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Assessing CONCOR's Rail-Linked Cold Chain and IceBattery Technology Through an Extended SCOR Framework

A Secondary Data Case Study of Multimodal Temperature-Controlled Logistics in India

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Abstract:

- ***Purpose:***

India’s fragmented cold chain constrains the reliable movement of perishable food over long distances. Container Corporation of India Limited (CONCOR), a rail-oriented public logistics enterprise, has combined terminals, specialised storage, refrigerated assets, digital monitoring, and phase-change-material-based Ice Battery systems. This paper assesses how these capabilities could support a scalable and lower-carbon multimodal cold chain and develops a performance framework suited to temperature-sensitive logistics.

- ***Design and Methodology:***

The study adopts an exploratory single-case design based on qualitative document analysis. Evidence is drawn from CONCOR annual reports, Government of India disclosures, technology-provider material and peer-reviewed literature on cold-chain performance, intermodal transport, phase change materials and the Supply Chain Operations Reference model. The analysis maps the case to Plan, Source, Transform, Deliver, Return and Enable processes and adds thermal integrity, product quality and environmental intensity to conventional SCOR attributes.

- ***Findings:***

CONCOR possesses strategically relevant nodes and intermodal capabilities, but the public evidence describes a portfolio of facilities and demonstrations more clearly than an integrated national service. Ice Battery systems may reduce dependence on continuous diesel refrigeration on validated lanes, particularly during rail and terminal dwell; however, performance is conditional on pre-cooling, insulation, ambient heat load, door openings, module conditioning and route duration. Commercial scaling therefore depends on commodity-corridor design, assured schedules, end-to-end thermal accountability, balanced equipment flows and independent trip-level validation.

- ***Originality and Value:***

The paper extends SCOR for rail-linked perishable logistics by treating thermal compliance and saleable-product retention as components of reliability, and by integrating operational, asset, quality, energy and emissions metrics in one case-specific framework. It also provides testable propositions and a matched-trip protocol for subsequent empirical research.

Keywords: *Cold-Chain Logistics; CONCOR; Ice Battery; Phase Change Material; Rail Freight; SCOR; Intermodal Logistics; India.*

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I. INTRODUCTION

Cold-chain logistics is not simply refrigerated storage or transport. It is an end-to-end control system in which commodity temperature, humidity, handling time, sanitation, packaging, information and responsibility must remain aligned from origin to final handover. A local failure can shorten shelf life even when later stages operate within specification. This makes conventional logistics measures such as on-time delivery and vehicle utilization necessary but insufficient. A consignment delivered on time after an unrecorded temperature excursion is operationally punctual but commercially unreliable.

India's geography and production diversity create both a need and an opportunity for long-distance temperature-controlled transport. Production is dispersed and seasonal, while major consumption, processing and export centres are spatially concentrated. Road transport offers flexibility, but long-haul cold-chain movement also faces diesel use, driver and equipment variability, congestion and fragmented handovers. Rail can provide lower-emission line haul where volumes are consolidated and schedules are dependable, yet perishable cargo cannot be shifted to rail by haulage capacity alone. It requires pre-cooling, aggregation, terminal discipline, power or stored cooling, monitoring, rapid interchange and last-mile delivery.

CONCOR is therefore an analytically important case. As a Navratna central public sector enterprise under India's Ministry of Railways, it combines rail haulage, inland terminals, containers, warehousing, road linkages and digital logistics systems. Its wholly owned subsidiary Fresh and Healthy Enterprises Limited (FHEL), perishable cargo facilities and IceBattery initiatives provide a platform for diversification from general container freight into temperature-controlled services (CONCOR, 2024, 2025; Ministry of Railways, 2017, 2020). The case also exposes a central challenge in public logistics investment: the historical creation of assets does not by itself demonstrate current utilisation, thermal performance, customer value or financial sustainability.

➢ *This Paper Addresses three Research Questions:*

- RQ1: How do CONCOR’s cold-chain facilities, multimodal assets and IceBattery initiatives map onto an end-to-end cold-chain operating model?
- RQ2: Which performance dimensions and indicators are required to assess the reliability, responsiveness, cost, asset efficiency and sustainability of this system?
- RQ3: Under what operational conditions could phase-change-material-based passive or hybrid cooling create value relative to conventional active reefers?

