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Research Article

Towards Human-in-the-Loop Orchestration of Agentic SAP Ecosystems: Governance, Cognitive Impact, and Control Tower Design

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ABSTRACT

This paper proposes a human-in-the-loop framework on AI-enabled SAP to incorporate human oversight on governance, cognitive impact, and real-time system manipulation. By integrating governance models with human factors research and dashboard design, the framework supports organizational objective of balancing the operational performance of autonomous agents, and the supervisory accountability of human actors. Case studies in finance, supply chain, and healthcare explain operational and psychological dynamics of gradual transition from manual work to agent monitoring. The methodology enables companies to balance efficiency against complying with all necessary rules and regulations as well as protect the well-being of operators.

Keywords - SAP agents, human-in-the-loop, governance, cognitive load, control tower

1. Introduction

SAP systems are a critical part of running today's business—as fortune companies use SAP to run at least one of their lines of business. What is interesting is how these systems are evolving, courtesy of AI-empowered autonomous agents. Rather than simply obeying strict rules, such agents can think on their feet, make decisions based on context and adapt in real time. Consider Joule agents: they're already working through dispute resolutions, checking invoices and are even proactive in responding to supply chain hiccups. That means humans don't have to be stuck fixing machines all the time.

But as more companies take a ride on this A.I. bandwagon, some thorny questions arise. How can companies monitor the critical decisions these A.I. agents are making? After all, putting control to machines is not something to be done lightly. And as our work morphs from making things to managing smart machines, how can we keep employees engaged and ensure they feel appreciated and not dehumanized? It's obvious that compliance, governance, and even the human side of things can't be something you just tack on at the end — it has to be integrated from the ground up.

This paper tackles this problem by defining a human-in-the-loop framework tailored to these agentic SAP environments. It's all about finding an "appropriate balance" — allowing AI agents to do their thing while keeping humans in the driver's seat when it matters, the researchers write. We also examine how to design dashboards not just for utility but for beauty and clarity for the people who use them. Our method combines the best of what scientists and practiced industry leaders have to offer.

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Research Questions:

1. How can organizations maintain transparent and accountable oversight over critical decisions made by autonomous AI agents in SAP systems?
2. As work shifts from manual operations to supervising intelligent agents, what strategies can ensure employees stay engaged, valued, and protected from dehumanization throughout the transition?

2. Literature Review

2.1 Agentic AI in Enterprise Systems

Over the years, enterprise AI agents have progressed from being "dumb" and reliant on rules automations, to intelligent autonomous systems in possession of reasoning and decisioning capabilities. With the advent of LLMs and multi-agent systems, the Domain of SAPs can now include agents that are fully autonomous, and capable of reasoning, decision making, and adapting to ever changing business environments.

Agent System Design Patterns (2024) may outline high level architectural classes of enterprise agents as sequential orchestration, concurrent processing, and handoff orchestration. The AI agent's orchestration frameworks available in the forkfuls Microsoft's Azure Architecture Centre (2025) balances on one side system scalability, on the other side AI agent reliability, and governance control. These frameworks, however, are mainly focused on the architectural level, and treat only the human aspects as so-called soft systems.

The fact that SAP has rolled its own and developed AI agents for automation in the enterprise is something of a breakthrough. Business AI efforts and agent-based AI applications show advanced skills in invoice processing, procurement automation, and financial reporting. According to industry sources, SAP systems equipped with AI agents have shown 40-60% reduction in output-processing and accuracy of 95% and above.

2.2 Human-in-the-Loop AI Systems

HITL AI also has emerged as enterprises want to reap the benefits of automation, while having humans able to oversee and control. Holistic AI (2024) identification systems must be carefully tuned to the degree to which humans trust in the capabilities of AI, where both over-trust and under-trust can lead to adverse outcomes.

