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RESEARCH AND ANALYSIS OF NON-MANIPULATABLE MECHANISMS IN LOGISTICS AND SUPPLY CHAIN MANAGEMENT

Contemporary supply chains operate under growing pressures of globalization, digital transformation and increasingly complex coordination. Under these conditions, information asymmetry, limited transparency and opportunistic behaviour weaken operational performance and raise legal and organizational risks. The article examines non-manipulable mechanisms in logistics and supply chain management as institutional and technological arrangements that limit such distortions through transparency, verifiability, traceability and protection from unilateral influence. The study aims to determine how these mechanisms affect operational efficiency, customer satisfaction and risk reduction, proceeding from the idea that incentive alignment, transparency and verifiability jointly shape logistics outcomes and should be viewed as a unified governance approach. A mixed-method quasi-experimental comparative design was used. Data were collected from 80 enterprises, with an implementation group (50 companies) and a control group (30 companies). The empirical base includes standardized questionnaires, internal records, semi-structured interviews and comparable before–after indicators. Statistical analysis relied on Student's t-tests, and qualitative materials were examined using thematic analysis. Enterprises applying non-manipulable mechanisms, compared with those using standard practices, demonstrated shorter order processing times, lower inventory costs, higher customer satisfaction and lower fraud-related and legal risks, as well as better coordination and greater trust among partners. The study integrates mechanism design, transparency-oriented governance and logistics performance into a single analytical framework and provides empirical confirmation of the practical relevance of non-manipulable mechanisms for designing more transparent, resilient and efficient supply chain management systems.

Keywords: supply chain management, non-manipulable mechanisms, transparency, efficiency, risks, quantitative analysis, qualitative analysis.

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Логистика және жеткізу тізбектерін басқару саласындағы манипуляциялық емес механизмдерді зерттеу және талдау

Қазіргі заманғы жеткізу тізбектері жаһанданудың, цифрлық трансформацияның және үйлестірудің күрделене түсуінің қысымымен жұмыс істейді. Мұндай жағдайларда ақпараттық асимметрия, шектеулі ашықтық және оппортунистік мінез-құлық операциялық тиімділікті әлсіретеді және құқықтық және ұйымдастырушылық тәуекелдерді арттырады. Бұл мақалада логистика мен жеткізу тізбегін басқарудағы манипуляциялық емес механизмдер ашықтық, аудиторлық, бақылау және біржақты ықпалдан қорғау арқылы мұндай бұрмаланулардың шектейтін институционалдық және технологиялық механизмдер ретінде қарастырылады. Зерттеудің мақсаты – бұл механизмдердің операциялық тиімділікке, тұтынушылардың қанағаттанушылығына және тәуекелдерді азайтуға қалай әсер ететінін анықтау, ынталандыруды үйлестіру, ашықтық және аудиторлық логистикалық нәтижелерді бірлесіп қалыптастырады және оларды тұтас басқару тәсілі ретінде қарастыру керек деген идеяға негізделген. Аралас квазиэксперименттік салыстырмалы дизайн қолданылды. Деректер 80 кәсіпорыннан жиналды, енгізу тобы (50 компания) және бақылау тобы (30 компания). Эмпирикалық базаға стандартталған сауалнамалар, ішкі жазбалар, жартылай құрылымдалған сұхбаттар және салыстырмалы «бұрын» және «кейін» көрсеткіштері кіреді. Статистикалық талдау Студенттің t-тестін қолдану арқылы жүргізілді, ал сапалық деректер тақырыптық талдауды қолдану арқылы зерттелді. Стандартты әдістерді қолданатын компаниялармен салыстырғанда, манипуляциялық емес механизмдерді қолданатын компаниялар тапсырыстарды өңдеу уақытының қысқарғанын, тауарлық-материалдық құндылықтардың төмендеуін, тұтынушылардың қанағаттанушылығының

дерінің төмендегенін, сондай-ақ серіктестер арасындағы үйлестірудің жақсарғанын және сенімдің артқанын көрсетті. Зерттеу механизмді жобалауды, ашықтыққа бағытталған басқаруды және логистика тиімділігін бірыңғай аналитикалық негізге біріктіреді және жеткізу тізбегін басқарудың ашық, тұрақты және тиімді жүйелерін әзірлеу үшін манипуляциялық емес механизмдердің практикалық құндылығының эмпирикалық дәлелдерін ұсынады.

Түйін сөздер: жеткізу тізбегін басқару, басқарылмайтын механизмдер, ашықтық, тиімділік, тәуекелдер, сандық талдау, сапалық талдау.

