Економіка

UDC 658.7

Ieselev Oleksandr
Director of Intaleo Ukraine LLC
(Kyiv, Ukraine)

FORMATION OF A SUPPLY CHAIN IN THE PRODUCTION OF PROTECTIVE GLASSES FOR MOBILE DEVICES

Summary. *Introduction. The changes taking place in the mobile device market place increased demands on the quality and reliability of safety glasses, which makes it extremely important to form adaptive and transparent supply chains to ensure the competitiveness of manufacturers. The article analyzes the features inherent in the process of forming supply chains in the production of protective glasses for mobile devices. An integrated supply chain formation (SCM) model for the production of protective glasses for mobile devices is proposed, combining the Cyber-Physical-Social System (CPSS) approach.*

The purpose of the article is to analyze the specifics of the formation of supply chains in the production of protective glasses for mobile devices.

Materials and methods. The work is based on a comparative analysis of publications on key technologies (ultrathin chemical hardening, plasma treatment, nanocoating) and organizational as well as external obstacles, highlighting the mechanisms for overcoming them within the framework of CPSS.

Results. The main barriers are identified — outdated IT and shortage of IoT personnel, fragmentation of processes and volatility of raw material prices, solutions are proposed: modular equipment with unified APIs, cross-functional SCRUM teams, supplier diversification and commodity hedging to increase adaptability. The described CPSS model integrates IoT sensors, digital twins and a blockchain registry, providing end-to-end traceability and prompt response to quality deviations.

The prospects. Further research may focus on empirical validation of the model in an industrial setting, the development of digital twins and blockchain solutions for green supply chains, as well as the introduction of machine learning (LSTM models and Bayesian networks) to predict demand and optimize inventory.

Key words: *supply chain, safety glasses, mobile devices, CPSS model, TOE analysis, digital twins, blockchain, nanocoating.*

Introduction. The evolution of mobile devices imposes stringent requirements on protective glass: strength, damage resistance, enhanced optical performance, and tactile comfort have become baseline user expectations. At the same time, intensifying global competition among manufacturers demands not only the adoption of cutting-edge production technologies but also the establishment of reliable and flexible supply chains.

In recent years, the creation of effective supply chains in high-tech manufacturing—including the production of protective glass for mobile devices—has increasingly been linked to the cultivation of entrepreneurial mindsets among managers. Goldsby T.J., Kuratko D.F., and Goldsby M.G. [1] emphasize the need for an "entrepreneurial" approach to managing risks and opportunities within traditional logistics, arguing that this enhances both adaptability and innovation potential in supply chains. In the context of the Fourth Industrial Revolution, Chalmers D., MacKenzie N.G., and Carter S. [6] demonstrate that integrating AI tools drives not only technological advances but also strategic shifts in intrapreneurial ventures within corporations. Covin J.G. et al. [7], examining the autonomy of internal ventures in large firms, show that the degree of planning freedom directly correlates with the effectiveness of new-product launches.

Chen Z.S. and Ruan J.Q. [2] propose a conceptual "metaverse" supply-chain model, identifying key obstacles—from cross-platform integration complexity to cybersecurity challenges and legal uncertainty. Chen Z.S. et al. [5] further explore existing barriers by introducing a dynamic collective-opinion-generation model to analyze digital-transformation factors. Enz M.G. and Lambert D.M. [9] develop a general SCM framework for service supply chains, highlighting the value of real-time monitoring and forecasting modules.

Industry analysis published on SupplyChainDigital [3] points to the impact of adverse external factors on Ukraine's supply chains across all sectors, especially in high-tech segments where raw-material delivery disruptions trigger cascading failures. The Agchemigroup report [4] underscores logistics and production-capacity challenges, showing that secondary risks (personnel, financial) can already impede the scaling of protective-glass manufacturing. Dohmen A.E. et al. [8] conclude that preliminary risk-mitigation measures, without robust continuity processes and rapid re-evaluation capabilities, often prove insufficient.

From the perspective of sustainability and the circular economy, Delbari S.A. and Hof L.A. [10] illustrate how Industry 4.0 and 5.0 technologies enable high-value recycling of glass waste—recalibrating and recutting it into new protective-glass sheets—thereby reducing both environmental footprint and raw-material costs.

Thus, the literature reveals a tension: on one hand, the entrepreneurial approach stresses managerial autonomy and innovation; on the other, resilience models demand strict procedures and centralized decision-making. Methods for balancing innovation autonomy with the maintenance of robust backup supply chains remain underexplored.

The objective of the article is to analyze the distinctive characteristics of supply-chain formation in the production of protective glass for mobile devices.

The scientific novelty lies in the theoretical-analytical delineation of CPSS-framework features as they pertain to building supply chains for mobile-device protective glass, together with their preliminary conceptual synthesis.

The author's hypothesis is that integrating a CPSS management structure with a TOE-based analysis of barriers will not only enhance the adaptability and transparency of the protective-glass supply chain but also safeguard the end product's quality amid external fluctuations and production risks.

