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Modeling and Simulation of Weak Signal Life Cycle Using System Dynamics: Postprint

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Abstract

[Purpose/Significance] To enhance the connotative research of weak signals, this study explores the elements at each stage and their interconnections throughout the entire lifecycle process, aiming to achieve theoretical contributions while providing theoretical guidance for organizations engaged in weak signal management practices. [Method/Process] Based on a systematic review of the current research status of weak signal concepts, a conceptual definition is formulated by integrating sensemaking theory. Subsequently, the concept of weak signal lifecycle is proposed through analogy with information lifecycle and emerging issue lifecycle. Furthermore, system dynamics methodology is employed for systematic thinking, causal loop diagrams are utilized for system modeling, and stock-and-flow diagrams are applied for simulation. [Results/Conclusion] The weak signal lifecycle comprises four stages: detection, association, transmission, and decision-making. The realism of the corresponding system dynamics model is validated, and four key auxiliary variables are identified through scenario simulation: degree of external noise interference, weak signal analysis efficiency, degree of mutual trust within the organization, and decision-maker trust level. Based on the overall research, potential obstacles in the weak signal management process and corresponding coping strategies are presented.

Full Text

Preamble

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Modeling and Simulation of Weak Signals Lifecycle Based on System Dynamics Approach

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Abstract

[**Purpose/Significance**] To enhance the theoretical research of weak signals, this study explores the elements at each stage of their full lifecycle and the relationships between these elements, aiming to achieve theoretical contributions and provide guidance for organizations engaged in weak signals management practice. [**Method/Process**] Based on a review of current conceptual research on weak signals, this paper provides a conceptual definition of weak signals combined with sense-making theory. By analogy with information lifecycle and emerging issues lifecycle, the concept of weak signals lifecycle is proposed. System dynamics methodology is then employed for systems thinking, using causal loop diagrams for system modeling and stock-flow diagrams for simulation. [**Result/Conclusion**] The weak signals lifecycle comprises four stages: detection, relevance, transmission, and choice. The corresponding system dynamics model demonstrates realism, and scenario simulations confirm four key auxiliary variables: degree of external noise interference, weak signals analysis efficiency, degree of mutual trust within the organization, and decision-makers' trust level. Based on the overall research, this paper identifies potential obstacles in weak signals management processes and proposes coping strategies.

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Technological transformation, globalization, and information overload have made the entire socio-economic system increasingly complex, rendering accurate predictions of economic activities and management behaviors more difficult while simultaneously generating demand for higher-level predictive capabilities in uncertain environments. Against a backdrop of turbulence, chaos, and insecurity, the need for early warning of disruptive or catastrophic events becomes even more urgent. Consequently, the value of "weak signals (WS)" has gradually attracted attention from both industry and academia. Derived from indicators and originating from information, weak signals should similarly possess a complete lifecycle process. However, existing research remains largely focused on diversified extension studies, with insufficient exploration of theoretical research. A review of weak signals research under this paradigm reveals that scholars' conceptualizations of weak signals vary, but can generally be divided into three categories: (1) weak signals are associated with both phenomena and outcomes; (2) weak signals represent only changing phenomena; (3) weak signals constitute incomplete information for future change management. While conceptual definitions remain contested, there is broad consensus on uncertainty, ambiguity, and hiddenness, as well as shared views that weak signals represent incomplete information, involve complex interpretation, have lead time, can evolve into trends, and can guide change [].

The current conceptual definitions primarily cover the initial manifestations and ultimate impacts of weak signals, with uncertainty, ambiguity, and hiddenness receiving consistent recognition. The transition from weak to strong signals is a gradual, cumulative process focused on change. Yet questions remain: What does this process look like? Does it undergo stages of generation, development, maturity, and decline from capture to action, and what specifically constitutes each stage? What influence do individuals and organizations have on the weak signals lifecycle? These questions have rarely been deeply investigated by scholars. Therefore, this paper begins with the concept of weak signals, explores their lifecycle process, and conducts system dynamics modeling and simulation based on systems thinking.