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Исследование и анализ неманипулируемых механизмов в логистике и управлении цепями поставок

Современные цепочки поставок функционируют под растущим давлением глобализации, цифровой трансформации и все более сложной координации. В этих условиях информационная асимметрия, ограниченная прозрачность и оппортунистическое поведение ослабляют операционную эффективность и повышают юридические и организационные риски. В статье рассматриваются неманипулируемые механизмы в логистике и управлении цепочками поставок как институциональные и технологические механизмы, ограничивающие такие искажения посредством прозрачности, проверяемости, отслеживаемости и защиты от одностороннего влияния. Цель исследования – определить, как эти механизмы влияют на операционную эффективность, удовлетворенность клиентов и снижение рисков, исходя из идеи, что согласование стимулов, прозрачность и проверяемость совместно формируют результаты логистики и должны рассматриваться как единый подход к управлению. Использовался смешанный квазиэкспериментальный сравнительный дизайн. Данные были собраны у 80 предприятий, с группой внедрения (50 компаний) и контрольной группой (30 компаний). Эмпирическая база включает стандартизированные анкеты, внутренние записи, полуструктурированные интервью и сопоставимые показатели «до» и «после». Статистический анализ проводился с использованием t-критерия Стьюдента, а качественные материалы изучались с помощью тематического анализа. Предприятия, применяющие неманипулируемые механизмы, по сравнению с теми, кто использует стандартные методы, продемонстрировали сокращение времени обработки заказов, снижение затрат на складские запасы, повышение удовлетворенности клиентов и снижение рисков, связанных с мошенничеством и юридическими нарушениями, а также улучшение координации и повышение доверия между партнерами. Исследование объединяет разработку механизмов, ориентированное на прозрачность управление и эффективность логистики в единую аналитическую структуру и предоставляет эмпирическое подтверждение практической значимости неманипулируемых механизмов для разработки более прозрачных, устойчивых и эффективных систем управления цепочками поставок.

Ключевые слова: управление цепями поставок, неманипулируемые механизмы, прозрачность, эффективность, риски, количественный анализ, качественный анализ.

Introduction

Globalization and rapid technological advancements are fundamentally reshaping logistics and supply chain management, positioning them as critical factors in the competitiveness of modern enterprises. The effectiveness and transparency of these systems are contingent upon minimizing the risks arising from manipulative practices by stakeholders, thereby highlighting the necessity for thorough investigation and analysis of mechanisms that prevent such manipulation Hu & Haddud, (2020).

In supply chain management, manipulative practices by large corporations are particularly evident in the biased selection of suppliers, where criteria such as quality and cost-efficiency are overlooked in favor of personal preferences or external influence. These actions increase the likelihood of compromised product quality and rising operational costs. At the level of individual participants, data concerning inventories, delivery schedules, and quality metrics may be manipulated to serve personal interests, ultimately harming partners. The concealment of information regarding failures or delays can lead to significant disruptions in logistics planning. To mitigate such abuses, it is essential to implement transparent and independent supplier selection procedures based on objective, verifiable metrics, alongside the deployment of real-time monitoring and control systems that ensure data transparency for all supply chain stakeholders (Rogulin, 2023).

The existing body of research on supply chain management primarily emphasizes the optimization of individual operational processes, while the strategic behavior of actors pursuing their own interests has been largely overlooked. This disparity results in information asymmetry and contributes to inefficient resource allocation. The current study examines mechanisms that promote transparency and prevent manipulative practices within logistics and supply chain management Antyushin, (2020).

In this study, non-manipulable mechanisms are understood as institutional and technological configurations in supply chain management that limit the scope for individual actors to distort information or influence decisions in their own interest. Conceptually, this notion is not tied to any specific technology. It refers to management solutions that satisfy four key requirements: procedural transparency, the possibility to verify data and decisions, protection from one-sided interference, and the ability to trace operational actions. On this basis, blockchain platforms, IoT-based monitoring systems, audit practices, and formalized decision rules are considered not as synonymous terms, but as distinct implementation tools that can be used to achieve these requirements.

The relevance of this study stems from the increasing challenges faced by companies in the context of global instability. Of particular significance is the development of resilient and adaptive supply chains founded on trust and transparency. The purpose of this study is to examine which institutional and technological configurations make supply chain management less vulnerable to opportunistic manipulation, and to evaluate how the joint action of incentive alignment, transparency, and verifiability influences operational efficiency and the reduction of risks. The study will explore the characteristics of non-manipulable mechanisms, assess their impact on logistics performance, and provide practical recommendations for their implementation.

At the same time, analysing supply chains in transition economies requires going beyond a narrow, operational view of efficiency. It is necessary to take into account the institutional architecture of logistics systems and the behavioural limits of their participants, since opportunism, weak coordination and misaligned incentives can distort outcomes even where formal procedures look efficient. In this perspective, non-manipulable mechanisms are significant not only as technological instruments, but also as institutional arrangements that align incentives, reduce information asymmetry and restrict strategic distortions in supply chain interactions.