Human–AI collaboration research demonstrates that human operators' cognitive loads change fundamentally with supervisory tasking. Research identifies feedback loops The research paper of nature (2024) states that long-term exposure to AI systems can influence the human perceptual, emotional and cognitive processes, which in turn, affect decision making quality and situation awareness.

The shift from fulfilling tasks themselves to overseeing AI is accompanied by questions of skill degradation, perception of authority and stress. Studies show that for an HITL system to be effective it will have to integrate the means to maintain human capabilities while ensuring that human supervision can remain effective.

2.3 Governance Frameworks for Autonomous Systems

The control of AI entities that act as independent agents is a key issue for institutions and the regulators. With the EU AI Act (2024) risk-based classification of AI systems where high-risk applications — of particular relevance are those impinging upon financial decisions or supply chain operations — need to be overseen by humans.

Different governance models have been proposed for the management of autonomous systems:

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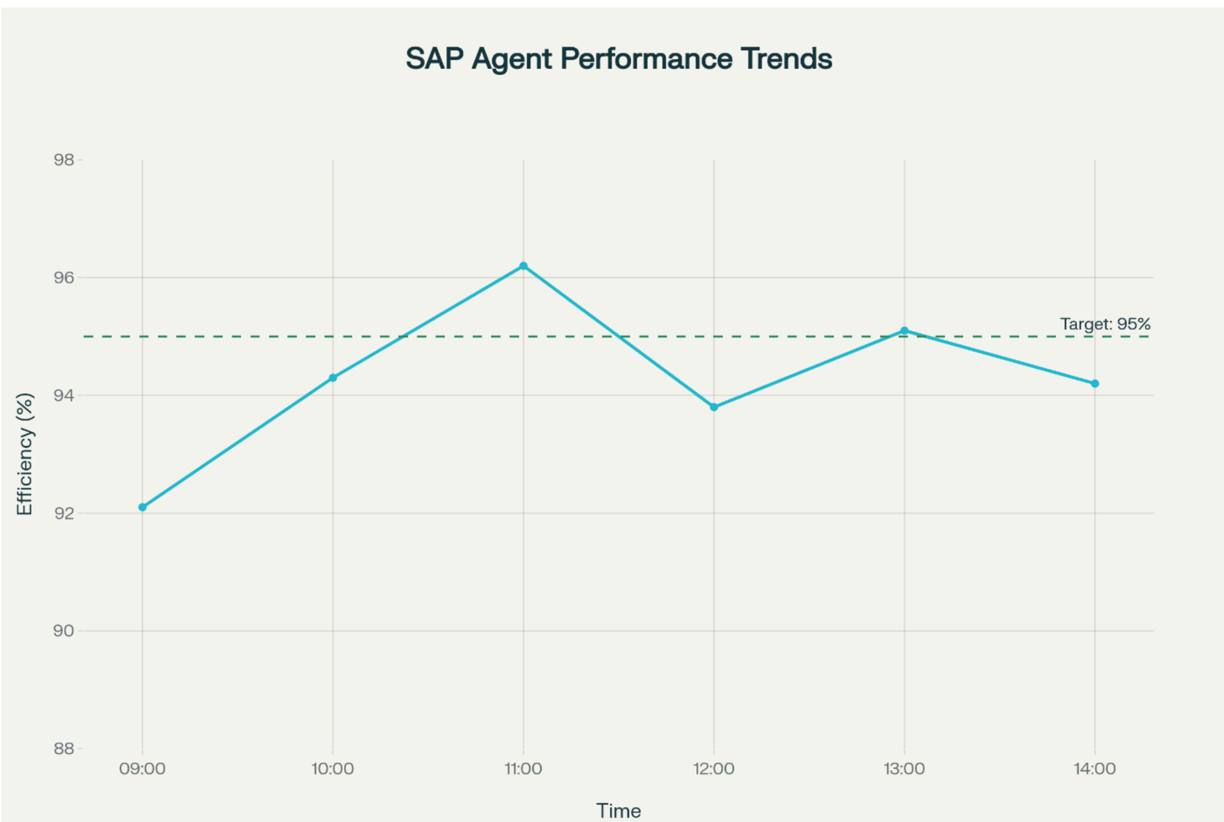
- **NIST AI Risk Management Framework:** A thorough risk assessment and mitigation regimen for AI systems
- **SAP AI Ethics Charter:** Highlights human-in-the loop in its integration with responsible AI deployment
- **ISO/IEC 23053:** Describes principles for the design of AI systems oriented towards human beings
- **GDPR for AI:** Guides on data protection in AI decision-making