1 Conceptual Definition of Weak Signals

The research object of this paper—weak signals—primarily refers to those oriented toward economic management. Why are certain weak signals identified first? How are they identified? This paper attempts to draw on K.E. Weick's sense-making theory (also called "interpretation theory") [] to redefine the concept of weak signals based on previous research. Sense-making research originates from cognitive psychology: (1) For organizations, the purpose is to explain unexpected, complex, and confusing events and problems occurring inside and outside the organization []; (2) For individuals, "people" are active actors who project their own perspectives, views, and experiences onto information []; (3) The environment is viewed as outputting rather than inputting information, with people, organizations, and environments interacting []. These three aspects of sense-making correspond precisely to the three dimensions of weak signals formation. Therefore, we define weak signals using Weick's sense-making theory: a continuous sense-making process that first notices vague and uncertain cues from anomalies in current experience flows, then extracts clues for further polishing and refinement to guide potential changes and trends, and finally determines effects through retrospective reflection.

2 Overview of Weak Signals Lifecycle Research

Overall, research on the weak signals lifecycle is scarce. A. Brizon and Y.L. Wybo first proposed it, but their research was limited to industrial production safety rather than weak signals in a general sense, and lacked holistic systems thinking []. Related research primarily focuses on weak signals identification processes or procedures.

H.I. Ansoff et al. proposed a "filter" method for capturing, enhancing, and supporting decision-making with weak signals, including monitoring, mental, and propulsion layers []. This method can be seen as an early conceptualization of the weak signals lifecycle. E. Hiltunen, based on E. Tarasti's existential semiotics, extended the concepts of exosigns (equivalent to weak signals) and endosigns in the future sign sense-making process, where interpretation is the transformation from exosigns to endosigns, forming secondary exosigns (equivalent to strong signals) for communication []. G.S. Day and P.J.H. Schoemaker proposed seven steps to improve weak signals identification capability: (1) define the scope of signal detection; (2) scan defined peripheral areas to capture and amplify emerging weak signals; (3) interpret weak signals; (4) explore their meaning; (5) take action to identify and verify; (6) improve organizational management to enhance sensitivity and alertness to weak signals; (7) integrate signal scanning, interpretation, exploration, and utilization into action plans []. Liu Qianli, using Weick's organizational sense-making framework as a blueprint, shaped the intelligence signal sense-making process, where ecological change, enactment, selection, and retention constitute organizational construction, while situational change, collection, analysis, and inference form intelligence information sense-making, creating five loops []. J. Ponomareva and A. Sokolova divided the weak signals identification process into: (1) defining objectives, main tasks, and investigation scope; (2) environmental scanning to collect information materials for analysis, screening, and sequencing; (3) clustering and identifying weak signals with further verification; (4) forming conclusions and recommendations to guide strategic action []. P. Meissner, C. Brands, and T. Wulf proposed a structured integration of expert judgment into scenario planning processes, covering weak signals detection, discussion, and action, thereby enabling quantitative analysis of weak signals [].

3 Exploration of Weak Signals Lifecycle

3.1 Connection and Distinction with Information Lifecycle

The information lifecycle represents the objective laws of information from generation, development, maturity to demise, characterized by abstraction, diversity, periodicity, and stage-specific features. Domestic and international academia has conducted rich research from perspectives of information movement and information management, evolving from 5-stage, 7-stage, and 10-stage models to the International Organization for Standardization's 11-stage model: creation, acquisition, indexing, storage, retrieval, distribution, presentation, migration, exchange, protection, and disposal or abandonment []. Do weak signals, derived from information, also possess lifecycle characteristics? This requires using emerging issues as a bridge to connect information lifecycle and weak signals lifecycle.

