ACROSS MARKETS AND BORDERS

Enterprise, Trade and Leadership with Purpose and Integrity

PART III | CORE BUSINESS FUNCTIONS AND RESPONSIBLE STRATEGY

CHAPTER 11

OPERATIONS AND GLOBAL SUPPLY CHAINS

Process Excellence, Logistics, Procurement and Resilience

Sixbert SANGWA
Department of International Business and Trade
African Leadership University, Kigali, Rwanda

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Process Excellence, Logistics, Procurement and Resilience

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Author: Sixbert SANGWA

Affiliation: Department of International Business and Trade, African Leadership University, Kigali, Rwanda

Corresponding author: ssangwa@alueducation.com

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Abstract

Operations turns customer promises into repeatable performance by coordinating people, processes, capacity, materials, information, technology and external partners. This chapter develops one continuous architecture from internal process excellence to cross-border supply-chain execution. It explains process mapping, productivity, capacity, bottlenecks, queueing, line balancing, lean systems, quality, asset reliability, inventory control, ERP and operational metrics before extending outward to network design, sourcing, procurement, transportation, warehousing, reverse logistics, Incoterms 2020, commercial documentation, customs, trade facilitation, corridors and resilience. Worked examples apply Little's Law, queueing intuition, EOQ, reorder-point logic, safety stock, line-balancing measures, asset availability and total landed cost. Ethiopian Cargo anchors the African opening case; Rwanda and the Northern Corridor provide current corridor evidence; Toyota provides a comparative global resilience case. Digital operations, AI, IoT, blockchain and digital twins are assessed through evidence, interoperability, cybersecurity and accountability. Christian moral reasoning frames operational excellence as truthful stewardship that protects workers, suppliers, customers and communities rather than shifting hidden costs onto less powerful parties.

Keywords: operations management; supply chain management; process excellence; inventory; procurement; logistics; trade facilitation; resilience; digital operations; African logistics

Learning Outcomes

Table 11.1. Learning outcomes for Chapter 11.

No.	Learning outcome
1	Explain operations as a value-creation system and distinguish operations strategy from general corporate strategy, marketing promises and financial reporting.
2	Map an end-to-end process, identify value-adding and non-value-adding activity, calculate throughput and flow time, and locate a binding bottleneck.
3	Calculate and interpret labour and multifactor productivity, design and effective capacity, utilization, efficiency, capacity cushion and takt time while recognizing the limits of local efficiency metrics.
4	Compare process, product, cellular and fixed-position layouts and apply scheduling, sequencing and line-balancing logic to manufacturing and service contexts.
5	Critically apply lean, just-in-time, Kanban, standard work and continuous-improvement principles, explaining the human and contextual conditions under which lean succeeds or fails.
6	Design a quality-management and asset-reliability system using prevention, appraisal, failure-cost, PDCA, statistical-process-control intuition, standardization, service recovery, maintenance logic and ISO 9001 awareness without treating certification or technology as proof of excellence.
7	Classify cycle, safety, pipeline, anticipation and decoupling inventory; calculate EOQ, reorder point and a basic safety-stock quantity; and explain the assumptions that make each calculation fragile.
8	Explain the roles and integration logic of MPS, MRP, ERP, MES, WMS, TMS, APS and S&OP/IBP while preserving data provenance, cybersecurity, exception ownership and human accountability.
9	Map a supply chain as a network of material, information and return flows and use SCOR as a reference architecture rather than a prescriptive substitute for contextual design.
10	Evaluate network design, inventory positioning, postponement and service-level trade-offs using total landed cost, responsiveness, risk and resilience rather than purchase price or transport cost alone.
11	Design a responsible procurement and supplier-management system using total cost of ownership, category segmentation, supplier qualification, performance management, development, concentration-risk analysis and fair purchasing practices.
12	Compare air, sea, road, rail and multimodal transport using cost, speed, reliability, capacity, accessibility, security, emissions, handling and disruption exposure.
13	Explain warehousing, cross-docking, distribution, cold chain, last-mile and reverse-logistics operations, including disposition and recovery choices and the distinctive constraints faced by landlocked and infrastructure-diverse African markets.
14	Apply Incoterms 2020 at an operational level, distinguish delivery, cost and risk allocation from title and payment, and identify when FCA is more appropriate than FOB for containerized movements.
15	Trace the operational document and customs flow of a cross-border shipment, including invoice, packing list, transport document, origin evidence, declaration, pre-arrival processing and single-window or one-stop-border mechanisms, while deferring trade-law doctrine to Chapter 19.
16	Diagnose supply-chain disruption risk, ripple effects, concentration and recoverability; distinguish robustness, agility, resilience and long-term viability; and design proportionate mitigation.
17	Evaluate AI, IoT, blockchain, control towers and digital twins through fit-for-purpose value, data quality, interoperability, cybersecurity, explainability and realistic evidence rather than technological fashion.
18	Apply Christian moral reasoning alongside serious alternative ethical perspectives to worker safety, supplier justice, procurement power, traceability, waste, hidden harms, continuity of essential goods and stewardship of resources.

Concept Map and Chapter Roadmap

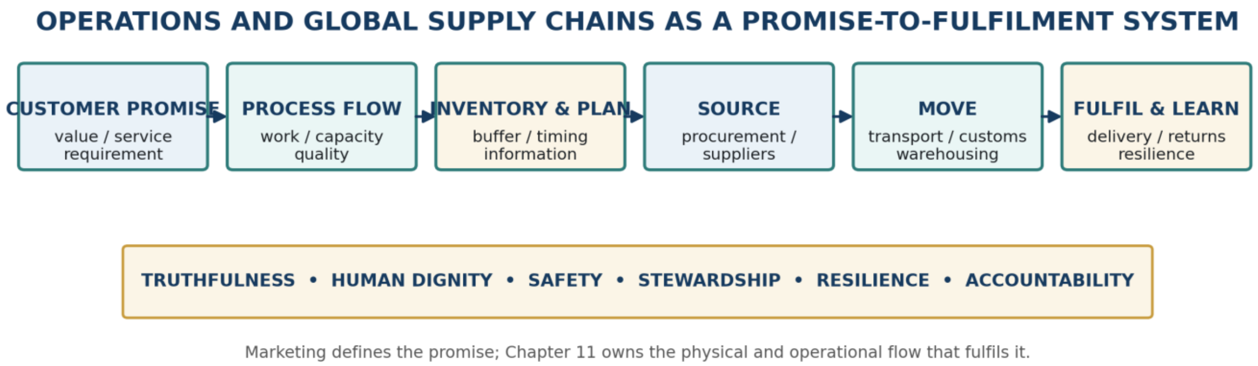

Figure 11.1. Operations and global supply chains as a promise-to-fulfilment system.

Source/Note: Author's synthesis. The architecture follows the approved Book Blueprint and the Chapter 10 hand-off from customer promise to operational fulfilment.

The chapter follows the flow of a customer commitment. Sections 11.1-11.3 establish operations as a transformation and value-creation system and locate the chapter within the cumulative textbook. Sections 11.4-11.10 move through process flow, capacity, productivity, layout, scheduling, lean, quality, maintenance reliability, inventory and digital planning systems. Sections 11.11-11.18 then extend the unit of analysis outside the organization through supply-chain architecture, network design, procurement, transportation, warehousing, reverse logistics, Incoterms, commercial documentation, customs, trade facilitation and corridors. Sections 11.19-11.21 examine disruption risk, resilience and digital visibility. Sections 11.22-11.23 apply the architecture to contemporary African and comparative global cases. Section 11.24 integrates faith, ethics and moral reasoning. The final sections provide a professional decision protocol, misconceptions, synthesis, questions, an applied case, an ethical dilemma, a data exercise, references and further reading.

SCOPE BOUNDARY | Chapter 11 owns physical and operational flows. It teaches internal operations first and then global logistics as one progression. It uses forecasting and optimization foundations from Chapters 4-5 without reteaching them; it uses customer-value and channel promises from Chapter 10 without repeating marketing; it does not teach full competitive strategy, which belongs to Chapter 12. Letters of credit, documentary collections and cross-border payment instruments belong to Chapter 17. Trade-law doctrine, legal remedies and formal policy negotiation belong to Chapter 19. Technology strategy belongs to Chapter 20 and sustainability strategy to Chapter 21.

Opening Case: Ethiopian Cargo and the Operations Problem of Moving Time-Sensitive African Goods Through a Global Network

A cargo customer does not buy an aircraft movement as an end in itself. A flower exporter buys usable market time before deterioration. A pharmaceutical distributor buys temperature integrity, traceability and dependable release. An e-commerce seller buys a predictable promise to a distant customer. A manufacturer with a stopped production line buys time. Ethiopian Cargo & Logistics Services therefore provides a particularly useful opening case because the visible flight is only the final expression of a much larger operating system: booking, acceptance, screening, documentation, cold-chain or special handling, build-up, aircraft assignment, transfer, customs coordination, ground handling, warehouse flow, last-mile hand-off and exception recovery must all work together.

Ethiopian Airlines' August 2026 fact sheet reports more than 145 international passenger and cargo destinations, including more than 60 African cities. For the 2025/26 financial year it reports cargo tonnage of 897,000 tonnes. The same fact sheet lists 12 Boeing 777-200LR freighters, three Boeing 767-300 freighters and four Boeing 737-800 freighters in the operating fleet, and identifies more than 70 cargo destinations. Ethiopian also describes its Addis Ababa cargo facility as having capacity of one million tonnes per year and as handling general and special cargo including horticulture, pharmaceuticals, valuables, live animals, e-commerce, mail and courier traffic (Ethiopian Airlines Group, 2026). These are company-reported operating signals, not independent proof of causal efficiency, but they make the scale and heterogeneity of the operating problem visible.

Special cargo makes process design consequential. Ethiopian's 2025 recertification under IATA's Center of Excellence for Independent Validators in Pharmaceutical Logistics highlights controlled processes, cold-chain infrastructure, specialist training and handling standards for pharmaceutical traffic (Ethiopian Airlines Group, 2025). A temperature-sensitive shipment can fail even when the flight departs on time. It can be exposed while waiting on a ramp, released late because a document is inconsistent, misrouted because master data are wrong, or rejected because packaging and handling requirements were misunderstood. Reliability is therefore an end-to-end property, not the sum of isolated departmental efficiencies.

Table 11.2. Ethiopian Cargo: operating signals and the operations questions they raise.

Operating signal	Current reported value	Operations and supply-chain question
2025/26 cargo tonnage	897,000 tonnes	How should capacity, labour, equipment, schedules and transfer processes be synchronized as volume grows?
Cargo network	More than 70 cargo destinations	How should the network balance reach, consolidation, connection reliability and aircraft utilization?
Dedicated freighter fleet	12 B777-200LRF; 3 B767-300F; 4 B737-800F	Which flows require dedicated capacity, which can use passenger belly capacity, and how should fleet differences shape planning?
Cargo facility	1 million tonnes annual capacity	How much nominal capacity is operationally usable after variability, maintenance, peak demand and product segregation are considered?
Special cargo	Horticulture, pharma, valuables, live animals, e-commerce, mail and courier	How should one system standardize core controls while differentiating temperature, security, speed and welfare requirements?
Pharma quality system	IATA CEIV Pharma recertification reported in 2025	How can a firm create traceable quality across multiple hand-offs rather than relying on a final inspection?

Source/Note: Ethiopian Airlines Group (2025, 2026). Company-reported figures are used as operating signals and should not be read as independent causal evidence of efficiency or social impact.

MANAGERIAL INSIGHT | The operating unit is rarely the department. It is the end-to-end flow required to fulfil a promise. A warehouse can achieve high picking productivity while shipments still miss departures; an airline can maximize aircraft utilization while transfer reliability collapses; a buyer can lower unit price while total landed cost rises. Operations management begins by defining the system boundary around the customer requirement and then asking where time, capacity, variability, information and responsibility actually constrain performance.

The case gives this chapter its central problem: **How can an organization design and govern end-to-end operating flows that are efficient in normal conditions, reliable under variability, resilient under disruption and morally responsible toward the people and communities that bear their hidden costs?**

11.1 Why Operations and Global Supply Chains Matter

Chapter 10 ended with a customer-side promise. Marketing can identify a valued segment, design an offering, choose a price and channel, and communicate a delivery proposition. Once that promise is made, however, it becomes an operational obligation. A same-day delivery claim requires inventory visibility, pick-pack capacity, cut-off discipline and transport availability. A premium-service promise requires process consistency and trained people. A reliable export promise requires production, packaging, documentation, carriage and border release to align. Operations is the discipline that converts what an organization intends to offer into what it can repeatedly deliver.

Operations management concerns the design, planning, control and improvement of processes that transform inputs into goods and services. Supply-chain management extends the unit of analysis beyond one organization to the coordinated network through which materials, services, information and returns move among suppliers, producers, intermediaries and customers. Logistics is the movement and storage component of that wider network. These concepts overlap, but they should not be collapsed. A firm can run an efficient plant and still have an unreliable supply chain because inbound materials fail. It can have efficient transport and still fail customers because order information is wrong. It can have a resilient supplier network and still waste resources through badly designed internal processes.

The approved chapter architecture deliberately combines operations and global logistics rather than treating them as unrelated courses. The logic is cumulative. First understand flow inside the organization: process, capacity, quality, inventory, planning and improvement. Then extend the same questions across organizational and national boundaries: where is the constraint, how much variability exists, which buffers are justified, who owns the hand-off, what information is authoritative, what risk transfers at which point, and what happens when a node or route fails? The physical flow is continuous even when accounting, legal and organizational boundaries change.

This chapter also preserves important boundaries. Chapter 5 already developed forecasting, optimization, simulation and decision architecture. Here those methods appear as operating inputs rather than being retaught. Chapter 12 will examine competitive and corporate strategy; this chapter focuses on operating choices such as capacity, process architecture, service levels and network flow, without turning each into a full strategic-management analysis. Chapter 17 will teach cross-border payment and trade-finance instruments. Chapter 19 will develop trade-law doctrine, legal remedies and policy negotiation. Chapter 11 explains what an operations professional needs to execute a shipment without pretending that operational awareness substitutes for legal or financial expertise.

EVIDENCE CHECK | Operational metrics are system-dependent. A high utilization rate can signal productive use of scarce assets or dangerous lack of slack. Low inventory can signal excellent flow or vulnerability to variability. Short supplier lead time can reflect genuine capability or unrecorded overtime. A metric becomes evidence only after its definition, denominator, scope, process mechanism and behavioural consequences are understood.

11.1.1 The transformation model: useful, but incomplete

A foundational operations model treats an organization as a transformation system. Inputs such as labour, materials, information, capital, energy, facilities and technology enter a process; activities transform them; outputs emerge as goods, services, experiences, information or combinations. The model is useful because it forces a manager to ask what resources are actually transformed and which resources perform the transformation. A hospital transforms patient condition and information through clinical capability. A university transforms knowledge and learner capability through teaching, assessment and support. A freight terminal transforms location, timing and shipment status through handling, storage and information processing.

The limitation is that real operating systems are open networks rather than isolated boxes. Customers can participate in the process. Suppliers shape quality before inputs arrive. Regulation constrains feasible methods. Waste and emissions leave the system even if accounting systems do not price them. Digital platforms coordinate work without owning every asset. A responsible operations model therefore includes feedback, externalities and institutional constraints, not only inputs and outputs.

11.1.2 Performance objectives are plural

Operations choices usually trade among several performance objectives. **Quality** concerns conformance to required characteristics and fitness for intended use. **Speed** concerns elapsed time. **Dependability** concerns whether promised timing and condition are actually achieved. **Flexibility** concerns the ability to change volume, mix, timing or method without unacceptable penalty. **Cost** concerns resources consumed. **Safety and responsibility** concern the human and environmental conditions under which performance is produced. These objectives can reinforce one another, but they can also conflict.

The classical claim that operations faces unavoidable trade-offs was sharpened by Skinner (1969), who argued that manufacturing choices should be focused rather than expected to excel equally at every dimension. Later operations research showed that improvement can sometimes shift the frontier, allowing better quality and lower cost together, particularly through learning and waste reduction. Schmenner and Swink (1998) emphasized flow and variability as underlying mechanisms that explain why faster throughput can also improve cost and quality. The correct conclusion is not that every performance dimension is permanently opposed, nor that all trade-offs disappear. Managers must distinguish **improvement that moves the frontier** from **positioning choices along the frontier**.

Table 11.3. Core operations performance objectives and their characteristic tensions.

