Analysis of the Risks of Damage to Perishable Goods During Transportation from Azerbaijan to Russia

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Abstract: This article is devoted to the optimization of supply chain management (SCM) for perishable goods transported by road from Azerbaijan to major industrial centers in Russia (Moscow, Saint Petersburg, Yekaterinburg, etc.), the identification of spoilage risks during transit, and the investigation of mitigation strategies. The study analyzes the specific characteristics of the cold chain within the International North-South Transport Corridor (INSTC). Utilizing the Arrhenius equation, a methodology is proposed to calculate the risk of physical damage to cargo due to temperature fluctuations, accompanied by an assessment of associated financial losses. Furthermore, the paper substantiates the effectiveness of implementing the Hub-and-Spoke model and IoT-based monitoring to enhance the resilience of the logistics network and minimize product losses during border crossings and transit.

Keywords: supply chains, perishable goods, Azerbaijan-Russia, cold chain, risk management, International North-South Transport Corridor (INSTC).

1. Introduction

Relevance of the topic. Within the context of the global restructuring of transport and logistics routes, the North-South Corridor has emerged as a vital artery for ensuring food security and fostering the development of the non-oil sector of the Azerbaijani economy. Russia remains the primary market for Azerbaijani fruit and vegetable products, with export volumes demonstrating stable growth in 2025. However, the transport of perishable goods over long-distance routes (e.g., exceeding 2,500 km to the Urals and Siberia) imposes exceptionally stringent requirements on the reliability of the "cold chain."

Traditional delivery methods on the Azerbaijan-Russia route frequently encounter bottlenecks at border crossing points (Samur-Yarag-Kazmalyar) and face various climatic risks. During road transport, even brief temperature fluctuations lasting a few hours can trigger irreversible biochemical degradation processes, leading to the loss of marketable appearance and a reduction in "residual shelf life." For businesses, this translates into direct financial losses, reaching 10-15% of the total cargo value.

Research objective: To develop a comprehensive supply chain management model that integrates mathematical risk assessment methods (degradation kinetics) with modern organizational solutions (the "Hub-and-Spoke" model).

Object of the study: The logistics system for the road transport of perishable goods from Azerbaijan to the major urban agglomerations of the Russian Federation.

Scientific Novelty: The novelty lies in the integration of predictive analytics (IoT monitoring) and insurance tools into a unified risk management algorithm along the route. This approach enables the minimization of losses and optimization of delivery times under conditions of high congestion within the transport corridor.

2. Methodology

This study employs a multi-criteria analytical approach to evaluate the efficiency and risks of the Azerbaijan-Russia perishable goods supply chain. The research methodology is based on the following key instruments:

Quantitative Risk Assessment: A risk-scoring model ($R = P \times S$) is utilized to quantify logistical hazards. The **Arrhenius Equation** and the Q_{10} **coefficient** are applied to calculate the **Remaining Shelf Life (RSL)** of products, providing a mathematical basis for the impact of temperature fluctuations on food degradation during transit.

Comparative Logistics Analysis: The study performs a comparative evaluation of three transport corridors (the Moscow-centric "Hub-and-Spoke" model, the direct "Agroexpress" rail route, and the Trans-Caspian route). These are assessed based on **Lead Time**, **Total Logistics Cost ($/t)**, and **Transshipment Frequency**.

Predictive Financial Modeling: A financial loss model ($L = V \times P_{los} \times C$) is developed to estimate the economic impact of cargo spoilage, incorporating logistics leverage and disposal costs.

Technological Integration: The framework integrates **IoT-based monitoring** and **Time-Temperature Indicators (TTI)** into the SCM logic to enable real-time risk mitigation and dynamic rerouting strategies.

3. Main Body

Azerbaijan is one of the largest suppliers of agricultural products (tomatoes, persimmons, and fruits) to Russia. By the end of 2025, Azerbaijani exports to Russia reached $1.184 billion, establishing the Russian market as the primary sales outlet for Azerbaijani agricultural cargo [9]. A significant portion of these exports consists of perishable fruits and vegetables, which necessitate a continuous **cold chain** and minimal delivery times. The international transport of perishable goods requires expedited customs procedures and the mitigation of delays at border crossings.

