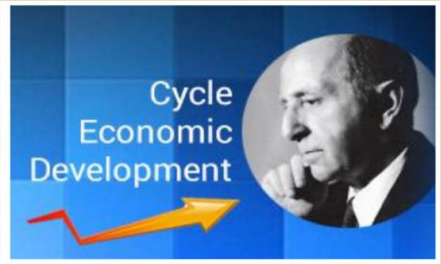
Simon Kuznets Kharkiv National University of Economics



Adaptive Framework for Logistics Supply Chain Planning Under Uncertainty

Speaker: ***Tetiana Kolodizieva,*** *Simon Kuznets Kharkiv National University of Economics, 61165 Kharkiv, Ukraine,*

Konstantia Darvidou*, University of Patras, 26504 Rio, Greece,*

Yaryna Pas*, Lviv University of Business and Law, 79021 Lviv, Ukraine*

Tetyana Hrinka*, Central Ukrainian National Technical University 25006 Kropyvnytskyi, Ukraine*

The Contemporary Operating Environment of Supply Chains

International and national supply chains are exposed to **substantial turbulence** driven by multiple global challenges, which significantly increase uncertainty and complexity in **logistics operations**.

Key Turbulence Drivers

Geopolitical risks
trade tensions, sanctions, political instability

Crises and armed conflicts
disruptions, supply chain blockages, humanitarian crises

Globalization
growing interdependence, wider markets, complex networks

Digitalization
new technologies, data flows, platforms, e-commerce

Intellectualization
knowledge-based economy, innovation, talent, AI

The Challenge

Traditional planning approaches
assume a relatively stable external and internal environment of economic systems and are becoming increasingly **incapable** of ensuring effective managerial decision-making, which is critical for logistics.

Traditional Planning

- Based on stability and predictability
- Limited scenario analysis
- Slow response to changes
- Higher risk of disruptions
- Lower decision-making effectiveness

Reactive approach

Need for Change

- Growing need for an **adaptive framework for logistics planning** under uncertainty.
- A structured approach to formulation and adjustment of logistics plans in response to changes in the operating conditions of supply chains.

Proactive & adaptive approach



The Goal

To develop an **adaptive framework** for logistics planning under **uncertainty** as a structured approach to the formulation and adjustment of logistics plans in response to changes in the operating conditions of supply chains.

From uncertainty to resilience — through adaptive logistics planning

*The **aim of this study** was to develop and substantiate an adaptive framework for supply chain logistics planning under uncertainty based on Industry 4.0 technologies.*

*The main research **objectives** were as follows:*

- to define the concept of an adaptive framework for supply chain logistics planning under uncertainty;
- to develop a model of adaptive logistics planning for supply chains under uncertainty;
- to develop an Adaptive Logistics Planning Index for quantitatively assessing the system's capacity for adaptation;
- to develop a mechanism for determining critical thresholds for switching between alternative logistics plans;
- to conduct a computational validation of the proposed tools and assess their ability to differentiate logistics system states according to the degree of necessity for changing the current planning scenario.

Key Characteristics of Supply Chains

A synthesis of scientific research indicates that adaptability is one of the key characteristics of supply chains, alongside:

- Flexibility
- Reliability
- Resilience
- Responsiveness
- **Adaptability**

Adaptability — a Broader Concept

Within the scope of this study, adaptability is proposed to be considered as a broader **systemic concept** that characterizes the ability of a supply chain to:

- timely detect changes and uncertainty
- respond by adjusting logistics decisions
- adapt operating parameters

→ **Ensure business continuity and performance**

Adaptive Logistics Planning Framework

Ensuring supply chain adaptability under conditions of uncertainty requires not only the development of optimal plans but also the establishment of a mechanism for their timely adjustment in response to changes in the internal and external operating conditions of the supply chain.



The framework is a dynamic system of principles, methods and tools that enables logistics operations to:

- **respond proactively** to changes,
- **rapidly reconfigure** processes,
- **maintain supply chain stability** even under conditions of uncertainty.