The paper makes three contributions. First, it organises dispersed institutional evidence into a coherent case architecture. Second, it adapts SCOR to perishable rail logistics by making thermal integrity and saleable-product retention explicit. Third, it develops propositions and an empirical protocol that distinguish plausible technological benefits from verified outcomes. The study does not claim causal impact or audited performance results; it identifies what must be measured before sustaining such claims.

II. LITERATURE REVIEW AND CONCEPTUAL BACKGROUND

➢ *Cold-Chain Performance as an End-to-End Outcome*

Temperature is cumulative in its effect on many foods: time spent outside the appropriate band accelerates biochemical and microbial deterioration and reduces remaining shelf life. Research therefore emphasises traceability, monitoring, risk management and coordinated control rather than isolated refrigeration assets (Aung & Chang, 2014; Mercier et al., 2017). Reviews of food cold chains also identify energy intensity, equipment heterogeneity, weak interoperability and fragmented responsibility as persistent constraints (Badia-Melis et al., 2018; Ndraha et al., 2018).

A suitable performance system must connect logistics outputs with product outcomes. Reliability should include completeness, timeliness, damage-free delivery and thermal conformity. Responsiveness should capture order-cycle time and exception recovery. Asset efficiency should measure usable rather than nominal capacity. Cost must be related to delivered and saleable quantity, since a low transport cost can conceal quality loss. Environmental performance should be measured per tonne-kilometre and per successful delivery, with boundaries that include cooling energy and repositioning.

➢ *Rail and Intermodal Cold-Chain Logic*

Intermodal systems divide a journey among modes according to their relative strengths. Rail is suited to consolidated long-haul movement, while road provides origin and destination reach. Containerisation can reduce repeated handling, but terminals introduce staging and interchange risks. For perishables, scheduled departure, reefer power or passive holdover, priority handling and last-mile synchronisation are therefore part of the product rather than auxiliary services. Rail's emissions advantage can be diluted by low load factors, circuitous routing, diesel-intensive first and last miles, and empty repositioning; comparison must be lane-specific.

➢ *Phase Change Materials in Temperature-Controlled Transport*

Phase change materials (PCMs) store and release thermal energy largely through latent heat. Modules are conditioned at a specified temperature and then absorb incoming heat as the material changes phase. Compared with purely sensible storage, latent storage can hold substantial

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energy near a designed transition temperature (Sharma et al., 2009; Oró et al., 2012). In transport, PCM systems can provide passive cooling or supplement active equipment, reducing continuous compressor or diesel-generator operation during a validated period.

The benefit is conditional. Thermal endurance depends on PCM chemistry and mass, insulation, ambient conditions, solar exposure, cargo entry temperature, respiration, airflow, loading density, door openings and journey time. PCMs may also reduce payload volume or weight and require charging infrastructure and reverse logistics. Accordingly, a vendor-stated holdover time cannot be transferred automatically across commodities and routes. Validation must reproduce the intended operating envelope and use independent calibrated sensors.

➢ *SCOR and the Need for Cold-Chain Extension*

SCOR provides common process categories and performance attributes for supply-chain diagnosis. The contemporary framework encompasses orchestration activities that can be represented as Plan, Source, Transform, Fulfil, Return and Enable, while earlier versions commonly used Plan, Source, Make, Deliver and Return (ASCM, 2022; APICS Supply Chain Council, 2017). Its strengths are process visibility, hierarchical metrics and links between performance, practices, people and technology. Its limitation in this case is not structural but interpretive: standard reliability metrics do not automatically reveal thermal exposure or biological quality loss. The present framework therefore uses the operational labels Plan, Source, Transform, Deliver, Return and Enable and embeds thermal and quality measures within them.

III. METHODOLOGY

➢ *Research Design*

An exploratory single-case study was adopted because CONCOR represents an unusual combination of public rail infrastructure, container logistics, agricultural facilities and emerging thermal-storage technology. Case study research is appropriate where organisational context and operational mechanisms cannot be separated cleanly (Yin, 2018). The unit of analysis is CONCOR's rail-linked cold-chain service system, including FHEL facilities, relevant terminals, temperature-controlled equipment, first- and last-mile interfaces and information flows.