Consequently, ensuring technical support for transportation and establishing a robust **SCM (Supply Chain Management)** strategy are essential for the timely and preserved delivery of goods. **Refrigerated (reefer)** and isothermal trucks are utilized to maintain required temperature conditions during transit. A critical prerequisite for minimizing losses is the implementation of **IoT sensors** for real-time monitoring of temperature and humidity. Furthermore, mandatory documentation for the international transport of perishable agricultural goods includes sanitary passports for vehicles and driver logbooks.

Efficient transport organization relies on a well-structured delivery network, optimal routing, and the strategic use of hubs. It is recommended to establish the delivery network based on the **"Hub-and-Spoke"** principle. The primary delivery destinations include Moscow, Saint Petersburg, and other Russian cities with populations exceeding one million. Transportation is carried out via high-capacity trucks, rail, and **multimodal (road + rail)** transport. Berries and high-value produce with limited shelf life are transported in restricted volumes via air freight. The logistics chain extending from Azerbaijan to the remote regions of Russia (Siberia and Central regions) operates on the "cold chain" principle, coordinated by the Trade Representation of Azerbaijan in Russia and specialized logistics companies.

The delivery network originates in the agricultural regions of Azerbaijan, passes through Russian logistics hubs as intermediate points, and terminates in major Russian cities. Strategic partnerships between Azerbaijan's **"Food City Agrocomplex"** and major Russian entities such as **"X5 Import"** facilitate the distribution of products to various regions and cities across Russia. The key nodes of the delivery network are:

- **Hub 1 – Departure Point:** Khachmaz, Guba (fruits and vegetables);
- **Hub 2 – Departure Point:** Ganja, Shamkir region (fruits and vegetables);
- **Hub 3 – Departure Point:** Lankaran, Astara (citrus fruits);

- **Customs crossing:** Yarag-Kazmalyar–Samur border crossing point. This checkpoint is utilized for expedited clearance, providing priority processing for perishable goods;
- **Southern Cluster (Derbent/Makhachkala, Rostov-on-Don):** Primary sorting and transshipment. Delivery time via road: 12-24 hours.
- **Central Hub (Moscow and Moscow Region):** The largest distribution node (including "Food City," and terminals in Vorsino and Selyatino). Delivery time via road: 3-5 days.
- **Regional Branches:**
  - **Volga Region:** Rostov-on-Don, Volgograd, Kazan, Nizhny Novgorod. Delivery time: 2-5 days.
  - **Urals:** Yekaterinburg (the main hub for subsequent distribution to Siberia), Chelyabinsk, Tyumen. Delivery time: 5-8 days.
  - **Siberia:** Omsk, Novosibirsk (regional hub), Krasnoyarsk. Delivery time: 8-11 days.
  - **West:** Voronezh, Tula. Delivery time: 3-5 days.
  - **North-West:** Saint Petersburg. Delivery time: 5-7 days.
- **Retail Networks in the Russian Federation:**
  - X5 Group (Pyatyorochka, Perekrestok, Chizhik), Magnit, VkusVill, Lenta, Auchan, etc.

Note: Delivery times are significantly influenced by customs factors, seasonality, and the mode of transport. The efficient organization of transport must satisfy criteria for optimization and risk mitigation. To reduce costs and downtime, **"Location-Inventory-Routing"** models (harmonizing warehouse location and route selection) should be employed, while accounting for seasonal demand and border delays to minimize spoilage risks.

Building an effective model for the Azerbaijan-Russia corridor relies on the synchronization of customs procedures and the use of a unified digital platform for cargo tracking. Moscow serves as the primary distribution center in the delivery network, from which goods are dispatched to major cities with populations exceeding one million. Agricultural cargo from Azerbaijan is primarily distributed through the **"Food City" wholesale center (agro-cluster)** in the Moscow region. This center serves as both Russia's largest fruit and vegetable market and the main logistics hub for the entry of Azerbaijani products into the Russian market. Azerbaijan's "Food City Agrocomplex" processes and distributes a significant portion of fruit and vegetable imports through this hub.

Agricultural cargo transported by rail (e.g., wagons loaded at the Khachmaz terminal) is delivered directly to the Selyatino and Vorsino stations near Moscow. Through the **"Agroexpress"** service provided by JSC RZD Logistics, cargo is directed from these terminals to large-scale logistics centers across Russia’s domestic regions. Due to the "Agroexpress" project, the share of rail transport has increased rapidly. Notably, by implementing "Green Corridor" principles and utilizing high-speed freight trains, rail delivery times are often shorter than road transport. Within the "Agroexpress" framework, delivery times from Azerbaijan are as follows:

- **Baku – Moscow (Selyatino/Vorsino):** Approximately 2-3 days (the most utilized and fastest route).
- **Baku - St. Petersburg:** Approximately 5 days (cargo is typically routed through the Moscow hub).
- **Baku – Siberia (Novosibirsk, etc.):** Approximately 7-10 days.