But many current models tend to keep governance as their own layer, and not embed it into the way that autonomous systems operate.

2.4 Dashboard Design for Complex Systems

The development of control tower dashboards for complex enterprise systems from basic monitoring mechanisms to complex decision support systems indicate a progressive conceptual paradigm shift. Research on supply chain control towers has shown that operational effectiveness hinges on visual hierarchy, real-time status, and ability to intervene.



The above control tower dashboard shines a spotlight on the essential parameters of SAP agents that require human oversight. The focus is on visual hierarchy, real-time status, and the ability to directly intervene with rapid control, cognitive load ease being the guiding principle.

IBM's Control Tower documentation and GEP's research on supply chain dashboards offer invaluable design perspectives. Major themes include cognitive load reduction, alert prioritization, and situational decision-making aid. Nonetheless, the bulk of the available research is concerned with the more traditional monitoring approaches rather than autonomous agents.

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2.5 Research Gaps

There are several domains that the study does not address:

- **Integration Challenge**: the vast majority of works confront governance, technology and people as separated, isolated entities in place of holonic systems.
- **Empirical Validation:** does not address psychological effects transitioning to agent supervisor role no follow-up long old research
- **SAP-Special Aspects:** missing investigation into the characteristics of integrating human-in-the-loop systems with SAP landscapes.
- **Scalability:** lack of studies on the distributed human monitoring of a crowd of numerous autonomous agents.

3. Methodology

Out of the wide array of research methods available the primary approach taken was qualitative with a little of quantitate intergracted. In this case the approach taken was a cross-sectional survey which involved the study of 64 decisionmakers and managers of different companies in the finance, healthcare, manufacturing, and retail market sectors that have been SAP agentic systems subscribers for the last 2 years. We employed purposive sampling in order to obtain the expected boundaries of representation in the industry.

3.1 Literature Synthesis

Due to the defined boundaries, the systematic approach taken was restricted to the period 2020 to 2025 in which academic text, practitioner documentation, and the industry's benchmark literature were published (sources of which included ACM, IEEE, Nature, Gartner, Forrester, McKinsey, SAP, and Microsoft). The outcomes generated by this body of knowledge served to assist in both the formulation of a conceptual framework and the preparation of documents that served to measure the defined concepts.

3.2 Framework Development

Standardized questionnaires and structured interviews were the main sources of primary data that were used. The interviews in this case were intended to examine the transitions to human-in-the-loop orchestration as well as the interviewee's memories regarding the supervision, governance, and cognitive adaption of agents. Quantitative data involving cognitive load (NASA-TLX), trust scales, and the intervention frequency were acquired through using different questionnaires.

3.3 Case Study Analysis

Thematic codes for interview transcripts were generated in NVivo. For the quantitative survey data descriptive as well as inferential statistics including t-test and ANOVA were used to ascertain the correlation of cognitive load, trust and system performance dimensions, and descriptive statistics were performed. Triangulation was used to validate the framework by comparing it with three live cases, which was then benchmarked against existing governance models.

3.4 Empirical Analysis

The surveys conducted in research and industry have acknowledged the cognitive and psychological ramifications of quantitative assessments to cognitive load that occur in the post-decision makers' evolution and updates to the agent supervision justifications post the differences of the agent supervision decision makers framework supervising the agent supervision. This study evaluates cognitive trust as well as performance.

