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Editorial

Charting the Unknown: formulating problem statements in the age of artificial intelligence

Where human insight and machine intelligence shape systems and missions

Eighteen years ago, Peter Hernon and Candy Schwartz (Hernon & Schwartz, 2007) posed a seemingly simple yet fundamentally important question in their editorial: *What is a problem statement*? Drawing from decades of scholarship in the social sciences, they emphasized the importance of conceptual clarity, purpose, significance, and scope. These elements remain vital. However, the landscape of scholarly inquiry has shifted dramatically.

This editorial revisits their question in light of advances in artificial intelligence (AI) and data analytics. As engineering and analytics researchers work at the intersection of computation and complexity, these technologies have reshaped not only how questions are answered but also how they are formulated. In today's complex data environments, algorithmic tools and socio-technical systems, the problem statement is no longer merely a rhetorical or literary form. It must also address system dynamics, performance trade-offs, resource allocation, and uncertainty, which are core concerns in engineering. It is the point where data meets design, where inference informs intervention, and where relevance must be demonstrated rather than assumed (see Figs. 1 and 2).

1. The unfinished business of the problem statement

Despite advances in modeling, data infrastructure, and algorithm design, one issue remains consistently underdeveloped: *the problem statement*. Across disciplines, we continue to encounter vague motivations, poorly defined research goals, and limited empirical grounding. Often overlooked or misunderstood, the problem statement remains one of the most inconsistently executed elements of academic writing.

What, then, does a problem statement look like in 2025?

Traditional research emphasized conceptual clarity, research gaps, and theoretical framing. While these elements are still essential, they are no longer sufficient. Today's research environment, particularly in AI and analytics, demands more. The problem statement must now function as the structural foundation that links knowledge to action, evidence to algorithms, and theory to measurable impact. For engineers, this means situating research within real operational systems, such as factories, supply chains, and service networks, where improvements can be quantified and implemented.

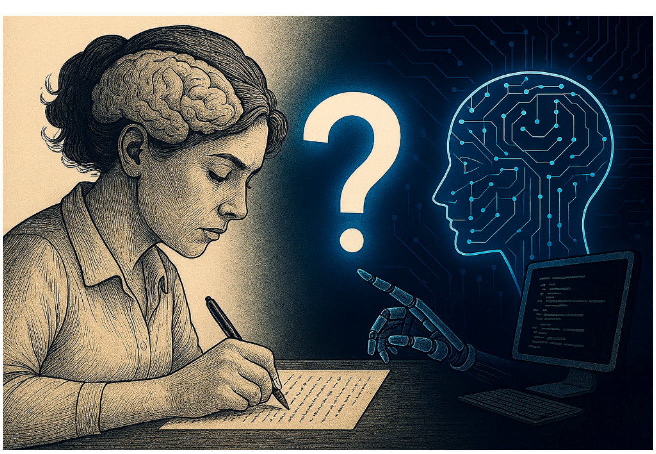

Fig. 1. Human Meets AI. Image generated by the authors using ChatGPT-4.0 (OpenAI, 2025).

2. Evolving components of a modern problem statement

Building on earlier foundations, contemporary problem statements in AI and analytics are expected to address a more comprehensive set of challenges. These include:

- **Empirical Grounding**

A well-formed problem should be rooted in data, emerging from patterns, anomalies, or observed model behaviors. It may arise from performance shortfalls, system failures, inequitable algorithmic outcomes, or unexplained real-world variation. Empirical grounding ensures the problem is both evident and relevant. In engineering contexts, this might involve sensor data from a production line, throughput analysis in logistics systems, or error propagation in scheduling algorithms.

- **Algorithmic or Computational Framing**

The problem should specify the type of computational task involved. Is it predictive, prescriptive, descriptive, diagnostic, or causal? Is the task classification, clustering, simulation, or optimization? This framing clarifies the analytical direction and the rationale behind it. For example, in production planning, the focus may be on mixed-integer

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optimization under uncertainty, while in quality control, it may involve anomaly detection using machine learning.

- **Declaration of Novelty and Knowledge Gap**

Researchers must identify what remains unexplored, poorly understood, or outdated, supported by critical literature review or motivated by changes in data, technology, or societal needs. For engineers, this often involves uncovering inefficiencies in established methods, limitations in model scalability, or outdated assumptions in cost-benefit analyses.

