or agreed proof of delivery, and whether acceptable substitutions count. A perfect-order measure extends completeness and timeliness to damage-free and documentation-accurate fulfillment; differences in definition prevent naive benchmarking.

Inventory turnover commonly equals annual cost of goods sold divided by average inventory valued on a consistent accounting basis; days of inventory outstanding may be estimated as 365/turnover (or using the organization's chosen day-count convention). Calculating turns with sales revenue in the numerator and inventory at cost in the denominator produces misleading values. Stock accuracy requires reconciled physical evidence. Dock-to-stock time measures receiving elapsed time from a declared start to available-stock status, not merely the time a truck waits at a gate. Transport cost per delivered unit, cost per tonne-kilometre and capacity utilization describe different levels of output; a carrier can improve truck fill but reduce route flexibility and increase emissions through detours. A balanced measurement system must make service, economic cost and physical consequences mutually visible.

Table 19.2

Logistics and inventory metric dictionary for an auditable scorecard.

Indicator	Operational definition	Interpretation and audit caution
Inventory turns	Annual COGS ÷ average inventory at cost	Exclude unlike accounting bases; disclose period and inventory averaging

Indicator	Operational definition	Interpretation and audit caution
Days inventory held	Days in reporting year ÷ inventory turns	Approximation; not an item-level replenishment lead time
Unit fill rate	Units delivered immediately ÷ eligible units requested	Requires explicit treatment of substitutions, cancellations and backorders
OTIF	Orders meeting both agreed timing and quantity ÷ eligible orders	Freeze original or mutually revised promise consistently
Perfect-order rate	Orders complete, on time, undamaged and document-correct ÷ eligible orders	Criteria and event timestamps must be specified
Stock-record accuracy	Correct physical-count lines ÷ counted stock lines	Define tolerance and stratify critical items; guard against count selection
Freight cost intensity	Total transport cost ÷ delivered units or tonne-km	Assign mode, fixed/variable and returns costs consistently
Cash-to-cash cycle	Inventory days + receivables days − payables days	Company-level liquidity measure with accounting and period assumptions
Transport GHG intensity	Defined transport-chain CO_2e ÷ tonne-km or units	Report boundary, factors, allocation and method under ISO 14083 where used

Note. Original metric definitions synthesized from conventional inventory analysis and ASCM's SCOR Digital Standard (ASCM, n.d.). Indicators are useful only if event definitions, data lineage and interpretation are controlled.

19.10.2 Reproducible example and a warning about gaming

Suppose a hypothetical firm fulfilled 950 of 1,000 eligible orders on time and in full, yielding OTIF = 95.0%. If 920 orders additionally met damage-free and accurate-documentation requirements, perfect-order performance = 92.0%, provided the 920 belong to the same eligible cohort. If 19,200 cartons were filled immediately out of 20,000 requested, the unit fill rate is 96.0%; the fact that this exceeds order-level OTIF is neither anomalous nor self-contradictory. These three indicators answer separate questions and should not be averaged into a new score without an explicit theory of how their dimensions matter.

Metrics can generate adaptation and gaming. A manager may redefine 'on time' as arrival at the carrier's depot rather than delivery to the user; staff may split large orders so partially fulfilled lines appear as successful transactions; a warehouse may exclude the stock location most likely to show discrepancies. These are measurement-governance problems, not simply software defects. The remedy is a controlled metric register, periodic independent re-performance from source records, a documented exception taxonomy, stable definitions and consultation with the customers and workers affected. Change in a KPI following a new policy does not establish that the policy caused the change; the counterfactual and concurrent changes must be examined (see Chapter 4).

A decision-oriented scorecard should be read as a configuration rather than a league table. A 95% OTIF may be unsatisfactory for a critical medical delivery but economically wasteful as an indiscriminate target for every nonessential low-margin item. The appropriate service benchmark depends on the product, contractual purpose and consequences of failure, and it must be compared with the incremental cost of improvement. Similarly, inventory turnover can rise because demand strengthens or because inventory collapses and stock-outs increase. Before endorsing any improvement, management should reconcile physical availability, demand lost to shortages, cash

tied up in goods in transit, worker safety and returns. A scorecard becomes a governance instrument when a responsible manager can interrogate anomalous results and authorize correction.