These routes utilize unified tariffs and expedited transit regimes coordinated by **ADY Express** and **RZD Logistics**. The primary advantage of "Agroexpress" is the simplified customs clearance via the "Green Corridor" and transportation in refrigerated wagons at stable temperatures, preserving the freshness of produce.

While road transport (reefer trucks) remains the dominant mode for reaching the Moscow distribution network, Siberian deliveries primarily utilize the **International North-South Transport Corridor (INSTC)** and domestic rail lines [8]. The main route to Siberia follows the Moscow – Kazan – Yekaterinburg – Novosibirsk axis. In Yekaterinburg, the "Sverdlovsk Logistics Center" and

"Sofiskiy" wholesale bases serve as transit points between the Urals and Siberia. Novosibirsk acts as the primary regional distribution hub for Siberia, with the **"Khiloksky" market** serving as the largest wholesale point for incoming produce. In Krasnoyarsk, the **"Agroterminal" complex** functions as a distribution center for Central and Eastern Siberia. From there, goods reach the Pacific coast via the Novosibirsk → Krasnoyarsk → Irkutsk → Khabarovsk → Vladivostok route.

Supply chain summary:

Field (AZ) ➔ Agropark (AZ) ➔ Agroexpress/TIR ➔ Food City (Moscow) ➔ Regional Hubs (Siberia/Urals) ➔ Retail Shelf

This scheme ensures the delivery of products from the field to consumers in Siberia within 7-10 days.

Figure. 1. Transportation of perishable goods by road - from Azerbaijan to Russia to the Food City Agrocomplex in Moscow

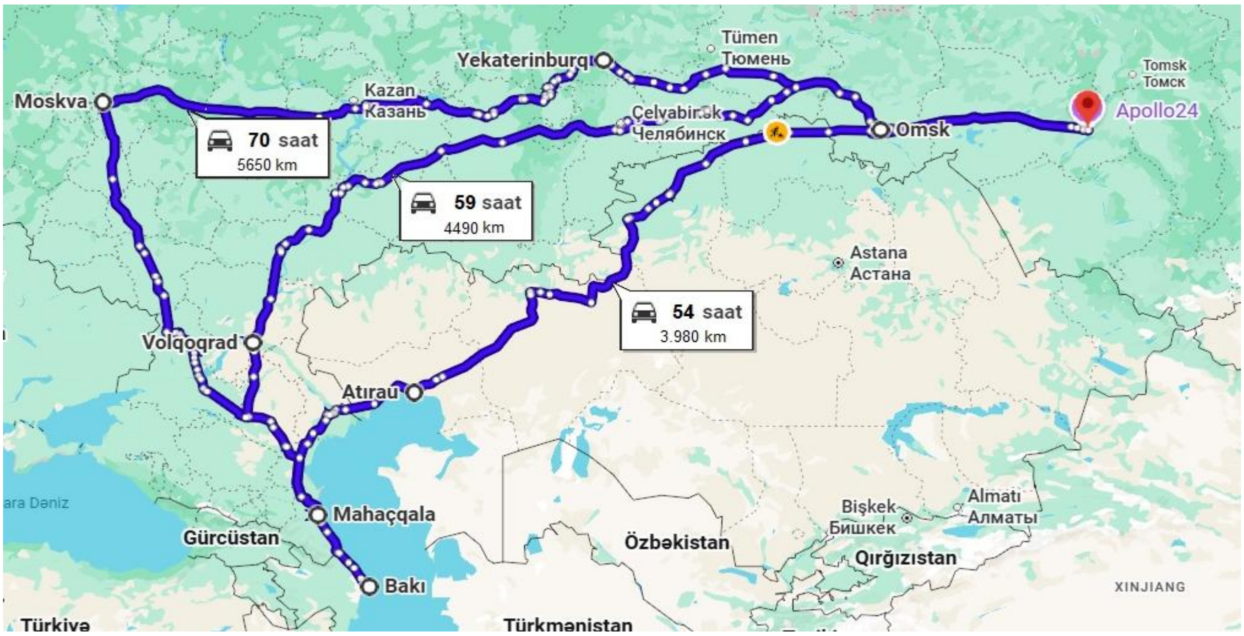

Figure 2. Transportation network for perishable agricultural cargo from Azerbaijan to the Siberian region of Russia