➢ *Evidence Base and Analytical Procedure*

The evidence base comprises CONCOR annual reports for 2023–24 and 2024–25; Ministry of Railways disclosures on perishable cargo facilities and insulated containers; public technical communications on CONCOR–ITE demonstrations; and peer-reviewed literature. Documents were examined for infrastructure, service process, technological capability, claimed operating outcomes, constraints and missing performance data. Claims from the technology provider were retained as attributed claims and were not treated as independently verified results.

Analysis proceeded in four stages. First, facilities and activities were organised chronologically and spatially. Second, the physical and information flows were reconstructed from aggregation to final delivery. Third, activities were mapped to the extended SCOR processes. Fourth, indicators were selected using three criteria: decision relevance, feasibility of trip- or facility-level measurement, and capacity to connect operational inputs to product, financial and environmental outcomes. Triangulation was used where official and provider accounts overlapped; uncertainty was retained where current operating status or audited performance was unavailable.

➢ *Scope and Validity Boundaries*

This is a framework-building study, not an experimental evaluation. It does not estimate spoilage reduction, cost savings or emission reductions attributable to CONCOR or IceBattery. Public documents are stronger on infrastructure and strategic intent than on throughput, utilisation, energy, claims and profitability. The findings are therefore analytical propositions that require interviews, operating records and matched-trip tests.

➢ *Case Description*

- *Organizational Platform and Facility Portfolio*

CONCOR's strategic advantage lies in combining rail-linked nodes with containers, handling equipment, warehousing and road distribution. FHEL provides a dedicated institutional vehicle for agricultural logistics. Its Rai facility in Sonipat has been associated with controlled-atmosphere storage, grading, packing, palletisation and dispatch, particularly for apples and other fruits. Controlled-atmosphere storage regulates gases and humidity in addition to temperature, slowing respiration and extending marketable life.

Other initiatives have reflected commodity-specific needs. Government disclosures describe banana ripening and pre-ripening activities at New Azadpur; perishable cargo centres at Ghazipur Ghat and Raja ka Talab; potato-oriented storage at Singur; a planned 2,500-tonne Lasalgaon facility with 1,500 tonnes intended for onions; a mango pack-house initiative at Sindhudurg; and cold-storage capability at Dadri (Ministry of Railways, 2017, 2020). The Ministry also reported procurement through CONCOR of 98 ventilated insulated rail containers with an indicated capacity of 12 tonnes each. These records establish an asset footprint, but current operating status and utilisation require facility-level verification.

- *CONCOR Rail-Linked Cold Chain Service Architecture*

✓ Digital Layer: booking -GPS- temperature & humidity-door events-dwell-alerts-proof of condition
✓ Control Objective: preserve thermal integrity and saleable product across every