19.11 SUSTAINABILITY AND CIRCULAR LOGISTICS

19.11.1 Environmental impacts travel beyond enterprise boundaries

A logistics system uses fuels, electricity, packaging, roads, buildings and land; it generates emissions, congestion, noise, damaged or discarded products and occupational risks. Transport emissions must be assessed over a declared boundary: vehicle operation, purchased transport service, terminals or more extensive life-cycle processes are not interchangeable. ISO 14083:2023 provides a methodology for quantifying and reporting greenhouse-gas emissions from passenger and freight transport-chain operations (ISO, 2023). It is a methodological standard, not a blanket assertion that a transport route is climate-neutral or that each enterprise must legally adopt it. A credible report defines shipment allocation, activity data, fuel or energy estimates, emission factors, data quality and the scope of uncertainties.

Per-unit emissions can fall when vehicle load factors rise, yet total emissions can increase if the business expands volume or induces longer trips. Centralizing warehouses can reduce building energy while increasing final-mile distances; changing to lighter packaging can reduce freight weight but increase product spoilage if protection is inadequate. Environmental reasoning must therefore use relevant system boundaries and counterfactuals instead of praising any single packaging label or technology. Carter and Rogers (2008) and Seuring and Müller (2008) emphasize the interdependence of economic, environmental and social objectives; their frameworks do not remove the need for empirical comparisons of particular alternatives.

19.11.2 Returns, repair, reuse and closed-loop design

Reverse logistics moves returned, defective, obsolete or reusable items toward inspection, repair, resale, remanufacture, recycling or safe disposal. Its economics depend on collection density, condition uncertainty, disassembly labor, market value of recovered material, transport distance and regulatory duties. A refillable container can reduce single-use packaging but impose reverse transport, washing-water, sanitation and deposit-accounting costs. Enterprises should model expected recovery fractions and quality, not assume every returned unit is reusable. Where returns contain confidential customer data or hazardous substances, secure handling and compliant treatment become part of material recovery.

Circular business models require coordination with design and marketing: products should be distinguishable by batch and ownership; customers need accurate deposit and return terms; finance must record the liability attached to deposits; warehouse staff need a defined quarantine and re-entry process; and the public should receive truthful environmental claims. The design question is not simply whether a recycling programme exists, but whether it demonstrably reduces adverse impacts relative to feasible alternatives while preserving financially sustainable and dignified work. Prior research in sustainable operations indicates the relevance of closed-loop flows and health, safety and environmental integration (Kleindorfer et al., 2005).

Circularity can be evaluated through an explicit unit economics boundary. For example, suppose a hypothetical reusable crate costs RWF 6,000, survives ten effective return cycles, and requires RWF 180 per completed cycle for washing and reverse handling. Ignoring losses, financing and final disposal for illustration, its allocated acquisition and cleaning cost is 6,000/10 + 180 = RWF 780 per effective use. This must be compared with the actual price and impacts of a compliant single-use alternative and adjusted for loss probability, sanitation, transport and breakage. If only six cycles are achieved, the analogous amount rises to RWF 1,180. The difference demonstrates why claims of circular superiority cannot be inferred from the visible use of a returnable container alone. An environmental comparison must also specify vehicle-load changes, product protection and the method used to assign emissions.

19.11.3 Human rights, local access and distributional impacts

Supply networks distribute benefits and burdens unequally. A powerful buyer can improve its stock turnover by transferring inventory carrying costs to small suppliers; relentless delivery deadlines can intensify unsafe driving and unpaid overtime; a route optimized solely for paying demand may leave low-income or distant communities underserved. These are not arguments against efficiency, but reasons to identify the parties whose costs have been excluded. A responsible logistics decision protects lawful wages and rest, safe loading, truthful transport documentation, fair supplier payment arrangements and access to remedy. It should record unavoidable trade-offs and resist claims that one favorable environmental metric cancels serious labor or safety harm. The enterprise's moral legitimacy is not a numerical residual after the freight budget is balanced.