Siberian deliveries are also conducted via direct routes, bypassing Moscow. This approach both saves time and reduces the total transit distance. The primary direct routes include:

• **By road:** After crossing the Azerbaijan-Russia border, cargo proceeds through the North Caucasus and Volga regions (via Astrakhan or Volgograd). Bypassing Moscow, it follows roads near the Kazakhstan border directly toward the Urals (Chelyabinsk/Yekaterinburg) and onwards to Siberia (Omsk, Novosibirsk) [12, 8].

• **By rail:** Certain routes organized by ADY Express and RZD Logistics can redirect cargo along Russia's southern rail lines directly toward the Urals and Siberia without entering the Moscow hub (Selyatino) [8].

Nevertheless, the majority of cargo still passes through Moscow, as massive centers like "Food City" facilitate sorting, documentation, and distribution to various buyers. However, for large-scale shipments (e.g., those destined directly for the Novosibirsk market), utilizing **bypass routes** is more efficient [9].

If goods are transported from Azerbaijan via the **Baku – Moscow – Yekaterinburg – Omsk – Novosibirsk** route, the total distance is 5,650 km. If the transport bypasses Moscow and moves directly toward Novosibirsk via Volgograd, the distance is reduced by approximately 1,150 km, totaling 4,490 km. A direct route via Astrakhan and the Caspian region shortens the distance by an additional 510 km; however, this route entails transit through Kazakhstan, leading to delays and two additional customs checkpoints. Furthermore, the poor technical condition of roads in northern Kazakhstan hampers transportation speed. Reducing both distance and transit time is critical for perishable goods, as increases in these factors heighten the risk of spoilage. Consequently, in this context, transportation is preferred to be carried out without entering Kazakh territory.

The following primary risks must be considered during the transportation of perishable cargo:

1. Temperature risk
2. Time risk
3. Commercial risk
4. Infrastructure risk
5. Regulatory/ Organizational risk
6. Financial risk

Table 1. Temperature risks

Route	🚚 Road Transport	🚆 Multimodal Transport
Via Moscow	Medium	**Down**
Via Volgograd	**High**	Medium

Key Risk Factors in Shipments via Moscow:

• Advanced refrigeration facilities;
• Control upon receipt (FOOD CITY);
• Probability of "back-loading" (securing additional cargo batches).

***Key Risk Factors in Direct Shipments via Volgograd / Astrakhan*:**

Long-distance transportation without backup refrigeration;
Violation of temperature regimes leading to instantaneous quality loss;
Compliance with temperature protocols is particularly critical for apricots, peaches, and berries.

⚠️ ***Highest Risk Option:*** Direct road transport of apricots and berries.

Table 2. Time Risks (Durations)

Risk factor	Via Moscow	Via Volgograd
Queues/Downtime	Medium	Down
Unpredictability	Down	**High**
Delay = Damage	Partially compensated	Not compensated

Shipments via Moscow serve as a **risk buffer**: in case of delays, goods can be redistributed, sold in parts, or the buyer can be changed. The Southern route lacks such a buffer.

Table 3. Commercial (Sales) Risks

Risk	Via Moscow	Via Volgograd

Customer Loss	Down	**Critical**
Price Impact	Medium	**High**
Alternative Sales	Yes	Almost none

In direct shipments to Siberia: **One buyer = Entire batch**; rejection leads to forced unloading.

4. Infrastructure risks

- 🚛 **Direct Road Transport:** Refrigeration unit failure, lack of emergency storage, high dependence on the driver.
- 🚆 **Multimodal Transport:** Risk of overloading, train delays; however, temperature stability is superior.

Table 4. Infrastructure Risks

Route	Overall Assessment
Rail via Moscow	Most Reliable
Rail via Volgograd	Medium
Road only	Highest Risk

Table 5. Regulatory and Organizational Risks

Factor	Moscow	Volgograd
Veterinary Control	Regulated	Inconsistent
Document Turnover	Standard	Region-dependent
Logistics Support	High	Medium

Table 6. Final Comparative Risk Profile

Scheme	Berry Transport	Tomato Transport
Rail via Moscow	Low	Low
Road via Moscow	Medium	Medium
Rail via Volgograd	Medium	Medium
Road via Volgograd	High	High-Medium

Conclusion of Risk Analysis:

The bypass via Moscow is preferred for persimmons, grapes, berries, batches < 22t, or when a 100% buyer is not guaranteed. Direct routes are efficient for tomatoes/apples and batches ≥ 22-24t with direct contracts.