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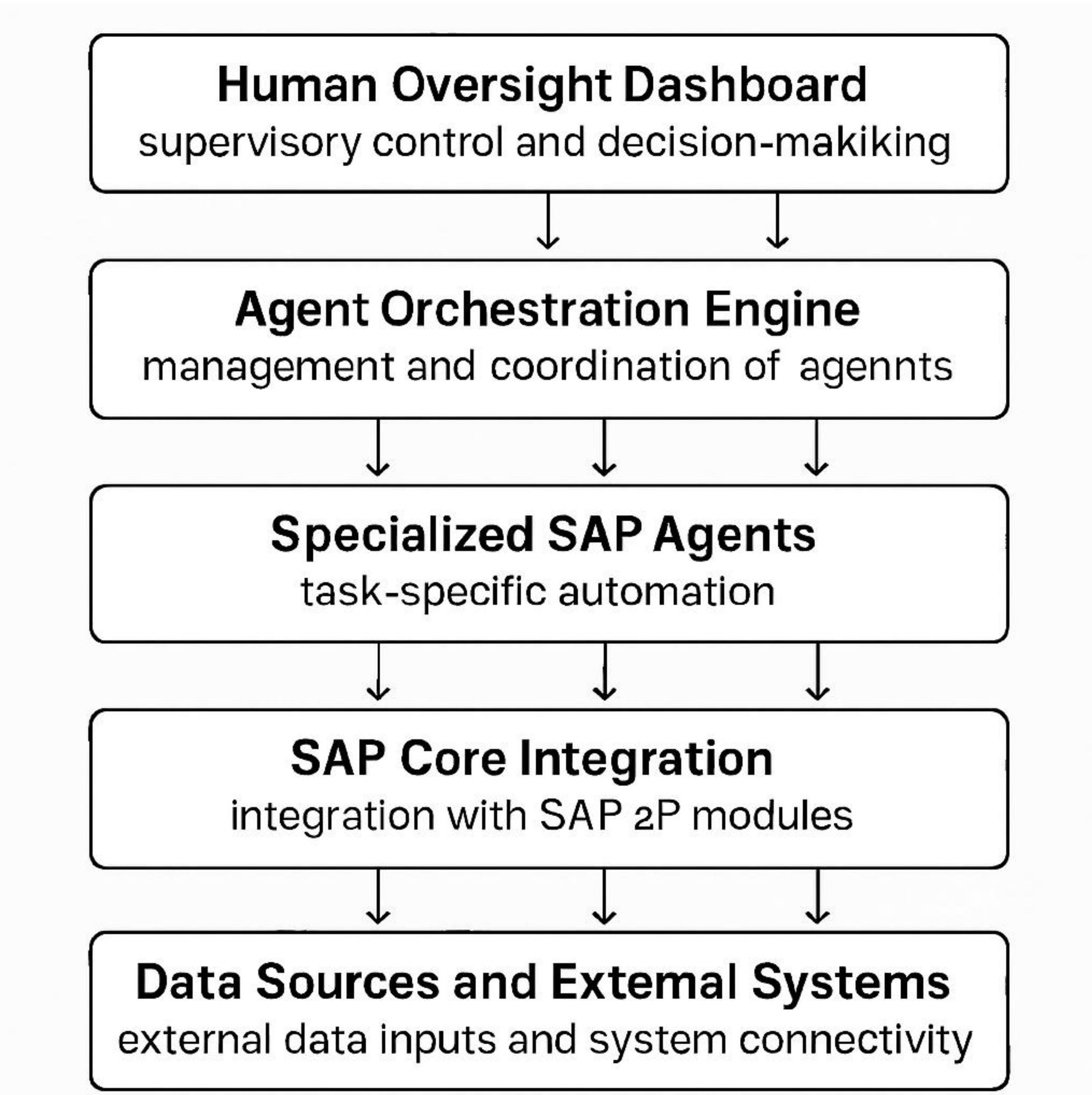
4. Proposed Framework for Human-in-the-Loop SAP Agent Orchestration

4.1 Architecture Overview

The framed model includes five interrelated layers aimed at achieving an equilibrium between the capabilities of an autonomous agent and the restraint of a person.