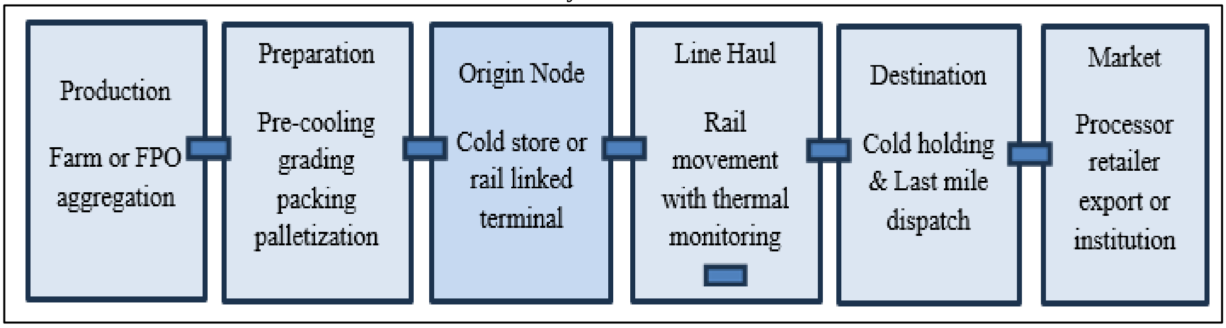

Fig 1 End-to-End Architecture of a CONCOR Rail-Linked Cold Chain

Table 1 Performance Evidence Required

Node or asset	Reported Role	Performance evidence required
Rai FHEL, Sonipat	Controlled-atmosphere, cold/frozen storage and value-added handling	Usable capacity, commodity throughput, utilisation, energy, loss and margin
New Azadpur, Delhi	Banana ripening, preparation and cold storage	Chamber cycles, uniformity, rejection, turnaround and market integration
Dadri, Uttar Pradesh	Rail terminal, cold warehousing and IceBattery demonstration context	Reefer dwell, service frequency, power continuity and trip records
Ghazipur, Raja ka Talab, Singur, Lasalgaon and Sindhudurg	Commodity- and location-specific perishable facilities	Current status, beneficiaries, seasonal use, quality outcome and revenue
Insulated and specialised containers	Intermodal carriage of temperature-sensitive cargo	Availability, payload, loaded ratio, thermal performance and repositioning

- *Ice Battery Configuration*

Innovation Thru Energy and CONCOR publicised IceBattery Express in 2020 and a digitally monitored 40-foot container demonstration in 2023. The provider described cooling for approximately three days without an external power supply during transport and monitoring of location, temperature, humidity and unauthorised access (ITE, 2020, 2023). CONCOR's recent corporate communication treats ice-battery-based cold-chain solutions as a strategic business area (CONCOR, 2025).

The term battery is functional: the system stores cooling rather than electricity. A hybrid configuration can condition PCM modules through active refrigeration and use stored thermal capacity during movement or dwell, with active backup where configured. This is particularly relevant to rail terminals and intermodal transfers where continuous plug-in power or diesel gensets create cost, maintenance, emissions and noise. Yet performance depends on disciplined pre-cooling, loading and monitoring; a passive system preserves a prepared load and should not be expected to remove uncontrolled field heat.

- *Ice Battery Passive and Hybrid Operating Principle*

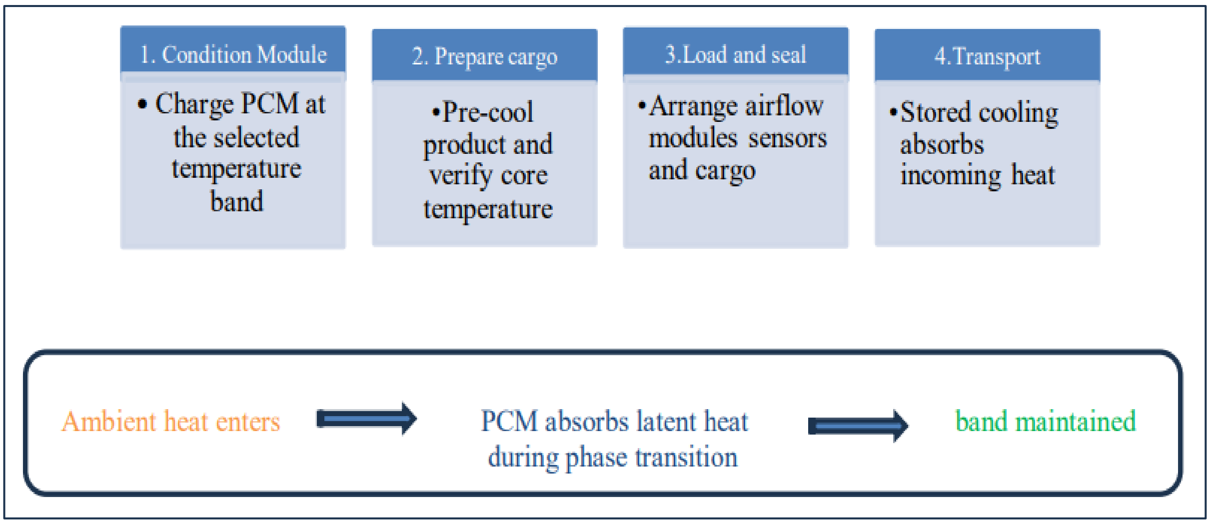

Fig 2 Ice Battery Passive and Hybrid Operating Principle

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IV. FINDINGS AND EXTENDED SCOR ASSESSMENT