A serious due-diligence process asks where harm may occur in the network, who has the power to prevent it, and whether those affected can obtain remedy. Subcontracted truck drivers, warehouse agency workers, informal loaders and small suppliers may be economically invisible in the focal enterprise’s payroll yet central to its service. Contractual obligations to comply with labour law should be combined with proportionate verification of driving hours, loading practices, remuneration, grievance access and correct handling of dangerous goods. Remedial action should protect affected people rather than merely remove a noncompliant supplier and transfer the risk elsewhere. Environmental improvements require equivalent scrutiny of distributional effects: emission-reduction decisions may shift costs to less-capitalized contractors, while service consolidation can burden isolated communities. Accountable stewardship means stating these trade-offs, identifying lawful minimum protections and evaluating the consequences of feasible alternatives rather than declaring every cost reduction an improvement.

19.12 FUTURE SUPPLY CHAIN MODELS

19.12.1 AI forecasting and decisions under model uncertainty

Artificial intelligence may support demand forecasting, shipment anomaly detection, routing, warehouse slotting, document extraction and maintenance prediction. Its value depends on a defined decision problem, reliable training data, feasible interventions and an appropriate benchmark. A forecasting model that reduces mean absolute error can still worsen service where errors are concentrated in critical low-volume items; a routing algorithm can improve estimated distance while imposing unsafe schedules; and automated purchase orders can reproduce outdated vendor prices. Forecast accuracy must be measured against transparent naive or current-process baselines, on holdout periods appropriate to the decision horizon, with attention to intermittent demand, shocks, nonstationarity and the error distribution. Demonstrating a predictive improvement is not the same as demonstrating financial or societal benefit after implementation.

A robust adoption programme first cleans item and location masters, documents the chosen planning decision, collects representative operational data, and pilots a bounded alternative against a meaningful comparator. Human oversight must be specific: who can override, on what evidence, how errors are logged and who has authority to discontinue the system. Where model monitoring identifies distribution shift, procurement and operations must consider reverting to a simple rule. Waller and Fawcett (2013) anticipated valuable roles for analytics but equally emphasized domain expertise; the principle remains relevant even as generative systems and foundation-model applications are introduced. The future is not determined by a technology category but by verifiable design choices.

AI procurement and routing tools additionally pose problems of objective specification and institutional power. An algorithm optimized to minimize measured kilometres may encourage dangerously narrow rest schedules or suppress low-priority stops; a purchasing system optimized to historical acceptance data can preserve exclusionary vendor practices. Responsible evaluation should test differential service across geographies, unusual demand weeks and small suppliers, in addition to aggregate prediction accuracy. Automated recommendations should operate within documented delegated powers: the system may flag an exception, while an identified person

remains responsible for approving a legally consequential substitution, hazardous shipment or customer-priority change. Such controls are not evidence that the technology is ineffective; they specify the conditions under which its use is legitimate and reviewable.

19.12.2 Autonomous logistics, digital trade and infrastructural preconditions

Automated material handling and advanced driver assistance are already used in selected settings; more ambitious autonomous freight operations depend on infrastructure, weather, road conditions, insurance, lawful authorization, maintenance and emergency control arrangements. In a Rwandan urban warehouse, narrow aisles, inconsistent packaging and unreliable electricity can affect the economics differently from those in a large high-throughput distribution centre. Cloud tracking may aid regional shipments but fail at the precise point where roaming or border data services deteriorate. Digital trade documents can reduce repeated submission where agencies exchange trustworthy information, yet their benefits depend on legal acceptance and practical interoperability, as the TFA single-window language recognizes (WTO, 2017).

Regional and global restructuring is often described as a move toward 'nearshoring' or 'friendshoring'. Those labels are descriptive strategies, not universal evidence of improved cost or resilience. Concentrating production in a politically aligned region can reduce some exposures while creating common climate or supplier risks; dispersed sourcing can improve option value while increasing coordination burdens. Managers should compare explicit route-, supplier- and lead-time scenarios and avoid assuming either globalization or regionalization is inherently the safest model. Dated monitoring of international standards and geopolitical developments is necessary, but long-run decision principles remain: maintain truthful records, protect essential service, quantify trade-offs, preserve feasible alternatives and govern information.