- **Systemic Relevance**

The problem should be anchored in a real-world system, such as a supply chain, transportation network, or healthcare infrastructure. The context should clarify where the problem arises and what broader implications it holds. Engineered systems often involve multiple interconnected subsystems, requiring the problem to reflect this interdependence, such as the ripple effects of supplier delays in just-in-time inventory environments.

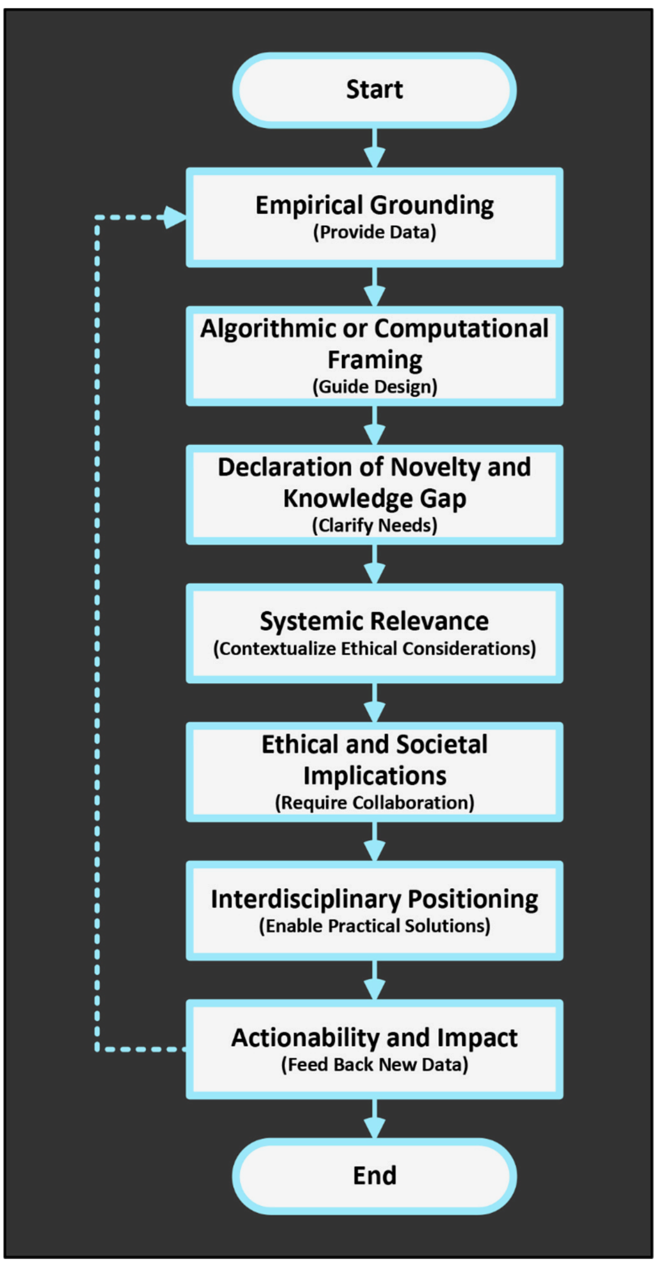

Fig. 2. From insight to inquiry: Problem statement flowchart.

- **Ethical and Societal Implications**

Modern problem statements must consider fairness, transparency, privacy, sustainability, and policy relevance. The question is no longer only "So what?" It must also include "So why?", "So who?", "So when?", and "So how?" In manufacturing, for instance, this may involve labor conditions, energy consumption, or the environmental cost of waste.

- **Interdisciplinary Positioning**

AI and analytics problems rarely exist in silos. Effective problem statements integrate perspectives by linking domain expertise with data science, ethics with engineering, or behavioral theory with computation. For example, industrial engineering is inherently interdisciplinary, connecting operations research, systems thinking, human factors, and sustainability.

- **Actionability and Impact**

A strong problem statement suggests a path forward through modeling, experimentation, simulation, or policy design. It should aim for outcomes that are both feasible and meaningful. In practice, this might involve deploying digital twins, real-time decision dashboards, or stochastic simulation environments to guide interventions.

3. Framing the mars mission: A case in space system strategy

Consider a real-world scenario: the design of a successful human mission to Mars. How might one formulate the problem within a modern problem statement framework?