Building on the previously presented conceptual framework, the empirical part of the study was structured around three working hypotheses.

H1: enterprises that introduce non-manipulable mechanisms achieve larger gains in operational efficiency than enterprises that rely on standard supply chain management practices.

H2: the use of non-manipulable mechanisms corresponds to a detectable decrease in fraud-related exposure and legal risk levels.

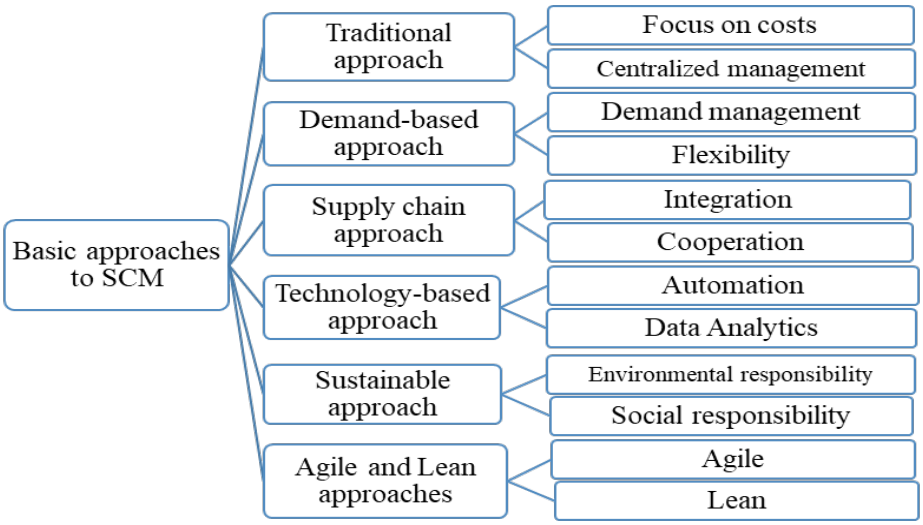
H3: non-manipulable mechanisms enhance coordination among supply chain participants, which is manifested in higher customer satisfaction and a stronger sense of trust in partner relationships.

Literature review

Supply chain management (SCM) is a set of conceptual models aimed at improving corporate processes, reducing costs, and increasing operational efficiency. Figure 1 shows the key approaches to implementing SCM.

Traditional approaches prioritize cost reduction through centralized decision-making, often at the expense of quality and responsiveness. Demand-driven methods use accurate forecasting and built-in flexibility to align production and inventory with customer needs. Supply-chain models integrate suppliers, manufacturers and distributors to synchronize activities and share data seamlessly. Technological strategies deploy ERP, IoT, blockchain and analytics to automate processes and boost transparency. Sustainable practices embed environmental stewardship and social responsibility – including labor and human-rights considerations – across the chain. Finally, Agile promotes rapid, iterative adaptation, while Lean focuses on eliminating waste and streamlining operations. In this study, Figure 1 is used to show non-manipulable mechanisms not as an independent SCM model, but as an overarching governance approach that can be built into demand-driven, technology-focused, and resilience-oriented supply chain designs.

Figure 1
Basic approaches to supply chain management



Note: compiled by the author based on the source Christopher, (2016); Gunasekaran & Ngai, (2004)

Each of the models considered is characterized by a unique set of advantages and limitations, and the choice of the most appropriate one is determined by the industry specifics, the company's strategic goals and current market conditions. In practice, enterprises often combine elements of different approaches to achieve the best optimization of supply chain management. A comparative analysis of existing management systems reveals significant differences between classical methods and mechanisms protected from manipulation. Traditional solutions often rely on techniques that allow for distortion of information, which reduces the transparency of processes and increases the risk of unfair actions.

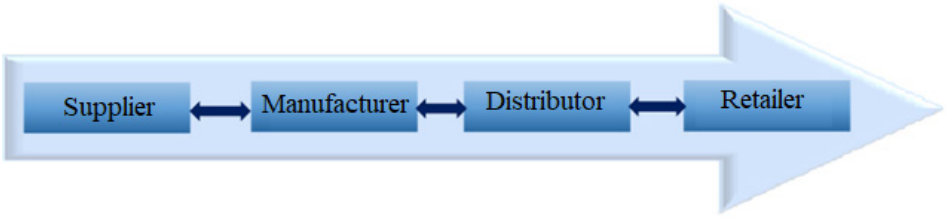
Conventional supply chains often use distortive practices – distorting data or hiding inventory delays – that erode trust. Opacity enables unethical behavior (e.g., forged documents, price manipulation), undermines traceability and reputation, and exposes firms to financial and legal risks. As networks globalize and grow more complex, these vulnerabilities intensify, underscoring the need for stronger, transparent governance.

