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The Engineering Economics of RFID Monitored Data Center Cooling System.

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Work-in-Progress: The Engineering Economics of RFID Monitored Data Center Cooling System

Abstract

Data centers devote a substantial share of their energy budgets to cooling, making thermal management a critical target for cost reduction and sustainability improvement. This paper presents a systems-thinking educational framework for teaching engineering economics using an RFID-enabled, AI-assisted data-center cooling context. Building on prior work in the engineering economics of RFID, the study reframes real-time sensing and analytics as inputs to economic reasoning rather than as purely technical optimizations. Students apply core engineering economic decision tools—including payback period, net present value, cost–benefit analysis, and sensitivity analysis—within a parameterized economic model that supports *what-if* exploration and decision justification. Illustrative scenario outputs, based on baseline assumptions adapted from a forthcoming data-center energy analysis, allow students to explore potential cooling-energy reductions of approximately 10–15% and payback periods on the order of 12–18 months under varying conditions. More importantly, student-controlled exploration demonstrates how economic conclusions shift under uncertainty. By integrating RFID-enabled monitoring with systems-thinking pedagogy, this work illustrates how modern cyber-physical systems can enhance engineering economics education and improve students' ability to reason about economic trade-offs in data-driven environments. The framework was introduced during the Spring semester in an upper-level Energy Systems Modeling course, and formal assessment data are currently being collected for presentation at the conference.

1. Introduction

Engineering economics is a foundational component of engineering curricula; however, instructors frequently observe a gap between students' ability to compute economic metrics and their ability to apply those metrics in realistic decision contexts. While students may correctly calculate payback period or net present value, they often struggle to apply these concepts to real world problems or to interpret results when assumptions change or when multiple decision criteria conflict. This challenge is particularly pronounced for modern engineering systems characterized by uncertainty, feedback, and real-time data.

Concurrently, cyber-physical systems enabled by sensing, connectivity, and analytics are increasingly common across engineering domains. Data centers provide a compelling instructional context due to their energy intensity, operational complexity, and sensitivity to information quality. For example, cooling systems can account for a significant portion of data-center energy consumption, and even modest efficiency improvements can yield meaningful economic impacts. Understanding these types of criteria and how they impact economic analysis means that students should be able to make better decisions.

This paper responds to these educational and technological trends by presenting a systems-thinking framework for teaching engineering economics using an RFID-enabled data-center cooling context. The primary contribution is pedagogical rather than technical. RFID sensing and AI-enabled analytics serve as a realistic setting in which students can explore economic decision tools, uncertainty, and trade-offs, rather than as the focus of technical optimization or system validation.

2. Related Work and Positioning

2.1 RFID and Engineering Economics Foundations

The application of RFID within engineering economics has an established precedent. Jones, Sprague, and McClendon (2007) demonstrated that RFID investments in specialized manufacturing environments can be rigorously evaluated using standard engineering economics tools, including payback period, net present value, and cost–benefit analysis. Their work, published in *The Engineering Economist*, established RFID as a legitimate subject of economic decision analysis rather than a purely operational or information-technology consideration.

That study emphasized how improved data availability reduces uncertainty in capital investment decisions. However, much of the subsequent RFID literature has treated engineering economics as a post-hoc justification rather than as an active component of learning or decision making. The present work extends this foundation by positioning RFID-enabled sensing and analytics as inputs to economic reasoning and education.

2.2 Engineering Economics Education and Systems Thinking

Within the ASEE Engineering Economics Division, prior research has emphasized the need to help students integrate economic tools into coherent decision frameworks. Gray (2016) showed that students benefit when costing concepts are embedded in active, comparative learning activities rather than taught as isolated calculations. Gray (2018) further demonstrated that structured instructional interventions improve retention and application of engineering economy concepts. More recently, Gray and Fragoso-Diaz (2025) highlighted the role of feedback—human or AI-supported—in deepening student engagement with economic reasoning.