➢ *Process Architecture*

Table 2 Process Architecture

Process	Application	Critical controls
Plan	Demand forecasting, corridor choice, seasonal capacity, schedules and thermal validation	Forecast accuracy, service frequency, route envelope and contingency
Source	Containers, PCM modules, packaging, road services, sensors and facility inputs	Availability, supplier compliance, calibration and conditioning lead time
Transform	Pre-cooling, grading, packing, ripening, palletisation and load preparation	Core temperature, rejection, cycle time, airflow and hygiene
Deliver	Booking, terminal handling, rail/road haulage, monitoring and handover	Dwell, thermal excursion, on-time delivery, damage and cost
Return	Rejected cargo, claims, reusable modules, containers and packaging	Claim closure, asset recovery, reverse time and empty ratio
Enable	SOPs, skills, IoT, governance, partnerships, finance and sustainability	Data completeness, sensor uptime, auditability and staff competence

The mapping shows that CONCOR's potential value is systemic. Facilities create value only when planning aligns commodity demand with scheduled movement, sourced assets are available, products are prepared correctly, terminal and transport delivery preserve temperature, reusable modules return efficiently and digital evidence enables accountability. A weak link can overwhelm the performance of the remaining system.

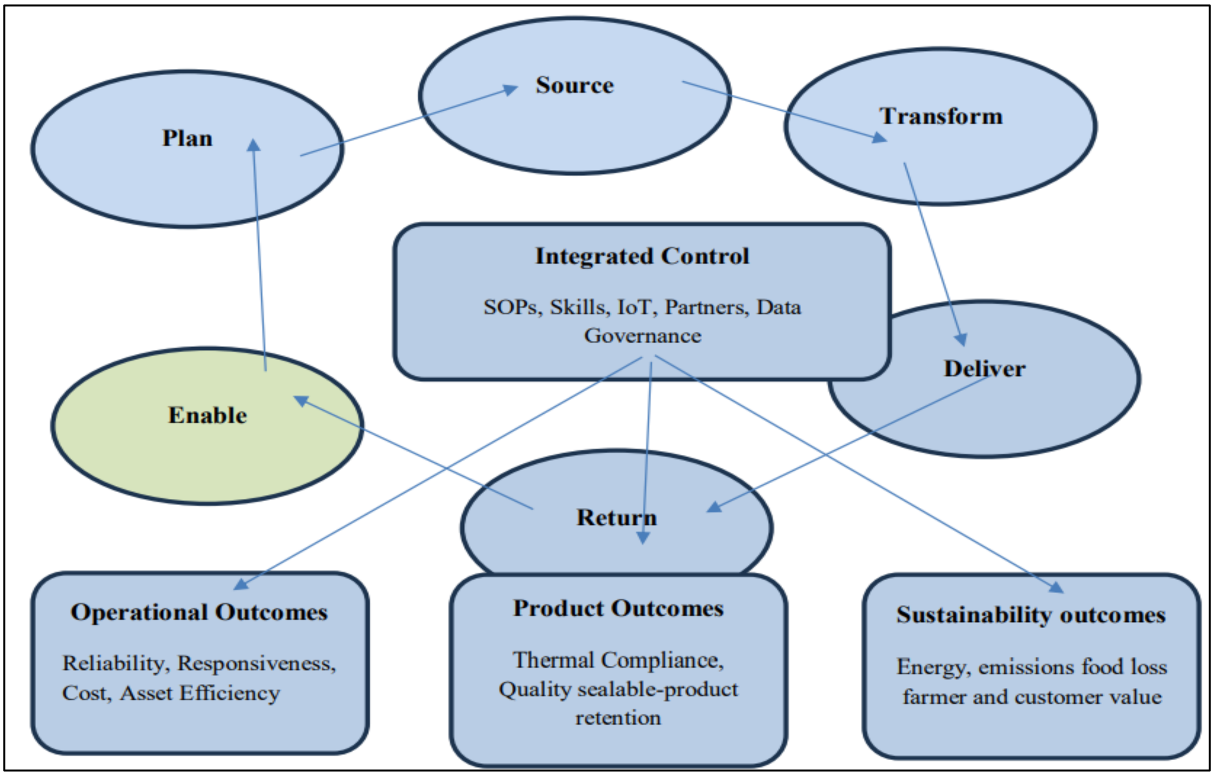

Fig 3 Extended SCOR framework linking processes with operational, product and sustainability outcomes