Technological tools, including blockchain platforms and Internet of Things (IoT) systems, can function as practical means for implementing non-manipulable mechanisms, as they enhance transparency, improve traceability, and limit the scope for information distortion within supply chains. Blockchain provides decentralized data storage, offering all participants equal and prompt access to up-to-date information, significantly reducing the risk of falsification. This technology allows for continuous monitoring of transactions and product status, creating a trusted environment and minimizing the likelihood of unethical practices.

IoT devices continuously collect and transmit real-time data on the status and location of cargo, significantly increasing the control and management of logistics operations. This functionality enables automation of processes, reduces the risk of errors and manipulations, and allows for rapid response to changes, which ultimately leads to optimization of operations and increased overall efficiency.

From a theoretical perspective, non-manipulable mechanisms can improve the interaction of supply chain participants by making information flows more transparent, verifiable, and mutually observable. Figure 2 shows a diagram of information flows and levels of trust between key stakeholders: suppliers, manufacturers, distributors, and retailers.

Figure 2
Interaction of supply chain entities



Note: compiled by the author based on sources Christopher, (2016); Wang et al, (2016); Waller & Fawcett, (2013); Ivanov& Dolgui (2020)

In this study, Figure 2 is used to depict the governance logic on which non-manipulable mechanisms rest. It highlights that the key issue is not simply the presence of information exchange between suppliers, producers, distributors, and retailers, but the way this exchange is organized: when information flows are open, checkable, and visible to several parties at once, the scope for unilateral manipulation is reduced. In this respect, the figure underlines the argument that transparency and traceability are not secondary technical options, but structural prerequisites for limiting opportunistic behaviour in supply chain coordination.

The body of literature relevant to this research can be grouped into three closely related lines of analysis. The first deals with mechanism design and the task of coordinating actors when information is unevenly distributed and incentives do not coincide. The second focuses on transparency, verifiability, and visibility as governance conditions that narrow the room for opportunistic intervention in supply chain operations. The third explores how such arrangements affect logistics performance, particularly with regard to efficiency, resilience, and risk mitigation. In this article, these three directions are considered as elements of a unified analytical framework. The term non-manipulable mechanisms is therefore used in a strictly analytical sense to describe coordination and control configurations that restrict opportunistic interference in information flows, operational choices, and transaction records. In this framework, such mechanisms are characterized by five basic properties: transparent procedures, traceable actions, adaptability to changing conditions, protection from unilateral influence, and verifiable data and decisions. Within this context, Klaus Schwab, in "The Fourth Industrial Revolution" (2016), underscores that trust and transparency – supported above all by blockchain technologies – are key to constructing more reliable and open organizational architectures. This research trajectory has gained particular importance under conditions of globalization, digitalization, and increasing complexity of supply chains.

Significant achievements in the study of this issue include the work of Michael Christopher "Logistics and Supply Chain Management" (2016), which examines the issues of sustainability of logistics systems. The author emphasizes the critical role of non-manipulable mechanisms in increasing the stability and adaptability of supply chains in changing conditions. According to Christopher, ensuring sustainability is impossible without the integration of effective management strategies and the implementation of technologies aimed at minimizing the risks associated with potential manipulation.

In the article "Blockchain Technology in Supply Chain Management: A Review" (2020), Kumar, S., et al., and co-authors consider blockchain as a technology that provides protection against manipulation. The researchers note its high efficiency in maintaining transparency and traceability of logistics operations, which helps reduce the likelihood of information distortion. The authors also emphasize that the implementation of blockchain solutions requires not only technical adaptation, but also deep transformations of management practices and corporate culture of organizations.

More recent studies develop this discussion by arguing that blockchain should be viewed not only as a traceability instrument, but also as a factor shaping overall supply chain performance. Shahzad *et al*., (2025); Grigoryev *et al*., (2021), in particular, show that the impact of blockchain on sustainable supply chain outcomes is mediated by supply chain ambidexterity and survivability, drawing attention to the fact that the effectiveness of digital anti-manipulation tools depends on organizational fit and the ability of firms to embed transparency-oriented technologies in everyday operations. From a broader methodological standpoint, Hübschke *et al.,* (2025) generalize approaches to evaluating blockchain use

in supply chains and single out transparency, traceability, and operational efficiency as central assessment dimensions.

Among Russian scientific works, the collective monograph edited by N. Grigorieva "Logistics and Supply Chain Management: Fundamental Principles. Volume 1. Theoretical Foundations" (2021) deserves attention. It analyzes modern approaches to supply chain management with an emphasis on non-manipulable mechanisms. The authors emphasize that when studying the features of the Russian market, it is necessary to take into account its specific economic and institutional characteristics.