Complementing these ASEE contributions, Hartman (1999) emphasized that effective engineering economy instruction should prioritize interpretation, judgment, and decision making over rote computation. Collectively, this literature supports a systems-thinking approach in which economic metrics are treated as interconnected indicators of system-level performance rather than as standalone outputs.

2.3 Sensitivity Analysis and Decision-Focused Learning

Sensitivity analysis has long been recognized as a critical component of engineering economics education. White (2003) demonstrated that allowing students to vary assumptions and explore scenario outcomes improves understanding of economic robustness and uncertainty. Decision-focused cases, as opposed to descriptive examples, require students to justify conclusions under varying conditions and competing criteria. The framework presented in this paper aligns with this tradition by emphasizing student-controlled exploration rather than predetermined outcomes.

3. Systems-Thinking Educational Framework and Learning Design

3.1 Rationale for Systems Thinking

Systems thinking is adopted as the organizing pedagogical principle for this work. In the context of engineering economics, systems thinking is defined as the ability to identify system boundaries, recognize interactions among technical and economic variables, and evaluate how changes propagate through economic outcomes over time. This approach directly addresses the tendency for students to treat economic tools as independent calculations rather than as elements of an integrated decision process (Hartman, 1999).

3.2 Framework Overview

The instructional framework is structured around a parameterized economic decision model and consists of four stages: system definition, baseline economic evaluation, sensitivity and scenario analysis, and decision justification. Students compute traditional engineering economic metrics while iteratively modifying assumptions and observing resulting changes in outcomes.

3.3 Economic Tools and Learning Outcomes

Core tools—including payback period, net present value, cost–benefit analysis, and sensitivity analysis—are explicitly integrated into the framework. Students are evaluated primarily on interpretation, reasoning, and justification rather than on numerical accuracy alone, reinforcing decision quality over procedural computation.

Table 1 summarizes the mapping between engineering economic tools, student actions, and intended learning outcomes.

Table 1. Mapping of Engineering Economics Tools to Learning Outcomes

Economic Decision Tool	Student-Controlled Action	Intended Learning Outcome
Payback Period	Modify capital cost and annual savings	Understand time-based recovery and its limitations
Net Present Value	Adjust discount rate and project life	Interpret long-term value creation and sensitivity
Cost–Benefit Analysis	Compare alternative system configurations	Evaluate trade-offs among cost, performance, and benefit
Sensitivity Analysis	Vary individual parameters	Identify dominant economic drivers
Tornado Diagram	Rank parameter impact on NPV	Visualize uncertainty and robustness

4. Case Context and Economic Model Implementation

The RFID-enabled data-center cooling system is introduced as an instructional context rather than as a technical optimization study. Embedded RFID sensors provide real-time environmental data, which are abstracted into adjustable efficiency improvements within the economic model. Capital costs, operating savings, project life, and discount rate are parameterized to support structured exploration.

Technical complexity is deliberately bounded. AI algorithms are treated as a black box with measurable economic impact, ensuring that instructional emphasis remains on economic reasoning rather than on system design or control theory.

5. Expected Outcomes from Student Exploration

5.1 Framing of Expected Outcomes

The results presented in this section are not offered as empirical validation of a deployed system. Instead, they represent illustrative outputs used to support student reasoning, comparison, and justification across economic scenarios. Baseline assumptions are adapted from a forthcoming data-center energy analysis and are used solely for instructional purposes. The assignment can be a small class project or a homework assignment where the students are given the scenario and asked to calculate a range of metrics explored below.

5.2 Baseline and Scenario Exploration

Under baseline assumptions, it is expected that students ~~typically~~ observe payback periods on the order of 12–18 months and a positive net present value over the assumed project life. Students then explore alternative scenarios by modifying key parameters. They are also introduced to energy-related economic metrics such as levelized cost of energy (LCOE), which includes all costs associated with power generation, and are asked to correlate LCOE with NPV.

Table 2 summarizes representative scenarios and their instructional insights.