It is an **important structural** component of the framework and is based on an integrated managerial and analytical approach.

Managerial approach + **Analytical approach**

The result of this integration is a continuous process that ensures the system's ability to adapt to changes and uncertainty.

From Concept to Practice: The ALPM

To move from the conceptual level to the practical application of this approach, it is necessary to define a sequence of specific managerial and analytical procedures through the development of an Adaptive Logistics Planning Model (ALPM).

ALPM — Adaptive Logistics Planning Model

Monitoring	Forecasting	Assessment	Scenario Selection	Adjustment
Continuous tracking of supply chain parameters	Prediction of potential changes	Evaluation of deviations and risks	Choosing an appropriate scenario	Timely change of the logistics plan

ALPM ensures that logistics operations remain flexible, resilient and effective, even in the face of uncertainty.

Table 1. *Functional and Technological Structure of the Adaptive Logistics Planning Model (ALPM) and Quantitative Indicators for Assessing Its Components.*

ALPM Stage	Main Purpose	Key Industry 4.0 Technologies	Technological Contribution	Potential Quantitative Indicators
1. Real-Time Data	Collection of current supply chain data	IIoT, Smart Sensors, RFID, 5G, CPS	Continuous collection of data on inventory, demand, transport, equipment, shipments and operating conditions	**Data timeliness**; **Data availability**; Data update frequency; Data coverage
2. Data Monitoring	Detection of changes and deviations	IIoT, Smart Sensors, RFID, Edge Computing, Cloud Computing, Big Data Analytics	Real-time monitoring, data integration, identification of deviations and early warning signals	**Monitoring frequency**; Deviation detection time; Data integration level; Early-warning capability
3. Predictive Analytics	Prediction of future conditions	AI, ML, Big Data Analytics, Data Analytics, Cognitive Computing	Demand forecasting, lead-time prediction, anomaly detection and prediction of potential disruptions	**Forecasting accuracy**; **Prediction horizon; Prediction update frequency**; Anomaly detection accuracy
4. Risk / Uncertainty Assessment	Identification and evaluation of uncertainty	AI, ML, Big Data Analytics, Cognitive Computing, Blockchain	Risk identification, probability assessment, detection of abnormal patterns and evaluation of uncertainty	**Risk detection rate; Risk assessment accuracy; Uncertainty coverage**; Risk assessment time
5. Scenario Generation	Development of alternative logistics plans	AI, ML, Digital Twins, Big Data Analytics, Cloud Computing	Generation of alternative scenarios considering changes in demand, supply, capacity, costs and risks	Number of feasible scenarios; **Scenario generation time; Scenario diversity;** Uncertainty coverage
6. Logistics Digital Twin	Virtual testing of alternatives	Digital Twins, AI, ML, IoT, CPS, Cloud Computing	Simulation of supply chain behaviour, testing of alternative scenarios and evaluation of their consequences	**Simulation accuracy;** Simulation time; Scenario testing capacity; Real-world synchronization level
7. Optimal Plan	Selection of the most appropriate logistics plan	AI, ML, Digital Twins, Cognitive Computing, Big Data Analytics	Multi-criteria optimisation of routes, inventory, capacity, suppliers and other logistics parameters	**Decision-making time;** Optimisation quality; Number of criteria considered; Plan adaptability
8. Implementation	Execution of the selected plan	Robotics & Automation, CPS, IIoT, Autonomous Vehicles, AR, Cloud Computing	Automated execution, coordination of logistics operations and real-time communication between system components	**Plan execution time; Execution accuracy**; Automation level; **Implementation responsiveness**
9. Performance Monitoring	Evaluation of plan implementation	IIoT, Smart Sensors, RFID, Big Data Analytics, Data Analytics, Edge Computing	Monitoring KPIs, detecting deviations and comparing actual and planned performance	KPI monitoring frequency; Deviation detection time; Plan–actual gap; Monitoring coverage
10. Adaptation Trigger	Determination of the need for plan adaptation	AI, ML, Big Data Analytics, Cognitive Computing, Edge Computing	Detection of critical deviations and comparison with predefined adaptation thresholds	Trigger detection time; **Trigger accuracy**; Threshold sensitivity; Adaptation decision time
11. New Plan / Replanning	Adjustment or replacement of the current plan	AI, ML, Digital Twins, Cognitive Computing, Cloud Computing	Rapid generation, simulation and selection of a revised logistics plan	**Replanning time**; **Plan adjustment frequency**; **Alternative plan availability;** Recovery/adaptation time