Current Market Share of Routes:

1. **Via Moscow (INSTC Western Corridor):** 70-80% of deliveries. Logic: Consolidation at Wholesale Distribution Centers (WDC) like "Food City."
2. **Bypassing Moscow (via Volgograd/Astrakhan):** 15-20% share, growing due to the **"Agroexpress"** project. Reduces transit by 2-3 days.
3. **Trans-Caspian Route (via Kazakhstan):** < 5%. Hindered by high ferry costs and road conditions.

Cost Comparison (2024–2025) for Reefer Trucks (20-ton):

- **Via Moscow:** $5,500–$7,000 (10–14 days).
- **Agroexpress (Direct Rail):** $4,500–$5,200 (5–8 days). Savings: 15–20%.
- **Estimated Cost:** Exceeding $8,000. The primary cost drivers are the ferry crossing fees (approximately $1,200 – $1,500 just for the Caspian Sea transit) and port charges.
- **Duration:** Unpredictable (highly dependent on weather conditions in the Caspian Sea), averaging 12–15 days.

Consequently, for comparative purposes, we can examine the transportation of two high-volume goods—persimmons and tomatoes—comparing routes via Moscow and direct routes via Volgograd (Table 7).

Table 7. Comparative Analysis of Persimmon and Tomato Transportation: Via Moscow vs. Direct to Novosibirsk

Parameter	Through Moscow (FOOD CITY)	Via Astrakhan/Volgograd
Total route distance	Longer	Shorter.
Number of transshipments	2–3	1–2
Quality assurance	Maximum	Medium
Market accessibility	Very high	Limited
Batch consolidation	Flexible	Limited
Delivery lead time	10–13 days	8–11 days
Spoilage risk (Persimmons)	Lower	Higher
Spoilage risk (Tomatoes)	Low	Medium.
Average logistics cost ($/ton)	435–600	380–520
Retail chain suitability	Yes	Limited
Wholesale suitability	Yes	Yes
Scalability	High	Medium

Logistics Plan and Estimated Timeline for the Baku–Novosibirsk Route

The following schedule outlines the primary stages and estimated timelines for the delivery of perishable goods along the Baku–Novosibirsk route. The total estimated transit time via road transport is approximately 9–10 days.

Table 8. Delivery Schedule for the Baku – Novosibirsk Route (Sample)

Stage	Operational Activity	Estimated Timeline
Stage 1	Loading and shipping (Baku, Azerbaijan). Cargo preparation (cooling, refrigerated packaging), preparation of primary documents (CMR, invoice, phytosanitary certificate).	Day 0
Stage 2	Drive to the border. Drive to the Yarag-Kazmalar (RF) / Samur (Azerbaijan) checkpoint. The distance is approximately 200-220 km.	Day 1
Stage 3	Customs and border control. Priority clearance of perishable goods at checkpoints. Procedures can take from several hours to a day, depending on the level of congestion at the checkpoint.	Day 2
Stage 4	Movement in the Russian Federation (Southern Federal District, North Caucasus Federal District, Volga Region). Movement along the route	Day 3-4

	through Dagestan, Kalmykia, Volgograd, Saratov, Samara and Orenburg regions (approximate route). Distance approximately 2000 km	
Stage 5	Travel through the territory of the Russian Federation (Urals). Travel from Bashkortostan, Chelyabinsk region to Yekaterinburg. Distance approximately 2930 km	Day 5-6
Stage 6	Movement through the territory of the Russian Federation (Siberia). Movement from Tyumen, Omsk, Novosibirsk region to Novosibirsk. Distance approximately 4540 km	Day 7-8
Stage 7	Arrival and unloading (Yekaterinburg, Russia). Customs clearance (if not completed at the border), phytosanitary inspection at destination, delivery to the customer's distribution center/warehouse.	Day 9-10

Key Supply Chain Management (SCM) Aspects for this Route:

- **Ensuring the "Cold Chain":** Continuous maintenance of the specified temperature within the refrigerated unit throughout the journey (up to 10 days) is critical.
- **Digitalization:** The utilization of **IoT sensors** (temperature and humidity) enables both shippers and receivers to monitor cargo status in real-time and respond immediately to any deviations from the planned transit schedule [10].
- **Optimization of Border Throughput:** Increasing the capacity of the **Yarag-Kazmalyar** checkpoint reduces downtime, which is vital for perishable goods.