➢ *Performance Measurement Framework*

Table 3 Performance Measurement Framework

Dimension	Core indicator	Operational definition
Reliability	Perfect cold-chain order	Complete, on time, damage-free and thermally compliant orders ÷ total orders
Thermal integrity	Excursion-free trip rate	Monitored trips without a threshold breach ÷ monitored trips
Quality	Saleable-product retention	Saleable quantity at handover ÷ accepted quantity at origin
Responsiveness	Order fulfilment cycle	Confirmed booking to compliant consignee handover

Terminal	Temperature-controlled dwell	Gate-in to departure plus arrival to compliant gate-out
Assets	Productive asset utilisation	Loaded compliant operating time ÷ available specialised-asset time
Cost	Cost per saleable tonne-km	Attributable end-to-end cost ÷ saleable tonne-km
Energy	Cooling-energy intensity	Electricity and fuel-equivalent energy ÷ saleable tonne-km
Environment	GHG intensity	Life-cycle kg CO2e ÷ saleable tonne-km and successful order
Visibility	Complete trip record	Trips with retrievable calibrated location and condition data ÷ monitored trips

Three adjustments are important. First, the denominator should be saleable output where possible, preventing apparent efficiency gains that sacrifice quality. Second, measures should be disaggregated by commodity, route, season, customer and equipment type; annual averages can hide extreme-weather or interchange failures. Third, reliability must be multiplicative in practice: timeliness without thermal conformity, or conformity with incomplete delivery, is not a perfect order.

➢ *Strategic Fit of Ice Battery*

IceBattery is most likely to add value on predictable lanes where cargo is properly pre-conditioned, door openings are controlled, the thermal envelope is validated and stored cooling bridges a rail or terminal segment that would otherwise require a genset. It is less suited as a stand-alone solution where journeys are highly uncertain, product enters warm, heat loads vary substantially or intervention is unavailable after stored capacity is exhausted. Hybrid backup can widen the operating envelope but changes both cost and emissions.

Table 4 Strategic Fit of Ice Battery

Decision factor	**Ice Battery or hybrid advantage**	**Principal risk**
Predictable route and dwell	Thermal capacity can be sized to the operating envelope	Delay beyond validated holdover
Pre-cooled cargo	Stored cooling preserves rather than pulls down temperature	Warm loading exhausts capacity early
Limited plug-in availability	Avoids continuous genset use during selected stages	Charging infrastructure shifts energy upstream
Intermodal handovers	Passive continuity during transfer	Door openings and staging create local heat load
Digital monitoring	Traceable condition and exception alerts	Sensor failure or unclear alert ownership
Reusable modules	Repeated use may improve lifecycle economics	Reverse logistics, loss and payload displacement

➢ *Research Propositions and Empirical Validation*

The case analysis supports propositions that can be tested once operational data become available.

- P1: On thermally validated long-distance lanes, IceBattery-enabled hybrid equipment is associated with lower in-transit diesel energy per saleable tonne-kilometre than conventional diesel-powered reefer equipment.
- P2: The positive effect of passive thermal storage on excursion-free delivery is moderated by cargo entry temperature, ambient heat load, door-opening frequency and unplanned dwell.
- P3: End-to-end digital condition visibility improves perfect-order performance only where alerts have predefined ownership, escalation and intervention protocols.
- P4: Rail-linked cold-chain cost advantage increases with shipment aggregation, scheduled service reliability and balanced return flows.
- P5: Facility and specialised-asset utilisation mediates the relationship between network scale and financial sustainability.
- P6: Saleable-product retention provides a more valid efficiency denominator than dispatched tonnage for comparing cold-chain technologies.