Table 2. Representative Economic Scenarios Used for Student Exploration

Scenario	Parameter Modified	Direction of Change	Observed Economic Effect	Instructional Insight
Baseline	Nominal energy price and performance	—	Positive NPV, 12–18 month payback	Establish reference case
A	Energy price	Increase	Shorter payback, higher NPV	Energy cost dominates outcomes
B	AI performance improvement	Decrease	Longer payback, reduced NPV	Performance uncertainty matters
C	Capital cost	Increase	Payback exceeds threshold	Capital constraints drive decisions
D	Project life	Decrease	Marginal or negative NPV	Time horizon affects conclusions

Across scenarios, sensitivity analysis consistently identifies energy price and achieved performance improvement as dominant drivers, reinforcing systems-thinking concepts and highlighting the role of uncertainty in engineering economic decision making. Students are expected to clearly show their calculations and reasoning, ensuring a strong mathematical foundation while using the scenario table to interpret economic implications.

5.3 Class Deployment Strategies

This framework can be implemented in a variety of classes at multiple levels. It can be entered into an undergraduate economics course to provide an exciting real world example to contextualize the topic. It can be implemented in an upper-level engineering course such as facility location or electives such as RFID and logistics. Furthermore, this can be implemented in graduate level courses such as Advanced Engineering Economics or Energy System Modeling.

6. Discussion, Implications for Engineering Economics Education, and Next Steps

The framework was introduced during the Spring semester in an upper-level Energy Systems Modeling course. The case was deployed as a structured instructional module in which students applied engineering economic decision tools to the RFID-enabled cooling scenario. Students were provided with a parameterized economic model and asked to perform baseline evaluation, sensitivity analysis, and scenario-based justification exercises. This Spring implementation serves as the pilot deployment of the framework.
The results illustrate how systems-thinking pedagogy addresses persistent challenges in engineering economics instruction, including overreliance on single metrics and limited appreciation of uncertainty. The framework is designed to strengthen students' confidence in decision making by embedding economic tools within a structured systems-thinking context.

Consistent with prior ASEE and *Engineering Economist* literature (Gray, 2016; Hartman, 1999; White, 2003), the framework emphasizes interpretation and justification rather than numerical precision. The approach is transferable across engineering domains and scalable across course levels, making it suitable for broad adoption in undergraduate and graduate engineering economics courses.

We plan to implement this framework as an example across multiple classes including Engineering Economics and Energy Systems Modeling and evaluate how it improves the students' understanding of both technical concepts, such as the NPV of a data center's energy use, as well as their systems-thinking capability—specifically, whether they understand how the components function within an integrated system.

6.2 Assessment plan

Formal assessment data are currently being collected from the Spring deployment. Student artifacts—including parameter sensitivity analyses, tornado diagrams, and written decision memoranda—are being evaluated using a rubric aligned with the learning objectives summarized in Table 1. Both quantitative and qualitative measures of reasoning depth and economic justification will be analyzed following course completion. Initial findings from this deployment will be presented at the conference.

6.3 Expected Learning Outcomes

Based on established engineering economics pedagogy literature, expected outcomes include increased use of multi-variable sensitivity reasoning, clearer identification of dominant economic drivers, and stronger justification of investment decisions under uncertainty.

6.4 Broader Implications for Engineering Economics Education

The framework is intended to address persistent challenges in engineering economics instruction, including overreliance on single performance metrics and limited treatment of uncertainty in decision making. By situating traditional economic tools within a cyber-physical systems context, students engage with dynamic trade-offs without additional mathematical complexity.

Following the Spring pilot, the framework will be expanded to additional courses, including Engineering Economics and Energy Systems Modeling, where formal evaluation of student reasoning and systems-thinking development will be conducted. The approach is transferable across engineering domains and scalable across course levels, providing a practical pathway for modernizing engineering economics instruction in data-driven environments.

7. Conclusion

This paper presents a systems-thinking framework for teaching engineering economics concepts using an RFID-enabled data-center cooling context. By enabling student-controlled exploration of economic assumptions, the framework moves beyond static case studies and supports deeper understanding of trade-offs, uncertainty, and decision robustness. The primary contribution lies in the educational design rather than in technical system optimization, offering a practical pathway for modernizing engineering economics instruction in data-driven engineering environments.

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