Based on the analysis and synthesis of potential performance indicators for each ALPM stage (Table 1), *six main dimensions of quantitative adaptability assessment were identified (Table 2), which, in turn, form the basis for the development of the **ALPI***. The 18 indicators were selected based on their alignment with the functional stages of ALPM and their ability to quantitatively characterize the timeliness of information acquisition, forecasting, risk assessment, alternative generation, decision-making, and adaptation.

Table 2. *Main Dimensions of Quantitative Adaptability Assessment and Their Measurement Indicators.*

Dimension	Indicator	Symbol	Measurement logic
D1. Data Responsiveness	Data timeliness		Speed of obtaining and updating relevant data
	Data availability		Share of required data available for planning
	Monitoring frequency		Frequency of real-time monitoring
D2. Forecasting Capability	Forecasting accuracy		Accuracy of demand/lead-time forecasts
	Prediction horizon		Time horizon over which reliable forecasts are available
	Prediction update frequency		Frequency of updating forecasts
D3. Risk & Uncertainty Awareness	Risk detection rate		Share of relevant risks detected before disruption
	Risk assessment accuracy		Accuracy of risk probability/impact assessment
	Uncertainty coverage		Share of relevant uncertainty factors incorporated into planning
D4. Scenario Flexibility	Scenario generation time		Time required to generate alternative plans
	Scenario diversity		Number/diversity of feasible alternative scenarios
	Scenario simulation accuracy		Accuracy of simulated scenario outcomes
D5. Decision & Execution Responsiveness	Decision-making time		Time from disruption detection to plan selection
	Plan execution responsiveness		Time required to implement a revised plan
	Execution accuracy		Degree of compliance between planned and executed actions
D6. Adaptation Capability	Adaptation trigger accuracy		Accuracy of identifying the need for replanning
	Replanning time		Time required to develop and approve a new plan

Table 3. *Interpretation of the Adaptive Logistics Planning Level Based on Adaptive Logistics Planning Index (ALPI) Values.*

ALPI Value	Adaptive Logistics Planning Level	Interpretation
0.00–0.20	Very Low	Limited ability to detect, assess, and respond to changes
0.21–0.40	Low	Adaptation mechanisms exist but remain limited
0.41–0.60	Moderate	Basic adaptive capabilities are present
0.61–0.80	High	Well-developed ability to adjust logistics plans
0.81–1.00	Very High	Highly developed and integrated adaptive planning capability

Note: The interval classification is adapted from Harrington's standardized desirability matrix. While providing a robust structural baseline for cross-industry benchmarking, the threshold boundaries remain computationally flexible and may undergo fine-tuning subject to context-specific empirical supply chain variance or historic disruption data.

The ALPI metric reflects a system's overall capacity for adaptive logistics planning, however, determining its level does not provide a basis for pinpointing the exact moment to switch between alternative logistics plans. *Therefore, an adaptation initiation mechanism –* ***Scenario Switching Trigger (SST)*** *was developed for this purpose which involves calculating the* ***Scenario Switching Trigger Index (SSTI),*** *a quantitative indicator used to assess the current need to revise the scenario.*

SST was designed to identify the specific moment when a shift from the current supply chain planning scenario to an alternative one is required. *It was proposed to consider four of the six adaptability dimensions (D1, D2, D3, and D6; Table 2); these are characterized by their measurability in real time and provide the data needed to promptly determine the D, R, P, and C parameters:*

D– performance deviation (deviation of actual performance indicators from planned values);

R– risk level (current level of risk);

P– disruption probability (predicted probability of disruption);

C– capacity/cost constraint violation (violation of capacity, time, cost, or other critical constraints).