- **Empirical Grounding**

A review of previous Mars missions (e.g., Mars Climate Orbiter, Schiaparelli lander) highlights issues with communication breakdowns, propulsion miscalculations, and life-support vulnerabilities. Analysis of telemetry data and system logs shows repeated technical problems that threaten mission reliability.

- **Algorithmic or Computational Framing**

The problem requires a prescriptive and optimization-driven approach. AI and analytics are needed to design mission parameters such as trajectory paths, energy allocation, failure prevention, and timing. Simulation-based optimization can improve safety, reduce costs, and enhance reliability.

- **Declaration of Novelty and Knowledge Gap**

Despite decades of planetary exploration, the integration of AI-based decision-making under uncertainty in deep-space missions remains limited. Moreover, few studies rigorously model the interactions of multiple failure scenarios across life-support, navigation, and communication subsystems.

- **Systemic Relevance**

The challenge involves multiple subsystems within the mission framework. It affects mission control operations, collaboration between robots and humans, and international space coordination efforts.

- **Ethical and Societal Implications**

Key ethical issues include planetary protection to prevent Martian contamination, fair collaboration among global space agencies, responsible use of public funds, astronaut safety, and the long-term ecological and societal effects of human presence on Mars.

- **Interdisciplinary Positioning**

Addressing this challenge requires expertise in aerospace engineering, AI and machine learning, systems engineering, planetary science, ethics, and human factors psychology. No single discipline can cover the full scope of the problem.

- **Actionability and Impact**

The problem lends itself to practical solutions using AI-driven simulation environments, risk modeling, and mission prototyping. This work can directly guide space agency protocols and the development of mission operations and support systems.

4. Framing the chip chain: A case in supply system stability

Now consider a high-impact industrial engineering scenario: strengthening supply chain resilience in semiconductor manufacturing following global disruptions.

- **Empirical Grounding**

Geopolitical tensions and raw material shortages have revealed persistent vulnerabilities in the semiconductor supply chain. Empirical data from lead time fluctuations, order backlogs, and capacity utilization expose systemic fragilities in wafer production, packaging, and logistics.

- **Algorithmic or Computational Framing**

The problem demands both predictive and prescriptive analytics. Machine learning models can forecast disruptions based on real-time signals (e.g., port congestion, geopolitical risk indices). However, robust optimization techniques are needed to reallocate capacity and buffer inventory across facilities.

- **Declaration of Novelty and Knowledge Gap**

While many studies examine supply chain optimization, few integrate real-time predictive disruption models with dynamic reconfiguration tools at the fabrication level. The literature often assumes fixed network structures, which is no longer realistic under volatile conditions.

- **Systemic Relevance**

The problem spans global operations and directly affects automotive, consumer electronics, and defense sectors. It impacts job markets, national economies, and control over key technologies.

- **Ethical and Societal Implications**

The shortage of semiconductors affects access to critical technologies like medical devices and renewable energy infrastructure. Ethical concerns include fair allocation, labor exploitation in mining key minerals, and environmental sustainability in fabrication plants.

- **Interdisciplinary Positioning**

Solving this problem draws on supply chain engineering, systems dynamics, operations research, international trade policy, and environmental science.

- **Actionability and Impact**

The research can support government policies, guide corporate investment in domestic manufacturing facilities, and help mitigate risks through digital supply networks. Implementing these models could reduce systemic risk, stabilize markets, and foster innovation resilience.

5. Concluding thoughts: From insight to impact

As decision analytics advances through intelligent systems and large-scale data, the problem statement must be more than a formal introduction. It forms the foundation of research design by clearly defining the gap between current realities and desired improvements, and between what is observed and what needs to be achieved.

In modern analytics research, the problem statement guides the identification of key questions, the choice of appropriate methods, and the setting of achievable goals. This is particularly critical in engineering contexts where poor framing can lead to wasted resources, safety risks, or suboptimal system performance. To unlock the full potential of any study, a clear and well-structured problem statement is essential. It directs the research process and helps keep efforts focused and relevant. A carefully formulated problem statement allows researchers to identify gaps in knowledge and practical challenges, ensuring that their work is meaningful and impactful.

Furthermore, the problem statement should reflect both present conditions and goals for innovation and change. By combining theoretical understanding, real-world needs, and practical constraints, it sets a clear path for research and application. This clarity is vital in engineering, where data-driven decisions shape real-world systems. Thus, the problem statement goes beyond a simple introduction to become a key driver of insight and progress in decision analytics.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Reference

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