An important contribution to the study of non-manipulable mechanisms in logistics and supply chain management was the work of N. A. Korgin (2003). It proposed a universal mathematical model of exchange problems in active systems with asymmetric information and developed both discrete and continuous methods for constructing effective non-manipulable exchange mechanisms. Korgin proved the equivalence of exchange and motivation problems under a number of special conditions and emphasized the practical applicability of the proposed solutions in real socio-economic systems. Particular attention is paid to the analysis of non-hierarchical bilateral exchanges involving "quasi-intelligent" and "intelligent" agents.

Korgin's theory is relevant to this study because supply chains function as multi-participant systems in which actors have uneven access to information and may pursue their own interests strategically. In this context, the task goes beyond solving purely operational coordination issues and extends to shaping rules that make opportunistic behavior economically disadvantageous. Korgin's approach thus provides a conceptual lens for viewing supply-chain relations as exchange mechanisms subject to incentive constraints: requirements of transparency, verifiability, independence, and traceable decision procedures can be treated as institutional tools that limit opportunism. This reading corresponds to the conclusions of Mukhamedova *et al.,* (2023) and Mukhamedova *et al.,* (2023) (2023), who maintain that logistics systems in transition economies should be evaluated in terms of how well economic mechanisms reflect participant incentives, rather than solely on the basis of technical performance metrics.

This institutional reading is likewise in line with recent empirical studies on transparency and visibility in supply chains. Li *et al.,* (2025) argue that strong firm performance is driven not by transparency in isolation, but by its interplay with supply chain visibility, particularly visibility of demand. Their results indicate that anti-manipulation mechanisms are most effective when clear, transparent rules are coupled with timely access to operational data, which directly reinforces this study's focus on verifiability, traceability, and coordinated decision-making. Taken as a whole, this body of work allows mechanism design theory to be directly related to current approaches to supply chain governance. In this view, the key analytical sequence can be described as follows: when participants in a supply chain interact under conditions of asymmetric information, institutional arrangements must first limit the scope for opportunistic behaviour; this, in turn, generates the requirement for procedures that are transparent, verifiable, and traceable; once such conditions are in place, they affect logistics performance by lowering coordination losses, decreasing the risk of manipulation, and supporting more reliable operational decisions. Accordingly, transparency in this study is understood not as an abstract normative principle, but as a functional link between incentive-compatible mechanism design and observable efficiency results.

An active contribution of Kazakhstani scientists to the study of this issue is presented by the work of Gabdullina, L. *et. al.,* (2020) and co-authors "Transport and logistics innovations in supply chain management: the experience of Kazakhstan", which analyzes the potential for introducing non-manipulable mechanisms in the context of the national economy. The authors note that the effective implementation of such mechanisms is impossible without the development of appropriate infrastructure and achieving a higher level of digitalization at the state level.

At the same time, recent studies more often associate non-manipulable mechanisms with digital twins, real-time analytics, and resilient decision-making architectures. Roman *et al.,* (2025) contend that digital twins strengthen supply chain resilience by improving visibility, responsiveness, and decision quality under disruption, while Pan *et al.,* (2025) show that logistics research is shifting toward sustainable, resilient, and digitally synchronized supply-chain configurations in which real-time data integration becomes a core managerial prerequisite. Taken together, these trends suggest that non-manipulable mechanisms should be viewed within the wider transformation of supply chains toward adaptive, data-driven forms of governance.

Modern theoretical approaches to the design of mechanisms and management of organizational

systems indicate that optimization of processes in conditions of high complexity and information inequality, typical of supply chains, is associated with a number of significant difficulties. Centralized management models, where key decisions are made by one participant, contradict the principles of trust and partnership interaction. At the same time, under certain conditions, models resistant to manipulation can be developed. The concept of "limited influence" assumes that the contribution of each participant to the final result is minimal, which helps to achieve optimal indicators. The use of the principles of openness and transparency reduces incentives for dishonest behavior, making it economically inexpedient. This approach is based on the construction of an effective information exchange system aimed at eliminating data asymmetry and ensuring coordination between all parties.