These parameters are then compared against corresponding critical threshold values to determine whether a change in the logistics planning scenario should be initiated.

Thus:

$$D_1, D_2, D_3, D_6 \rightarrow D, R, P, C \rightarrow SST \rightarrow ScenarioSwitching$$

where:

$$SST = f(D, R, P, C)$$

Table 4. *Determination and Normalization of Trigger Thresholds for Switching to Alternative Scenarios.*

Variable	What It Measures	Determination of the Critical Threshold	Critical Threshold	Normalized Critical Threshold
D – Performance Deviation	Deviation of actual performance from the plan	90th–95th percentile of historical deviations or service-level tolerance		
R – Risk Level	Current level of risk	Enterprise risk appetite/risk tolerance or an empirical critical percentile		
P – Predicted Disruption Probability	Probability of a future disruption	ROC (Receiver Operating Characteristic)/ PR (Precision-Recall) analysis of the predictive model	threshold calibrated by ROC/PR	
C – Constraint Violation	Violation of critical constraints	Actual exceedance of an established hard constraint	Hard constraint	

Normalization of D, R, P, and C and the assignment of weights to these indicators make it possible to calculate the integral ***Scenario Switching Trigger Index (SSTI)*** *and determine the corresponding zones of recommended managerial actions (Table 7):*

$$SSTI = w_D D + w_R R + w_P P + w_C C$$

To eliminate this systemic blind spot and improve managerial decision-making, a two-stage mechanism is proposed:

- Stage 1: Hard Constraint Filter (Boolean Check). The system first evaluates the status of the hard constraints. If any critical limit is violated ($\bar{C} = 1.0$), the system bypasses the additive index entirely. It triggers an immediate transition to the Critical Zone to initiate the alternative scenario generation procedure.

- Stage 2: Cumulative Risk Synthesis (Additive Index). If all hard constraints remain within safe operational limits ($\bar{C} < 1.0$), the algorithm calculates the aggregate SSTI. This stage evaluates the combined, gradual pressure of performance deviations (D), latent risks (R), and disruption probabilities (P) to determine if warning actions are required.

Mathematically, this conditional trigger logic is formalized as follows:

$$SST_{final} = \begin{cases} \text{Critical (Initiate Replanning)}, & \text{if } C \geq 1.0 \\ w_D D + w_R R + w_P P + w_C C, & \text{if } C < 1.0 \end{cases}$$

This two-stage approach ensures the supply chain network reacts instantly to both sudden physical bottlenecks (hard overrides) and the gradual build-up of systemic operational risks.

The reduction from the five maturity levels used in the prior ALPI stages to a compressed three-tier interval configuration for the SSTI is grounded in cybernetic control theory and the standard *Red-Amber-Green (RAG)* risk mapping paradigm.

Table 5. *Zones of Recommended Managerial Actions Depending on the Scenario Switching Trigger Index (SSTI) Value.*

SSTI	Zone	Managerial Action
0.00–0.40	Normal	Continue the current scenario
0.40–0.60	Warning	Intensify monitoring
0.60–1.00	Critical	Initiate the procedure for generating and evaluating an alternative scenario

***Note: The proposed three-tier scale is structurally mapped against empirical cybernetic control thresholds. While establishing a standardized baseline for operational responsiveness, these discrete interval boundaries remain mathematically flexible and can be dynamically calibrated to align with firm-specific historical volatility and structural tolerance limits.*

To provide illustrative computational validation the proposed methodology, a **hypothetical supply chain of an enterprise was considered to assess its adaptive logistics planning capacity under the current operating conditions.**

For each of the 18 indicators, an actual value was specified, along with minimum and maximum values derived from a hypothetical historical sample (Table 8).

Table 6. Hypothetical Input Data and Normalized Values.