It should be noted that the throughput capacity of the Russian-Azerbaijani border crossing points has been increased, and the reconstruction of the Yarag-Kazmalyar checkpoint has been completed. According to Valentin Ivanov, Deputy Minister of Transport of the Russian Federation, 1,700 vehicles now cross the Russia-Azerbaijan border daily, which is a fourfold increase compared to 2021.

A multi-factor model is employed to calculate the **Food Loss Risk**. The core expression is based on the kinetics of chemical reactions within the product and the probability of equipment failure.

4. Research Methods and Calculation Examples

The primary calculation methods applied during the transport of perishable goods are:

1. **"Remaining Shelf Life" (RSL):** This is the most accurate method, indicating the percentage of a product's lifespan lost during transportation.
   - **Arrhenius Equation:** This allows for the calculation of how much spoilage accelerates when the temperature regime is violated.
   - **Principle:** Every 10°C increase in temperature accelerates chemical processes within the product by 2–3 times (**Q10 coefficient**).
   - **Calculation Rule:** If a refrigerator maintains +14°C instead of +4°C for one day, the product "ages" by 3 days within that 24-hour period.
2. **Probability model (Risk Score):** Risk (R) is calculated as the product of the probability of an event (P) and the severity of the consequences (S):

$$R = P \times S$$

Where:

- ***P*** **(*Probability*):** Depends on the technical condition of the vehicle fleet and delay statistics at the border (Samur/Yarag-Kazmalyar).
- ***S*** **(*Severity*):** Depends on the type of cargo. For instance, the severity (S) for tomatoes from Azerbaijan is higher than for potatoes.

3. Comprehensive Risk Assessment: To evaluate all risks collectively:

$$R_{total} = \sum_{i=1}^{n} R_i$$

Where:

- ***n*****:** Number of risk factors
- ***R***

4. Weighted Risk Model (Realistic Approach): Since some risks are more critical than others, a weighted model is used:

$$R_{weighted} = \sum_{i=1}^{n} (w_i \times R_i)$$

Where:

w_i**:** Weight of the risk factor.

Condition: $\sum w_i = 1$

5. Risk Factors for Perishable Cargo: The following factors can be utilized in the model:

1. Cold chain violation;
2. Border delays;
3. Vehicle malfunction;
4. Document discrepancy;
5. Fuel prices fluctuations;
6. Market price volatility.

Calculation example

Risk	P_i	S_i	w_i	*Risk*
Cold chain disruption	P_1	Q_1	w_1	R_1
Border delay	P_2	Q_2	w_2	R_2
Transportation failure	P_3	Q_3	w_3	R_3
...	...	...	...	...
Market price change	P_i	Q_i	W_i	R_i

By performing a pairwise comparison of factors using the **Analytic Hierarchy Process (AHP)**, we can conduct a risk assessment to determine the **weight (*w_i*)** of each risk factor.

6. Logistics Risk Function

The overall risk of the transportation process can be modeled as follows:

$$R_{total} = f\left(T, B, V, D, M\right)$$

Where:

- ***T*** **(Temperature Risk):** Violation of the cold chain;
- ***B*** **(Border Delay):** Delays at customs and border crossing points;
- ***V*** **(Vehicle Risk):** Technical malfunction of the transport vehicle;
- ***D*** **(Document Risk):** Discrepancies in documentation;
- ***M*** **(Market Risk):** Fluctuations in market prices.

7. Financial Risk Assessment (*L*)

This assessment helps determine the potential monetary loss of a company by accounting for probabilities:

$$L = V \times P_{loss} \times C$$

Where:

- V **(Volume/Value):** The total volume or cost of the cargo;
- P_{loss} **(Spoilage Coefficient):** The statistical percentage of defects recorded for a specific route;
- C **(Current Market Price):** The prevailing market price at the destination point (e.g., Moscow or Yekaterinburg).

8. Integration of IoT Data (Real-time Risk)

Modern SCM systems utilize the Time-Temperature Indicator (TTI) index. Sensors installed in the vehicle transmit data every 15 minutes. If the temperature profile deviates from the "green zone," the system automatically calculates the risk percentage. For example: "*Under current conditions, the batch write-off risk is* 15%."