First, although many scholars treat weak signals and emerging issues as equivalent, in Hiltunen's "future sign" formulation, weak signals are more often considered signals of emerging issues. Issues imply the diffusion degree of phenomena, composed of a series of events. Understanding the lifecycle process of issues is crucial for weak signals sense-making []. Second, from an information perspective, A.C. Wygant and O.W. Markley believe emerging issues also have a process like the information lifecycle, dividing it into six stages based on media and public awareness levels []. As signs of emerging issues, weak signals are often embedded in the first two stages—"idea generation" and "elite attention." "Public attention," "government attention," and even "universal acceptance" mean strong signal release, while the final "record retention" stage represents signal silence rather than demise or abandonment. Therefore, to discover opportunities or threats before emerging issues receive widespread attention, weak signals must be captured before becoming strong signals, requiring understanding of what stages the weak-to-strong transition includes and how, as information, they are generated, transmitted, and adopted. Thus, weak signals also have lifecycle characteristics awaiting further exploration.

On the other hand, the lifecycles of information and weak signals differ. First, although weak signals originate from information, they are also a continuous sense-making process, so their lifecycle should be tightly coupled with the subject's sense-making process. If analogized to information or emerging issues lifecycles, sense-making in the weak signals generation period should be weak signals detection, in the development period should be weak signals tracking, in the maturity period should be weak signals credibility and validity assessment, and in the decline period should be weak signals "noise" removal and re-detection. Additionally, this process must consider weak signals transmission methods and channel selection, interpretation mechanisms, and whether "noise" removal and re-capture truly represent the final stage of the weak signals lifecycle or whether recipient reaction behaviors should be considered.

Second, the purpose of weak signals is to discover possible changes and trends while pursuing time value in a state of low information content. That is, analysts hope to discover weak signals early and form possibilities, leaving decision-makers more response time. Hiltunen illustrated the relationship between two types of change (sudden and gradual) and signal information volume, as shown in Figure 1 [Figure 1: see original paper]. Weak signals mixed with noise lie below the noise level, with strong signals above. When uncertain events occur, change is produced []. Therefore, for weak signals, the lifecycle should be a rapid turnover process consisting of few stages, not "declining" at the end but rather transforming into strong signals to bring management behavior or strategic action to the organization before becoming strong signals, thereby creating organizational benefits. Thus, the final stage of the weak signals lifecycle should make decision-makers believe that transmitted weak signals are crucial and should prompt specific actions.

3.2 Stages of Weak Signals Lifecycle

Based on existing research, this paper divides the weak signals lifecycle process into four stages, as shown in Figure 2 [Figure 2: see original paper].

(1) **Stage 1—Detection**: The stage where weak signals are initially identified. Due to their low information volume, weak signals are difficult to discover, requiring strong alertness from individuals and organizations to

monitor and filter required weak signals.

(2) **Stage 2—Relevance**: This stage reflects the correlation between weak signals and future changes or trends, representing further understanding of detected weak signals through sense-making to form scenarios or interpretations.

(3) **Stage 3—Transmission**: Not all weak signals indicate significant changes or trends. Based on sense-making, appropriate selection must be made to transmit key weak signals to decision-makers.

(4) **Stage 4—Choice**: The time value of weak signals depends on the management behavior or strategic action they can bring before becoming strong signals. The final stage should make decision-makers believe transmitted weak signals are crucial and should prompt specific actions.

4 System Dynamics Modeling of Weak Signals Lifecycle

4.1 Research Approach Based on System Dynamics

The core idea of system dynamics lies in systems thinking. As a thinking mode opposite to reductionism, it adopts holistic philosophy and dialectical materialism analysis methods, teaching us to avoid linear thinking in a nonlinear world and to delineate appropriate system boundaries when facing each system []. Currently, research applying system dynamics to weak signals lifecycle in economics and management fields remains limited, with related research mainly involving early warning and risk themes. For instance, Zhang Shuang constructed a real estate risk early warning index system through system dynamics, deriving corresponding warning signals to form a comprehensive real estate market risk index []; Zhao Hui et al. used improved system dynamics methods to evaluate key risk factors in the lifecycle of environmental protection PPP projects []; Zhang Cheng applied system dynamics theory to research on financial risk signal monitoring and control in small and medium-sized enterprise supply chains [].