19.13 RWANDA-BASED APPLICATION AND INTERNATIONAL COMPARISON

19.13.1 What the official evidence establishes and what it does not

NISR's 2024 Integrated Business Enterprise Survey reports 278,060 business enterprises and states that at least 87% of the business landscape was informal. It also reports that 62.6% of surveyed manufacturing companies did not use full production capacity, with low demand and problems affecting input availability among the reported explanations (NISR, 2025). These figures establish that enterprise scale, recordkeeping and demand conditions must be considered when designing inventory systems. They do not measure aggregate warehouse stock accuracy, true stock-out risk, national digital-traceability penetration or the return on ERP investment. A chain-wide model designed for a large listed multinational is therefore an analytic starting point, not an operating template to be imposed indiscriminately.

The 2025 NCTO corridor measurements, summarized in Section 19.6, provide a second kind of evidence: observed administrative transport indicators. The reported Mombasa–Kigali monthly averages of 168, 154 and 181 hours should be understood as a time-bounded route measurement, not a forecast for a food-processing consignment in 2026. The dispersion among monthly averages indicates that a single constant lead time may be an inadequate planning representation, but the available aggregate data alone cannot identify parcel-level variance or the precise cause of a given delay. A sound case therefore uses the published observations to motivate firm-level data collection without pretending that public data determine a particular firm's optimal ROP.

19.13.2 Fully constructed teaching case: Kigali packaged-food distribution

The teaching enterprise imports cartons and food-safe packaging via a regional transport corridor and sells packed household food products to retailers and institutional users. It has no identified name and no asserted employees, managers or financial statements. Its illustrative parameters are the D, S, H, d and uncertainty values in Section 19.3, plus the six-day exceptional delay scenario in Section 19.7. Sales promises an eligible order service target,

operations requires packaging by a specified production date, and finance imposes a capital ceiling. The logistics manager must reconcile the approximately 849-carton EOQ and 920-carton ROP with warehouse capacity, pack size and the sensitivity to long lead times.

The baseline recommendation is a controlled continuous-review pilot using inventory position rather than physical stock alone, approximate 850-carton replenishment lots after checking actual packaging constraints, a nominal 95% cycle-service safety buffer of roughly 279 cartons under the assumed independent normal model, and systematic reconciliation of receipts, transit orders and exceptions. Before implementation, the firm must establish that the cost of RWF 18,000 is per order rather than per unit, that RWF 1,200 includes an appropriate annual capital and storage allowance, and that the lead-time data actually warrant independence and normality. Where orders arrive in full truckload or fixed pallets, compare feasible order quantities by total cost. Where shelf life is binding, an inventory ceiling and expiry policy may dominate the EOQ recommendation.

The disruption exercise is not a recommendation to eliminate redundancy. Under its intentionally narrow one-event probability assumption, an expected RWF 45,180 annual emergency premium is below the RWF 576,000 annual holding cost for a standing 480-carton reserve. The enterprise nevertheless requires an operationally credible alternative supply source and an explicit service-priority rule. If available funds are too limited to hold incremental stock but substitute shipments are unreliable, a hybrid plan could allocate a smaller critical buffer and maintain qualified alternative carriers. Selecting the hybrid requires new evidence rather than a numerical answer invented here. The appropriate deliverable is a management memorandum disclosing both the cost comparison and its fragility under correlated border disruptions.

19.13.3 International transferability: comparisons of mechanism, not prestige

International practice offers at least three useful comparators. The SCOR Digital Standard provides a process taxonomy and performance dimensions that can organize a Rwandan firm's measurement vocabulary (ASCM, n.d.). Fisher's (1997) functional/innovative product framework illustrates why predictable staples and fashion or innovation-sensitive goods should not share a single replenishment policy. The World Bank's 2023 Logistics Performance Index (LPI), covering 139 economies, identifies border control, infrastructure, logistics services, timeliness and tracking as system-level logistics dimensions (World Bank, 2023). These sources do not establish that a selected country's technology or ranking can be reproduced by purchasing identical software in Kigali.