Practical example for the Baku-Yekaterinburg route: If a truck is delayed at the border for 48 hours instead of 12, and the ambient outdoor temperature is +30°C, the risk of damage increases exponentially.

Table 9. Cargo Spoilage Risk Calculator (Model)

No.	Parameter	Value (Sample)	Explanation
A	Product type	Tomato / Persimmon	Influences the base **Shelf Life**
B	Planned Delivery Time (hours)	144	E.g., 6 days to Yekaterinburg
C	Base temperature (°C)	+4	Set refrigeration regime
D	Average deviation temperature (°C)	+12	If the unit fails or is opened for inspection
E	Duration of Deviation (hours)	12	Time spent outside the required regime
F	Acceleration coefficient (Q_{10})	2.5	Standard for vegetables (spoilage accelerates 2.5x per +10°C)

Calculations are performed via Excel as follows:

1. **Calculating Spoilage Acceleration:**

$$Q_{10\_adj} = F^{((D-C)/10)}$$

In our sample (at +12°C instead of +4°C), the product spoils 2.08 times faster.

2. **Lost Time Equivalent (hours):**

$$T = E \times \left(Q_{10\_adj} - 1\right)$$

For every 12 hours of deviation, the product loses an additional 13 hours of "shelf life."

3. **Risk index (%):**

$$R = (\text{Equivalent Loss/Total Shelf Life}) \times 100$$

If the total shelf life of tomatoes is 14 days (336 hours), then the spoilage risk for this batch increases by 4–8% due to a single border delay event.

It is crucial to emphasize that the Samur checkpoint is a critical bottleneck in the Azerbaijan-Russia supply chain. At ambient temperatures of +30°C, even with functioning refrigeration units (which consume significant fuel and resources), delays at this point heighten the risk of price markdowns upon arrival in Yekaterinburg.

For a 20-ton truckload of tomatoes, if 10% of the cargo is spoiled, the estimated financial loss – excluding logistics and disposal costs – is approximately \$3,000 (5,100 AZN / 285,000 RUB). The calculation steps are as follows:

Step 1: Determining the Market Value of the Cargo

Since losses are calculated based on the selling price rather than the purchase price, the total value (V) of the shipment upon arrival at the destination (e.g., Yekaterinburg) must be determined:

$$V = Q \times P$$

Where:

- ***Q (Quantity):*** *Standard reefer truck capacity (20,000 kg).*
- ***P (Price):*** *Average wholesale price per kg (assumed at 1/50 for 2026)/*
- ***Total Value:***

V = 20,000 \times 1.5 = \$30,000\$

Step 2: Calculating Direct Financial Losses

Direct losses (L_{direct}) arise from the physical spoilage of a portion of the goods, calculated using the risk index (R) derived in previous sections:

$$L_{direct} = V \times R$$

For a 10% spoilage risk ($R = 0.1$):

- **In USD:**

$$L_{direct} = 30{,}000 \times 0.1 = \$3{,}000$$

- **In AZN (rate 1.70):** 5,100 AZN.
- **In RUB (rate ~95):** 285,000 RUB.

Step 3: Accounting for Associated Damages (Logistics Leverage)

The actual damage to the SCM system is higher because freight has already been paid for spoiled goods, and disposal costs must be incurred:

$$L_{total} = L_{direct} + (C_{log} \times R) + C_{util},$$

Where:

- C_{log} **(Logistics Cost):** Freight rate (approx. \$4,500–\$5,500 for Baku-Yekaterinburg in 2026).
- C_{util} **(Disposal Cost):** Costs for removing and destroying spoiled products.

Total Financial Risk: If 10% of the cargo is damaged, in addition to losing \$3,000 worth of goods, approximately \$500 in logistics expenses is "sunk," increasing the total loss to \$3,500.

To mitigate these losses, it is recommended to utilize extended carrier liability insurance (CMR insurance) covering temperature violations and to apply dynamic routing: if sensor-measured spoilage risk exceeds 5%, the cargo can be diverted to the nearest major city (e.g., Samara instead of Yekaterinburg) to be sold before total quality loss occurs.