Therefore, the weak signals lifecycle shown in Figure 2 only reflects the linear process and sequence of weak signals evolution, not the result of systems thinking. To further comprehensively analyze the connotation of the weak signals lifecycle, this section conducts systems thinking, treating the four stages as four subsystems. Although the entire process starts with “detection” and ends with “choice,” subsystems have repetitive and feedback situations. The system boundary is demarcated by the source of weak signals and the implementation of actions, as shown in Figure 3 [Figure 3: see original paper].

Based on the determined system boundary and according to multi-faceted theory and signal analysis practice, relevant elements are identified to construct a causal loop diagram of the weak signals lifecycle, as shown in Figure 4 [Figure 4: see original paper]. This diagram is an important tool for representing the system feedback structure of the weak signals lifecycle and forms the basis for subsequent stock-flow diagrams. The entire loop includes four subsystems:

detection subsystem, relevance subsystem, transmission subsystem, and choice subsystem. Finally, through stock-flow diagrams, equation setting, and numerical simulation, key auxiliary variables are identified and important scenarios discovered, enabling deeper exploration of the practical significance of weak signals lifecycle research.

4.2 Detection Subsystem

Detection is the starting point of the weak signals lifecycle. Given the characteristics of weak signals and J.A. Swets et al.'s signal detection theory [], the key in this subsystem is to improve the "signal-to-noise" ratio to discover possible weak signals as alternatives. From signal transmission theory perspective, "noise" plays a negative role—it not only reduces signal detectability but may also drown out signals, causing transmission errors and distortions []. Therefore, facing "external noise interference," weak signals detection must rely on two capabilities: attention and alertness.

Attention, drawn from W. Ocasio's attention-based view of the firm, systematically explores the role of attention in organizational action and adaptation processes, arguing that organizational behavior is determined by how decision-makers allocate attention []. Alertness originates from Austrian School scholar I.M. Kirzner's entrepreneurial alertness, which refers to entrepreneurs' ability to alertly discover profit opportunities in non-equilibrium markets and respond quickly, fundamentally explaining this previously overlooked important coordination factor in free market economies [].

In the detection subsystem, attention and alertness also differ. On one hand, attention is the perception capability for known signals, relying on detectors' "personal domain knowledge" to compare with known signal lists, assessing whether one or several signals may appear, then evaluating, selecting, and clustering them into "potential known change signals." On the other hand, alertness reflects the ability to detect unexpected anomalies, mainly depending on detectors' "personal experience" to form targeted "unknown anomaly signals" not on signal lists. The detection activities based on these two capabilities correspond to two types of scanning: "routine scanning" and "specific scanning." In existing research, environmental scanning and horizon scanning are commonly used methods, with routine scanning operating periodically and specific scanning starting anytime based on detectors' sensitivity. Ultimately, detected potential known change signals and unknown anomaly signals together form "alternative weak signals," while also constituting two reinforcing loops: - Attention → Routine scanning → Potential known change signals - Alertness → Specific scanning → Unknown anomaly signals

4.3 Relevance Subsystem and Transmission Subsystem

The relevance subsystem focuses on sense-making of alternative weak signals to obtain "transmittable weak signals." Due to their "weak" nature, weak signals are difficult to interpret accurately. From Liu Qianli's intelligence signal sense-making process, analysis and inference should be two important components forming weak signals relevance []. In the weak signals lifecycle, analysis is an individual's information selection and reorganization process based on relevance, used to form "possible changes and trends." Under different time constraints, requirements for "weak signals analysis efficiency" and "weak signals analysis rate" vary, but they always maintain a positive feedback relationship.