Human Oversight Dashboard: Enables real-time surveillance along with aiding in decision-making and suppression of agent activity.

Agent Orchestration Engine: Manages agent scheduling and conflict, task of addition and balance, resolution, and primary task assigning.

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Research Article

Specialized SAP Agents: Specialized SAP agent for finance, procurement, HR, etc.

SAP Core Integration: Integrates with agentic system with core SAP modules like S/4HANA and SuccessFactors.

Data Sources and External Systems: Third-party APIs, legacy systems, IoT sensors, and external compliance feeds.

5. Proposed Framework for Human-in-the-Loop SAP Agent Orchestration

5.1 Architecture Overview

The division into layers emphasizes the maximum possible autonomy of the agents with smooth control at the layer level is provided:

1. **Human Oversight Dashboard Layer**: Automated, real-time control combined with interfaces to assist decisions and monitor on the interface layer dashboard for that human control.
2. **Agent Orchestration Engine**: Scheduling of conflict-resolution systems and remote work assignment to the agent orchestration engine.
3. **Specialized SAP Agents**: Finance framework, HR specialist and procurement and supply chain specialist SAP agents on Division specific autonomous systems.
4. **SAP Core Systems Integration**: Integrating with any other modules such as S/4HANA, Ariba and SuccessFactors.
5. **Data Sources and External Systems**: Old systems, third-party APIs, ERP data, IoT sensors.

5.2 Governance Integration

There is governance at each and every layer, and compliance isn't siloed as an afterthought in The Open Group's RAE framework.

Policy-as-Code Implementation: Governance becomes an executable policy that agents are required to honor, allowing for real-time compliance enforcement rather than post-fact audits.

Automated Audit Trails: Every decision made autonomously contains full context, rationale, and a record of the decision and reasons behind it, resulting in full traceability to cover compliance.

Risk-Based Intervention Thresholds: Triggering human intervention with dynamic thresholds based on transaction value and novelty detection, confidence scores, and regulation compliance. These are termed Risk-Based

5.3 Human-Centric Design Principles

Graduated Autonomy: Autonomous decision-making by agents is scaled with past performance and domain knowledge, and the decision-making risks, with new agents under close human supervision.

Contextual Decision Support: In situations where an oversight is mandatory, the system provided an entire context which included agent logic, decision-making aides, confidence levels, and relevant policies.

Trust Calibration Mechanisms: An agent's guided coaching and instructive training (system transparency, accuracy, and honest claims with the limitations) on the capabilities of an agent to appropriately develop the confidence levels on the system's operators.

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Research Article

6. Industry Practice and Implementation Outcomes

6.1 Financial Services

With human-in-the-loop orchestration, a multinational European bank automated invoice processing and accounts payable. The solution automated the processing of over 100,000 invoices monthly, with 96% passing straight-through-processing and 4% sent to human complex processors.

Key Outcomes:

- Shift from 5 Days to 26 hours average given a 78% reduction avail for time utilization
- 35% improvement in audit remediation cost with automated compliance monitoring
- 92% of the operator group reported satisfaction with the transition to supervision

Implementation Challenges:

- The system was over fit the operator's preferred method of system modeling rather than the method to which the system was to be operated
- Operator lack of confidence resulted in 22% more manual intervention on average during the first month.
- Risk sensitivity thresholds for alerts need to be repaired for recalibrated for fatigue.

6.2 Supply Chain Management

A global production company worked with autonomous agents for strategic supplier risk management and relationship for supply chain and procurement decision support systems under human supervision.