The relevant transfer test asks whether the source setting and local setting share the proposed mechanism's prerequisites. Automated picking depends on volume, standardized units, maintenance and energy; vendor-managed inventory depends on credible shared transactions and negotiated rights; near-zero-stock production depends on replenishment reliability and capable recovery; high-frequency direct delivery depends on density and transport economics. In a country whose imports require inland transit from maritime gateways, tail lead-time risk may justify a larger strategically selected buffer than a coastal comparison. Conversely, severe liquidity constraints may make trusted consolidation or shared storage more attractive than expensive redundancy. The lesson is conditional transfer with explicit feasibility tests, not the rejection of international theory or its unquestioned adoption.

The 2011 Great East Japan Earthquake provides a documented international comparison of structural interdependence and recovery. Toyota reported that disruption to its parts suppliers and infrastructure interrupted production following the 11 March earthquake. Its April 22, 2011 announcement projected staged normalization, with different timelines for Japan and overseas plants; its later regulatory reporting recorded that factories recovered earlier than initially anticipated (Toyota Motor Corporation, 2011a, 2011b). These are organizational disclosures, not independent causal estimates of the value of particular resilience investments. Their value here is analytical: production sites that were not themselves destroyed still depended on components and capabilities located elsewhere, and restoration required coordination across supplier tiers, plants and regions.

The transferability lesson is not that a Rwandan food distributor should replicate Toyota's supplier network or hold the same level of redundancy. Scale, product criticality, capital access, production technology and institutional conditions are different. The transferable mechanism is the need to identify hidden common dependencies, specify recovery authority and build feasible alternatives before an interruption. Toyota's experience also cautions against presenting lean production as synonymous with zero resilience: the relevant question is how buffer placement, flexibility and information interact in a particular network, not whether an entire managerial philosophy should be accepted or rejected because of one major disruption. Comparing a multinational manufacturing network with a small landlocked distributor is therefore a test of conditions and mechanisms, not corporate prestige.

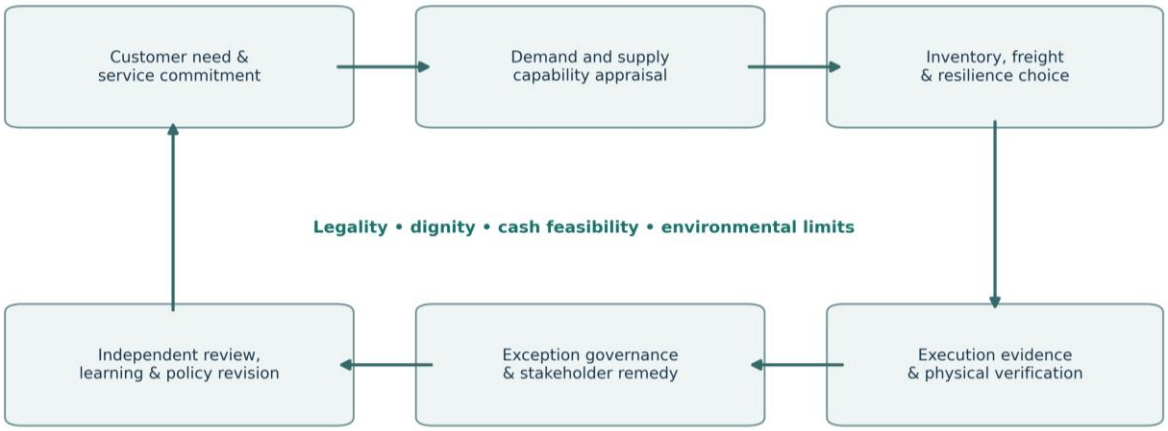
19.14 CROSS-FUNCTIONAL SYNTHESIS, ETHICS AND RESEARCH AGENDA

19.14.1 Integrated supply-chain value as a set of constraints

The foregoing analysis supports an analytical framework comprising six linked capabilities: **network intelligibility** (knowing nodes and dependencies), **demand interpretation** (distinguishing consumption from orders), **stock discipline** (declared replenishment rules and valid records), **execution reliability** (warehousing, transport and borders), **adaptive capacity** (credible response and recovery), and **legitimate governance** (lawful, fair, environmentally responsible and accountable decisions). Their relationship is not claimed to be a newly validated structural model. It is a testable synthesis suggesting that an improvement in one capability produces durable value only when the other capabilities do not impose a binding contradiction.