Weak signals inference represents the retention of individual weak signals sense-making, playing an important role in screening "transmittable weak signals." Through "weak signals inference validity," it acts on the intermediate variable "transmittable weak signals ratio," transforming "possible changes or trends" into weak signals recognized by the majority. However, organizational-level sense-making is not individual behavior, and weak signals interpretation should not blindly pursue inference precision and diversity—more precise conclusions are more likely to be analysts' arbitrariness. Therefore, "weak signals inference validity" requires team argumentation to determine. "Degree of mutual trust within organization" often affects "team argumentation efficiency" and indirectly affects inference validity. Trust here includes multiple factors such as sense-making capability, personal interests, and reliability of weak signals scanning sources.

The transmission subsystem plays a connecting role between relevance and choice subsystems. When interfacing with the relevance subsystem, it can help analysts overcome cognitive bias problems to some extent. This is because in weak signals sense-making, analysts cannot be overly optimistic, always affirming their analysis, nor completely pessimistic or underestimating future changes revealed by weak signals. Therefore, balancing loops are needed to allow analysts to view their work with a dialectical or contradictory mindset, enabling sustained and stable weak signals relevance. Thus, the variable "transmittable difference" is introduced, setting "transmittable upper limit" and "transmittable lower limit" to trigger necessary "re-analysis" or even "re-scanning." Specific threshold values should be dynamically adjusted according to organization, individual, or current objectives and tasks. Ultimately, this subsystem forms three balancing loops: - Weak signals analysis rate → Possible changes or trends → Transmittable weak signals ratio → Transmittable weak signals → Transmittable difference → Re-analysis - Alternative weak signals → Weak signals analysis rate → Possible changes or trends → Transmittable weak signals ratio → Transmittable weak signals → Transmittable difference → Routine scanning → Potential known change signals - Alternative weak signals → Weak signals analysis rate → Possible changes or trends → Transmittable weak signals ratio → Transmittable weak signals → Transmittable difference → Specific scanning → Unknown anomaly signals

4.4 Transmission Subsystem and Choice Subsystem

After weak signals undergo individual analysis and team inference, if they indicate significant events will occur—whether "black swan" or "gray rhino" events—as "worthwhile transmittable weak signals," they must be transmitted to decision-makers. This is the role of the transmission subsystem when interfacing with the choice subsystem.

However, organizational weak signals lifecycle processes are not merely epistemological issues but also sociological ones. In transmission and choice subsystems, "decision-makers' trust level" is a key factor. Through interactive game-playing between decision-makers and analysts, accompanied by "degree of mutual trust within organization" affecting "analysts' transmission willingness," it influences the transformation of valuable weak signals, namely "worthwhile transmittable weak signals ratio," while also constituting analysts' own weak signals adoption tendency—"adoption ratio." On the other hand, decision-makers must also consider "complexity of organizational environment" and, based on their own "(decision-makers') knowledge structure," adopt transmitted weak signals to form corresponding strategic actions that realize weak signals value, and through "action transformation rate," update previous organizational objectives and tasks to lay the foundation for a new round of weak signals lifecycle.