Dimension	Indicator	Type				
D1		+	8	2	10	0.750
		+	92%	60%	100%	0.800
		+	24	4	30	0.769
D2		+	91%	65%	95%	0.867
		+	14 days	3	21	0.611
		+	12/day	2	24	0.455
D3		+	85%	50%	95%	0.778
		+	82%	50%	95%	0.711
		+	80%	40%	100%	0.667
D4		−	30 min	10	120	0.818
		+	6	2	8	0.667
		+	88%	60%	95%	0.800
D5		−	45 min	10	120	0.682
		−	3 h	1	8	0.714
		+	90%	70%	95%	0.800
D6		+	86%	60%	95%	0.722

**Note: «+» - Positive-impact indicators, «−» - Negative-impact indicators.*

Table 7. *Normalized Indicator Values for Each Dimension of Supply Chain Planning Adaptability*

Dimension	Valu
D1. Data Responsiveness	0.773
D2. Forecasting Capability	0.644
D3. Risk & Uncertainty Awareness	0.719
D4. Scenario Flexibility	0.762
D5. Decision & Execution Responsiveness	0.732
D6. Adaptation Capability	0.653

Table 8. *Real-Time Parameters of the Current State of the Supply Chain and Calculation of the Scenario Switching Trigger Index (SSTI).*

Indicator	Notation	Current Value			Critical Threshold	Normalized Indicator Value	Normalized Critical Threshold
1. Deviation of actual performance from the plan		8%	0%	20%	10%	0,400	0,500
2. Current risk level		0.65	0.20	0.90	0,70	0,643	0,714
3. Probability of future disruption		0.48	0.10	0.80	0,60	0,543	0,714
4. Constraint violation		5%	0%	10%	10%	0,500	1,000
SSTI	-	-	-	-	-	0,522	0.600

Table 9. *Scenario-based computational experiment for the Scenario Switching Trigger Index (SSTI)*

Supply Chain State	Deviation of actual performance from the plan, D	Current Risk Level, R	Probability of future disruption, P	Constraint violation, C	SSTI	Managerial Zone	Recommended Action	Supply Chain State
Stable	0.200	0.250	0.150	0.300	0.225	Normal	Continue the current planning scenario	Stable
Warning	0.400	0.643	0.543	0.500	0.522	Warning	Intensify monitoring and repeated forecasting	Baseline
Critical	0.950	0.960	0.940	0.966	0.954	Critical	Initiate evaluation of an alternative planning scenario	Critical

**Note: The normalized value ranges in the current computational experiment are illustrative rather than universal constants.*

In the validation of the proposed methodology, equal weights were conditionally assigned to the adaptability dimensions. The resulting ***Adaptive Logistics Planning Index (ALPI) = 0.714 corresponds to a high level of adaptability of the planning system according to the proposed scale.***

At the same time, the ***Scenario Switching Trigger Index (SSTI) = 0.522 characterizes the current situation as being within the Warning zone, in which intensified monitoring and repeated forecasting are appropriate, while automatic scenario switching is not yet activated.***

Adaptation Trigger Mechanism

The Adaptation Trigger Mechanism incorporates the quantitative **Scenario Switching Trigger Index (SSTI)**, which makes it possible to determine the recommended managerial action. In contrast, the Adaptive Logistics **Planning Index (ALPI)** characterizes the system's overall capacity for adaptive logistics planning.

SSTI
Trigger for scenario switching (operational level)

ALPI
Overall capacity for adaptive logistics planning (strategic level)

SSTI – Recommended Managerial Action

Scenario Switching Trigger Index (SSTI)

Quantitative indicator that determines which managerial action to take.

Continue
the current planning scenario

Intensify
monitoring

Initiate
the procedure for generating an alternative scenario

ALPI
Adaptive Logistics Planning Index

Reflects the system's overall capacity for adaptive logistics planning.