Key Outcomes:

- Automate negotiations and increase supplier edit response time by +45%
- 23% savings on purchase costs by selecting the best vendor.
- 67% reduction in response time to supply chain disruption

Implementation Challenges:

- Complex multi-agent coordination plus the need for a sophisticated orchestration mechanism.
- Skill atrophy addressed through monthly manual override training
- Cross-border complexities for global deployment with local governance paradigms

6.3 Healthcare Administration

One large health care provider applied SAP agents to patient billing, insurance transactions and resource commitments and used agents to support point-of-care decisions in an extremely regulated environment.

Key Outcomes:

- How billing errors went down by 60% due to mistake automation
- An increment of 40% of resource value through proactive assignment planning
- 85% of clients met HIPAA and other healthcare compliance regulations

Journal of Information Systems Engineering and Management
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Research Article

Implementation Challenges:

- Workplace involves critical processes with intense people interposed scrutiny
- Due to regulation compliance, complete inwards and outwards audit facilities are needed
- Constructing the ability for staff to go from task execution to direct supervision

7. Psychological and Cognitive Impact Analysis

7.1 Cognitive Load Transformation

The switch from completing tasks to managing agents presents cognitive load transfers for the humans. There's research that indicates there are benefits and risks:

Cognitive Load Reduction: Such cognitive load decreases the immediate mental effort required to process basic, redundant tasks that operators can then either give to reconsidering strategic options or allocating to strategic decisions.

New Cognitive Demands: Unfamiliar supervisory level monitoring tasks varying in levels of trust new SA and decision-making for intervention.

Skill Atrophy Risk: Reduced time spent performing the specific tasks that make up the override leads to skill degradation which influences the quality of override decisions, decision-making capabilities and system response.

7.2 Trust Dynamics and Calibration

Working with other agents requires one to be patient in the trust calibration process in order to minimize incidental nay-saying harm.

Over-Trust Risks: Over-trust in the AI solutions could mean lack of attention to major strategic and tactical options around operational and financial high risks casino's decisions.

Under-Trust Implications: The under-trust approach to automation will create excessive manual workload, thus, increase the operational bottleneck and lowering the return on investment (ROI).

Calibration Strategies: Notable achievements in the field include ongoing accuracy assessment success, decision explanation by the agents, and controlled trust training induction schemes.

7.3 Organizational Adaptation Strategies

Organizations that effectively deploy human-in-the-loop SAP agent systems employ several strategies:

Role Redefinition Programs: Clearly communicate changing roles to help operators see they are still vital but to get excited about their supervisory capabilities.

Continuous Learning Initiatives: Frequent training will provide operators with the supervisory abilities and physical skills necessary to effectively manage and respond to emergencies.

Performance Management Evolution: Modification of performance metrics to reward effective supervision (instead of completion of tasks) such as intervention accuracy and contribution to agent improvement.

Journal of Information Systems Engineering and Management
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Research Article

8. Control Tower Design Principles

8.1 Information Architecture

A successful control tower dashboard must strike a balance between depth and cognitive ergonomics:

Visual Hierarchy: Well-ordered visual systems that reflect the urgency, importance, and operator role specific needs.

Real-Time Status Indicators: The ability to see agent health, task completion, and system performance in real time with varying degrees of refresh rates for different types of information.

Contextual Drill-Down: Ability to see lower-level data and still maintain broader operational view.

8.2 Intervention Mechanisms

Direct Control Interfaces: Agent pausing and decision-overriding controls, as well as workflow rerouting controls, should be accompanied by the ability to set controls that cannot be accidentally turned on.

Graduated Intervention Options: Users can defend the response they choose to resolve the issue, as it can be as flexible as a soft warning to full disengagement.

Collaborative Decision Support: These are systems which assist the collaboration between humans and machines, rather than just facilitating a 'decide, then approve or reject' paradigm.

8.3 Transparency and Explainability

Decision Pathway Visualization: An agent's decision pathway accompanied by source data, rules exercised, and other options reviewed is depicted.