Table 1
Analytical criteria used to operationalize non-manipulable mechanisms

Name	Description
Transparency	Full transparency of the planning process implies providing all interested parties with access to the initial data, methods and criteria for decision-making. The presence of hidden parameters or hidden evaluation indicators is excluded. Each stage of the procedure is documented in detail and is subject to verification. In addition, information on the weighting factors involved in the decision-making algorithms must be publicly available, which ensures control over the process and allows for the prompt identification of possible attempts at manipulation.
Traceability	The mechanism provides for tracking and reconstruction of all actions, transactions, and decision steps along the supply chain. This is supported by continuous logging of operational events, open documentation, time-stamped records, and protected digital registers that allow identification of who carried out a particular action, at what time, and on what grounds. As a result, traceability limits the scope for hidden interference and reinforces the responsibility of all parties involved.
Adaptability	The mechanism must be adaptable, allowing for the prompt revision of plans when external conditions or participant preferences change: for this purpose, regulated procedures for adjustment are introduced based on new data, feedback and emerging circumstances, and the chosen planning method allows for such changes without compromising the integrity and openness of the process, ensuring an effective response to unforeseen situations while maintaining transparency and independent verification.
Independence	The mechanism should exclude the possibility of unfair influence of individual participants by implementing a distributed management model, involving impartial mediators to resolve conflicts, introducing regulated procedures based on clear objective rules and creating conditions that prevent collusion of participants for personal gain to the detriment of the system.
Verifiability	Each stage of the process, including final decisions, is monitored by independent experts or auditors by checking the reliability of the initial data, the correctness of the methodological approach and the integrity of the decision taken, and the use of electronic signatures and hash functions increases verifiability, eliminates the possibility of data falsification and ensures the reliability of the results obtained.

Note: compiled by the author based on sources (Ivanov, 2020; Waller & Fawcett, 2013; Tseng et al., 2018; Melnyk, 2014)

Table 1 summarizes the analytical criteria used in this study to operationalize non-manipulable mechanisms. On their basis, the focal phenomenon can be separated from related, but not identical, notions such as purely technical protection against unauthorized access, simple immutability of records, or broad organizational transparency. In this framework, non-manipulability is not treated as a solely technical attribute; it is seen as an institutional and operational quality that arises when transparency, verifiability, independence, and adaptability are built into a single, coherent management configuration. This perspective sharpens the boundaries of the research object and offers a more robust foundation for interpreting the empirical findings.

Although the number of recent studies is growing, a significant conceptual gap still persists. In much of the literature, mechanism design, technologies that increase transparency, and logistics performance are discussed as related topics, but they are not brought together into a single coherent framework. Consequently, there is still no fully developed analytical model showing how incentive-compatible arrangements lead to operational improvements via transparency, verifiability, and traceability.

In this article, non-manipulable mechanisms are treated as the linking category between these strands. Understood as institutional and technological configurations, they limit the scope for opportunistic distortion, enhance the quality and observability of information flows, and thus influence concrete indicators such as processing times, costs, customer satisfaction, and risk levels. This integrated view forms the conceptual foundation for the empirical analysis presented in the subsequent sections.

Methodology

The study was based on a mixed-method quasi-experimental comparative design aimed at evaluating how non-manipulable mechanisms affect supply chain performance and risk management. The empirical sample comprised 80 enterprises: 50 firms formed the implementation, or experimental, group, while 30 firms were included in the control group. The groups were not created through random assignment; instead, they were formed according to observed characteristics. Enterprises were assigned to the experimental group if they had used non-manipulable mechanisms for at least six months and were able to provide comparable operational data for the periods before and after implementation. The control group consisted of firms that continued to use standard supply chain management practices during the same observation period.

The analysis was built around five key indicators: order processing time, inventory management costs, customer satisfaction, fraud incidence, and level of legal risk. Order processing time was defined as the number of hours between receiving an order and confirming its execution. Inventory management costs were taken from firms' internal accounting records and covered storage, handling, and inventory maintenance expenses. Customer satisfaction was calculated as the proportion of positive responses in internal feedback forms and post-service surveys. Fraud incidence reflected changes in the number of recorded cases related to document falsification, reporting discrepancies, and other internal violations. Legal risk was measured using a relative expert-based index that considered compliance-related events, contractual disputes, and alerts from internal legal reviews.

Quantitative data were gathered using standardized questionnaires, internal company records, and comparable indicators measured before and after the observed period. In the experimental group, the baseline covered the six months preceding the introduction of non-manipulable mechanisms, and the follow-up covered the first six months of their use. In the control group, the comparison was based on two consecutive six-month periods of equal duration. Operational indicators were analyzed in their original measurement units, whereas fraud incidence and legal risk were expressed as index values, with the baseline level set at 100.

Qualitative information was obtained through semi-structured interviews with logistics directors and supply chain managers representing both groups. The interview questions addressed issues of process transparency, trust among supply chain partners, difficulties encountered during implementation, and the organizational effects associated with the use of these mechanisms.

Quantitative data were processed using Student's t-test at a significance level of $p < 0.05$. Independent-samples t-tests were applied to compare the changes observed in the experimental and control groups, whereas paired-samples t-tests were used for before-and-after comparisons, including the customs-post data presented in Tables 3 and 4. Before conducting the tests, the dataset was examined for distribution symmetry, outliers, comparability of measurement scales, and homogeneity of variance. In cases where the assumption of equal variance was not satisfied, unequal-variance estimates were taken into account. The qualitative interview data were analysed through thematic analysis, which made it possible to identify recurring themes, common patterns, and repeated managerial interpretations.