Nevertheless, considering decision-makers' knowledge structure limitations and bounded rationality in external environment perception, control mechanisms are needed in the choice subsystem to avoid excessive adoption or non-adoption due to individual reasons. Similar to the relevance subsystem, variables "adopted difference," "adopted upper limit," and "adopted lower limit" are introduced to form balancing loops with "re-scanning" and "re-analysis," ensuring weak signals adoption rationality. Specific threshold settings are also dynamically adjusted. Therefore, the choice subsystem ultimately has two reinforcing loops and three balancing loops: - Adoption ratio → Adopted weak signals → Action transformation rate → Consistency with organizational objectives and tasks → Attention → Routine scanning → Potential known change signals → Alternative weak signals → Weak signals analysis rate → Possible changes or trends → Transmittable weak signals ratio → Transmittable weak signals → Worthwhile transmittable weak signals ratio → Worthwhile transmittable weak signals - Adoption ratio → Adopted weak signals → Action transformation rate → Consistency with organizational objectives and tasks → Alertness → Specific scanning → Unknown anomaly signals → Alternative weak signals → Weak signals analysis rate → Possible changes or trends → Transmittable weak signals ratio → Transmittable weak signals → Worthwhile transmittable weak signals ratio → Worthwhile transmittable weak signals - Adopted weak signals → Adopted difference → Re-analysis → Weak signals analysis rate → Possible changes or trends → Transmittable weak signals ratio → Transmittable weak signals → Worthwhile transmittable weak signals ratio → Worthwhile transmittable weak signals → Adoption ratio - Adopted weak signals → Adopted difference → Re-scanning → Routine scanning → Potential known change signals → Alternative weak signals → Weak signals analysis rate → Possible changes or trends → Transmittable weak signals ratio → Transmittable weak signals → Worthwhile transmittable weak signals ratio → Worthwhile transmittable weak signals → Adoption ratio - Adopted weak signals → Adopted difference → Re-scanning → Specific scanning → Unknown anomaly signals → Alternative weak signals → Weak signals analysis rate → Possible changes or trends → Transmittable weak signals ratio → Transmittable weak signals → Worthwhile transmittable weak signals ratio → Worthwhile transmittable weak signals → Adoption ratio

5 System Dynamics Simulation of Weak Signals Lifecycle

Causal loop diagrams, as output results of causal models, are suitable for expressing correlations and feedback processes. However, to further understand existing feedback structures and infer corresponding dynamic behaviors, stock-flow diagrams with equations are needed for quantitative simulation, as shown in Figure 5 [Figure 5: see original paper].

5.1 Determining Equations and Initial Conditions

Based on system structure and combined with survey results from experts and doctoral students studying intelligence signals, equations and initial conditions for weak signals lifecycle variables are obtained. Given the large number of variables involved, Table 1 only lists equations and initial conditions for main variables. Custom units "signals" represent the number of weak signals, and "Month" represents system operation time in months.

5.2 Assignment and Scenario Simulation

To examine whether the established model is realistic and to confirm key variables identified in causal analysis, simulation experiments were conducted. First, model fitting was checked, and through manual assignment, the fitting effect basically conformed to the weak signals lifecycle process. Subsequently, values of several key auxiliary variables considered important in causal analysis were adjusted to form different scenarios, with specific assignments shown in Table 2 .

5.2.1 Scenario 1: Reduced External Noise Interference As previously mentioned, the key in the detection subsystem is to improve the "signal-to-noise" ratio, indicating that "degree of external noise interference" is a critical auxiliary variable. Therefore, this variable was adjusted to 0.5 (smaller values indicate greater interference), revealing that the stock "alternative weak signals" showed significant improvement and could be obtained faster than the initial state, as shown in Figure 6 [Figure 6: see original paper].

5.2.2 Scenario 2: Improved Weak Signals Analysis Efficiency Weak signals relevance is formed through sense-making, where analysis is equivalent to "selection"—the process by which organizational members attempt to assign different relational structures to previously established intuitive information. Therefore, the relevance level of selected information in the analysis stage affects subsequent inference. In this model, it significantly affects the stock "possible changes or trends" and flow "transmittable weak signals ratio," with both variables increasing, as shown in Figure 7 [Figure 7: see original paper].

5.2.3 Scenario 3: Enhanced Trust Trust has long been an unavoidable topic in human interaction, with its importance fully demonstrated in sociology, psychology, economics, and organizational behavior. In the weak signals lifecycle process, the subject is always "people." On the other hand, human decision-making behavior is always subject to bounded rationality—limited by knowledge, cognitive capacity, and time []. One way to overcome these limitations is cooperation based on trust, whether equal collaboration within teams or subordinates' decision-making assistance to superiors. Moreover, trust itself is considered a decision made after weighing rational and irrational trust costs, and an effective mechanism to help decision-makers save mental costs []. Therefore, the two auxiliary variables "degree of mutual trust within organization" and "decision-makers' trust level" were adjusted to examine whether trust can act as a "lubricant" promoting weak signals transmission and adoption.