A matched-trip design should compare conventional road reefers, powered reefer containers and IceBattery-enabled systems while holding commodity, route, season, load, packaging and service level as constant as feasible. Each trip should record product core and air temperature at origin; calibrated multi-point temperature and humidity; GPS trace; door events; terminal dwell; active refrigeration run-time; electricity and fuel; ambient temperature; arrival quality; rejection or spoilage; payload; and total cost. Mixed-effects regression can account for repeated routes, commodities and equipment, while life-cycle assessment can estimate emissions under consistent boundaries. Sensitivity analysis should vary electricity mix, return movement and payload penalty

V. DISCUSSIONS

➢ *From Asset Portfolio to Integrated Service*

The central finding is an integration gap. Public evidence indicates strategically placed facilities, specialised assets and promising demonstrations, but an integrated cold-chain service requires common standards, coordinated schedules, unified data and commercial accountability across organisational boundaries. CONCOR's advantage is not that it owns every cold-chain function; it is that its rail-linked network can orchestrate partners around corridors. This shifts managerial attention from facility counts to flows, service levels and repeatable lane economics.

Commodity corridors should be selected using production concentration, seasonality, shelf life, buyer demand, rail transit and backhaul potential. Anchor customers can stabilise base demand, while FPOs and shared-user aggregation can include smaller producers. Modular pre-cooling and cold rooms at origin nodes may be preferable to large fixed investments where demand is uncertain. At destination, booked last-mile capacity should be synchronised with rail arrival to prevent avoidable dwell.

➢ *Sustainability Without Overclaiming*

A lower-carbon narrative is plausible but must be measured. Rail can reduce line-haul emissions relative to road on suitable corridors, while thermal storage can avoid some continuous diesel refrigeration. The combined benefit is not additive by assumption. Electricity used to charge modules, refrigerant leakage, module manufacture and life, payload displacement, first- and last-mile transport and reverse logistics all influence net performance. Emissions should therefore be reported per functional unit—preferably one saleable tonne delivered within specification over a defined lane—and accompanied by boundary and load-factor disclosure.

➢ *Managerial Implications*

- Establish corridor-level profit and performance accounts rather than aggregating all cold-chain activity.
- Create commodity-specific SOPs covering acceptance, pre-cooling, module conditioning, airflow, loading, monitoring, handover and claims.
- Use independent calibrated loggers during validation, even when equipment contains an integrated sensor platform.
- Define service-level agreements for temperature band, permissible excursion, maximum dwell, data availability and liability.
- Integrate booking, rail events, GPS, temperature, humidity, door status and exception response in a cold-chain control tower.
- Publish a limited annual dashboard of throughput, usable capacity, utilisation, perfect orders, quality loss, energy and emissions intensity.

➢ *Policy Implications*

Public support should prioritise interoperable corridors and verifiable outcomes rather than isolated capacity. Rail-linked cold hubs can be connected with FPO aggregation, pack houses, food parks, ports and urban distribution centres. Standards for sensors, calibration, data retention and thermal qualification would reduce disputes and enable cross-operator benchmarking. Green finance or incentive support should be tied to independently verified fuel, emissions and food-loss outcomes.

VI. CONCLUSION

CONCOR offers a distinctive pathway for extending India's cold chain through rail-linked multimodal logistics. FHEL, selected perishable cargo centres, cold-storage capability, specialised containers and digital systems provide a foundation, while IceBattery technology offers a means of storing cooling in conditioned phase-change modules for use during transport and dwell. The technology's strategic relevance lies in reducing dependence on continuous diesel refrigeration on suitable, validated lanes—not in eliminating active cooling under all conditions.

The extended SCOR framework developed in this paper shows how planning, sourcing, transformation, delivery, return and enabling processes must work together. It redefines reliability to include thermal conformity and quality retention, and it links cost, asset, energy and emissions indicators to saleable delivery. The immediate managerial priority is to validate commodity corridors through matched trips, publish comparable operational evidence and convert demonstrations into scheduled services with clear accountability. Until those data are available, claims of cost, spoilage or emissions improvement should remain conditional. With disciplined aggregation, reliable rail schedules, integrated first and last miles, and transparent measurement, CONCOR can become an important institutional platform for a more efficient and lower-carbon Indian cold chain.

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