The interpretation of the findings should take into account several limitations: the groups were not formed randomly, company data may be incomplete, and the fraud and legal-risk indicators partly rely on expert assessment. For this reason, these indicators are better understood as structured comparative estimates rather than fully standardized external measurements.

Results and discussion

The empirical analysis first considers the changes recorded in enterprises that introduced non-manipulable mechanisms. Table 2 includes ten participating enterprises from different sectors of Kazakhstan's economy and compares the dynamics of three indicators after implementation: order processing time, inventory management costs, and customer satisfaction.

Table 2
Examples of study participant enterprises and changes in key indicators

№	Company	Sector	Reduction in order processing time	Reduction in inventory management costs	Increased customer satisfaction levels
1	«OASIS BREEZE» LLP	Production of consumer goods	–30%	–22%	+17%
2	ENERGYGROUP-PVL LLP	Energy	–25%	–18%	+14%
3	IKON TIRES KAZAKHSTAN LLP	Automotive industry	–28%	–20%	+16%
4	LLP «STUWA/SHTYUVA»	Metal products	–32%	–24%	+19%
5	SATORY KZ LLP	Mechanical engineering	–27%	–17%	+15%
6	SHYMKENT GROUP STROY LLP	Construction	–29%	–21%	+18%
7	ABSOLUTE SALE LLP	Trade	–26%	–19%	+13%
8	PE «CHARGE LTD.»	Logistics and service	–24%	–16%	+12%
9	Alex Group LLC LLP	Import-export	–31%	–23%	+18%
10	«FACTORY OF METAL STRUCTURES UKO-S STAR» LLP	Metal structures	–33%	–25%	+20%

Note: compiled by the author

As Table 2 shows, in every example examined the implementation of non-manipulable mechanisms led to a substantial reduction in order-processing time (–24% to –33%), lower inventory-management costs (–16% to –25%), and an increase in customer satisfaction (+12% to +20%).

Table 3 reports four key performance indicators for eight selected customs posts before and after the introduction of non-manipulable mechanisms: declaration processing time, delay rate, number of administrative adjustments, and the level of foreign-trade participants' satisfaction. To evaluate the statistical significance of the observed changes, a paired t-test was employed; its results are shown in Table 4.

The data in Table 3 indicate that the average declaration-processing time across all posts fell by roughly 30–35 %, the delay rate dropped by 40–50 %, the number of administrative adjustments more than halved, and the satisfaction level of foreign-trade participants rose by 20–25 %.

Table 3
Customs posts: before and after indicators

Customs post	Processing time before (h)	Processing time after (h)	Delays before (%)	Delays after (%)	Administrative adjustments before (pcs)	Administrative adjustments after (pcs)	Satisfaction before (%)	Satisfaction after (%)
Zhetysu	55	38	25	12	75	30	65	85
Almaty-Center	60	42	28	15	80	35	60	88
Almaly – CTO	58	40	30	14	70	28	68	90
Ile	54	36	22	10	65	25	66	87
Altynkol	62	44	27	13	85	40	62	84
Nur Zholy	50	35	24	11	60	22	70	89
Park InfoTech	57	39	26	12	78	32	64	86
Temirzhol	59	41	29	14	82	38	63	88

Note: compiled by the author based on the customs post performance indicators; calculations by the author

Table 4
Paired t-test results for PTO indicators

Metric	t-statistics	p-value
Time (h)	46.30	$p < 0.001$
Delays (%)	30.34	$p < 0.001$
Adjustments (pcs)	42.79	$p < 0.001$
Satisfaction (%)	–22.01	$p < 0.001$

Note: compiled by the author based on paired t-test calculations for customs post performance indicators

As shown in Table 4, all recorded changes were statistically significant ($p < 0.001$), which provides empirical support for the effectiveness of the implemented non-manipulable mechanisms. In addition to meeting conventional significance thresholds, the changes observed are large enough to matter in practice: shorter processing times, fewer delays, and reduced administrative rework point to tangible improvements rather than minor statistical variation. This distinction is crucial for interpreting the findings in real-world logistics operations.

The quantitative results that follow are examined with reference to the three working hypotheses set out in the introduction. They rely on the unified indicator definitions specified in the methodology and cover both directly recorded operational measures (order processing time in hours, cost indicators, proportions of satisfied customers) and relative shifts computed from documented baseline values (for fraud incidence and legal risk). This arrangement makes it possible to evaluate not only the fact of change, but also whether the identified trends correspond to the anticipated effects of non-manipulable mechanisms.

H1: non-manipulable mechanisms are associated with higher operational efficiency. The comparative results are in line with this hypothesis. In the experimental group, all core operational indicators improved: order processing times shortened, inventory management costs declined, and customer satisfaction increased. In the control group, by contrast, changes were either marginal or did not reach statistical significance. Table 5 presents the detailed indicators for the experimental group. In combination with the previously discussed control-group results, the consistent improvements in the main operational measures are unlikely to be attributable to normal random fluctuations in activity.