Figure 19.2

The supply-chain decision and accountability loop.



Note. Original conceptual synthesis. The cycle links service commitments, capability appraisal, logistics choice, execution evidence, exception governance and learning; legality, dignity, cash feasibility and environmental limits constrain each stage. Proposed for analysis, not empirically validated.

Supply chain management affects and is affected by at least five specialized functions. Marketing's service promise changes the shortage penalty and required response time; procurement's contract defines supplier lead-time and alternative-source options; operations determines consumption rates and acceptable input substitutions; finance decides how much capital can remain in transit or storage; governance and HR determine whether deviations can be reported honestly and handled safely. Quality management, developed in Chapter 20, determines whether a physically delivered item is suitable for release. Therefore an enterprise can report faster transport and higher sales while reducing its real capacity to fulfill safe, paid-for commitments. Cross-functional performance must reconcile these consequences rather than privilege one departmental KPI.

The framework proposes a distinction between the descriptive question of whether the network can coordinate an outcome, the explanatory question of which mechanisms account for variation, and the normative question of

whether the outcome is justified. The three should be investigated together without treating them as interchangeable. For example, reducing delivery delay by holding more safety stock may improve service through a measurable buffer mechanism, yet the judgment remains incomplete until financing, expiry, supplier payment and recipient welfare are considered. Conversely, a principled commitment to equitable access does not determine an economically feasible allocation rule without information on quantity, urgency, time and resources. The best decisions explicitly preserve this tension rather than conceal it under a generic assertion of sustainability.

19.14.2 Unresolved theoretical and empirical questions

A first research question concerns the resilience–efficiency frontier in small enterprises with weak liquidity. Conventional redundancy calculations often assume that the firm can finance additional inventory and that alternatives remain available during systemwide disruption. Research should estimate how informal credit, product criticality and corridor dependence alter the feasible policy set. A second question concerns the difference between digital visibility and trusted physical traceability: future work could compare phased barcode adoption with fuller ERP deployment while independently auditing receiving, inventory accuracy and fulfillment. A third concerns the environmental distribution of regional trade: transport consolidation may reduce unit emissions but affect access, truck-worker conditions and small-producer participation. Each question demands a research design that distinguishes selection, trend and causal impact.

Four provisional propositions follow. **P1:** Conditional on comparable products and demand volatility, firms that explicitly measure inventory position and replenishment lead-time distributions should exhibit fewer avoidable stock-outs than firms relying only on unverified physical estimates. **P2:** The relationship between shared forecasts and upstream order variance should be moderated by incentive alignment, promotional cycles and record quality. **P3:** For highly corridor-dependent enterprises, the benefit of alternative transport or supply arrangements should increase with common-mode exposure and the expected consequence of service interruption, but may be constrained by cash availability. **P4:** The net environmental impact of logistics digitization should depend on changes in physical routes, load factors and product waste, not software adoption alone. None of these propositions is empirically tested in the present chapter.

An additional methodological challenge concerns the identification of cross-boundary spillovers. A warehouse intervention may improve the focal firm’s reported inventory turns while pushing storage and financing demands onto small suppliers. Evaluating a supposed improvement therefore requires linked observations across at least the principal buyer–supplier interface and attention to bargaining power, selection into collaboration and downstream service displacement. Future research should compare enterprises with differing corridor dependence and financial constraints using common definitions, while avoiding the mistake of interpreting a cross-sectional association as the causal effect of managerial sophistication. Ethical and ecological outcomes should be measured, not inferred from the presence of a policy or software licence.

19.14.3 A defensible research protocol for future evaluation

An empirical programme might assemble a longitudinal panel of voluntary enterprise transaction records, geotemporal shipment events and independent stock counts, with documented informed access, privacy safeguards and data quality audits. It should predefine units, time boundaries, affected customers and primary outcomes, including OTIF, item fill, verified shortages, inventory capital, work injury exposure and per-unit transport emissions. If a new replenishment system is introduced, staggered rollout or a credible comparison group could support stronger inference than a simple before-and-after dashboard, provided contemporaneous demand and supplier shocks are measured. A failure to obtain comparable data is a limitation to report, not a justification to fabricate counterfactual precision.