Objective	Managerial question	Useful indicators	Characteristic tension
Quality	Does the output conform and work for its intended use?	first-pass yield; defect rate; complaints; rework; condition	extra inspection can detect defects but not remove their causes
Speed	How quickly does the flow move from request to fulfilment?	flow time; order cycle time; dock-to-stock time	speed purchased with premium transport may raise cost and emissions
Dependability	Do we deliver when and as promised?	OTIF; schedule adherence; perfect order	high averages can hide severe tail failures
Flexibility	Can the system change volume, mix, route or sequence?	changeover time; surge capacity; response time	flexibility often requires cross-training, modularity or spare capacity
Cost	What resources are consumed per relevant output?	unit conversion cost; logistics cost; total landed cost	local cost reduction can shift cost to inventory, suppliers or customers
Safety/responsibility	What human and environmental conditions produce the output?	injuries; near misses; overtime; waste; energy; supplier findings	unrecorded harm can make an apparently efficient process morally and economically misleading

Source/Note: Author's synthesis drawing on operations-strategy and quality-management literature. Indicator choice must be tailored to process and risk.

11.2 Historical and Theoretical Foundations: From Task Efficiency to Flow, Quality and Networks

11.2.1 Scientific management and the measurement of work

Modern operations management inherited a strong concern with measurement from scientific management. Frederick W. Taylor's early twentieth-century work sought systematic methods for task design, standardization and performance measurement. The contribution was substantial: managers should not rely only on habit or arbitrary rules when work can be observed and improved. The limitation was equally important. Strong forms of scientific management tended to separate planning from doing and could treat the worker as an input to be optimized rather than a knowledgeable participant in improvement. Chapter 6 has already developed the human consequences of authority and work design; Chapter 11 inherits the operational lesson that standardized work must not become standardized disregard for persons.

11.2.2 Mass production, statistical quality and the move from inspection to prevention

Mass production increased the importance of stable processes, interchangeable parts, line balance and quality control. Statistical methods made variation visible rather than leaving quality to final inspection. The deeper intellectual shift was from asking whether a defective unit could be found to asking why the process created the defect. Deming (1986) argued that management systems, not only individual workers, shape quality and that continuous improvement requires attention to process variation, feedback and learning. This is a durable idea because it moves accountability upstream. If a target repeatedly requires unsafe shortcuts, blaming the last operator is analytically weak and morally evasive.

11.2.3 Toyota, lean and the centrality of flow

The Toyota Production System synthesized just-in-time flow, built-in quality, problem visibility, standard work, rapid changeover, supplier coordination and employee problem solving. Ohno (1988) described the elimination of waste and the use of pull as means to expose rather than hide process problems. The later term **lean production** spread beyond automotive manufacturing through research and practitioner work, including Womack et al. (1990). Holweg (2007) traces this development and shows that lean is not a single technique but an evolving production philosophy. Netland (2016) further shows that lean implementation success is contingent on organizational and operating context rather than a universal recipe.

Empirical evidence reinforces the need to treat lean as a system. Shah and Ward (2003) found that bundles of just-in-time, total quality, preventive maintenance and human-resource practices were associated with operational performance, while contextual factors affected adoption. Bortolotti et al. (2015) found that successful lean implementation was associated not only with hard technical practices but with organizational culture and people-related practices. Lean therefore should not be reduced to inventory cutting, 5S posters or a demand for workers to move faster.

11.2.4 Supply-chain management: from dyadic logistics to coordinated networks

As outsourcing, specialization and cross-border production expanded, the operating unit extended beyond the firm. Mentzer et al. (2001) distinguished supply chains as sets of connected organizations from supply-chain management as deliberate coordination across them. Lambert and Cooper (2000) similarly emphasized integration of key business processes across the network. The theoretical shift matters because a buyer can no longer treat a supplier as an external black box when supplier capacity, labour practice, quality or concentration can determine the buyer's performance and responsibility.

Two additional ideas sharpen supply-chain design. Fisher (1997) argued that supply chains should fit product demand characteristics rather than follow one universal model: relatively predictable functional products can reward efficiency, while innovative and uncertain products require greater responsiveness. Lee (2002) extended fit to both demand and supply uncertainty. Lee's later Triple-A formulation emphasizes agility, adaptability and alignment (Lee, 2004). These models are heuristics rather than laws, but they correct a recurring error: adopting a fashionable operating model without asking what uncertainty, margins, service requirements and supply conditions the model must handle.

11.2.5 Resilience after globalization and disruption

Longer and more tightly coupled supply chains can lower ordinary cost while increasing exposure to disruption. Christopher and Peck (2004) framed resilience as a response to rising vulnerability; Ponomarov and Holcomb (2009) emphasized readiness, response and recovery. Hohenstein et al. (2015), reviewing the resilience literature, likewise found a field rich in concepts but still developing common definitions and empirical grounding. Tang (2006) argued for robust strategies that create value in normal conditions while also reducing disruption consequences. Later work on the ripple effect shows that a local failure can propagate through a network, altering capacity and inventory far from the original node (Dolgui et al., 2018). The post-pandemic literature has further distinguished short-run recovery from long-run viability. Ivanov (2022) conceptualizes a viable supply chain as one able to adapt structures and survive sustained change rather than merely return to a prior configuration.

CRITICAL DEBATE | Does efficiency make supply chains fragile? The claim is too simple. Efficiency initiatives can reduce error, shorten flow time and improve visibility, all of which can strengthen resilience. Fragility arises when efficiency is pursued by removing buffers or alternatives without understanding variability, critical dependencies and recovery time. Lean and resilience are not opposites. The professional question is which forms of waste should be removed and which forms of slack, optionality or redundancy are economically and morally justified because failure would be severe.

11.3 Operations Strategy as a Value-Creation System

11.3.1 From customer requirement to operating specification

An operating system cannot be designed from slogans such as "fast", "high quality" or "low cost." It needs an operating specification. The specification translates a customer or institutional requirement into measurable conditions: quantity, quality tolerance, lead time, delivery window, service availability, traceability, security, regulatory condition, returnability and acceptable failure. A vaccine distribution system may require temperature control and chain-of-custody evidence. A mass-market cement operation may prioritize high utilization, predictable maintenance and bulk movement. A professional service may require response-time targets, expertise routing and confidentiality rather than physical inventory.

The translation matters because different promises create different resource structures. If management promises 99.9% availability but funds capacity as if ordinary demand were certain and uniform, the promise is internally incoherent. If marketing promises customization while operations is designed for long homogeneous runs and slow changeovers, the mismatch appears later as delay, expediting or hidden overtime. Operations strategy at this level is the disciplined alignment between the promise and the process required to fulfil it.

11.3.2 The four Vs and operating variety

A useful diagnostic asks how an operation differs in **volume, variety, variation in demand and visibility or customer contact**. High volume can justify dedicated equipment and standardization. High variety creates scheduling, information and changeover complexity. High demand variation creates a need for capacity, inventory, pricing or queue-management responses. High customer visibility can reduce opportunities to buffer work invisibly and makes service behaviour part of the product. The framework is descriptive rather than deterministic, but it helps explain why a method that works in a beverage bottling plant may fail in a hospital emergency department or a project-based engineering service.

11.3.3 Order penetration and decoupling points

Operations also differ according to when a specific customer order enters the flow. In **make-to-stock**, output is produced before individual orders and inventory absorbs demand variation. In **assemble-to-order**, common components are held and final configuration waits for the order. In **make-to-order**, production begins after commitment. In **engineer-to-order**, even design is customer-specific. Moving the customer-order decoupling point upstream can reduce finished-goods inventory but lengthen response time. Moving it downstream can improve speed but requires better demand forecasting and inventory risk. Postponement seeks to keep common form for as long as economically useful, delaying final differentiation until information improves.

11.4 Process Mapping, Flow Time and Bottleneck Management

11.4.1 Map what actually happens, not what the procedure says

A process is a sequence of activities and decisions that converts an input or request into an output. Process mapping makes that sequence visible. At a high level, a SIPOC map identifies suppliers, inputs, process, outputs and customers. A swimlane map adds responsibility across functions. A value-stream map adds information flow, inventory and timing. The choice of tool should follow the diagnostic question. A manager who needs to locate a customs-document hand-off problem may need a swimlane map; a plant manager diagnosing excess lead time may need activity time, waiting time and WIP at each stage.

Maps should be built from evidence. Procedure manuals can describe the intended process, while event logs, observation and interviews reveal the actual process. Process mining can reconstruct flows from timestamped system events, but it inherits the quality of those logs and can miss work done outside formal systems. The objective is not to produce an attractive diagram. It is to expose hand-offs, rework loops, waiting, ambiguity and decision rights that determine performance.

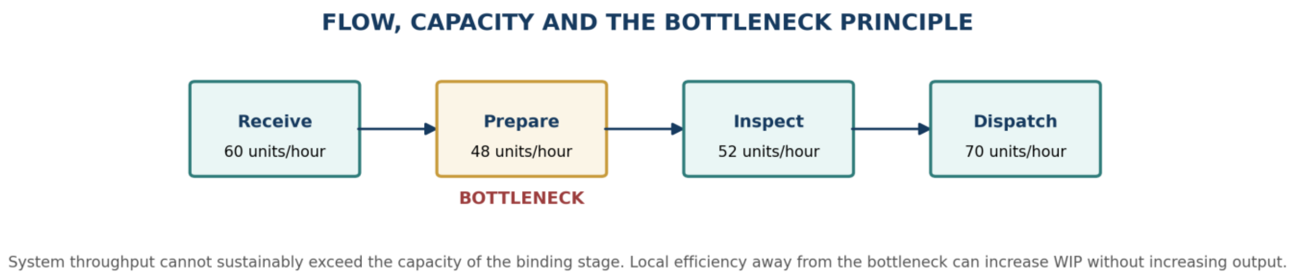

Figure 11.2. Flow, capacity and the bottleneck principle.
Source/Note: Constructed example. Capacities are illustrative.

11.4.2 Little's Law: WIP, throughput and flow time

One of the most powerful relationships in operations is Little's Law. Under stable long-run conditions, average work in process equals average throughput rate multiplied by average flow time:

WORKED EXAMPLE | Little's Law: L = lambda W, where L is average number of flow units in the system, lambda is average throughput rate, and W is average time a unit spends in the system. Suppose a distribution process completes 40 orders per hour and averages 120 orders in process. W = 120 / 40 = 3 hours. If the operation can reduce average WIP to 80 orders while sustaining the same throughput, average flow time falls to 2 hours. The calculation does not prove how the reduction can be achieved; it shows the accounting relationship among flow, inventory and time.

Little's Law is deceptively simple. It does not require each order to spend exactly the same time in the process, but the system boundary and averaging period must be coherent. Hidden backlogs outside the defined system invalidate a managerial claim that WIP has fallen. If orders are removed from the queue by refusing or delaying their entry while customer waiting is simply moved upstream, measured internal flow time improves without improving the customer experience. Metrics must follow the real boundary of responsibility.

11.4.3 Bottlenecks and the theory of constraints intuition

A bottleneck is the resource or stage whose effective capacity constrains system throughput over the relevant period. In Figure 11.2, the preparation stage can process 48 units per hour while adjacent stages can process more. The line cannot sustainably exceed 48 units per hour without inventory accumulating before preparation. Improving the dispatch stage from 70 to 90 units per hour will not raise line throughput. It may only increase idle capacity at dispatch.

Bottleneck management therefore follows a sequence: identify the binding constraint, protect its productive time, subordinate upstream release and downstream coordination to it, add or redesign capacity where justified, and then reassess because the bottleneck can move. A bottleneck can be physical equipment, scarce expertise, a regulatory approval, a gate, a cold room, a customs inspection channel or an information dependency. In service systems it can shift by time of day. The strongest managers distinguish the current bottleneck from an emotionally salient but non-binding problem.

11.4.4 Variability creates queues before average capacity is exhausted

A common operational mistake is to assume that if average demand is below average capacity, waiting should be negligible. Queueing systems behave differently. When arrivals and service times vary, high utilization produces disproportionate waiting as the system loses the slack needed to absorb randomness. This is why a border crossing, call centre, clinic or loading dock can experience long queues even when daily average throughput appears adequate. The managerial response can include reducing variability, changing appointments or release rules, pooling capacity, shortening service time, adding flexible capacity, or segmenting priority work rather than simply buying more fixed capacity.

A compact queueing model makes the non-linearity visible. In the standard single-server M/M/1 model, arrivals are assumed Poisson, service times exponential, the queue discipline non-prioritized, and the long-run arrival rate lambda lower than the service rate mu. Utilization is rho = lambda/mu; expected total time in the system is W = 1/(mu - lambda), while expected queueing time is Wq = lambda/[mu(mu - lambda)]. If a service point can complete 10 jobs per hour and receives 8 per hour, rho = 0.80, W = 0.50 hour and Wq = 0.40 hour. If arrivals rise only to 9 per hour with service capacity unchanged, rho = 0.90, W doubles to 1.00 hour and Wq rises to 0.90 hour. The example is deliberately stylized: multiple servers, priorities, appointments, abandonment, non-exponential service and time-varying arrivals require richer models. Its managerial lesson is durable: in variable systems, removing the last units of slack can create disproportionate waiting.

11.5 Capacity, Layout and Scheduling

11.5.1 Design capacity, effective capacity, utilization and efficiency

Design capacity is the theoretical maximum output under specified design conditions. **Effective capacity** is the output realistically available after planned losses such as maintenance, changeovers, product mix and operating hours. **Actual output** is what the system produces. Two ratios are useful when definitions are explicit:

PRACTICE TOOL | Utilization = Actual output / Design capacity. Efficiency = Actual output / Effective capacity. Suppose a packaging line has design capacity of 1,000 cases per shift, effective capacity of 850 after planned changeovers and maintenance, and actual output of 765. Utilization is 76.5%; efficiency relative to effective capacity is 90.0%. Calling the line "only 76.5% efficient" would confuse two different denominators.

Capacity cushion is the deliberate difference between expected demand and available capacity. It is not automatically waste. Emergency services, essential infrastructure, volatile demand and high-cost stockouts can justify more cushion than predictable, non-urgent processing. The right cushion depends on uncertainty, service consequences, flexibility, lead time for adding capacity and the possibility of demand shaping or inventory buffering.

11.5.2 Capacity decisions across time horizons

Capacity is managed at multiple horizons. Long-term decisions include facilities, major equipment, automation and network nodes. Medium-term decisions include shifts, subcontracting, workforce levels, seasonal inventory and maintenance windows. Short-term decisions include overtime, sequencing, routing, appointments and exception handling. A capacity plan fails when it treats all gaps as if they can be solved at the same speed. A port crane cannot be added tomorrow; a trained cold-chain specialist cannot be created instantly; some flexible labour can be scheduled in days.

11.5.3 Layout: arranging resources around flow

Layout determines physical or virtual relationships among resources. **Product layouts** arrange resources by processing sequence and fit high-volume repeatable flow. **Process layouts** group similar capabilities and support variety but can increase movement and scheduling complexity. **Cellular layouts** organize resources around families of flows, seeking a balance between repetition and variety. **Fixed-position layouts** keep the product or project stationary while people and equipment move, as in construction, ship repair or large infrastructure. Service layouts also shape customer movement, privacy and experience. The lowest travel distance is not always the best design if it creates unsafe congestion or weak segregation.

11.5.4 Scheduling, sequencing and the discipline of priorities

Scheduling assigns work to resources through time. A master schedule converts demand and capacity plans into executable commitments. Detailed sequencing rules include first-come-first-served, shortest processing time, earliest due date and priority-class rules. Each rule optimizes a different concern. Shortest processing time can reduce average flow time but continually postpone long jobs. Earliest due date supports lateness control but may not protect high-consequence work. Priority systems therefore require explicit criteria and ethical safeguards when service affects essential needs.

In repetitive systems, **takt time** translates customer demand into the pace required of the process: Takt time = available production time / customer demand. If a line has 420 productive minutes per shift and must produce 210 units, takt time is 2 minutes per unit. Takt is a demand-derived rhythm, not an instruction that each worker must always finish every task in two minutes. Process design, work content, ergonomics, variability and quality must make the rhythm feasible.

11.5.5 Line balancing and workstation assignment

Line balancing assigns work elements to stations so that each station can meet the required cycle time while respecting task precedence, technology, ergonomics and quality constraints. If total task time is T and the target cycle time is C, a useful lower bound on the number of stations is Nmin = ceiling(T/C). For an actual design with N stations, balance efficiency can be expressed as T/(N x C). These measures do not produce the assignment by themselves; they make the unavoidable relationship among work content, cycle time and station count explicit.

Consider a process whose tasks require 11.4 minutes in total and whose customer requirement implies a 3.0-minute cycle time. The theoretical minimum is ceiling(11.4/3.0) = 4 stations. If precedence and indivisible task times force a feasible design with five stations, balance efficiency is 11.4/(5 x 3.0) = 76%. The remaining 24% is not automatically evidence of idle or unproductive workers. It may arise from precedence restrictions, walking, inspection, safe recovery time, skill constraints or task indivisibility. Improvement should first redesign work, interfaces and task groupings rather than simply compressing human recovery time. In service and knowledge work, variability and customer interaction often make deterministic line balancing less appropriate, but the same principle remains useful: distribute work so one overloaded station does not become the effective system bottleneck.