H2: non-manipulable mechanisms are associated with lower fraud-related and legal risks. The empirical material does not contradict this assumption. Based on combined survey responses and supporting documentation, the experimental group reported a 22% decline in fraud incidence, while no change was observed in the control group. Expert comparative scoring also indicated a 17% drop in legal risk for the experimental group, whereas the control group showed a 4% increase. Although both indicators represent structured comparative assessments rather than externally standardized measures, the direction of change in each case points to a reduction in exposure to opportunistic behaviour and compliance-related risks under non-manipulable mechanisms.

H3: non-manipulable mechanisms improve coordination and perceived trust among supply chain participants. The qualitative materials are in line with this hypothesis. Interview and survey data suggest that the introduction of non-manipulable mechanisms made operations more transparent, facilitated interaction between supply chain participants, and reinforced confidence in counterparties. Representatives of the experimental group also noted that supply relationships became more predictable, while at the same time pointing out that these improvements were accompanied by additional investment and the need to revise internal procedures.

To increase the precision of the quantitative analysis, the principal effects of introducing non-manipulable mechanisms are shown in a structured table. Table 5 presents the main performance indicators for the experimental group (companies that implemented non-manipulable mechanisms), including initial and post-implementation values, relative changes, and, where relevant, measures of statistical significance. This tabular representation ties the analysis more directly to the empirical data and enables a clearer, methodologically consistent interpretation of the main effects of the implemented mechanisms.

Table 5
Quantitative measures for the experimental group following the introduction of non-manipulable mechanisms

Indicator	Unit of measurement	Experimental group (n = 50), before	Experimental group (n = 50), after	Change (%)	Statistical significance
Order processing time	hours	52	37	–28	$p < 0.01$
Inventory management costs	USD	1,600,000	1,312,000	–18	$p < 0.05$
Customer satisfaction	%	75	86	+14.7	$p < 0.01$
Fraud incidence	% change from baseline	100	78	–22	based on survey results
Legal risk level	% change from baseline	100	83	–17	based on expert assessment

Note: Order processing time is reported in hours; inventory management costs are given in USD; customer satisfaction is indicated as the percentage of positive responses. Fraud incidence and legal risk level are shown as index-based relative changes, where the baseline pre-implementation value is set equal to 100

As shown in Table 5, the introduction of non-manipulable mechanisms in the experimental group coincided with consistent improvements across all key indicators. The directions of change align with each other: operational measures became more favourable, customer satisfaction increased, and both fraud incidence and legal risk moved down from their baseline levels. For the main operational indicators, these changes were statistically significant, and their scale suggests a noticeable practical effect rather than a purely formal one. While the research design does not allow for a strict experimental causal claim, the contrast with the control group and the coherence of the results indicate that non-manipulable mechanisms were an important factor contributing to the observed improvements.

Overall, the empirical results support all three working hypotheses and show that the influence of non-manipulable mechanisms extends beyond single operational improvements. The effects manifest along several connected dimensions: higher efficiency, more reliable procedures, and lower susceptibility to opportunistic behaviour. This configuration corresponds to the conceptual model outlined in the literature review, where incentive alignment, transparency, and verifiability together determine observable logistics performance.

Conclusion

The study found that the implementation of non-manipulable mechanisms, including blockchain-based transaction registration, IoT-based monitoring and distributed ledger solutions, was associated with significant improvements in supply chain efficiency and reliability. After transparent, auditable and more autonomous procedures were introduced in the surveyed companies, key operational indicators showed marked improvement. A comparable trend was recorded in the separate customs-post dataset, where declaration processing times, delays and administrative adjustments decreased following the adoption of non-manipulable mechanisms. At the same time, the satisfaction level of participants in foreign trade operations increased by 15-20%. All changes were statistically significant ($p < 0.001$). The qualitative analysis of interviews also indicated that the introduced mechanisms strengthened trust and improved the quality of communication between participants, although their implementation required initial investment in technical infrastructure and staff training. In future work, it is important to investigate how non-manipulable mechanisms operate in small and medium-sized enterprises, where financial and organizational limitations may strongly influence implementation results. It would also be valuable to analyse their long-term impact in various sectors and under different levels of digital maturity within supply chain systems.

Conflicts of Interests
The authors declare no conflict of interest

Author Contributions
KZh.Zh: Conceptualization, Formal Analysis, Investigation, Resources, Data Curation, Writing – Original Draft Preparation, Writing – Review & Editing, Visualization.

ASK: Methodology, Validation, Writing – Review & Editing, Supervision, Project Administration, Funding Acquisition.

All authors discussed the research results, reviewed the final version of the manuscript, and approved its submission to the journal.

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