A stronger explanatory programme would preregister a defined primary comparison, distinguish the treatment from the implementation process and document the statistical assumptions underlying uncertainty intervals. Researchers

should anticipate spillovers when participating enterprises share carriers or suppliers; untreated firms may nevertheless benefit from a changed corridor service. Missing shipment records may be informative rather than random if delays are precisely the events least likely to be entered. Suitable sensitivity analyses should examine selection into the pilot, record completeness, temporal autocorrelation, seasonality and the consequences of substituting alternative service-level definitions. Ethical review and data-sharing arrangements are necessary where identifiable employees, customer locations or commercially sensitive costs enter a linked dataset. The conclusion should describe what the evidence identifies, for whom, at what cost and under which conditions it could reasonably transfer.

19.15 CHAPTER SYNTHESIS AND CONCLUSION

The central contribution of this chapter is a disciplined distinction between local efficiency and network viability. The classical ordering calculation makes one cost trade-off transparent, but its usefulness depends on real lead-time and loss distributions; a lower warehousing cost can coexist with lost customers; a faster shipment can create unsustainable fuel or worker burdens; and digitized tracking can coexist with inaccurate physical custody. Effective coordination is therefore the integration of technically credible flow decisions, liquidity, service, environmental constraints and recoverable accountability. Rwanda's enterprise structure and corridor dependence make this integration especially visible, but the underlying mechanisms are not uniquely African.

Six conclusions should remain with the reader. First, supply chains are multi-tier networks with reciprocal information and cash commitments, not merely transport routes. Second, demand forecasts and purchasing orders must be distinguished to prevent amplification. Third, EOQ and safety stock are conditional models requiring dimensional and distributional discipline. Fourth, cross-border transit and warehouse activity must be observed through dated events rather than assumed constant lead times. Fifth, resilience requires identifying common vulnerabilities and feasible alternatives rather than indiscriminately accumulating buffers. Sixth, performance must be assessed simultaneously through service, cash, physical accuracy, human safety and environmental effects. The chapter prepares the ground for Chapter 20, where conformance, variation and operational quality determine whether coordinated supply actually results in suitable goods and services.

19.16 KEY TERMS, RESEARCH QUESTIONS AND ASSESSMENT PACKAGE

19.16.1 Selected glossary

Flow and coordination concepts. A supply chain is a network of enterprises and activities linking production and use; logistics governs the movement and storage within that network. Inventory position equals usable on-hand stock plus outstanding replenishments minus backorders, whereas lead-time demand is the quantity demanded before a released replenishment becomes usable. The bullwhip effect describes amplified variation in upstream orders relative to final demand when compared over specified and aligned periods. Traceability is the capacity to substantiate product identity and custody through recorded events; it differs from generalized real-time visibility.

Inventory economics. Cycle stock arises from ordering in batches, whereas safety stock protects a declared service objective against specified uncertainty. EOQ is the replenishment quantity minimizing fixed ordering and proportional cycle-stock holding costs under restrictive assumptions. The reorder point is an inventory-position trigger; a cycle-service level measures the modeled probability of avoiding a stock-out in a replenishment cycle, while a unit fill rate measures the proportion of eligible demand units satisfied immediately. These service concepts cannot be substituted for on-time customer delivery.

Warehouse and recovery concepts. First-expire, first-out (FEFO) means allocating items whose approved expiry dates occur earliest, subject to quality and eligibility controls. On-time-in-full (OTIF) is the proportion of eligible orders delivered on or before the governing commitment and in the correct quantity, according to a documented

event clock. Reverse logistics refers to the controlled movement, identification and disposition of returned goods and recoverable materials. Network resilience is the ability to anticipate disruption, maintain acceptable service, recover and adapt; simple robustness is only resistance to a disturbance without major change.

Institutional concepts. Trade facilitation comprises changes to import, export and transit processes that improve transparency, predictability and efficiency while retaining justified regulatory controls. An Incoterms rule allocates specified tasks, costs and risk between buyer and seller but does not itself determine title or all contractual remedies. A cash-to-cash cycle relates inventory and receivables days to payment timing, so inventory choices must be appraised in the context of funding, not only physical availability.