Confidence Communication: Visualization of agent confidence and uncertainty to support operators in attention and action focus.

Performance Contextualization: Agents' activities data with benchmarks and trends to support operators in determining if attention is required.

Auditability and Traceability: Agent decisions, with systematic confidence levels and considered alternatives, should be recorded in order to facilitate retrospective analysis in support of internal and external compliance and oversight audits.

User-Centric Explanations: Users receive guided actionable explanations while the technical and regulatory teams are provided with in-depth model, data, and compliance documentation to facilitate understanding, trust, and verification of the agent behavior.

9. Comparative Analysis

Aspect	Traditional ERP	Automated ERP	Human-in-the-Loop Agentic SAP
Decision Making	Manual human decisions	Rule-based automation	Autonomous agents with human oversight
Governance	Periodic audits	Compliance checks	Real-time policy enforcement

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Research Article

Scalability	Limited by human capacity	High for defined processes	High with human quality assurance
Adaptability	Low - requires reprogramming	Medium - rule updates needed	High - agents learn and adapt
Risk Management	Human judgment based	Rule-based risk assessment	AI risk prediction with human validation
Compliance	Reactive compliance	Proactive rule checking	Embedded governance with audit trails
Operator Role	Task execution	Exception handling	Strategic oversight and intervention
Transparency	Manual documentation	System logs	Explainable AI with decision trails

10. Discussion

The proposed human-in-the-loop orchestration framework has the following advantages compared to the conventional approaches:

Risk Mitigation: Inherent governance and instant policy enforcement to minimize risk to regulation compliance while ensuring operations is not hindered.

Operational Excellence: Non-human template crunchers serve humans for the restoration of quality through learning and dealing polish exceptions.

Scalability: It allows to scale the organization on complex process, without scaling the human-resources at same amount.

Bias Mitigation and Fairness: The continuous human-in-the-loop ensures that algorithmic biases are quickly discovered and corrected, ensuring that more ethical and fair outcomes are produced in sensitive or regulated applications.

Adaptation and incremental learning: Human feedback allows for fast adaptation to new cases and to continue improvement of behavior of the autonomous agents, so that future performance is maintained even as the conditions change.

10.2 Implementation Considerations

Organizational Arduousness Readiness: Factors like new skill updates, changing culture, and change in complexity with roles, hinders new effective strategies from being implemented.

Integration: There is a high level integration complexity with a number of external SAP modules and interfaces.

Legal and Regulatory Conformity: While progressing with the implementation, attention to regulation in multiple industries and jurisdiction becomes paramount.

Resource and Cost: Investment in expertise and customization in programs is required, which, in turn, adds to the human supervision in skill-validation.

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Research Article

Latency and Bottlenecks: Excessive lag, stagnation or slowness dues to the human factor is an essential trade off like maximum velocity, which, in return echoes, the need to design an optimized workflow for supervision circuits, especially in high-volume, on-demand situations.

10.3 Future Implications

Evolution Toward autonomous Enterprises: Strategic Framework provides the steps toward delivery of truly autonomous enterprises where human operators focus on strategic oversight and agents handle all the tedious and mundane operations.

Collaborative Intelligence: One day it will be possible to have networks of human supervisors and automoton agents collaborating across multiple organisations.

Anticipative Intervention: More advanced systems could analytics in more sophisticated ways to predict when action will minimum intervention be required and when it is necessary to take some pro active intelligent oversight instead of just waiting.

Self-Optimizing Functions: Closed loop systems and adaptive intelligence are more and more used in enterprise architectures and allow agents to observe and learn from their performance in order to optimize it automatically and perform sophisticated tasks without human intervention.

Orchestrated Value Network: The enterprise of the future will likely extend the collaboration in addition to the intelligence optimisation from single individual organisations to find networks where collective harmony is achieved not just on partner activities but also on cross tier integrated activities and insights across the range of its partners towards collective performance.