11.6 Productivity and Operational Performance

11.6.1 Partial and multifactor productivity

Productivity relates output to resources consumed. Labour productivity can be expressed as units per labour hour, but a gain can be misleading if it comes from substituting expensive equipment, outsourcing work or shifting tasks to suppliers. Multifactor productivity reduces this distortion by comparing output with a weighted or monetary combination of inputs. The measures remain sensitive to quality, product mix, inflation and denominator choices. A hospital that increases patients per clinician by shortening consultations may report higher labour productivity while worsening outcomes. A warehouse that increases picks per hour by moving quality checks downstream may merely relocate work.

WORKED EXAMPLE | A service centre completes 600 transactions using 120 labour hours. Labour productivity is 5 transactions per labour hour. After automation it completes 720 transactions using 100 labour hours, apparently 7.2 per labour hour, a 44% increase. But if automation creates 50 extra hours of exception-resolution work in another team that is excluded from the denominator, the productivity claim is incomplete. Measure the end-to-end process, not only the visible station.

11.6.2 Overall Equipment Effectiveness and metric discipline

Overall Equipment Effectiveness (OEE) is often expressed as **Availability x Performance x Quality**. It can help decompose lost equipment potential into downtime, running-rate loss and defective output. OEE is useful for a constrained asset when definitions are stable. It is not a universal score of business value. Raising OEE on a non-bottleneck machine can create unnecessary inventory. A plant can achieve high OEE while producing the wrong mix. Managers should connect equipment metrics to system throughput, customer service, safety and cash rather than optimizing them in isolation.

11.6.3 Metric hierarchies and Goodhart effects

Operational dashboards should link leading process indicators to customer and economic outcomes. A useful hierarchy can move from process stability and quality to flow time, service reliability, inventory and total cost. Metrics need an owner, definition, source system, frequency, target logic and escalation rule. When a measure becomes a target, people can rationally game the measure rather than improve the process. On-time dispatch can be improved by changing the promised time; inventory turns can be improved by starving service; injury rates can appear better when reporting is discouraged. A responsible metric system therefore includes counter-metrics, auditability and protected channels for reporting inconvenient evidence.

11.7 Lean Systems, Just-in-Time, Kanban and Continuous Improvement

11.7.1 Lean is a system for exposing and removing non-value-creating work

Lean begins with value from the customer's perspective, then examines the flow required to produce it. Common categories of waste include overproduction, waiting, unnecessary transport, over-processing, excess inventory, unnecessary motion, defects and underused human capability. The categories are diagnostic prompts, not moral labels. Inventory can be waste when it hides unstable flow, but safety stock can be a justified protection against uncertainty. A quality check can be non-value-adding in the narrow customer sense while still necessary because the process has not yet become capable enough to prevent failure.

The most important lean principle is often misunderstood: **make problems visible**. If a process is buffered by large queues, urgent defects can be hidden for days. If work is released only at a controlled pace and inventory is limited, a defect or breakdown becomes visible quickly. The goal is not to make workers absorb the disruption; it is to create fast feedback that allows causes to be corrected.

11.7.2 Just-in-time and pull

Just-in-time seeks to produce and move what is needed, when needed, in the required quantity. A pull system authorizes replenishment based on downstream consumption rather than unrestricted upstream production. Kanban is a visual or digital authorization mechanism that limits WIP and signals replenishment. The number of cards or containers effectively sets a buffer. Reducing that buffer can shorten lead time and expose instability, but reducing it below the variability the system can absorb creates stockouts and expediting.

JIT therefore depends on prerequisites: relatively reliable processes, manageable setup times, stable information, disciplined maintenance, supplier coordination and rapid problem solving. Treating JIT as "zero inventory" reverses the logic. The system removes inventory because causes of uncertainty have been reduced; it should not remove the protection while leaving the causes untouched.

11.7.3 Continuous improvement, PDCA and standard work

Continuous improvement converts operational learning into repeated small changes. The Plan-Do-Check-Act cycle creates a disciplined sequence: define a problem and hypothesis, test a change at proportionate scale, compare evidence, then standardize or revise. Standard work captures the current best-known method so that variation becomes visible and improvement has a baseline. Standardization should not suppress judgment in situations where legitimate exceptions exist. A high-reliability operation specifies which elements must not vary and where professional judgment is required.

11.7.4 Lean and labour standards: evidence rather than ideology

Lean has been criticized as a possible vehicle for work intensification, and it has also been defended as a means of safer, more participative problem solving. The empirical record does not justify either universal claim. Distelhorst et al. (2017), studying Nike supplier factories across developing countries, found lean adoption associated with a reduction in noncompliance on labour standards related mainly to wages and work hours, but found no effect on health and safety standards. The result suggests that capability-building can improve some social outcomes while also showing that technical management systems do not automatically solve every labour problem. The moral quality of lean depends partly on how targets, voice, staffing, purchasing pressure and safety are governed.

> **FAITH AND VOCATION |** Work should not be treated as a residue after process optimization. A Christian view of work sees persons as image-bearers whose dignity precedes their output. Standard work can support fairness and safety; it becomes morally defective when it erases legitimate human needs, punishes voice or hides harmful workload behind productivity targets. Operational excellence should make good work more possible, not merely make labour less visible.

11.8 Quality Management: Building Reliability Into the Process

11.8.1 Conformance, fitness for use and the cost of quality

Quality has at least two operational meanings. **Conformance quality** asks whether an output meets specified requirements. **Fitness for use** asks whether the specification itself serves the intended need. A perfectly produced unsafe product can conform to an inadequate design. Operations professionals therefore need both control of variation and disciplined escalation when requirements are incomplete or wrong.

The cost of quality can be organized into **prevention costs** such as training and process capability; **appraisal costs** such as inspection and testing; **internal failure costs** such as scrap and rework before delivery; and **external failure costs** such as returns, recalls, claims and reputational loss after delivery. The categories reveal why quality investment cannot be evaluated only as an expense. Prevention can reduce much larger failure costs, although not every possible prevention measure is economically justified.

11.8.2 Common-cause and special-cause variation

Statistical process control distinguishes variation that is inherent in the current system from unusual signals suggesting a specific change. A control chart plots process data against statistically derived control limits to detect non-random patterns. Control limits are not customer specification limits. A process can be statistically stable and consistently produce output outside customer tolerance; conversely, a capable process can produce a rare special-cause deviation. Chapter 4 taught statistical inference; here the operational principle is to avoid tampering with random noise while reacting quickly to genuine process shifts.

11.8.3 Quality at source and error-proofing

Quality at source places responsibility for detecting and correcting problems close to where they arise. Poka-yoke or mistake-proofing redesigns work so an error is prevented or immediately obvious. Examples include keyed connectors that cannot be reversed, required barcode matches before loading, electronic validation of mandatory fields, and physical separation of incompatible materials. Error-proofing should target foreseeable failure modes without making workers unable to exercise judgment when systems are wrong.

11.8.4 ISO 9001, certification limits and the 2026 transition

As of 28 August 2026, ISO 9001:2015 remains the current published edition of the quality-management-system requirements standard. It is supplemented by ISO 9001:2015/Amd 1:2024, which introduced climate-action changes to the management-system context requirements (International Organization for Standardization [ISO], 2015, 2024). ISO announced on 7 August 2026 that ISO/FDIS 9001 had been approved and that the sixth edition was scheduled for publication on 16 September 2026 (ISO, 2026). Because this textbook is being prepared during that transition, practitioners should verify the edition and transition requirements in force when they implement, certify or audit a quality-management system.

Certification can provide evidence that a defined management system has been independently assessed against a specified standard. It does not prove that every product is defect-free, that every process is capable, that an organization is ethically exemplary, or that its quality exceeds competitors. Standards are governance tools whose value depends on implementation, competence, evidence, corrective action and the integrity of the certification process. The same caution applies during a standards transition: changing clause language is not itself improvement unless operating practice and outcomes improve.

11.8.5 Service quality and recovery

Service operations face failures that cannot always be inspected before the customer experiences them. Recovery therefore becomes part of quality design. A strong recovery process detects the failure, protects the customer from compounding harm, explains what is known, provides a proportionate remedy, corrects the operational cause and feeds learning into the system. Fast apology without root-cause correction is communication, not quality management. Equally, root-cause analysis without fair treatment of the affected customer is incomplete responsibility.

11.8.6 Reliability, maintenance and asset availability

Maintenance is an operations capability because equipment condition changes effective capacity, quality, safety, energy use and schedule reliability. Corrective maintenance restores an asset after failure. Preventive maintenance intervenes at planned time or usage intervals. Condition-based maintenance uses measured condition to determine whether intervention is needed, while predictive approaches estimate likely degradation or remaining useful life. The categories overlap in practice, and the best policy depends on failure consequence, detectability, repair economics, redundancy, regulation and the cost of false alarms or missed failures. Safety-critical assets should not be pushed beyond manufacturer, engineering or regulatory limits merely because a predictive model reports a low short-term failure probability.

Two simple reliability indicators help make the operating consequences visible. Mean time between failures (MTBF) summarizes average operating time between failures of a repairable asset under a defined failure rule; mean time to repair (MTTR) summarizes average restoration time. Under a simple steady-state approximation, inherent availability can be written as $A = MTBF/(MTBF + MTTR)$. An asset with MTBF of 90 hours and MTTR of 3 hours has availability of about 96.8%. If repair capability reduces MTTR to 1.5 hours with MTBF unchanged, the approximation rises to about 98.4%. The arithmetic is not a complete availability model: planned maintenance, logistics delay, waiting for technicians, setup, product changeovers and common-cause failures may sit outside the chosen definitions. The point is to connect maintainability with usable capacity rather than treating breakdowns as random bad luck.

Total productive maintenance broadened maintenance from a specialist repair function toward organization-wide attention to equipment effectiveness, operator care, planned maintenance and continuous improvement (Nakajima, 1988). Later condition-based maintenance research formalized the chain from data acquisition through diagnostics and prognostics to maintenance decisions (Jardine et al., 2006). Contemporary sensors and AI can improve that chain, but they do not remove the need for failure definitions, maintenance competence, spare-parts policy, cybersecurity, safe work authorization and human accountability. For a bottleneck asset, maintenance priority should be connected to system throughput and risk; for non-bottleneck assets, maximizing a local maintenance metric can create cost without increasing customer value.

11.9 Inventory Control, Service Levels and the Economics of Buffers

11.9.1 Why inventory exists

Inventory is a buffer between processes that do not occur at exactly the same time or rate. **Cycle stock** arises from ordering or producing in batches. **Safety stock** protects against uncertainty in demand or replenishment. **Anticipation inventory** is built ahead of predictable peaks or closures. **Pipeline inventory** is material already moving between nodes. **Decoupling inventory** allows adjacent stages to operate with some independence. The same physical item can serve more than one purpose. Before reducing inventory, the manager should identify which uncertainty or economic batching logic the inventory is buffering.

11.9.2 Economic order quantity

The basic economic order quantity model balances ordering cost against holding cost. Under restrictive assumptions of known stable annual demand, constant ordering cost, constant unit holding cost, no stockouts and instantaneous or separately managed replenishment, the cost-minimizing order quantity is:

WORKED EXAMPLE | Q = *sqrt(2DS/H). Let annual demand D = 24,000 units, ordering cost S = CU50 per order, and annual holding cost H = CU6 per unit.* Q = sqrt((2 x 24,000 x 50) / 6) = sqrt(400,000) = approximately **632 units**. EOQ is a benchmark, not an instruction. Quantity discounts, minimum order quantities, capacity, perishability, uncertain demand, variable lead time, transport consolidation and cash constraints can justify a different quantity.

The relevant annual ordering-plus-cycle-stock holding cost can be represented as (D/Q)S + (Q/2)H. Because the cost curve is relatively flat around the minimum in many practical cases, managers should not chase false precision. A slightly non-optimal quantity that aligns with pallet size, container fill or supplier reliability can be economically superior once omitted costs are included.

11.9.3 Reorder points and safety stock

A reorder point determines when replenishment should be triggered. With expected demand during lead time plus a protection quantity, **ROP = expected lead-time demand + safety stock**. If average daily demand is 80 units and lead time is six days, expected lead-time demand is 480 units. If daily demand standard deviation is 20 units, lead time is constant, demand is independent across days and a normal approximation is acceptable, lead-time standard deviation is 20 x sqrt(6), approximately 49 units. A 95% cycle-service target uses z approximately 1.645, producing safety stock of about 81 units and ROP of about 561 units.

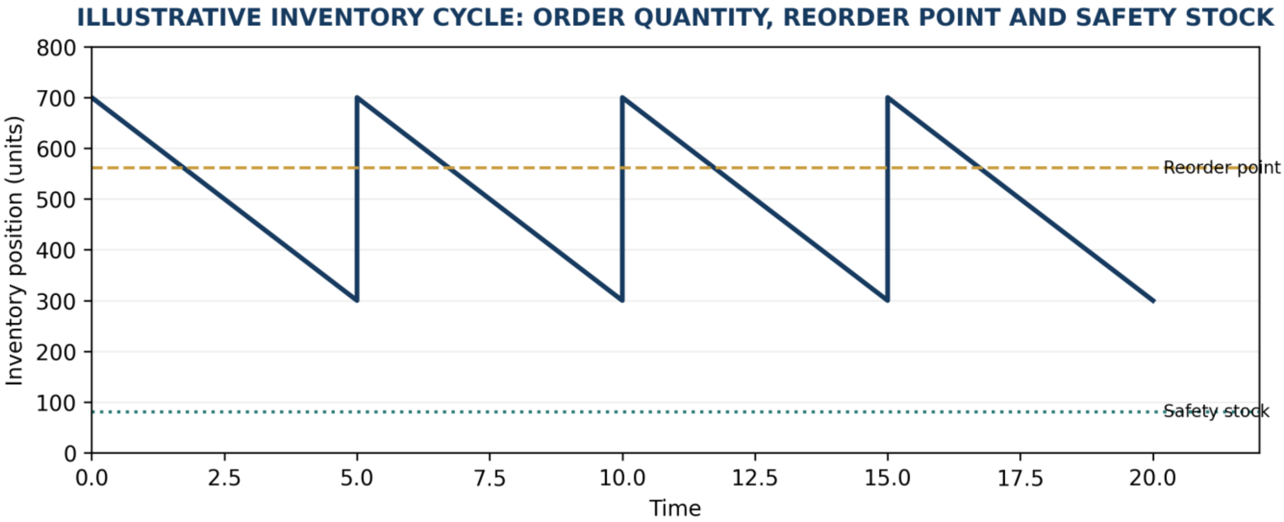

Figure 11.3. Illustrative inventory cycle: order quantity, reorder point and safety stock.
Source/Note: Author's constructed illustration using the worked-example reorder point. Real inventory paths are stochastic, not perfect sawtooths.

The assumptions matter more than the arithmetic. Variable lead time, correlated demand, intermittent demand, minimum order quantities, spoilage, multi-echelon inventory and service penalties can make the simple formula inappropriate. A service-level target is also a managerial choice, not a mathematical constant. A 99.9% target may be justified for a life-critical item and wasteful for a low-consequence spare. The target should reflect shortage consequence, replenishment flexibility and the distribution of harm.

11.9.4 ABC analysis and criticality

ABC classification ranks inventory by a chosen importance measure, commonly annual consumption value. It helps concentrate control effort where financial exposure is high. Financial value alone is insufficient for critical spares. A low-cost sensor can stop a production line, and a low-volume medicine can be clinically essential. A stronger classification combines value, criticality, lead time, substitutability, expiry risk and supply concentration.

11.9.5 Bullwhip, batching and distorted information

The **bullwhip effect** describes amplification of demand variability as orders move upstream. Promotions, batch ordering, rationing behaviour, forecast updating and long lead times can cause suppliers to see much greater variability than final customers generate. A simple amplification indicator is Var(orders) / Var(customer demand). Ratios above one suggest that upstream ordering is more variable, although the statistic alone does not identify the cause. Better point-of-sale visibility, smaller batches, stable pricing, collaborative planning and shorter lead times can reduce amplification, but shared data only help if definitions are trusted and incentives do not encourage gaming.

11.10 Planning Systems, ERP and Digital Operations

11.10.1 MPS, MRP and dependent demand

A Master Production Schedule (MPS) specifies end-item quantities and timing over a planning horizon. Material Requirements Planning (MRP) explodes that schedule through bills of material, inventory status and lead-time assumptions to determine time-phased component requirements. MRP is particularly useful for **dependent demand**, where component needs derive from the schedule for a parent item. Its apparent precision can be dangerous when bills of material, inventory balances or lead times are wrong. An MRP system can compute an exact answer to inaccurate master data.