The methodology is grounded in a comparative analysis of publications in which researchers explored the challenges and dynamics inherent to organizing supply chains in the manufacture of mobile-device protective glass.

Conceptual Model for Integrating Production and Supply (CPSS Approach)

Optimization of manufacturing processes for protective glass must be accompanied by a well-structured logistics network for raw materials, reagents, and ancillary equipment. Table 1 compares key production technologies for protective glass with the corresponding logistical requirements.

Table 1

Comparison of key technological processes for the production of protective glasses and their logistical requirements (compiled by the author based on the analysis [1; 2; 4; 5; 10]

Technology	Primary Mechanism	Key Materials / Reagents	Logistical Requirements
Ultrathin Chemical Tempering	$Na^+ \rightarrow K^+$ ion exchange in molten KNO_3	Ultrafine aluminosilicate glass; KNO_3	Storage of KNO_3; temperature control; airtight packaging of dry reagent
Nanocoatings with PFPE Silanes and SiO_2	Self-assembled PFPE monolayers on SiO_2 nanostructures	PFPE silanes; SiO_2 nanoparticles	Inert-gas (N_2) storage; PFAS labelling (UN 3077); dosing modules
Plasma Treatment	Atmospheric plasma (Ar/O_2) for surface cleaning and activation	Gas mixtures (Ar/O_2)	Cylinder delivery; leak monitoring; seal replacement

* DOC (depth of compression) – depth of the compression layer after ion exchange.
* PFPE (perfluoropolyether) – base component of oleophobic coatings.
* Plasma activation enhances coating adhesion by increasing surface energy.

Under volatile demand for mobile-device protective glass, firms must shift from classical linear SCM to a holistic management model that unites physical operations, digital technologies, and social coordination. The Cyber-Physical-

Social System (CPSS) framework—elaborated here in the context of a "metaverse" SCM—provides precisely this synergy.

Figure 1 illustrates the interrelated layers of the CPSS model.

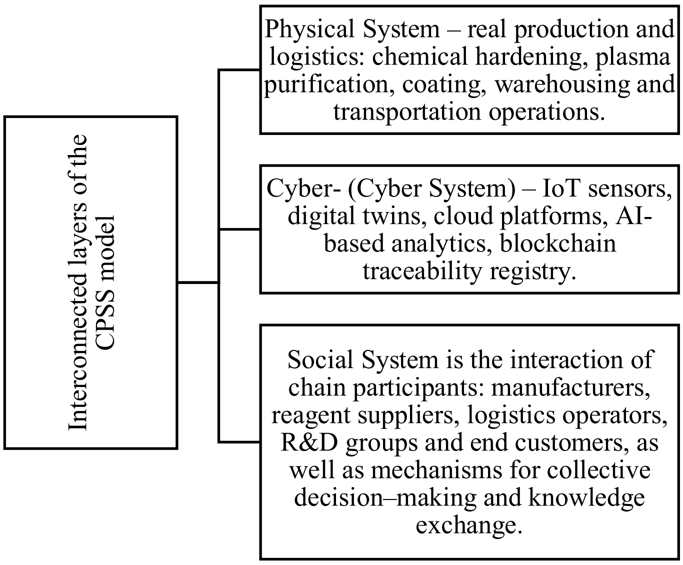

Fig. 1. Interconnected layers of the CPSS model (compiled by the author based on the analysis of [2; 5; 6]

CPSS adaptation aims to ensure:

- end-to-end traceability of glass quality and location at every stage;
- real-time monitoring of process parameters (Digital Twin models for chemical tempering and plasma treatment);
- cross-departmental collaboration through a centralized planning platform (PLM/SCM tools such as PTC ThingWorx or Siemens) [1].

Next, examining the interactions among the CPSS layers, note that when blanks arrive at the chemical-tempering workshop (Physical), IoT sensors record thickness and temperature (Cyber), automatically compare them to tolerances, and notify operators via the corporate mobile CRM/SCM dashboard. After tempering, a digital twin predicts the residual depth of compression (DOC) and records the data in a blockchain ledger to guarantee an immutable processing history. Similarly, plasma treatment and coating application are managed through the same digital platform, where quality engineers and reagent suppliers can adjust formulations and inventory levels online.

The interplay of these three layers creates an end-to-end conveyor—from reactant ordering to glass shipment—minimizing delays and defects through synchronized management of technological, informational, and organizational processes [2; 7].

For a comprehensive analysis of the obstacles to forming the protective-glass supply chain, we apply the classic TOE framework (Technology–Organization–Environment). Table 2 lists the main barriers and the mechanisms for overcoming them.