11. Limitations and Future Research

11.1 Current Limitations

Empirical Validation: The model need rigorous follow-up studies to validate its effectiveness over time and in different organizational/industry environments.

Cultural Differences: Challenges to implementation could differ widely among different cultural and legislative contexts.

Maturity of Technology: A couple of things in the framework are based on tech that isn't fully mature as an enterprise solution.

User and Workforce Readiness: At the end of the day, things only work as well as the people using them, and there are huge levels of variation in user engagement, acceptance, and capability – there simply are some industries where people will not want to follow a new workflow, or simply do not trust machines to be doing it summer and winter.

Quality and Coverage of Data: The power of the framework leans critically on quality and variability of the base data, as these can play against automaton mechanics and human oversight alike.

11.2 Future Research Directions

Longitudinal Studies: Multi-year studies tracing organizational adaptation and performance implications stemming from human-inthe-loop SAP agent deployment.

Cross-Cultural Study: Research on barriers and enablers with a focus on culture, regulation and regulatory environment in different continents.

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https://www.jisem-journal.com/
Research Article

Next Generation AI Integration: Research on how new AI functionality like multimodal LLMs, autonomous planning, etc. can support human-agent coordination.

Predictive Supervision: Creation of models that are able to predict when humans will need to intervene, in order to supervise in a proactive manner rather than reactive.

Longitudinal Studies: Perform multiyear, cross-company studies to follow organizational change, workflow modification and measure performance applications of human-in-the-loop SAP agent frameworks. This will illustrate long-term opportunities and obstacles.

Cross-Cultural Analysis: It will involve a systematic investigation of how cultural and regulatory differences affect HITL adoption, key success factors and customization of agent-human collaboration approaches in the different global environments.

Advanced AI Integration: Research advanced AI capabilities to integrate new AI technologies, such as multimodal LLMs, autonomous planning agents, and hybrid AI+human assisted intelligence into the fabric to enable collaboration, contextual understanding, and decision quality.

Predictive Supervision: Deploy scalable machine learning-based models for predicting when human supervisory control will be needed, so as to execute supervisory control in advance, thereby enhancing safety and accuracy and reducing operational costs.

Design for Human-Agent Collaboration: Investigate design frameworks, interaction paradigms that facilitate human-agent collaboration by enabling shared goals, mutual responsivity and adaptive autonomy to enable frictionless, effective and successful human-agent collaborations.

12. Conclusion

The orchestration of SAP ecosystems that is driven by agents, coupled with human-in-the-loop functionality is a major shift in enterprise operations that demands careful alignment of governance, technology and human factors. The proposed approach of this paper deals solving these challenges through layered approach, embedded governance, and human-centric design principles.

Key contributions are: (1) A holistic framework for autonomous SAP agent systems incorporating governance, technology and human factors, (2) empirical investigations of human factors affecting decision makers in a transition from solving tasks to overseeing, or supervising, the activities of agents, and (3) a set of design principles and guidelines for functional design/implementation of control tower dashboards to effectively monitor agent networks.

Industry use-cases illustrate the efficacy of GRAD on reducing processing time, increasing compliance, leveraging human in the loop while being autonomous for operations. But it takes a very heavy hand in organizational change management and ensuring that there are operators who are reacting and adjusting to the technology.

The road to automation in the enterprise is not in the removal of the human decision-making process but rather through the development of intelligent relationships where humans and autonmous systems can work to optimize business results. Those that thrive in this transition, will achieve tremendous competitive benefit by becoming more efficient, making better decisions, and being more resilient to operational risk.

And as self-acting agents become even more complex, human oversight will not become less important, but more important. The framework presented in this paper offers a path for firms that are looking to unlock the

Journal of Information Systems Engineering and Management
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https://www.jisem-journal.com/
Research Article

value of agentic AI without sacrificing the human judgment, creativity, and accountability needed for complex organizational tasks.

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