11.10.2 ERP as an integration architecture

Enterprise Resource Planning integrates transactions and master data across functions such as procurement, inventory, manufacturing, sales, finance and human resources. The operational benefit is not merely one software brand. It is a shared record structure that reduces contradictory data and enables coordinated planning. The implementation risk is equally systemic. If process definitions are weak, ERP can standardize poor practice at scale. If item masters, units of measure or location codes are inconsistent, automation spreads rather than removes error.

11.10.3 MES, WMS, TMS and advanced planning

A Manufacturing Execution System (MES) manages shop-floor execution and production records. A Warehouse Management System (WMS) manages receiving, location, replenishment, picking and dispatch. A Transportation Management System (TMS) supports routing, carrier selection, tendering, tracking and freight execution. Advanced Planning and Scheduling (APS) systems use richer constraint models to plan production or distribution. These labels describe functional roles, not guarantees of interoperability. The most valuable architecture is one in which data definitions, event ownership and exception processes align across systems.

11.10.4 S&OP and integrated business planning

Sales and Operations Planning (S&OP) creates a recurring cross-functional process for reconciling expected demand, supply capability, inventory, capacity and financial implications over a medium-term horizon. Integrated Business Planning (IBP) usually broadens this logic to stronger financial, strategic and scenario integration. The process matters more than the label. A monthly meeting that merely reports last month's numbers is not integrated planning. A useful cycle makes assumptions explicit, identifies gaps, assigns decision rights and records what will change if demand or supply deviates from plan.

11.10.5 Operational data governance and cybersecurity

Digital operations depend on accurate clocks, identifiers, units, locations, master data and event status. A tracking dashboard can create false confidence if a shipment is only visible when a partner voluntarily sends an update. A "real-time" inventory figure can be wrong when physical movements bypass scanning. Data governance therefore includes source authority, validation, lineage, role-based access, retention, change control and exception reconciliation.

Cybersecurity is an operations issue when digital systems control physical flows. Ransomware can stop warehouses, ports or production even if inventory physically exists. Connectivity between suppliers, IoT devices and cloud services expands the attack surface. Chapter 20 will examine technology strategy in depth; the operational responsibility here is continuity: identify critical systems, secure access, patch appropriately, segment networks, maintain tested recovery, preserve manual fallback where justified and ensure that a cyber incident does not silently invalidate operational data.

11.11 From Internal Operations to Supply-Chain Architecture

11.11.1 A supply chain is a network, not a line

The phrase "supply chain" can imply a simple upstream-to-downstream line, but most modern systems are networks. A manufacturer can have multiple tiers of suppliers, shared logistics providers, ports, consolidation centres, distributors, repair loops and customers who return products. One supplier may serve many competitors. One port closure can therefore affect several industries at once. Network thinking asks about nodes, links, capacities, lead times, ownership, dependencies, alternatives and information visibility rather than assuming one linear sequence.

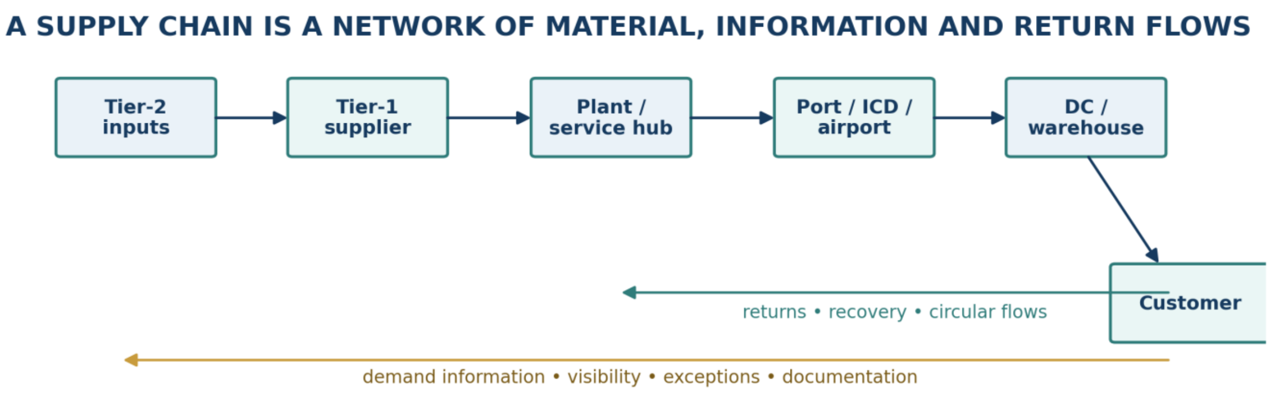

Figure 11.4. A supply chain is a network of material, information and return flows.

Source/Note: Author's synthesis. The figure is deliberately simplified; real networks contain multiple suppliers, nodes, modes and institutional hand-offs.

11.11.2 SCOR as a common process language

The Association for Supply Chain Management's SCOR Digital Standard provides a widely used reference architecture. At its highest level, Orchestrate connects governance and enabling capabilities; six Level-1 processes are Plan, Order, Source, Transform, Fulfill and Return (Association for Supply Chain Management [ASCM], n.d.). The model can help organizations standardize definitions, map processes and connect performance measures across functions and partners. In the current architecture, Return is the explicit reverse-flow process, while circular supply-chain management is situated among orchestration capabilities, reinforcing the need to integrate recovery rather than treat it as an afterthought.

SCOR should not be treated as a universal answer. ASCM itself describes the model as a reference structure rather than a prescription for exactly how an organization must operate. A humanitarian supply chain, airline cargo network, mining operation and digital-service business require different controls. The framework is most useful as a common vocabulary that makes gaps visible, not as proof that a process is well designed.

Table 11.4. SCOR Digital Standard at a high level and the Chapter 11 interpretation.

SCOR process	Core idea	Chapter 11 operating question
Orchestrate	Integrate rules, performance, data, technology, people, contracts, network, risk and related enabling capabilities	Who owns end-to-end design, standards, exceptions and learning?
Plan	Balance requirements and resources	What demand, capacity, inventory and supply assumptions must be reconciled?
Order	Capture and manage customer order information	Is the demand signal complete, feasible and traceable?
Source	Procure and receive required goods and services	Which suppliers, terms, quality, timing and risks govern inbound flow?
Transform	Create, assemble, maintain or otherwise transform	Where are capacity, quality, flow and bottlenecks located?
Fulfill	Pick, pack, ship, install or otherwise execute customer fulfilment	How will the promise be delivered through warehouse and transport execution?
Return	Manage reverse flows and disposition	How are returns, repair, recovery, reuse and circular flows handled?

Source/Note: ASCM (n.d.). Interpretations in the third column are the author's synthesis for this chapter.

11.11.3 Financial signals are present, but payment mechanics belong elsewhere

Physical supply chains generate financial consequences at every hand-off: inventory ties up working capital; supplier terms affect cash; transport creates freight obligations; customs can create duties and taxes; returns create credits. Chapter 9 introduced cash-conversion logic. Chapter 11 uses these financial consequences to evaluate operational choices but does not teach letters of credit, documentary collections, open-account risk, foreign-exchange settlement or cross-border payment infrastructure. Those instruments belong to Chapter 17. Keeping the distinction clear prevents operations professionals from confusing a shipping document with a payment guarantee or an Incoterm with a payment term.

11.12 Supply-Chain Network Design and Inventory Positioning

11.12.1 Nodes, arcs and the design problem

Network design determines where suppliers, plants, consolidation points, ports, warehouses, service hubs and inventory should be located and how flows should move among them. The design usually balances fixed facility cost, transport cost, inventory, service time, capacity, taxes and border effects, risk, market access and resilience. Chapter 5 owns optimization methods, but Chapter 11 owns the operational meaning of the variables. A mathematically optimal network is only as valid as its representation of actual capacity, lead times, service requirements and disruption exposure.

11.12.2 Centralization and decentralization

Centralizing inventory can reduce aggregate safety stock through risk pooling and can improve specialized control. It can also increase outbound distance, cross-border exposure and recovery time if the single node fails. Decentralization brings inventory closer to customers and can improve response speed, but usually increases duplicated stock and facility cost. The decision depends on demand correlation, value density, service urgency, transport reliability, border friction, replenishment frequency and the consequence of node failure. The right answer for vaccines can differ from the right answer for low-value spare furniture parts.

11.12.3 Postponement and modularity

Postponement delays final differentiation until demand information improves. A manufacturer can hold a generic base product and customize packaging, language, power supply or configuration later. The benefit is lower finished-goods uncertainty and greater flexibility. The requirement is modular design and a later-stage process capable of rapid differentiation. Postponement is particularly valuable when variety is high but components can be standardized. It fails when local customization itself has long lead times or when regulatory approval requires the final configuration far in advance.

11.12.4 Total landed cost rather than visible price

Network and sourcing choices should be compared through **total landed cost**, not only purchase price or headline freight. A practical expression is:

PRACTICE TOOL | Total landed cost = purchase price + freight + insurance + non-recoverable duties/taxes + brokerage + handling + storage + expected quality cost + inventory carrying cost + expected disruption/expediting cost + other decision-relevant compliance and service costs. The formula is a decision template, not an accounting standard. Recoverable taxes, sunk costs and costs borne by different contractual parties must be treated consistently.

The difficulty is uncertainty. A supplier with a low quoted price but high defect rate, long variable lead time and concentration in one fragile route can be more expensive after disruption and inventory are considered. Expected cost should therefore be accompanied by tail scenarios and non-monetary constraints such as safety, human rights, security and continuity of essential supply.

Table 11.5. Illustrative supplier comparison: why unit price is not total cost.

Decision factor	Supplier A	Supplier B	Interpretation
Unit purchase price	CU10.00	CU10.50	A appears cheaper before other consequences.
Inbound freight/unit	CU0.60	CU0.25	B benefits from route/location economics.
Observed defect rate	2.0%	0.5%	Expected rework/return cost differs.
Typical lead time	30 days, variable	12 days, more stable	A requires more pipeline and safety protection.
Supply concentration	single site	two qualified sites	B has more structural optionality.
Supplier-development potential	moderate	high	Long-run cost and quality can change with collaboration.
Decision conclusion	Do not choose from price alone	Do not assume B is automatically superior	Quantify total landed cost and risk, then test capacity, quality, ethics and continuity.

Source/Note: Constructed teaching example. CU denotes currency units. Real supplier decisions require verified quotations, quality evidence, capacity and contractual terms.

11.13 Procurement, Global Sourcing and Supplier Management

11.13.1 Procurement is a capability, not a price-negotiation event

Procurement converts organizational demand into an externally sourced capability. It includes requirement definition, market analysis, supplier discovery, qualification, tendering or negotiation, contracting, ordering, performance management, development, renewal and exit. Weak procurement begins with a specification copied from the last purchase and ends with the lowest visible bid. Strong procurement asks whether the requirement is necessary, whether the specification is outcome-oriented, which supplier market can satisfy it, what risks are created by dependence, and how the relationship will be governed after award.

11.13.2 Category segmentation and Kraljic logic

Kraljic (1983) proposed a portfolio logic that distinguishes purchases by profit impact and supply risk. Common interpretations classify items as non-critical, leverage, bottleneck and strategic. The value is not the four labels themselves. It is the recognition that procurement approach should differ when a category is easy to source and low consequence versus scarce, high impact and dependent on few suppliers. A routine office item can reward automation and competition; a sole-source safety-critical component may require long-term collaboration, engineering involvement and contingency planning.

The model has limitations. "Profit impact" is difficult to define in public, non-profit and safety-critical settings. Supply risk changes over time. A low-spend item can be operationally critical. Category matrices therefore need additional dimensions such as human-rights exposure, geopolitical concentration, technology dependency, switching time and regulatory qualification.

11.13.3 Total cost of ownership

Ellram (1993) formalized total cost of ownership as a way to assess costs before, during and after acquisition rather than focusing on purchase price. Relevant costs can include qualification, ordering, transport, inventory, quality, downtime, maintenance, disposal, warranty and administrative burden. TCO improves sourcing discipline, but it can become pseudo-precision when analysts invent uncertain cost estimates merely to justify a preferred supplier. Uncertain components should be shown as ranges or scenarios.

11.13.4 Supplier qualification, performance and development

Qualification verifies that a supplier can meet technical, capacity, quality, legal, security and ethical requirements before dependence is created. Performance management then monitors agreed indicators such as quality, on-time delivery, responsiveness, corrective action and cost. The strongest supplier scorecards distinguish outcomes from leading process evidence and allow contextual explanation. A low delivery score caused by the buyer's unstable schedules should not be blamed entirely on the supplier.

Supplier development goes beyond monitoring. A buyer can share process expertise, forecast information, quality methods, training or investment support to improve joint capability. Development is especially valuable where supplier markets are thin and replacing a supplier would destroy local capability. It also creates responsibility: a buyer that demands process investment and then shifts volumes unpredictably can impose costs that the supplier cannot recover.

11.13.5 Purchasing power and unfair risk transfer

Large buyers can improve their own working capital and flexibility by demanding long payment periods, short order freezes, frequent design changes, penalty clauses and last-minute capacity. Those practices can simply transfer inventory, financing and labour pressure downstream. Research on global supply chains has repeatedly shown that purchasing practices influence working conditions because suppliers respond to buyer lead times, prices and volatility through staffing, overtime and subcontracting. Responsible procurement therefore evaluates **how the buyer buys**, not only whether the supplier signs a code of conduct.

ETHICAL DILEMMA | A procurement team may be technically compliant with its supplier code while creating conditions that make compliance difficult. If the buyer continually changes forecasts, insists on unrealistic lead times and refuses price adjustments after input inflation, a supplier can face a choice among missed delivery, financial loss and abusive labour practices. Ethical sourcing therefore requires symmetry between the standards imposed on suppliers and the commercial behaviour of the buyer.

11.13.6 Single, dual and multi-sourcing

Single sourcing can create scale, learning, quality consistency and deeper collaboration. It can also create dependency and a single point of failure. Dual or multi-sourcing creates optionality but can dilute volumes, increase qualification burden and reduce learning. The appropriate design depends on switching time, tooling, intellectual property, regulation, capacity, supplier economics and the severity of interruption. Resilience is not achieved by mechanically adding suppliers; two suppliers in the same industrial park or dependent on the same sub-tier component can represent one underlying risk.

11.14 Transportation Economics and Mode Choice

11.14.1 Transport creates place and time utility

Transportation moves goods between nodes, but the decision is not simply "cheapest mode." A mode choice changes lead time, reliability, batch size, inventory in transit, product condition, theft exposure, carbon intensity, handling risk and customer responsiveness. The relevant cost is therefore the cost of the transport decision to the entire operating system.

11.14.2 Air, sea, road, rail and multimodal systems

Table 11.6. Comparative operating characteristics of major transport modes.

Mode	Typical operational strengths	Characteristic constraints	Best-fit questions
Air	very high speed; long-distance reach; strong fit for urgent/high-value/perishable cargo	high cost; capacity and dimensional limits; airport handling dependency; security requirements	Does the value of time, shelf life or interruption justify the premium?
Sea	very high bulk/container capacity; low unit cost on large international flows	slow transit; port dependency; schedule disruption; transshipment and inland leg required	Can inventory and customer lead time absorb long and variable transit?
Road	door-to-door reach; flexible routing; strong regional and last-mile role	congestion; border queues; driver and road-safety exposure; vehicle capacity limits	Does route reliability and border process support the promised time?
Rail	high capacity; efficient over dense corridors; potentially lower emissions per tonne-km	network/frequency constraints; terminal transfers; less door-to-door flexibility	Is there sufficient volume, corridor connectivity and terminal reliability?
Multimodal	combines strengths of modes; containerization can reduce handling friction	more hand-offs; coordination and documentation complexity; connection risk	Are transfer points synchronized and is responsibility clear across modes?

Source/Note: Author's synthesis. These are qualitative tendencies, not universal performance rankings. Actual cost, emissions, lead time and reliability depend on route, equipment, utilization, energy mix and service design.

11.14.3 Freight rate is only one component of mode economics

Faster transport can lower pipeline inventory and sometimes safety stock because replenishment is quicker and more predictable. Slower transport can reduce freight cost but require larger order quantities and longer forecast horizons. A high-value electronics shipment can rationally move by air because inventory carrying cost and obsolescence make time expensive. Low-value dense bulk commodities generally favour sea or rail where available. The decision should compare the value density of the product, demand uncertainty, deterioration, service penalty and disruption exposure, not apply a universal rule.

11.14.4 Maritime transport and geoeconomic disruption

Maritime transport remains central to global merchandise trade. UN Trade and Development estimates that around 80% of international trade in goods by volume moves by sea (UNCTAD, 2025a). Recent disruption demonstrates why route distance is not fixed. UNCTAD's 2025 Review of Maritime Transport reports that rerouting increased tonne-miles sharply in 2024 and that by May 2025 tonnage through the Suez Canal remained about 70% below 2023 levels (UNCTAD, 2025b).

