AMERICAN UNIVERSITY OF BEIRUT
ADVISORY

SUPPLY-CHAIN INNOVATION

THE 45% FRESHNESS EDGE

Research insight based on work by
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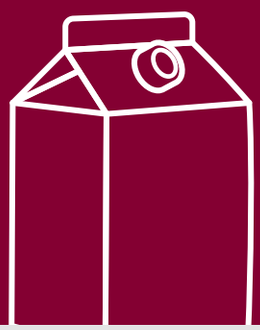
How smart labels and artificial intelligence could turn product freshness into better inventory decisions, lower waste, and stronger cold-chain resilience

[1] "Towards Optimized Perishable Inventory Systems: Integrating Time-Temperature Indicators with Deep Reinforcement Learning", *International Journal of Production Research.*

Two cartons of milk can carry the same expiration date and have very different remaining lives.

One may have spent an hour on a hot loading dock; the other may have remained perfectly refrigerated.

Yet most inventory systems treat them as identical. New research shows how that information gap can become a source of competitive advantage.



Across food and pharmaceutical supply chains, temperature is not simply a logistics detail. It determines quality, safety, and value. The Food and Agriculture Organization has documented substantial losses, 14 percent of its food supply, a shocking $936 billion in annual global losses, across global food supply chains, much of it before products reach consumers. In healthcare, an interruption in refrigeration can compromise vaccines and medicines, creating both financial losses and public-health risks.

A recent study by Sirine Taleb of the American University of Beirut, Chaaben Kouki of ESSCA School of Management, and Lama Moussawi of the American University of Beirut examines a more intelligent way to manage this uncertainty. Their approach connects real-time evidence about product condition with an artificial intelligence system that learns how much inventory to order. In the study's modeled settings, this combination generated profit improvements of up to 45 percent under the conditions in which freshness information was most valuable.

WHY EXPIRATION DATES ARE NOT ENOUGH

Conventional expiration dates are designed to be simple and safe, but they are also static. They usually reflect assumptions about how a product should be handled rather than its actual thermal history, making them an imperfect proxy for remaining shelf life: a poorly handled item may deteriorate before its printed date, while a consistently chilled item may retain quality longer.

The operational problem is even harder. Managers must decide what to order while demand changes, stock arrives in different age groups, and temperature excursions accelerate deterioration. Each additional product condition creates another state the decisionmaker must track. Traditional inventory rules can work well in stable environments, but they are inadequate when product quality is continuously changing and the number of possible scenarios becomes too large.

A SMARTER PAIRING: SENSING PLUS LEARNING

The researchers' contribution is not a sensor alone or an algorithm alone. It is the integration of the two.

1. SMART LABELS REVEAL ACTUAL PRODUCT CONDITION

Time-Temperature Indicators, or TTIs, are labels attached to temperature-sensitive products. The labels change color according to the product's accumulated exposure to temperature and degradation history. Instead of relying exclusively on the calendar, a business gains information about how much useful life may remain.

2. ARTIFICIAL INTELLIGENCE LEARNS THE ORDERING DECISION

The model integrates Deep Reinforcement Learning, which is based on an algorithm called Proximal Policy Optimization (PPO). In plain language, the system tests thousands of simulated decisions, observes their consequences, and progressively learns how much to order in each period. The objective is to improve profit while accounting for spoilage and the changing quality of inventory.

3. FRESHNESS INFORMATION BECOMES OPERATIONAL

This is the crucial link. A label has limited business value if the information it contains does not change what the company does. By feeding quality information into the ordering policy, the proposed system turns freshness from a passive observation into an active management input.

THE MANAGEMENT TAKEAWAY

Visibility creates value only when inventory replenishment, pricing, and sales decisions respond dynamically to new information that the sensor reveals.

WHAT THE STUDY FOUND

The researchers compared the AI-driven method with two alternatives: the familiar base-stock policy, which orders up to a predetermined inventory level, and a more recent projected-inventory-level policy. The learning-based approach was consistently more profitable in the simulations. In addition, its advantage grew when products deteriorated more quickly and demand became more variable.

The headline result, however, should not be read as a universal guarantee. The largest gains emerged when the pace of deterioration was well matched to the share of customers seeking fresher rather than discounted products. When those conditions were poorly aligned, profit could decline. The economics of the label also matter: the per-unit cost must be low enough to be recovered through better decisions (Taleb et al., 2026).

These boundary conditions make the research more, not less, useful. They give managers a practical investment test. Before deploying smart labels at scale, a company should understand deterioration rates, demand volatility, customer sensitivity to freshness, its ability to differentiate prices and the cost of integrating sensor data with inventory systems.

WHY THE MENA REGION HAS MUCH TO GAIN

The implications are especially significant for the Middle East and North Africa. Many countries in the region depend heavily on imported food and operate in conditions of extreme heat, which raises the cost of maintaining product integrity across long and sometimes disrupted routes. At the same time, demand for fresh food, pharmaceuticals, and other temperature-sensitive goods is rising. The regional cold-chain sector is already expanding its use of artificial intelligence, connected sensors, and real-time monitoring (Maersk, 2025).

In this setting, TTI-enabled inventory management can support three priorities at once. First, it can strengthen food security by helping importers and distributors identify which products should move first and how replenishment should adjust after delays.

Second, it can reduce waste by distinguishing fresher products from aging stock and enabling differentiated pricing or faster sales before spoilage. Third, it can improve resilience when geopolitical disruptions or transportation bottlenecks affect refrigerated goods (GCCA, 2026).

The same logic applies to healthcare. Medicines and vaccines require tightly controlled storage and transport. Hospitals, pharmacies, and distributors could use real-time quality signals to protect efficacy, reduce avoidable disposal, and prioritize critical supplies. In both food and pharmaceuticals, better information can help scarce imported resources travel further.



FROM PROMISING MODEL TO PRACTICAL INVESTMENT

The study points toward a staged implementation path. Companies who are considering implementation would be well advised to begin with a product category in which spoilage is costly, demand is uncertain, and temperature exposure materially affects quality. A pilot project should be organized to connect the label data to an actual decision—ordering, allocation, markdowns, or stock rotation. Improvement should then be measured against the full cost of labels, data capture, system integration, and process change.

Managers should also resist treating artificial intelligence as a stand-alone technology purchase. The value of AI comes when it is integrated as part of a decision system: reliable sensing, usable data, an algorithm trained for the operating environment and people who know when to trust, test or override its recommendation. Governance is particularly important in pharmaceutical settings, where safety requirements and traceability must remain paramount.

THE BROADER LESSON IS SIMPLE:

freshness should be managed in real-time as it can create value that drives better decisions. By combining real-time information on product condition with AI-driven, adaptive inventory policies, companies can move beyond managing perishability based on fixed shelf-life assumptions. They can respond dynamically to how products are actually aging, reducing waste and costs, improving product availability, and making cold chains more efficient and resilient.

SOURCES

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