19.16.2 Questions and applied exercises

Foundational conceptual question (LO1–LO2). Explain why material, information, cash and rights must be mapped separately in a supply chain. Construct a four-tier example and identify one failure that cannot be detected using a physical-flow diagram alone.

Analytical question (LO2, LO7). Compare the arguments of Fisher (1997), Lee et al. (1997) and Ivanov and Dolgui (2020), identifying what each explains, what it excludes, and how their recommendations might conflict for a Rwandan medical supply chain.

Quantitative exercise (LO3). Recalculate EOQ, annual cycle costs, ROP and modeled fill rate in Worked Example 19.1 if H rises 25%, mean lead time rises to ten days, and σ_L becomes three days. Keep daily demand assumptions unchanged; report your units and explain why any new z-score should not be introduced without a chosen service objective.

Audit exercise (LO6). Reconcile a fictional month with 500 customer orders, 470 on time, 460 in full and 445 satisfying both conditions; compute OTIF and explain why multiplying the two marginal percentages is not justified without independence.

Applied Rwanda exercise (LO4–LO7). Using the NCTO's July–September 2025 report, describe the definition and data source of the Mombasa–Kigali transit-time indicator; propose a minimally intrusive shipment record that would enable an enterprise to estimate its own 90th-percentile usable-stock lead time.

Capstone decision assignment (LO1–LO8). Prepare a 2,500–3,500-word board memorandum for the constructed Kigali enterprise. The memorandum must (a) depict its multi-tier supply network and identify cross-functional decision rights; (b) build a transparent inventory workbook with an alternative lot-size and lead-time scenario; (c) compare buffer, emergency supply and corridor diversification responses; (d) include a warehouse integrity and OTIF measurement plan; (e) evaluate working-capital, labor-safety and environmental consequences; and (f) propose a six-month evidence collection and review schedule with explicit trigger thresholds. Students must label all hypothetical data and cite independently retrieved, dated sources for external conditions. Claims of causal policy effectiveness require a feasible identification design.

19.16.3 Educator scoring guidance and answer notes

A defensible capstone rubric assigns 20% to conceptual and network accuracy, 25% to reproducible calculations and sensitivity, 20% to appropriate use and limitation of Rwanda/international evidence, 15% to integrated organizational feasibility, 10% to sustainability and ethical reasoning, and 10% to source transparency, coherent structure and APA 7 citations. For the analytic question, a high-level response contrasts demand–product fit, induced order amplification and systemic continuity rather than presenting all three as synonyms. For the quantitative exercise, instructors should verify that students change H and the mean and variability of lead time in the correct parts of the formulas; inventory position must remain the trigger variable. For the audit exercise, OTIF is 445/500 = 89.0%, not 470/500 × 460/500 = 86.48%; the latter product incorrectly assumes independence.

Evidence from the NCTO report should be described as corridor-level observation, not as an individual company's observed service history.

In the quantitative sensitivity exercise, retaining D = 24,000, S = RWF 18,000 and z = 1.645 while increasing H to RWF 1,500 produces EOQ = √576,000 = 758.95 cartons. With a ten-day mean lead time, daily standard deviation of 20 cartons and lead-time standard deviation of three days, the independent-demand approximation yields σ_LT = √61,600 = 248.19 cartons, safety stock 408.28 cartons and ROP 1,208.28 cartons. The associated normal-loss approximation gives expected shortage of about 5.18 cartons per order cycle, and an illustrative unit fill rate of about 99.32%, subject to the same modeling assumptions. Award credit for explaining that the 95% cycle-service target remains unchanged and for refusing to interpret the modeled result as observed stock-out performance.

19.16.4 Further reading

For core inventory and network design, consult Simchi-Levi et al. (2021); for information distortion, Lee et al. (1997); for vulnerability and disturbance-response distinctions, Christopher and Peck (2004), Tang (2006) and Ivanov and Dolgui (2020); for the sustainability boundary problem, Carter and Rogers (2008) and Seuring and Müller (2008). For practice, use the current ASCM SCOR Digital Standard alongside the appropriate ICC, WTO and ISO primary documents rather than substituting a secondary synopsis for a binding rule.

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