Longer routes raise transit time, vessel capacity requirements, fuel use, emissions and inventory exposure even if the physical quantity of trade changes little.

The managerial lesson is that transport capacity depends on **time as well as physical assets**. If the same vessel spends more days completing a round trip, effective network capacity falls. A procurement or sales plan that assumes the historical route while carriers reroute can therefore fail even when ports and vessels still exist. Scenario planning should include alternate gateways, transit-time ranges, inventory consequences and contractual cut-offs rather than a single freight-rate forecast.

POLICY LENS | Geopolitical fragmentation, sanctions and security shocks can change route availability, insurance, port access and carrier behaviour. Chapter 19 will examine legal rules and geoeconomic statecraft. Chapter 11's narrower responsibility is operational preparedness: know which lanes and nodes are critical, which alternatives are genuinely qualified, how much extra time they require, and what service or inventory decisions are triggered when a route changes.

11.14.5 Consolidation, containerization and economies of density

Freight economics often reward consolidation because fixed handling and transport costs can be spread over more units. Full-container or full-truck movements can lower unit cost and damage compared with frequent small shipments. The trade-off is waiting: accumulating enough cargo for consolidation increases order cycle time. Cross-docking, scheduled milk runs, consolidation centres and vendor-managed pickup can reduce this tension by coordinating flows. The correct batch size is therefore a joint inventory-transport decision, not a transport decision alone.

11.15 Warehousing, Distribution, Cold Chain and the Last Mile

11.15.1 What a warehouse actually does

A warehouse can buffer inventory, consolidate or break bulk, postpone differentiation, support returns, protect product condition and coordinate transport. Its operating flow typically includes receiving, verification, put-away, storage, replenishment, picking, packing, staging and dispatch. Each hand-off can create delay or error. A well-designed warehouse therefore begins with product and order profiles: dimensions, velocity, temperature, security, order lines, peak patterns and service cut-offs determine layout and technology.

11.15.2 Slotting and travel

Order picking is often a labour-intensive warehouse activity. Slotting places high-velocity items where travel and congestion are reduced while preserving ergonomic and compatibility requirements. ABC velocity analysis can guide placement, but frequency alone is insufficient. Heavy items, hazardous incompatibility, theft risk, temperature zones and co-order patterns matter. A fast-moving item should not be placed where congestion or unsafe lifting creates larger losses than travel savings.

11.15.3 Cross-docking

Cross-docking moves inbound goods toward outbound dispatch with little or no storage. It can reduce inventory and handling when inbound and outbound schedules are synchronized and product information is accurate. It performs poorly when arrivals are unreliable, product is not pre-allocated, quality inspection is intensive or outbound demand is uncertain. Cross-docking is therefore a coordination capability rather than merely a warehouse layout.

11.15.4 Cold-chain operations

Cold chains protect temperature-sensitive products through controlled storage, packaging, monitoring, hand-offs and transport. The operating challenge is cumulative exposure. A compliant warehouse cannot compensate for prolonged ramp exposure or an unqualified last-mile vehicle. Good cold-chain control defines temperature ranges, qualification protocols, sensor placement, alarm thresholds, excursion response, calibration, packaging duration and chain-of-custody responsibilities. The Ethiopian Cargo opening case shows why specialist logistics is an end-to-end quality system rather than a refrigerated room.

11.15.5 Last-mile logistics and African operating diversity

Last-mile delivery can be the most fragmented part of the network because shipment size becomes small while address, traffic, payment, security and customer-availability uncertainty increase. African markets illustrate why formal maps and digital addresses cannot be assumed uniformly. Firms often combine formal courier networks, pickup stations, agents, mobile communication and local route knowledge. The appropriate design differs between dense urban centres, secondary cities and rural areas. The analytical task is to build service around observed access conditions rather than import a metropolitan model from another region.

11.15.6 Reverse logistics, returns and circular operating flows

The forward flow does not end when a customer receives a product. Returns, reusable packaging, warranty failures, repairs, recalls, excess stock, end-of-use products and recoverable materials create reverse flows that must be authorized, collected, identified, transported, inspected and assigned to a disposition. Reverse logistics is therefore the planning and execution of those downstream-to-upstream movements and the information required to control them. A weak returns process can destroy value through lost identity, unnecessary freight, long credit delays, unsafe mixing of products or premature disposal.

Disposition is an operations decision under uncertainty. After inspection, an item may be returned to stock, repaired, refurbished, remanufactured, harvested for parts, reused in another application, recycled or sent to controlled disposal. The preferred path depends on verified condition, customer and warranty obligations, safety, regulatory restrictions, remaining useful life, recovery yield, market demand, transport distance, contamination risk and total recovery economics. Circularity should not become a slogan that requires recovery at any cost. A process that consumes disproportionate energy, creates unsafe exposure or returns a degraded product to service can be less responsible than controlled disposal.

Closed-loop supply-chain research integrates forward fulfilment with product recovery and value-recapture decisions. Guide and Van Wassenhove (2009) show how the field evolved from isolated remanufacturing problems toward an integrated business perspective on returned products. The current SCOR architecture likewise includes Return as a core process and treats circular supply-chain management as an enabling orchestration concern (ASCM, n.d.). Operationally, this means that returns need ownership, authorized disposition codes, traceability, quality gates, inventory status rules and financial reconciliation rather than being treated as exceptions that disappear into a warehouse corner.

African operating contexts make reverse-flow design especially consequential where repair ecosystems, spare-parts access, cross-border returns, used-equipment markets and waste-handling capacity differ sharply among locations. The same analytical discipline applies globally: map who can collect, inspect and recover the item; estimate the time and condition loss created by the reverse route; preserve chain of custody; and distinguish legitimate reuse from the transfer of unsafe or unusable goods to weaker markets. Chapter 21 develops the wider strategy of sustainability, circularity and responsible trade. Chapter 11 owns the physical execution question: how reverse and recovery flows can be designed, controlled and learned from.

11.16 Incoterms 2020: Operational Allocation of Delivery, Cost and Risk

11.16.1 What Incoterms do

The ICC Incoterms 2020 rules provide standardized trade terms that allocate specified seller and buyer responsibilities concerning delivery, carriage-related costs, risk of loss or damage, and certain export/import formalities. They reduce ambiguity when incorporated correctly into a sales contract. The safest operational form identifies the rule, the named place, port or point, and the version, for example: "FCA Kigali Logistics Platform, Incoterms 2020." The named point matters because a broad place can leave uncertainty about exactly where delivery and risk transfer.

11.16.2 What Incoterms do not do

Incoterms are frequently asked to answer questions they were not designed to answer. ICC guidance is explicit that the rules do **not** determine whether a contract of sale exists, the specifications of the goods, the method or currency of payment, most remedies for breach, sanctions, tariffs, force majeure, intellectual-property rights, dispute-resolution law or transfer of title/ownership (International Chamber of Commerce [ICC], 2019). Payment mechanics belong to the sales contract and, in this textbook, are developed in Chapter 17. Trade-law consequences belong to Chapter 19.

11.16.3 The eleven rules and mode groups

Table 11.7. Incoterms 2020 rules by transport mode.

Rule group	Incoterms 2020 rules	Operational reminder
Any mode or modes	EXW, FCA, CPT, CIP, DAP, DPU, DDP	Can be used for road, rail, air, containerized/multimodal and other movements where the named delivery point fits the actual hand-off.
Sea and inland waterway only	FAS, FOB, CFR, CIF	Delivery/risk logic is tied to a port and vessel context. Do not use mechanically for container hand-off before loading.

Source/Note: ICC Incoterms 2020 guidance. This table is a high-level operational orientation and does not reproduce the full copyrighted rule obligations. Users should consult the official ICC rules for transaction-specific application.

11.16.4 Container shipments and the FCA versus FOB problem

FOB remains widely used in practice, but it is a sea/inland-waterway rule designed around delivery when goods are on board the vessel. ICC guidance notes that FCA is often more appropriate where containerized goods are handed to a carrier or terminal before loading because the delivery point then matches the physical hand-off (ICC, 2024). The operational principle is simple: choose a rule whose delivery point corresponds to what the parties can actually control and evidence. Habit is not a sufficient reason to choose an Incoterm.

11.16.5 Risk transfer is not the same as who pays the main carriage

Some "C" rules create a counterintuitive split: the seller can pay for main carriage to a named destination while risk transfers earlier at origin according to the specific rule. This is why operations teams should not infer risk from who pays freight. A shipment status dashboard should make the contractual delivery point, physical custody and current risk allocation visible to responsible staff rather than relying on informal phrases such as "seller delivers to destination."

11.17 Commercial Documentation and Customs Execution

11.17.1 Documents coordinate physical and institutional reality

Cross-border goods move through legal and administrative systems as well as physical networks. Documentation identifies what is moving, in what quantity and value, between which parties, under which transport and origin conditions. A physically perfect shipment can stop if the paperwork is inconsistent. Conversely, digitally complete documentation does not prove that the physical goods match it. Strong execution links documents to verified physical events and master data.

Table 11.8. Common cross-border shipment documents and their operational roles.

Document	Operational role	Common failure mode
Commercial invoice	Identifies seller/buyer, goods, value, currency and transaction information used by parties and customs	description or value inconsistent with declaration or contract
Packing list	Details packages, weights, dimensions and contents	package count or weight differs from physical shipment
Bill of lading / sea waybill	Carrier evidence and transport document for sea movement; legal functions differ by document type	wrong consignee, port, package count or release instruction
Air waybill	Air transport document and shipment reference	routing or handling code incomplete
Certificate or declaration of origin	Supports origin claims where required	unsupported or incorrectly completed origin claim
Permits / certificates	Evidence for controlled, sanitary, phytosanitary or other regulated goods where applicable	permit expired, missing or inconsistent with shipment
Customs declaration	Structured statement submitted to customs for the relevant procedure	HS classification, quantity, value, origin or procedure inconsistent
Insurance evidence	Shows cover where required by contract or rule	coverage terms do not match actual risk or route

Source/Note: Author's synthesis. Document requirements vary by commodity, route, country, transport document and transaction. Legal advice or official customs guidance should be used for specific shipments.

11.17.2 Classification, valuation and origin: operational awareness, not legal doctrine

Customs declarations often require commodity classification under the Harmonized System, customs value, origin and procedure. These fields affect duties, controls, statistics and admissibility. Chapter 19 will examine the legal rules in depth. At the operational level, Chapter 11 requires three disciplines: maintain accurate product master data; escalate ambiguous classification or origin questions to qualified specialists; and ensure the physical product, invoice, permits and declaration tell a consistent story. A hurried warehouse clerk should not be forced to resolve a complex tariff-classification dispute at the loading dock.

11.17.3 Pre-arrival processing and single windows

Border delay can be reduced when information arrives before the physical goods and authorities can process risk and documentation in advance. The WTO Trade Facilitation Agreement, which entered into force on 22 February 2017 for accepting members, contains provisions to expedite movement, release and clearance, including goods in transit (World Trade Organization [WTO], 2017). Article 10.4 encourages members to establish or maintain a **single window** through which traders can submit required import, export or transit data through a single entry point to participating authorities (WTO, 2017).

A single window is not automatically a single process. If agencies continue to require duplicate checks, inconsistent data or sequential approvals behind the interface, digitization can reproduce administrative fragmentation. Effective facilitation requires process redesign, data interoperability, risk management, institutional accountability and trusted digital identity in addition to software.

11.17.4 Customs brokers and control

Firms often use customs brokers or freight forwarders because border processes are specialized. Outsourcing execution does not outsource accountability. The principal should define authorized activities, retain document visibility, reconcile declarations to commercial records, monitor exceptions and prohibit informal payments. Anti-corruption control is especially important at high-discretion hand-offs. A broker who "makes problems disappear" without transparent evidence can create legal and ethical exposure that remains with the firm.

11.18 Trade Facilitation, Corridors, Dry Ports and Special Economic Zones

11.18.1 Corridors as extended operating systems

For a landlocked economy, the effective port is not only the maritime terminal. It is the entire corridor linking origin to seaport, including roads or rail, inland depots, border posts, customs transit, weighbridges, security, driver processes and information systems. Rwanda illustrates this systems logic. Goods moving to or from maritime markets depend heavily on regional corridors and neighbouring infrastructure. A firm therefore cannot treat border and corridor performance as an externality that disappears from operations planning.

11.18.2 One Stop Border Posts and process integration

One Stop Border Posts (OSBPs) seek to reduce duplicate border processes by coordinating agencies from adjoining states. The East African Community reported in July 2026 that OSBPs had significantly reduced crossing times but argued that the next generation of improvement must move beyond physical co-location toward smarter, technology-driven border management (East African Community [EAC], 2026b). In a separate July 2026 mission, the EAC Secretary General emphasized that domestic administrative bottlenecks continued to delay goods and increase business costs (EAC, 2026a). The evidence reinforces a basic operations principle: putting functions under one roof does not eliminate poor sequencing, duplicate information or weak exception ownership.

11.18.3 Inland container depots, dry ports and consolidation nodes

An inland container depot or dry port can move customs and logistics functions away from a congested seaport, provide storage and consolidation, support rail-road transfer and bring container services closer to inland markets. The node adds value only if it reduces total system time, cost or risk. If it creates an additional compulsory hand-off without reliable rail or data integration, it can add dwell time. Network nodes should therefore be justified through flow analysis rather than institutional fashion.

11.18.4 Special economic zones as operating environments

Special economic zones can concentrate infrastructure, customs arrangements, utilities, suppliers and services to reduce operational friction. Their economic and political merits vary, and Chapter 14 will examine broader trade and development effects. Chapter 11's narrower question is operating fit: does the zone improve access to reliable power, transport, customs, skills, suppliers and customers enough to offset lease cost, location constraints and dependency on zone-specific rules? A zone is an operating environment, not a guarantee of competitiveness.

11.19 Supply-Chain Risk, Concentration and the Ripple Effect

11.19.1 Risk begins with dependency mapping

Supply-chain risk is the possibility that uncertain events or conditions impair the ability of the network to achieve legitimate objectives. Sources include supplier failure, quality problems, capacity shortfalls, strikes, transport disruption, infrastructure failure, conflict, cyberattack, fraud, weather, regulatory change, exchange-rate movements, demand shocks and human error. The list is less important than the dependency structure. A firm should know which products, processes and customers depend on which nodes and which nodes depend on common sub-tier inputs.

11.19.2 Probability-impact matrices are insufficient for severe operational risk

A probability-impact matrix can prioritize ordinary risks, but it compresses important dimensions. Two disruptions with the same probability and financial impact can differ in speed of onset, duration, detectability, recoverability, geographic correlation, safety consequence and customer substitutability. A stronger risk register includes at least likelihood or plausibility, severity, time to impact, duration, time to recover, visibility, alternative capacity and affected commitments. For rare strategic shocks, scenario narratives can be more defensible than fabricated probabilities.

11.19.3 Supplier concentration and common-cause failure

Concentration should be assessed beneath the direct supplier tier. Two first-tier suppliers may rely on the same semiconductor fab, port, cloud provider, mine, chemical precursor or energy system. Geographic diversification can also be superficial if several locations share one transport corridor or political dependency. Mapping critical bill-of-material and service dependencies is therefore a resilience activity, not merely a procurement database exercise.

11.19.4 Ripple effect

Dolgui et al. (2018) use the term **ripple effect** for the propagation of a disruption through the supply chain, changing performance and sometimes network structure beyond the initially affected node. A plant closure can deplete customer inventory, shift demand to alternate plants, overload those plants, create transport congestion and then cause shortages of inputs at the alternatives. The effect is dynamic. A static supplier-risk score cannot capture it without understanding inventory, capacity and time.

11.19.5 Currency and political risk in an operations chapter

Currency movements can change landed cost, supplier viability and transport rates even though foreign-exchange hedging belongs to Chapter 17. Political events can close borders, change inspections or affect permits even though geoeconomic statecraft belongs to Chapter 19. Chapter 11 includes these risks only to the extent that operations must prepare physical alternatives, lead-time ranges, inventory triggers and supplier contingencies. Financial and legal treatment is cross-referenced rather than duplicated.

11.20 Resilience, Robustness, Agility and Long-Term Viability

11.20.1 Distinguishing related concepts

Table 11.9. Robustness, agility, resilience and viability.

Concept	Core question	Illustrative capability	Characteristic misuse
Robustness	Can the system continue acceptable performance without major reconfiguration?	protective capacity, stable design, qualified substitutes	confusing expensive redundancy with automatic robustness
Agility	How quickly can the system sense and respond to change?	fast information, flexible capacity, rapid decision rights	equating speed with ungoverned improvisation
Resilience	Can the system absorb disruption, recover and adapt?	buffers, alternatives, recovery playbooks, learning	treating resilience as a one-time risk project
Viability	Can the system survive prolonged structural change by redesigning itself?	network reconfiguration, product/process adaptation, ecosystem change	assuming return to the pre-shock state is always desirable

Source/Note: Author's synthesis drawing on Ponomarov and Holcomb (2009), Tang (2006), Ivanov (2022), and resilience literature.