Table 2

The main barriers and mechanisms for overcoming them within the framework of TOE [1; 2; 3; 7]

Barrier Category	Key Obstacles	Mechanisms for Overcoming
Technological	• Outdated equipment and IT• Shortage of IIoT specialists• Heterogeneous protocols	1. Modular equipment with OPC UA/MQTT2. Training in IIoT and blockchain3. Cross-system API gateways
Organizational	• Fragmentation between R&D, production, and logistics• Resistance to change• Unclear roles	1. Cross-functional SCRUM teams (RACI)2. Unified PLM/SCM platform3. Incentive systems for innovation
Environmental	• Volatile prices for KNO_3 and PFAS• REACH regulations• Logistics disruptions	1. Diversification and long-term contracts2. Raw-material hedging3. Multimodal routing and cargo insurance

The CPSS (Cyber-Physical-Social System) methodology serves as a unified, integrated management ecosystem for the manufacture of protective glass. It provides end-to-end traceability via a decentralized Hyperledger Fabric ledger.

The deployment of networked IoT sensors, process digital twins, and distributed ledgers creates a seamless chain from reagent procurement to finishedproduct shipment, minimizing downtime and defects through synchronous control of technological, informational, and organizational flows.

It is preferable to establish direct contracts with vetted quarries and chemical plants. For timely recipe adjustments, regular batch analysis by XRF and ICP-MS is advisable [8; 9].

A combination of LSTM networks and Bayesian algorithms enables forecasting flagship-smartphone replacement cycles, significantly reducing excess inventory and "bottlenecks." Critical-reagent supplies (lithium, sodium, potassium) should be segmented according to the Kraljic matrix and evaluated via multifactor AHP analysis to optimize the trade-off between cost and supply resilience.

Conclusion. This study analysed the critical manufacturing processes for protective glass—ultrathin chemical tempering, plasma treatment, and nanocoatings—and established detailed logistical requirements for raw materials, reagents, and equipment. In doing so, it revealed the unique inventory-management and quality-control needs at each stage of production.

Building on the Cyber-Physical-Social System framework, we adapted a conceptual schema that seamlessly integrates the "physical" manufacturing floor with "cyber" tools (IoT sensors, digital twins, blockchain) and "social" coordination mechanisms. The proposed model delivers dynamic, real-time monitoring of process parameters; guaranteed end-to-end traceability of glass batches; and rapid correction of any quality deviations through collaborative planning.

Overall, embedding the CPSS model provides a holistic instrument for boosting the adaptability, transparency, and resilience of the supply chain in high-tech protective-glass production—thereby strengthening manufacturers' competitive edge in the fast-evolving mobile-accessory market.

References

1. Goldsby, T.J., Kuratko, D.F. & Goldsby, M.G. (2024) Developing an entrepreneurial mindset in supply chain managers: Exposing a powerful potential. *Journal of Business Logistics.* Vol. 45, № 2. DOI: 10.1111/jbl.12372.

2. Chen, Z.S. & Ruan, J.Q. (2024) Metaverse healthcare supply chain: Conceptual framework and barrier identification. *Engineering Applications of Artificial Intelligence.* Vol. 133. DOI: 10.1016/j.engappai.2024.108113.

3. Supplychaindigital (2022). Ukraine war hitting all supply chain sectors, says Scoutbee. URL: https://supplychaindigital.com/supply-chain-risk-management/ukraine-war.

4. Agchemigroup (2023). The Manufacturing and Supply Chain Challenges in Ukraine. URL: https://blog.agchemigroup.eu/the-manufacturing-and-supply-chain-challenges-in-ukraine/.

5. Chen, Z.S. et al. (2024) Dynamic collective opinion generation framework for digital transformation barrier analysis in the construction industry. *Information Fusion.* Vol. 103. DOI:10.1016/j.inffus.2023.102096.

6. Chalmers, D., MacKenzie, N.G. & Carter, S. (2021) Artificial intelligence and entrepreneurship: Implications for venture creation in the fourth industrial revolution. *Entrepreneurship Theory and Practice*. Vol. 45, № 5. P. 1028–1053. DOI: 10.1177/1042258720934581.

7. Covin, J.G. et al. (2021) Internal corporate venture planning autonomy, strategic evolution, and venture performance. *Small Business Economics*. Vol. 56. P. 293–310.

8. Dohmen, A.E. et al. (2023) When preemptive risk mitigation is insufficient: The effectiveness of continuity and resilience techniques during COVID-19. *Production and Operations Management*. Vol. 32, № 5. P. 1529–1549. DOI: 10.1111/poms.13677.

9. Enz, M.G. & Lambert, D.M. (2023) A supply chain management framework for services. *Journal of Business Logistics.* Vol. 44, № 1. P. 11–36. DOI: 10.1111/jbl.12323.

10. Delbari, S.A. & Hof, L.A. (2024) Glass waste circular economy – Advancing to high-value glass sheets recovery using Industry 4.0 and 5.0 technologies. *Journal of Cleaner Production.* Vol. 462. DOI: 10.1016/j.jclepro.2024.142629.