As shown in Figure 8 [Figure 8: see original paper], when "degree of mutual trust within organization" and "decision-makers' trust level" increased from 0.3 to 0.8, the quantity of weak signals transmission and adoption increased significantly. Unlike the initial state where decision-makers might fail to adopt weak signals for extended periods due to bounded rationality, even though the increase rate of "transmittable weak signals" after month 9 was not as high as the initial state, this precisely demonstrates that the "transmittable difference" set in the system played an inhibitory role, preventing blind optimism or excessive expansion triggered by decision-makers' trust.

6 Results and Discussion

Based on conceptual definition of weak signals and literature review of lifecycle research, this paper analogized information lifecycle and emerging issues lifecycle to summarize four stages of weak signals lifecycle: detection, relevance, transmission, and choice. System dynamics methodology was further used for systematic modeling and simulation, identifying relevant elements at each stage, forming corresponding causal loop diagrams and stock-flow diagrams. Through assignment simulation, the model demonstrated certain realism while confirming four key auxiliary variables: degree of external noise interference, weak signals analysis efficiency, degree of mutual trust within organization, and decision-makers' trust level.

Additionally, this research produced the following innovative insights and applications:

(1) Weak signals generation depends on human inference under certain environmental backgrounds and experience flows, serving organizational existence and competition. Human and organizational behaviors exert positive or negative influences on the weak signals lifecycle circulation. Weak signals from detection, sense-making to transmission and adoption all require human participation.

(2) As signals with low information content mixed with noise, weak signals are easily missed by organizations and individuals. Through systems thinking of weak signals lifecycle, organizations can identify potential obstacles in weak signals management. For example: insufficient alertness or attention in the detection subsystem causes potential weak signals to be overlooked, or over-reliance on single detection capability indirectly increases "degree of external noise interference"; time barriers in the relevance subsystem require overcoming because weak signals sense-making pursues not precision but judgment of future trends under time constraints, requiring analysts to possess strong sense-making capability and strong relevance willingness; transmission and choice subsystems involve game-playing between weak signals transmitters and decision-makers—not transmitters' one-sided statements must be accepted by decision-makers, requiring screening mechanisms where trust plays an important role, though whether this trust is built on interpersonal relationships or institutions and methods warrants consideration.

(3) To address these obstacles, several strategies can be considered: (1) Organizations should develop toward learning organizations, cross-disciplinarily training individuals to correctly detect and interpret weak signals, cultivating self-confidence to dare integrate diverse heterogeneous information sources inside and outside the organization, forming optimized value combinations of weak signals perception breadth, depth, and continuity; (2) Organizations should provide appropriate tools and methods for weak signals relevance and transmission, using ICT technology and ontological methods to establish weak signals semantic relevance mechanisms, transforming detected data or information into shareable and reusable knowledge; (3) Organizations should grant clear priority to decision-makers responding to weak signals, allowing them to use their own evaluation systems to screen weak signals, which typically consist of organizational trust atmosphere, decision-makers' knowledge structure, external environment perception, and decision-makers' own external information sources.

Weak signals research in the intelligence studies context is still in its infancy in China. The weak signals lifecycle concept and system dynamics model proposed in this paper represent only a theoretical attempt. Although the model has passed dimensional consistency and extreme value tests, deficiencies and inadequacies certainly remain, and undiscovered variables may exist, requiring further refinement and revision in future continuous research and practice.

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Author Contributions

Dong Yin: Designed overall structure, wrote Sections 2, 3, and 4, and finalized the manuscript;
Liu Qianli: Wrote Section 5;
Song Jiwei: Wrote Introduction and Sections 1 and 6.

Note: Figure translations are in progress. See original paper for figures.

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