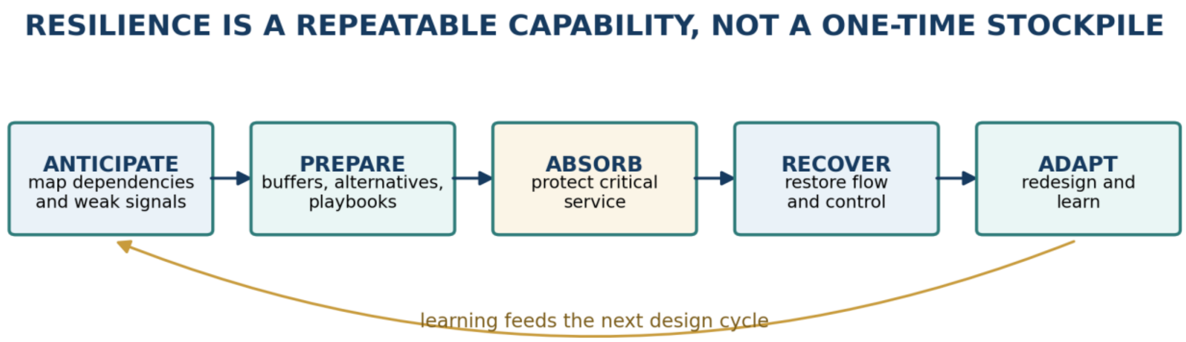

Figure 11.6. Resilience as a repeatable capability from anticipation to adaptation.

Source/Note: Author's synthesis, informed by supply-chain resilience literature.

11.20.2 Redundancy, flexibility and optionality

Resilience strategies include safety stock, backup capacity, dual sourcing, alternate routes, standard components, postponement, cross-trained labour, reserve transport contracts, emergency procedures and financial buffers. Each has a carrying cost. Roshani et al. (2024), in a systematic review of resilient supply-chain network design, classify mitigation strategies across proactive, reactive and design-quality capabilities and show that strategy effectiveness depends on disruption context. There is no universally best resilience portfolio.

11.20.3 Time to recover and time to survive

A useful practical comparison asks how long a disrupted node would take to recover and how long downstream operations can survive before the interruption becomes unacceptable. If survival time is shorter than recovery time, the system needs another intervention: more buffer, alternate supply, substitution, demand prioritization or faster recovery. Exact calculation can be difficult, but the concept forces managers to connect disruption duration with inventory and capacity rather than treating a supplier as simply "high risk."

11.20.4 Resilience and essential goods

Continuity has moral as well as financial value when the supply chain serves medicines, food, water, energy, communications or safety-critical equipment. A purely margin-based prioritization can underweight low-profit products whose shortage creates severe human consequences. Organizations need explicit crisis allocation principles before scarcity occurs. Those principles should distinguish contractual priority, clinical or safety consequence, vulnerability, substitutability and fairness rather than relying only on which customer can pay the most.

MANAGERIAL INSIGHT | Resilience is not the opposite of efficiency. It is the disciplined design of options before they are urgently needed. The strongest options often create ordinary value as well: shorter setup times improve flexibility; better supplier visibility improves quality; standardized interfaces make alternate sourcing easier; cross-training improves daily scheduling and crisis response.

11.21 Visibility, Traceability, AI, IoT, Blockchain and Digital Twins

11.21.1 Visibility is the ability to know relevant state, not the number of dashboard screens

Supply-chain visibility means timely access to reliable information about relevant orders, inventory, capacity, shipment location, condition, exceptions and dependencies. Visibility has a scope: a firm may know where its containers are but not whether a sub-tier supplier has stopped production. More data are not always better. The goal is decision-relevant state information with known provenance and latency.

11.21.2 Traceability and chain of custody

Traceability links a product, batch, component or event backward and forward through the process. It supports recall, quality investigation, regulatory control, authenticity and responsible sourcing. A traceability claim is only as strong as identity integrity at each hand-off. A blockchain record cannot prove that the physical item scanned is the one described if the initial association was false. Physical controls, identifiers, audit and data governance remain necessary.

11.21.3 Internet of Things

IoT devices can capture location, temperature, vibration, equipment condition and other operational signals. Their value is strongest when the signal changes a decision: a temperature excursion triggers intervention; predictive maintenance detects degradation; geofencing identifies route deviation. Device programmes fail when sensors are deployed without calibration, connectivity, battery, data-retention, cybersecurity and escalation design. A million readings with no accountable exception process create data volume rather than control.

11.21.4 Artificial intelligence in supply-chain management

AI can support forecasting, anomaly detection, routing, scheduling, supplier-risk screening, document extraction, computer vision, maintenance and exception prioritization. Toorajipour et al. (2021) mapped a broad research landscape, while Culot et al. (2024) reviewed empirical AI-in-supply-chain studies and warned that managerial discussion can run ahead of substantiated evidence. The professional response is neither enthusiasm nor rejection. AI should be evaluated against a baseline process, with out-of-sample performance, decision consequences, data drift, explainability appropriate to the use, human override and monitoring.

Generative AI adds a distinctive risk in logistics documentation. It can draft shipment instructions, classify emails and summarize exceptions, but a plausible sentence is not evidence that a permit exists or a commodity code is correct. High-consequence outputs should be verified against authoritative records. The person authorizing the shipment remains accountable for the operational decision.

11.21.5 Blockchain and shared ledgers

Blockchain can be useful where multiple parties need a shared tamper-evident record without one party controlling the ledger, but it should not be used merely because traceability is desired. Saberi et al. (2019) identify potential relationships between blockchain and sustainable supply-chain management, but practical value depends on governance, data quality, standards, onboarding and the physical-digital link. If a trusted central database already solves the problem more simply, blockchain can add complexity without benefit.

11.21.6 Digital twins

A digital supply-chain twin is a computerized representation of network state used to analyze current conditions and possible disruptions. Ivanov and Dolgui (2021) show how digital twins can support disruption-risk and resilience management. A twin can combine inventory, capacity, routes and demand to test what happens when a node fails. It remains a model. If supplier capacity is stale, lead-time distributions are unrealistic or second-tier dependencies are missing, the twin can produce precise but false reassurance.

11.21.7 Control towers and human accountability

A supply-chain control tower integrates data and exception visibility across functions and partners. Its operational purpose should be to accelerate coordinated action, not centralize every decision. Local teams often know context the centre cannot see. Good architecture defines which exceptions are automated, which are escalated, which authority sits locally, and how conflicting data are reconciled. Technology changes information and decision rights, but it does not remove moral or managerial responsibility.

11.22 African Case: Rwanda, the Northern Corridor and the Difference Between Distance and Transit Time

Rwanda's geography makes corridor performance an operating variable rather than a background condition. For a firm in Kigali sourcing inputs through Mombasa or serving customers beyond the region, the relevant lead time includes port handling, road transport, border processes, transit controls, breaks, queuing and final release. Distance is therefore only one component of time. The Northern Corridor Transport Observatory provides unusually useful evidence because it measures actual corridor movement rather than relying only on generalized infrastructure scores.

Its January-March 2026 quarterly report shows marked improvement on two Kenyan trunk routes. Average Mombasa-Malaba transit time fell from 102 hours in Q1 2025 to 68 hours in Q1 2026, a reported improvement of roughly one-third.

Mombasa-Busia fell from 90 to 67 hours. Both remained above the corridor's distance-based targets of 55 and 57 hours respectively (Northern Corridor Transit and Transport Coordination Authority [NCTTCA], 2026). The data show two truths at once: improvement can be real while a performance gap remains.

The Rwanda route data also reveal why definitions matter. NCTTCA defines transit time in Rwanda as the duration from electronic authorization of a truck's journey in the Rwanda Revenue Authority system to cancellation of the transit bond at the exit border. For Gatuna-Kigali, the Q1 2026 average was 42 hours over 79.8 km against a distance-based target of about five hours. Such a difference should not be misread as forty-two hours of continuous driving. It can contain administrative timing, queuing, processing, stops and the specific start/stop definitions of the metric. An operations analyst therefore investigates the event sequence before prescribing more road capacity.

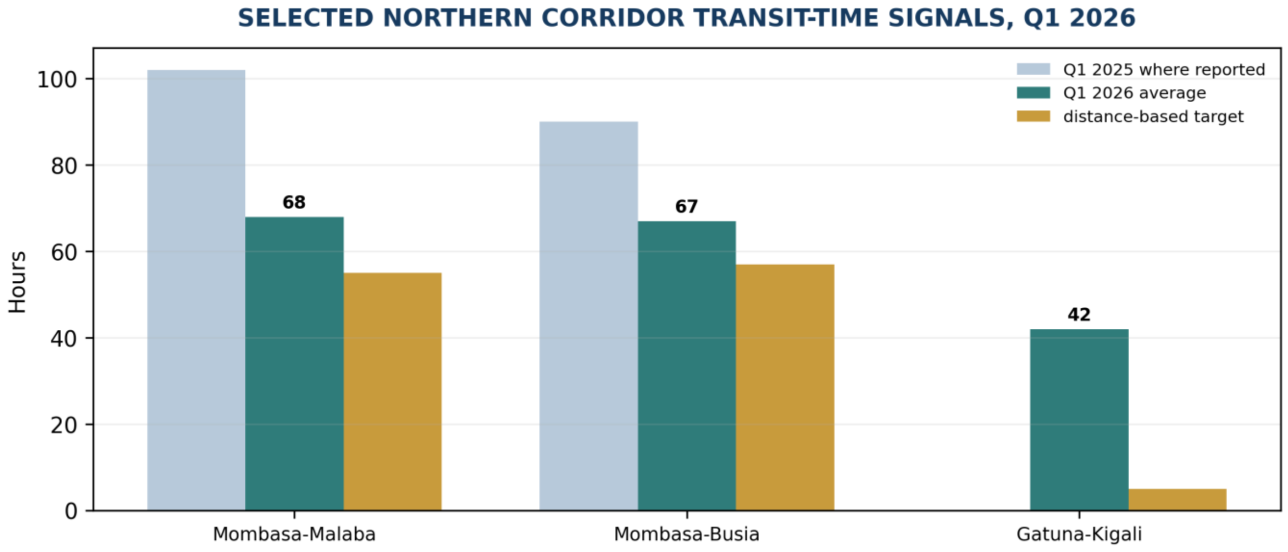

Figure 11.5. Selected Northern Corridor transit-time signals, Q1 2026.

Source/Note: NCTTCA (2026). Q1 2025 comparator values are shown only for the two Mombasa-border routes where the quarterly report provides them in the cited comparison. Gatuna-Kigali shows Q1 2026 average and the corridor distance-based target. Metric definitions differ by route and should be checked before cross-route comparison.

Table 11.10. Northern Corridor evidence translated into operating questions.

Observed signal	Operational interpretation	Evidence needed before action
Mombasa-Malaba: 102h to 68h year-on-year	Flow improved substantially, but average remains above 55h distance-based target	dwell by event; border queue; stops; inspection; time-of-day; shipment segment
Mombasa-Busia: 90h to 67h	Similar improvement, still 10h above 57h target	same event decomposition plus route-specific capacity and border data
Gatuna-Kigali: 42h over 79.8km vs 5h distance target	elapsed transit process is dominated by more than driving distance	authorization time; stop events; bond cancellation timing; driver rest; waiting; data completeness
EAC 2026 OSBP reviews	co-location helped, but administrative and digital integration remain constraints	time-release studies; duplicate data requirements; agency sequence; system downtime; exception ownership

Source/Note: NCTTCA (2026); EAC (2026a, 2026b). The table interprets published operating signals and does not attribute a causal mechanism without event-level evidence.

11.22.1 Diagnose the process before buying infrastructure

The most expensive explanation is not always the correct one. A long corridor time can result from poor roads, but it can also result from a queue at a gate, sequential inspections, inconsistent operating hours, documentation errors, uncoordinated stops, information-system downtime or delayed bond cancellation. A process map with event timestamps can separate travel time from dwell time. Only then can managers distinguish whether the bottleneck is road capacity, border processing, documentation, driver scheduling or an internal release process.

11.22.2 Corridor variability changes inventory policy

A firm planning inbound inventory should not use only average corridor time. Safety stock and reorder points depend on variability and the consequences of late replenishment. If average transit improves but the right tail remains severe, service risk can remain high. Conversely, a slightly longer route with low variability can support lower safety stock than a faster but unpredictable route. This is why corridor performance should be represented by distributions or percentile ranges where data allow, not a single "days from port" assumption.

11.22.3 Trade facilitation is process excellence at institutional scale

The EAC's 2026 observation that OSBPs have reduced crossing times while additional technology and process reform are still needed mirrors internal operations management. Physical co-location resembles a layout redesign. Single-window data resemble information integration. Risk-based inspections resemble quality-at-source and exception management. Time-release studies resemble process measurement. The analogy should not erase public-law responsibilities, but it helps managers understand that border reform is partly an operations problem involving flow, sequencing, information and accountability.

11.22.4 African-rooted operations does not mean Africa-only explanations

Infrastructure constraints are real in parts of Africa, but deficit narratives become analytically lazy when they attribute every delay to geography. Some African logistics systems are highly innovative in mobile coordination, corridor monitoring, agency networks and multimodal adaptation. Conversely, advanced economies also experience congestion, port strikes, cyber incidents, extreme weather and supplier concentration. Good analysis compares mechanisms rather than regions. The relevant question is what constraint exists in this network, what evidence identifies it, and what design is feasible under local institutional conditions.

AFRICAN CONTEXT | For landlocked firms, border processes and corridor partners are part of the operating system even when they sit outside the firm's hierarchy. The manager cannot command customs, a port or a neighbouring state, but can improve documentation quality, choose realistic lead times, diversify gateways where economically feasible, negotiate service-level visibility with logistics partners, and participate in evidence-based public-private problem solving.

11.23 Comparative Global Case: Toyota, the Tohoku Earthquake and the Limits of Invisible Dependencies

Toyota is often used to teach lean production, low inventory and close supplier coordination. The 2011 Tohoku earthquake and tsunami created a harder lesson: the same system had to respond to a severe, geographically concentrated disruption. Matsuo (2015) documents the shortage of automotive microcontrollers produced by Renesas Electronics and supplied to Toyota through first-tier suppliers such as Denso. The case explains why it took roughly three months for Toyota to recover to its pre-earthquake production level and examines the coordination mechanisms required across execution, design and supply-chain relationships.

The disruption exposed a structural problem. A manufacturer can know its direct suppliers and still lack visibility into critical sub-tier dependencies. A small semiconductor component can have low purchase value yet high operational criticality. Traditional spend-based supplier segmentation can therefore miss the component that stops the system. Toyota's later efforts to deepen supplier mapping and continuity planning are consistent with the broader resilience lesson: identify critical dependencies before the crisis, not while production is already stopped.

11.23.1 Lean did not cause the earthquake, but lean changes the consequence of disruption

It is analytically incorrect to say that lean "caused" Toyota's supply disruption. The earthquake was an external shock. It is also incomplete to say inventory levels are irrelevant. Buffers determine how long operations can continue after supply stops. The right question is whether inventory, alternative supply, product design and recovery capability were proportionate to the interruption risk and recovery time of the specific component. A lean system that removes generic waste while deliberately protecting rare critical dependencies can be more resilient than a high-inventory system with poor visibility.

11.23.2 Supplier governance after resilience becomes visible

Toyota's Integrated Report 2025, published in 2026, describes supplier-sustainability governance that asks Tier-1 suppliers to extend expectations to Tier-2 and beyond. It reports that approximately 1,000 major Japanese suppliers had signed the Toyota Supplier Sustainability Guidelines as of March 2025, and that a 2024 self-assessment questionnaire was shared with 980 major suppliers, with 814 responses, followed by targeted audits and improvement activity (Toyota Motor Corporation, 2026). These are company-reported governance signals rather than independent proof that all lower-tier risks are controlled. They nevertheless illustrate the widening unit of responsibility in modern supply chains.

11.23.3 Coordination capacity is a resilience asset

Resilience is often discussed as spare inventory, but the Toyota case also highlights coordination. When a critical supplier fails, rapid recovery requires technical information, authority to redesign or requalify, transparent communication, priority rules and trust among organizations. These capabilities are relational and organizational. A buyer that treats suppliers purely as interchangeable price points during normal times may discover during crisis that it lacks the information and cooperation required for recovery.