SSTI Composition and Calculation Process

1. Information Foundation
Based on **4 of 6** ALP dimensions (with real-time measurable indicators)

- **D1** Data Responsiveness (e.g., real-time data, system response)
- **D2** Forecasting Capability (e.g., forecast accuracy)
- **D3** Risk & Uncertainty Awareness (e.g., risk level, disruption probability)
- **D6** Adaptation Capability (e.g., flexibility, reconfiguration speed)

Indicators are monitored and quantitatively assessed in real time.

2. Key Indicators for SSTI

- **Deviation** between actual and planned performance
- **Risk level** of potential disruptions
- **Predicted probability** of disruption
- **Violation of critical logistics constraints** (e.g., time, capacity, cost)

3. Calculation Process

1. Obtain indicator values (real-time data)
2. Compare with critical thresholds (based on historical data)
3. Apply weighting coefficients (based on relative significance and empirical validation)

SSTI
Scenario Switching Trigger Index

4. Result

SSTI value

- < threshold 1 — Continue current scenario
- threshold 1 – 2 — Intensify monitoring
- > threshold 2 — Initiate alternative scenario

Thresholds are determined using historical data of the specific supply chain.

ALPI
System's overall capacity for adaptive logistics planning



ALPI is calculated as a weighted aggregate of the selected dimensions and their indicators.

Adaptive Logistics Planning Model (ALPM)

An integrated model for supply chains under uncertainty, combining real-time data, analytics and adaptive decision-making.

Real-time Data Monitoring	Predictive Analytics	Risk & Uncertainty Assessment	Alternative Scenario Generation	Logistics Digital Twin	Plan Selection & Implementation	Performance Monitoring	Adaptation Mechanism
• IoT • Smart sensors • RFID • 5G • CPS	• AI / ML • Big Data • Data Analytics • Cognitive Computing	• AI / ML • Big Data • Cognitive Computing • Blockchain	• AI / ML • Digital Twin • Big Data • Cloud	• Simulation • Data Integration • Real-time Modelling	• Optimization • Decision Support • Automation	• KPIs • Dashboards • Analytics	• Scenario Switching • Re-planning • Continuous Learning

Continuous cyclical process

Monitoring → Forecasting → Scenario Modelling → Decision-Making → Adaptation

From Periodic to Adaptive Planning

Traditional approach

Periodic plan adjustments

- scheduled reviews
- limited reaction speed
- higher risk exposure

Adaptive approach (ALPM)

Continuous, dynamic adjustments

- real-time response
- proactive decision-making
- stable performance

Adaptive Logistics Planning Index (ALPI)

ALPI encompasses six dimensions of adaptive logistics planning.



Calculation

18 indicators
(Min–Max normalization)

Integral ALPI value
0.714
(High level of adaptability)

Very low	0.00 – 0.20
Low	0.21 – 0.40
Moderate	0.41 – 0.60
High	0.61 – 0.80
Very high	0.81 – 1.00

Scenario Switching Trigger Index (SSTI)

SSTI determines the need for scenario switching based on key risk and performance indicators.

Key indicators (4 of 6 ALP dimensions)

- Deviation of actual from planned performance
- Current risk level
- Predicted probability of disruption
- Violation of critical logistics constraints

Calculation

Weighted sum
(with critical thresholds)

SSTI
0.522

Warning zone

Result & recommended action

Warning zone

Intensified monitoring and repeated forecasting (without automatic scenario switching).

Normal	Warning	Critical
< 0.400	0.401 – 0.700	> 0.701

The main methodological contribution of this study is the development of a **two-level quantitative assessment approach that distinguishes the adaptive capability of supply chain planning from the operational pressure to revise the current logistics scenario**.

The proposed **Adaptive Logistics Planning Index (ALPI) captures the multidimensional readiness of the planning system to adapt, while the Scenario Switching Trigger Index (SSTI) translates operational deviations, risks, disruption probabilities, and constraint violations into actionable decision-support signals.** The integration of these instruments provides a structured basis for linking adaptability assessment with scenario-based logistics planning decisions.

Thank you for your attention!