Insurance and Claims Processing

In the Azerbaijan-Russia logistics sector, CMR insurance covering thermal risks is the primary document for claims. Insurance companies typically process payouts in three stages: Insurance companies calculate payments in 3 stages:

1. **Verification of the Insurance Event (Causality):**
   - **Data Logger File:** The primary evidence. An event is compensable if the sensor detects a deviation from the prescribed temperature of more than 2-3°C for several hours.
   - **Technical Condition of the Reefer:** If the failure is due to wear and tear of a non-maintained unit, the claim may be denied due to "gross negligence."
2. **Loss Assessment (The "Markdown" Method):**

- Payouts are calculated as: **Payout = (Invoice Value) × (% Quality Loss) – (Deductible)**.
- **Note:** The value is based on the **invoice (purchase) price**, not the market price at the destination. Lost profits are generally not covered.

3. **Mitigation Measures:**
Under insurance terms, the carrier is obligated to minimize losses. If a reefer fails, the carrier must attempt to sell the product locally at a discount or transship the goods to another refrigerated unit. Failure to take these steps may result in a reduced payout.
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5. Conclusion and Recommendations

1. Transition to Active Monitoring. The implementation of end-to-end control systems using **IoT sensors** is not an overhead cost but a vital risk mitigation tool. It is recommended to shift from passive data loggers, which are only read at the destination, to real-time sensors. This enables **dynamic rerouting**; if the spoilage risk becomes critical before reaching Yekaterinburg, the cargo can be redirected to the nearest high-population urban centers (e.g., Samara or Kazan) to ensure timely sale.

2. Diversification and the "Hub-and-Spoke" Model. To enhance supply chain resilience, the adoption of **cross-docking** systems within the Southern Federal District is advised. Establishing buffer zones with refrigerated storage capacities near the border (Dagestan) allows for the temporary "holding" of products during customs delays without compromising quality.

3. Optimization of the "Green Corridor." It is essential to maximize the potential of simplified customs procedures under the **Agroexpress** project and ensure priority passage for perishable goods at the Yarag-Kazmalyar checkpoint. Synchronizing electronic document exchange between shippers and the Federal Customs Service of the Russian Federation can reduce border idle time by 30–40%.

4. Insurance Hygiene. SCM managers should strictly vet carriers operating without extended temperature-risk insurance. Incorporating contract clauses that mandate **"unconditional liability for temperature monitoring compliance"** instills discipline in logistics partners and protects overall revenue.

5. Predictive Analytics. The application of mathematical models (e.g., the Arrhenius equation and Q_{10} coefficient calculations) should be integrated into operational workflows. This allows sales departments to anticipate the volume of defective goods and adjust marketing activities at retail outlets accordingly.

References

1. **Ait-Oubahman, A., & Johnson, A.** (2020). *Quantitative Risk Assessment in Cold Chain Logistics: A Mathematical Approach*. Journal of Food Engineering, 274, 109845.
2. **Badia-Melis, R., Garcia-Hierro, J., & Ruiz-Garcia, L.** (2018). *The role of IoT in the management of the food cold chain*. Food Control, 34(1), 129-140.
3. **Bowersox, D. J., & Kloss, D. J.** (2008). *Logistical Management: The Integrated Supply Chain Process*. McGraw-Hill Education.
4. **Chopra, S., & Meindl, P.** (2016). *Supply Chain Management: Strategy, Planning, and Operation*. Pearson Education.
5. **Eurasian Economic Union.** (2024). *Customs Code of the Eurasian Economic Union: Regulations on the Movement of Goods Requiring Special Transportation Conditions*.
6. **Food and Agriculture Organization (FAO).** (2024). *Technological Standards: Guidelines for the Implementation of IoT and Time-Temperature Indicators (TTI) in Cold Chains*. Rome: FAO Publications.

7. **Hsiao, H. I., van der Vorst, J. G., & Kemp, R. G.** (2010). *A classification of logistics outsourcing in food supply chains*. British Food Journal.
8. **INSTC.** (2025). *North-South Logistics Corridor Reports: Strategic Analysis of the International North-South Transport Corridor for 2024-2025*.
9. **State Customs Committee of the Republic of Azerbaijan & Federal Customs Service of Russia.** (2025). *Statistical Bulletins: Analysis of Agricultural Product Turnover and Trade Dynamics*.
10. **Tadei, R., & Perboli, G.** (2015). *The Location-Inventory-Routing Problem in Perishable Goods Logistics*. Transportation Research Part E: Logistics and Transportation Review.
11. **UNCTAD.** (2023). *Review of Maritime Transport and Land-Based Logistics: Focus on International Transport Corridors*.
12. **United Nations.** (2016). *Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be Used for Such Carriage (ATP)*. Geneva: United Nations Publications, 99 p.