11.23.4 Comparative lesson for African firms

The lesson transfers without requiring African firms to imitate Toyota's scale or production system. A Rwandan manufacturer can map which imported input has no local substitute, how many days of cover exist, whether the alternative requires recertification, and which corridor or currency exposure is common across suppliers. A Kenyan agribusiness can map cold-chain bottlenecks and spare capacity. A pan-African digital infrastructure operator can identify single cloud, fibre or power dependencies. Resilience begins with criticality and time, not with firm size.

EVIDENCE CHECK | Company sustainability guidelines, supplier questionnaires and audits are governance evidence, not outcome evidence. They show that a system exists and may reveal coverage, but they do not by themselves prove that labour, environmental or resilience outcomes improved. Independent verification, incident data and supplier experience remain important.

11.24 Faith, Ethics and Moral Reasoning: Excellence Without Exploitation

Operations management is often presented as morally neutral because its tools concern flow, capacity, inventory and cost. That view is untenable. Every operating design distributes time, risk, workload, bargaining power, environmental burden and continuity. A low-cost sourcing decision can transfer financial stress to a supplier. A high-utilization schedule can shift variability onto workers through unpredictable overtime. A resilience stock can protect essential medicines or hoard scarce goods from others. A routing algorithm can improve speed while creating unsafe driving incentives. Technical excellence therefore requires moral judgment about what may legitimately be optimized and which harms must remain outside the objective function.

11.24.1 Truthfulness: operational information as a moral obligation

The biblical condemnation of false measures provides a direct moral analogy for operational metrics. Proverbs 11:1 rejects dishonest scales, while Deuteronomy 25:13-16 condemns unequal measures. The modern equivalent is not only a fraudulent weight. It includes manipulated service definitions, hidden defects, inaccurate inventory, false origin records, understated lead-time risk and dashboards designed to create confidence rather than reveal reality. These are biblical moral claims about honesty. Empirically, transparent data also improve problem solving, but efficiency is not the reason truth becomes obligatory.

11.24.2 Human dignity, safety and the limits of throughput

Christian moral reasoning begins with the worth of persons rather than their productivity. A worker is not a unit of capacity whose wellbeing can be traded away whenever the spreadsheet shows a positive margin. Safety procedures, reasonable rest, voice, fair treatment and respect for conscience therefore impose moral constraints on scheduling and process design. Colossians 4:1 requires masters to deal justly and fairly, a principle that speaks to the asymmetry of organizational authority. Legal compliance remains necessary but is not a complete moral test. A schedule can be technically lawful and still exploit vulnerability through coercive pressure, unsafe fatigue or manipulation of temporary labour.

11.24.3 Supplier justice and the morality of purchasing power

The fact that a supplier signs a contract does not erase unequal bargaining power. Powerful buyers can impose prices, lead times and payment terms that suppliers formally accept because losing the customer would be catastrophic. Christian ethics therefore asks whether the buyer's demand is just, truthful and neighbour-regarding, not merely enforceable. James 5:4 treats withheld wages as a grave injustice, reminding managers that labour conditions deep in a supply chain remain morally significant even when they do not appear on the buyer's payroll. A procurement team should examine whether its purchasing practices predictably encourage unpaid work, unsafe subcontracting or impossible delivery schedules.

11.24.4 Stewardship, waste and care for creation

Operations consumes materials, energy, land and transport capacity. Stewardship does not mean that every resource must be preserved from use; production is part of human vocation. It means resources should be used responsibly rather than wastefully and that foreseeable environmental harms should not be externalized merely because they are not priced. Genesis 2:15 presents cultivation and keeping together, a useful moral pattern for productive use joined with care. Lean waste reduction can align with stewardship when it reduces defects, excess movement, spoilage and energy. It does not become morally complete simply by reducing waste if the same process exploits labour or transfers pollution downstream.

11.24.5 Neighbour-love and continuity of essential goods

Supply continuity can become a question of neighbour-love when failure deprives people of essential medicine, food, water, communication or safety. Matthew 7:12 provides a moral test for allocation and contracting: would we regard this treatment as fair if our organization occupied the weaker position? This does not dictate one inventory formula or route. It changes what consequences count in the decision. A low-margin essential item may deserve more resilience than a high-margin discretionary item if shortage consequences are severe.

11.24.6 Alternative ethical perspectives and what they illuminate

Christian moral reasoning should not be confused with refusing serious alternative frameworks. A **consequentialist** approach asks which operating choice produces the best overall outcomes, drawing attention to safety, cost, access and externalities. Its weakness appears when aggregate benefit permits severe burdens on a vulnerable minority. A **deontological or rights-based** approach emphasizes duties, consent, safety rights and non-deception, protecting moral boundaries that should not be crossed merely because a harmful practice is efficient. A **justice** perspective asks how gains, risks and delays are distributed, including whether powerful buyers shift risk to weaker suppliers. A **care-ethics** perspective emphasizes relational dependence and attentiveness to vulnerability. **Stakeholder** approaches widen managerial attention beyond owners and customers to workers, suppliers and communities.

These traditions often converge in practice while differing in foundation. Christian ethics grounds dignity in creation, moral duty in accountability to God, work in vocation and neighbour-love, and stewardship in entrusted responsibility. It also refuses the reduction of persons to stakeholder weights. Alternative frameworks can nevertheless sharpen analysis by exposing consequences, rights, distribution and relationship. Intellectual seriousness requires engaging those insights without pretending that all moral theories are interchangeable.

Table 11.11. Moral questions embedded in ordinary operations decisions.

Operations decision	Technical question	Moral question
Capacity and scheduling	How much capacity and labour are required to meet demand?	Does the schedule predictably rely on unsafe fatigue, coercive overtime or disposable labour?
Inventory	How much buffer minimizes relevant cost for a service target?	Whose shortage is being protected against, and who bears the cost of scarcity or hoarding?
Procurement	Which supplier offers best total cost and capability?	Are price and lead-time demands fair, and do buyer practices undermine supplier compliance?
Transportation	Which mode and route meet cost/time requirements?	Are safety, emissions, community effects and driver conditions treated as real constraints?
Traceability	How much visibility is economically useful?	Does monitoring protect integrity without unjustified surveillance or misuse of worker/supplier data?
Resilience	Which redundancy and alternatives are worth funding?	Are continuity priorities proportionate to human consequences, not only revenue?
Automation/AI	Can technology improve decisions or flow?	Who can challenge errors, whose work is intensified or displaced, and who remains accountable?

Source/Note: Author's synthesis. Technical and moral questions are related but not identical; a legally or economically feasible action can remain morally unacceptable.

11.24.7 Moral red lines in operations

A Christian operations professional should treat certain practices as red lines rather than variables to optimize: falsifying quality or origin records; bribing officials; concealing safety hazards; deliberately misclassifying goods; knowingly using forced or abusive labour; retaliating against workers who report danger; exploiting supplier dependence through deception; and knowingly shifting serious foreseeable harm onto parties unable to protect themselves. Profit pressure, senior instruction or industry custom does not transform these practices into stewardship.

FAITH AND VOCATION | The vocation of operations is faithful fulfilment. It is the work of making promises physically true: the right product or service, in the right condition, through a process that can be explained and defended. Excellence therefore includes not only speed and cost but honest measurement, safe work, fair dealing, responsible use of creation, care for the vulnerable and courage to stop a process when the means have become morally wrong.

11.25 Professional Toolkit: The FULFIL Operations and Supply-Chain Protocol

The following protocol integrates the chapter into a repeatable professional workflow. It is deliberately not an optimization algorithm. It is a governance sequence that ensures the manager frames the promise, maps the flow, quantifies the system, examines cross-border execution, tests resilience and moral constraints, then learns from outcomes.

Table 11.12. The FULFIL protocol for responsible operations decisions.

Step	Professional action	Minimum evidence
F - Frame the promise	Define customer/service requirement, scope, criticality, time horizon and non-negotiable safety or ethical constraints.	service specification; customer requirement; legal/quality conditions; decision owner
U - Understand the end-to-end flow	Map material, information, responsibility, waiting, rework and hand-offs across internal and external nodes.	process map; event timestamps; SIPOC/swimlanes; document flow; partner roles
L - Locate constraints and variability	Quantify throughput, capacity, WIP, flow time, demand variability, lead-time variability and bottlenecks.	capacity data; Little's Law checks; queue/dwell data; defect and delay distribution
F - Fit buffers, sourcing and network choices	Choose inventory, capacity, suppliers, routes, warehouses and postponement based on total system economics.	EOQ/ROP where appropriate; TCO; total landed cost; service-level analysis; supplier capability
I - Integrate cross-border and digital execution	Align Incoterms, documents, customs, systems, master data, visibility and exception responsibilities.	contracted delivery point; document checklist; system interfaces; customs requirements; escalation map
L - Learn, protect and renew	Stress-test disruption, worker/supplier impact and moral red lines; implement controls; review outcomes and redesign.	risk map; recovery options; safety/ethics review; resilience trigger; post-decision review

Source/Note: Author's synthesis. FULFIL is a chapter-level practice protocol, not an external standard and not a substitute for transaction-specific legal, safety or technical requirements.

11.25.1 Decision memo template

PRACTICE TOOL | A one-page operations decision memo should state: **Promise:** what must be fulfilled and by when. **Current flow:** where time, inventory and responsibility sit. **Constraint:** what binds performance and what evidence shows it. **Alternatives:** process, capacity, sourcing, inventory, route or technology options. **Economics:** total relevant cost, not only local cost. **Risk:** failure modes, time to impact, recovery and fallback. **People and ethics:** safety, workload, supplier justice, community and environmental consequences. **Implementation:** owner, trigger, metric, escalation and review date.

11.25.2 Red-team questions before implementation

Before approving an apparently efficient design, a review team should ask whether the bottleneck could move, whether the average hides tail delay, whether the data omit manual work, whether two suppliers share one hidden dependency, whether Incoterms match the actual hand-off, whether the fastest route is robust to closure, whether the service target justifies the buffer, whether a supplier can meet the schedule without harmful practices, whether automation can be overridden, and whether the organization can explain the decision to the party bearing the greatest risk. These questions make assumptions contestable before they become incidents.

11.26 Common Misconceptions, Analytical Errors and Professional Pitfalls

Table 11.13. Common operations and supply-chain misconceptions.

Misconception	Why it fails	Better discipline
"High utilization is always efficient."	Near-full utilization in variable systems can create disproportionate queues and fragility.	Optimize system flow and service, not asset busyness.
"Low inventory is always lean."	Inventory can be a rational buffer against uncertainty, batch economics or critical shortage.	Identify why inventory exists before reducing it.
"The cheapest supplier has the lowest cost."	Purchase price omits freight, quality, inventory, disruption and coordination.	Use TCO and total landed cost with risk scenarios.
"More suppliers always mean resilience."	Nominally separate suppliers can share sub-tier, geographic or infrastructure dependencies.	Map common-cause risk and switching feasibility.
"ERP creates process integration."	Software can standardize fragmented or inaccurate processes.	Integrate process definitions, master data and decision rights before automation.
"Incoterms define ownership and payment."	ICC explicitly excludes title and payment mechanics from Incoterms.	Use Incoterms for specified delivery/cost/risk responsibilities and contract other matters separately.
"FOB is the default for every export."	FOB is sea/inland-waterway specific and may mismatch container terminal hand-off.	Choose the rule and named point that fit the physical transaction.
"Digitization eliminates border delay."	A digital interface can preserve duplicate approvals and poor sequencing.	Redesign institutional process, data and exceptions.
"Visibility means collecting more data."	Unverified or unactionable data can create noise and false confidence.	Define decision-relevant state, provenance, latency and owner.
"AI makes supply-chain decisions objective."	Models encode targets, data and thresholds and can fail under drift or poor data.	Keep purpose, validation, human review and accountability explicit.
"Resilience means holding large buffers."	Buffers are one strategy and can be costly or obsolete.	Combine visibility, flexibility, alternatives, recovery capability and proportionate redundancy.
"If the supplier signed the code, the buyer is ethical."	Buyer pricing, forecast changes and lead times can undermine supplier ability to comply.	Audit purchasing practices as well as supplier practices.
"If it is legal, it is ethically acceptable."	Law sets enforceable minima and can lag foreseeable harm.	Evaluate truth, dignity, justice, vulnerability and responsibility separately.
"Circularity means every returned item should be reused."	Recovery can be unsafe or uneconomic when condition, contamination, regulation, transport or processing losses outweigh legitimate recovered value.	Choose disposition from verified condition, safety, legal requirements, life-cycle consequences and realistic recovery value.

Source/Note: Author's synthesis based on the theories, standards and cases developed in this chapter.

11.27 Chapter Synthesis

Chapter 11 has developed operations and global supply chains as one continuous promise-to-fulfilment system. Inside the organization, operations begins with an explicit service or product requirement and then designs flow, capacity, layout, scheduling, quality, inventory and information to meet it. Process maps reveal where work and waiting actually occur. Little's Law connects WIP, throughput and flow time. Bottleneck analysis explains why local efficiency does not guarantee system output. Capacity measures distinguish theoretical, effective and actual performance; takt time translates demand into a required rhythm; productivity measures become meaningful only when the system boundary and quality consequences are visible.

Lean and quality management move the focus from inspection and local busyness toward stable flow, visible problems, prevention and learning. Just-in-time and Kanban are not synonyms for zero inventory; they are disciplines for synchronizing flow under conditions that make pull reliable. Inventory remains an economic buffer whose appropriate level depends on ordering economics, demand and lead-time uncertainty, service consequence and product criticality. EOQ and reorder-point formulas are useful precisely when their assumptions are made visible. ERP, MRP, WMS, TMS and related digital systems can integrate execution, but no software can rescue false master data or ambiguous decision rights.

The chapter then extended the same logic across the network. Supply-chain architecture connects suppliers, operations, logistics nodes, customers and returns through material and information flows. SCOR provides a common reference language; network design, postponement and inventory positioning manage responsiveness and risk; procurement should optimize total value and capability rather than visible price; transport mode and route affect inventory and resilience as well as freight; warehouses and cold chains are process systems rather than storage boxes. Incoterms 2020 clarify specified delivery, cost and risk responsibilities but do not determine title or payment. Customs and trade facilitation add institutional processes whose delays must be measured through event-level evidence rather than blamed generically on borders.

Contemporary disruption makes resilience a normal design responsibility. Robustness, agility, resilience and viability answer different questions. Mapping critical dependencies, comparing time to recover with time to survive, qualifying alternatives, protecting critical service and learning after disruption create a more disciplined response than either extreme stockpiling or faith in perfect prediction. AI, IoT, blockchain and digital twins can increase visibility and decision quality when the business problem, data, interoperability and governance are sound. They can also amplify error and surveillance when technology outruns accountability.

Finally, the chapter has argued that operations is morally consequential. Truthful metrics, worker safety, supplier justice, honest documentation, stewardship of resources and continuity of essential goods are not decorative additions to process excellence. They define whether efficiency is legitimate. A process that meets its numerical target by shifting hidden harm to workers, suppliers or communities is not excellent in any adequate account of responsible enterprise.

11.27.1 Hand-off to Chapter 12: From Operational Capability to Competitive Choice

Operations capability creates possibilities but does not by itself determine which competitive position an enterprise should pursue. A firm can learn to deliver faster, operate at lower cost, customize efficiently or recover from disruption. Chapter 12 asks how those capabilities interact with industry structure, rivals, resources, strategic positioning, corporate scope and long-term renewal. The hand-off is deliberate: Chapter 11 has shown **how value is reliably produced and moved**; Chapter 12, *Business Strategy and Competitive Advantage: Analysis, Choice, Execution and Strategic Renewal*, will ask **which value system and competitive choices the enterprise should commit to, why those choices can create defensible advantage, and what moral constraints should govern them**.

Key Terms

Table 11.14. Key terms and working definitions.

Term	Working definition
ABC inventory analysis	A classification approach that concentrates management attention on items according to consumption value or other importance criteria; criticality may require dimensions beyond spend.
Agility	The capability to sense and respond rapidly to change in demand, supply or operating conditions.
Bottleneck	The resource or stage whose effective capacity constrains system throughput over the relevant period.
Bullwhip effect	Amplification of demand variability in upstream orders relative to final-customer demand.
Capacity cushion	Deliberate capacity above expected demand to absorb uncertainty, growth or high-consequence service requirements.
Closed-loop supply chain	An operating network that integrates forward fulfilment with reverse flows for returns and technically, economically and morally appropriate recovery, repair, remanufacture, reuse, recycling or disposal.
Cycle stock	Inventory created by ordering or producing in batches.
Decoupling point	The point at which a specific customer order enters or differentiates the operating flow; it separates forecast-driven from order-driven activity.
Digital supply-chain twin	A computerized representation of network state used to analyze current and possible future operating conditions.
Economic order quantity (EOQ)	A benchmark order quantity that balances ordering and cycle-stock holding costs under restrictive assumptions.
ERP	Enterprise Resource Planning, an integrated transaction and master-data architecture across organizational functions.
Incoterms 2020	ICC trade rules that allocate specified delivery, cost, risk and formalities responsibilities between seller and buyer when incorporated into a sales contract.
Inventory position	A planning measure generally reflecting on-hand plus on-order inventory minus relevant commitments or backorders, with exact definition determined by system context.
Just-in-time (JIT)	An operating philosophy seeking to supply or produce what is needed, when needed and in the required quantity, supported by reliable processes and fast problem solving.
Kanban	A visual or digital authorization signal used to control replenishment and limit WIP in a pull system.

Term	Working definition
Line balancing	Assignment of work elements to stations so workloads fit a target cycle time and precedence constraints while minimizing avoidable imbalance without compromising safety or quality.
Little's Law	Under stable long-run conditions, average WIP equals average throughput rate multiplied by average flow time: L = lambda W.
Logistics	The planning and execution of movement, storage and related information within the wider supply chain.
MTBF	Mean time between failures: an average operating-time indicator for repairable assets whose meaning depends on the defined failure event and operating context.
MTTR	Mean time to repair: the average time required to restore a failed repairable asset under a defined maintenance and restoration scope.
Multifactor productivity	Output relative to a combination of multiple resource inputs rather than one partial input alone.
OEE	Overall Equipment Effectiveness, commonly calculated as availability x performance x quality for an equipment context.
One Stop Border Post	A coordinated border arrangement intended to reduce duplicated processes by bringing neighbouring-country agencies into an integrated crossing environment.
OTIF	On Time In Full, a service metric assessing whether the promised quantity arrives within the defined delivery window.
Postponement	Deliberate delay of final product or process differentiation until demand information improves.
Reorder point	The inventory position at which replenishment is triggered, commonly expected lead-time demand plus safety stock.
Resilience	The capability to prepare for, absorb, recover from and adapt after disruption.
Reverse logistics	The planning and execution of product, packaging, material and information flows from downstream points back toward inspection, recovery, reuse, recycling or responsible disposition.
Robustness	The capability to maintain acceptable performance under disturbance without major reconfiguration.
Safety stock	Inventory held to protect service against uncertainty in demand or replenishment.
SCOR Digital Standard	ASCM reference architecture organized around Orchestrate, Plan, Order, Source, Transform, Fulfill and Return.
Single window	A trade-facilitation arrangement through which traders can submit required import, export or transit data through a single entry point to participating authorities.
Takt time	Available productive time divided by customer demand over the same period, indicating the pace required to meet demand.
Total cost of ownership	A purchasing perspective that considers costs before, during and after acquisition rather than purchase price alone.
Total landed cost	The decision-relevant cost of getting a product to the intended node, including purchase, logistics and other relevant consequences under consistent assumptions.
Traceability	The capability to follow the identity, history, location or application of an item or batch through recorded events.
Utilization	Actual output relative to defined design capacity.
Viability	The ability of a supply chain to survive sustained structural change by adapting or redesigning its configuration and plans.
WIP	Work in process, the average number of flow units currently inside the defined process system.

Concept-Check Questions

1. What is the difference among operations management, logistics and supply-chain management?
2. Why can a department be locally efficient while the end-to-end process performs poorly?
3. State Little's Law and explain the conditions under which its managerial use can be misleading.
4. Distinguish design capacity, effective capacity, utilization, efficiency and capacity cushion.
5. What does takt time represent, and why should it not be interpreted as a command to intensify work regardless of process feasibility?
6. Why is lean more than inventory reduction? Name the enabling conditions required for a reliable pull system.
7. Distinguish prevention, appraisal, internal failure and external failure costs of quality.
8. What assumptions underlie the basic EOQ model?
9. Distinguish cycle stock, safety stock, pipeline inventory and anticipation inventory.
10. What is the bullwhip effect, and which operating practices can reduce it?
11. Explain the distinct roles of ERP, MRP, WMS and TMS.
12. Name the seven high-level SCOR processes and explain why SCOR is a reference model rather than a prescription.
13. Why can two suppliers still represent one underlying supply risk?
14. Which factors should be considered when choosing among air, sea, road, rail and multimodal transport?

15. What do Incoterms 2020 govern, and what important matters do they not govern?
16. Why is FCA often operationally preferable to FOB for containerized shipments handed to a carrier before vessel loading?
17. What is the purpose of a trade single window? Why can digitization fail to reduce delay?
18. Distinguish robustness, agility, resilience and viability.
19. Why does traceability require more than a digital ledger?
20. Give three examples of operational decisions that are technically feasible but could still be morally unacceptable.
21. How are theoretical minimum stations and balance efficiency calculated in line balancing, and why can a low balance efficiency have causes other than worker effort?
22. Distinguish corrective, preventive and condition-based maintenance. How do MTBF and MTTR jointly affect a simple availability estimate?
23. What is reverse logistics, and which evidence should govern whether a returned product is restocked, repaired, remanufactured, recycled or disposed of?

Higher-Order Analytical and Critical-Thinking Questions

1. A plant reports 92% equipment utilization but persistent late orders. Develop at least four competing explanations and identify the evidence that would discriminate among them.
2. Under what conditions can reducing inventory increase total cost? Build an argument using lead-time variability, stockout consequences, transport batching and supplier reliability.
3. Critically evaluate the statement: "A resilient supply chain should always dual-source every critical item." Identify conditions under which dual sourcing could reduce rather than improve resilience.
4. Explain how a low-price procurement policy can create hidden labour and quality risk even when suppliers formally comply with a code of conduct.
5. Using the Northern Corridor case, show why an average transit-time measure should not be interpreted before examining start/stop definitions and event-level dwell.
6. Compare a centralized African regional distribution centre with three national warehouses. Which demand, border, inventory and disruption characteristics would make each design preferable?
7. Design a governance rule for using AI to prioritize supplier-risk investigations without allowing the model to automatically exclude suppliers or become a self-fulfilling risk score.
8. A company claims that blockchain will "solve traceability." Develop a technical and moral critique that distinguishes ledger integrity from physical identity, data accuracy, governance and accountability.
9. Explain how operational excellence can serve competitive advantage without collapsing operations strategy into the general strategic-management theory reserved for Chapter 12.
10. In a severe medicine shortage, should a distributor allocate scarce stock by highest price, first order, clinical criticality, equal shares or another principle? Compare economic, rights-based, justice, care and Christian moral reasoning.
11. A manufacturer claims that predictive maintenance will eliminate unplanned downtime. Critique the claim by distinguishing sensor quality, diagnostics, prognostics, maintenance decision rules, spare-part availability, repair capability and common-cause failure.
12. Design a reverse-logistics policy for a regional electronics firm that receives products in mixed condition across several countries. Explain how you would separate customer service, value recovery, safety, cross-border compliance and responsible end-of-life disposition.

Applied Case: Imanzi Health Products and a Cold-Chain Network Under Growth Pressure

CASE STATUS | The following is a **constructed teaching case**. Imanzi Health Products is fictional. The quantities and costs are designed for analytical practice and should not be interpreted as market data for any real company.

Imanzi Health Products distributes temperature-sensitive diagnostic kits from a Kigali facility to hospitals and laboratories in Rwanda and neighbouring markets. Demand has grown quickly after a new institutional contract. The commercial team has promised 98% on-time-in-full delivery for domestic customers and reliable two-day dispatch for regional orders after export documentation is complete. Operations now faces three linked problems: inventory policy for a critical kit, supplier choice for insulated packaging, and a decision about whether to hold regional safety stock at one central node or split it across two smaller facilities.

Case Exhibit A: Critical-kit inventory

Annual demand for Kit K is expected to be 36,000 units. The supplier charges a fixed order-processing and inbound coordination cost of CU90 per order. Annual holding cost, including controlled storage and capital, is estimated at CU12 per unit. Average daily demand is 120 units based on a 300-day planning year. Supplier lead time averages eight days. Daily demand standard deviation is estimated at 25 units; assume lead time is constant and daily demand is independent for the basic exercise. Management uses a 95% cycle-service target for this item.

Table 11.15. Imanzi Kit K planning data.

Input	Value
Annual demand D	36,000 units
Ordering cost S	CU90/order
Annual holding cost H	CU12/unit/year
Average daily demand	120 units/day
Lead time	8 days
Daily demand standard deviation	25 units/day
Cycle-service planning target	95%, z = 1.645 for this simplified exercise

Case Exhibit B: Packaging suppliers

Table 11.16. Competing insulated-packaging suppliers.

Factor	Supplier Nyota	Supplier Atlas
Unit price	CU4.60	CU5.10
Inbound freight	CU0.55/unit	CU0.20/unit
Observed incoming defect rate	1.8%	0.4%
Normal lead time	24-34 days	12-16 days
Minimum order	5,000 units	2,500 units
Qualified production sites	1	2, in different countries
Corrective-action responsiveness	mixed over last four issues	strong over last four issues
Supplier-labour evidence	recent audit has one open excessive-overtime corrective action	recent audit has no critical findings, but relies partly on self-assessment
Commercial relationship	offers 4% additional discount for one-year exclusivity	no exclusivity discount

Source/Note: Constructed teaching data. Audit evidence is deliberately incomplete so that students must distinguish evidence from certainty.

Case Exhibit C: Network options

Table 11.17. Regional network alternatives.

Dimension	Option 1: Kigali central stock	Option 2: Kigali + secondary regional stock
Facility fixed cost	lower	higher by CU90,000/year
Aggregate safety stock	lower through pooling	higher because protection is duplicated
Domestic response	strong	strong
Regional response	more exposed to border/corridor variability	faster when regional stock is available
Disruption exposure	single-node concentration	two-node operating complexity but greater node optionality
Cold-chain governance	one controlled system	two sites must maintain qualification and monitoring
Data requirement	central inventory accuracy	near-real-time synchronization and disciplined transfer logic

Required Analysis

1. Calculate EOQ for Kit K using the simplified model. Show the formula and round to a practical whole-unit quantity.
2. Calculate expected lead-time demand, lead-time demand standard deviation, safety stock and reorder point under the stated assumptions.
3. Explain at least five reasons why the calculated reorder point could be unsafe or wasteful if management applies it mechanically.
4. Build a total-cost-and-risk comparison of Nyota and Atlas. Which additional data would you request before recommending either supplier?

5. Evaluate the one-year exclusivity discount. Under what conditions could the 4% unit-price reduction be outweighed by concentration risk and working-capital effects?

6. Compare the two network options. Do not choose only from fixed cost. Consider service, risk pooling, border variability, cold-chain quality, data integrity and resilience.

7. Design a FULFIL protocol memo recommending an integrated inventory, supplier and network decision.

8. Identify the moral obligations created by Nyota's open overtime corrective action. What evidence is needed, and what purchasing behaviour by Imanzi could worsen the problem?

9. Propose six operating metrics that would reveal whether the chosen design is working without incentivizing harmful gaming.

10. Specify what would trigger a post-implementation review or reversal of the decision.

WORKED ANSWER CHECK | For the basic inventory arithmetic only: EOQ = sqrt((2 x 36,000 x 90) / 12) = sqrt(540,000) = approximately **735 units**. Expected lead-time demand = 120 x 8 = **960 units**. Lead-time standard deviation under the stated constant-lead-time and independent-demand assumptions = 25 x sqrt(8) = approximately **70.7 units**. Safety stock = 1.645 x 70.7 = approximately **116 units**. Reorder point = 960 + 116 = approximately **1,076 units**. The case is intentionally designed so that a correct calculation is only the beginning of the decision.

Ethical and Faith-Informed Dilemma: The Shipment That Can Still Make the Quarter

A regional food manufacturer is three days from quarter-end. A major export order will count toward the quarter only if containers leave the plant tonight. A first-tier packaging supplier has missed two deliveries after a machine breakdown. The supplier now offers to complete the order by running two consecutive extended shifts using temporary labour. A buyer on the manufacturer's team learns privately that the supplier's overtime controls are weak and that some workers may exceed the company's stated working-hour limit. No confirmed injury or legal violation has been documented. If the manufacturer rejects the shipment, it will miss the customer vessel cut-off, lose a significant incentive payment and may face a contractual late-delivery claim. Senior management tells procurement to "do whatever is lawful and get the containers out."

Questions for Reasoned Judgment

1. What facts are known, what is uncertain, and what evidence must be obtained before authorizing the rush plan?

2. Separate the legal question from the moral question. Why is "if it is lawful" an incomplete decision criterion?

3. How has the buyer's own forecasting, order timing or supplier concentration possibly contributed to the emergency?

4. Apply consequentialist, rights-based, justice, care and stakeholder reasoning. Where do the frameworks converge and where might they differ?

5. Apply Christian moral reasoning concerning truth, worker dignity, neighbour-love, justice and responsibility for foreseeable harm. Which options are morally unavailable even if the financial cost is high?

6. Design a practical response that protects the customer and supplier workers while preserving as much commercial value as legitimately possible.

7. What governance changes should follow after the immediate decision so that the organization does not repeatedly create "exceptional" emergencies that depend on supplier overtime?

Data and Evidence Exercise: Diagnosing Northern Corridor Transit Performance

Use the selected official Q1 2026 Northern Corridor data below. The purpose is not to rank countries or infer causes from averages. The task is to practice disciplined operational interpretation of time data and target definitions.

Table 11.18. Selected Northern Corridor transit-time data for analysis.

Route / indicator	Q1 2025 average	Q1 2026 average	Distance-based target	Distance
Mombasa-Malaba	102 h	68 h	55 h	921 km
Mombasa-Busia	90 h	67 h	57 h	949 km
Gatuna-Kigali	not used in this exercise	42 h	5 h	79.8 km

Source/Note: NCTTCA (2026). Gatuna-Kigali uses the Rwanda transit-time definition in the report: time from electronic journey authorization in the RRA system to transit-bond cancellation at the relevant endpoint. Cross-route comparison must therefore consider definitions and process boundaries.

1. Calculate the percentage reduction in average transit time for Mombasa-Malaba and Mombasa-Busia from Q1 2025 to Q1 2026.

2. Calculate the absolute Q1 2026 gap between average time and target for each route.

3. Why would it be analytically weak to conclude from the Gatuna-Kigali figures that road driving itself is 37 hours too slow?

4. Design a minimum event log that would let you decompose total elapsed time into travel, queue, inspection, document, rest and other dwell components.

5. Propose three process interventions that could be tested without first constructing new road infrastructure. For each, specify the evidence that would support or reject the intervention.

6. Suppose average transit falls but the 95th percentile does not improve. How should an importer change its inventory and service interpretation?

7. Develop a two-paragraph management brief that communicates the improvement without overstating causality or ignoring remaining performance gaps.

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Annotated Further Reading

Table 11.19. Annotated further reading.

Source	Why it is worth reading
Holweg (2007), "The genealogy of lean production."	A historically grounded explanation of how lean developed and why it should not be reduced to a handful of tools. Read this before treating lean as a universal checklist.
Mentzer et al. (2001), "Defining supply chain management."	A foundational conceptual article that clarifies the distinction between a supply chain and supply-chain management and helps establish the network perspective used in this chapter.
Tang (2006), "Robust strategies for mitigating supply chain disruptions."	A durable bridge between ordinary operating performance and disruption preparedness. Particularly useful for thinking about strategies that create normal-time value while preserving resilience.
Roshani, Walker-Davies, and Parry (2024), "Designing resilient supply chain networks."	A recent systematic review of resilience mitigation strategies and quantitative network-design research. Valuable for readers moving from conceptual resilience to formal modelling.
Culot, Podrecca, and Nassimbeni (2024), "Artificial intelligence in supply chain management."	A current review focused on empirical AI studies that helps separate demonstrated applications from technology hype and identifies important implementation conditions.
UNCTAD (2025b), Review of Maritime Transport 2025.	Authoritative current evidence on maritime trade, freight, fleet, port performance and disruption. Especially useful for understanding how rerouting changes effective capacity, cost and emissions.
NCTTCA (2026), Northern Corridor Transport Observatory Quarterly Report, January-March 2026.	A strong African operational-data source that allows students to work with transit times, targets and route definitions rather than relying on generalized narratives about logistics performance.
ICC (2019), Incoterms 2020.	The authoritative source for Incoterms. Secondary summaries are useful for orientation, but transaction-specific use should be checked against the official rules and the actual sales contract.
Guide and Van Wassenhove (2009), "The evolution of closed-loop supply chain research."	A seminal operations-research synthesis of reverse logistics and closed-loop supply chains. It clarifies the business and process logic of product recovery and is especially useful for designing returns, repair, remanufacturing and value-recovery flows.
Jardine, Lin, and Banjevic (2006), "A review on machinery diagnostics and prognostics implementing condition-based maintenance."	A highly cited review of condition-based maintenance, diagnostics and prognostics. It connects sensor data, fault detection and maintenance decisions while showing why predictive technology must sit inside a disciplined maintenance policy.