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Human-Machine Interaction in Future Chemical Supply Chain Management: A Conceptual Framework

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Abstract
One of the most important pillars of the global economy is the chemical industry. It is complex and needs to be run like a well-oiled machine owing to its length. The chemical supply chain usually extends from manufacturers to distributors, retailers, and consumers. Balancing all dynamics and stakeholders (chemical manufacturers, distributors, and retailers) makes it difficult to maintain smooth operations. A complex supply chain with producers, distributors, and retailers in the chemical sector is vital. The human-machine interface is located at the interface between the biosphere and the technosphere, thus integrated with natural sciences, biological sciences, and techno-sciences. The task of chemical manufacturers is to overcome challenges such as low visibility, quality-assured standards for production planning, coordination of material delivery, and management of hazardous chemicals and inventory levels for cost reduction. Human-machine interaction (HMI) is used by the chemical industry for particular purposes (production optimization, risk assessment, and inventory management). In this study, we proposed models using HMI to combat problems such as optimization and risk assessment. This will help supply chain management in the transparency of inventory and correct demand signals, making it clear to provide maximum performance across all levels.

Keywords: global economy, chemical industry, supply chain, human-machine interference, optimization, risk assessment.

1. Introduction
Over the last few decades, chemical supply chains have changed and adapted to new digital technologies. This trend also applies to chemical industries, which use HMI as a solution tool for inventory management, risk assessment, mitigation, chemical allocation management, and production optimization. The management of the supply chain was transformed by HMI. HMI can optimize performance across all levels of the chemical supply chain, increasing revenues through more effective procedures, while still safeguarding public health and environmental quality. Thus, the industry is in a super wide range in terms of both the quantity and variety of items, for large array applications. The materials are solids and fluids, and some are flammable and hazardous gas products. Every product requires special attention and handling, storage, and transportation because they are chemically and physically different. Chemical products are widely used in various industrial applications. But, at least in some fields (pharma, automotive to say one hand) they are crucial and time-critical. A sound chemical logistics system is important to suppliers, manufacturers, and its consumption end. The small variations, either passive delays or minor oscillations in the supply chain, translate to an entire

system-level change. In addition, if there is a bottleneck in production downtimes and delivery to end customers (customer order backlogs only grow), the scenario may be worse. Procurement, logistics, and supply chain managers are often required to complete massive projects in very short time frames.

1.1. The Structure of the Chemical Industry

Chemical industry is a basic industry that converts raw materials into products. The chemical industry is central to modern world economy. It produces more than 70,000 different products, including:

- Petrochemicals: Polymers for plastics and synthetic fibers
- Inorganic chemicals: Acids and alkalis
- Agricultural chemicals: Fertilizers, pesticides, and herbicides
- Other categories: Industrial gases, specialty chemicals, and pharmaceuticals

The chemical industry comprises two major sectors.

- Specialty chemicals
- Commodity chemicals: Also known as basic chemicals

The chemical industry is diverse and is divided into six sectors.
Bulk chemicals, Specialty chemicals, Agrochemicals, Petrochemicals, Polymers, Fertilizers

1.2. Current Scenario of Chemical Supply Chain

India's chemical industry is one of the major industries, contributing 7% to the Country's GDP. The market size of chemical and petrochemical segments in India is approximately USD 215 billion and it is anticipated to cross US$ 300 billion by the year 2025.
Here are some challenges facing the chemical industry:

- Managing raw materials
- Transportation disruptions
- Regulations
- Large amounts of data
- Complex supply chains
- Lack of visibility
- Climate change pressure

Artificial intelligence can help chemical companies work smarter and faster. It can automate tasks, provide insights into how chemicals react, and improve the manufacturing environment.
Global chemical production is expected to grow by 2.0% in 2023, slower than that in the previous year (2022: +2.2%), and chemical production is expected to expand by 0.6% by 2023. However, a stronger growth of 3.5% is expected in 2024 as global industrial production increases.

1.3. Artificial Intelligence and Machine Learning (AI&ML)in Supply Chain

Balancing the strengths of machines and humans and understanding their interaction dynamics are crucial for maximizing project performance. Integrating AI into teams effectively requires careful consideration of how tasks are allocated, establishing communication channels are established, and structuring decision-making processes.
Some firms are still in the process of exploring and fine-tuning their integrations. Finding the right balance between the computational prowess of AI and the nuanced, contextual understanding that humans bring is a work in progress. The time came to change the old

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strategy and come up with advanced technology that optimizes human-AI collaboration will likely continue to evolve as well. It is going to be a game changer and will play a significant role in revolutionizing supply chain management in the chemical industry. The most important tasks such as forecasting demand and optimizing inventory can be easily tackled by the advancement of AI and ML.

2. Leveraging Human-Machine Interaction (HMI) for Chemical Supply Chain Solutions

In recent years has moved towards practical applications throughout the global economy. According to McKinsey's research statement in 2018, 47% of the firms adopted the HMI, and around 71% expected to invest in it. Many respondents agree that HMI will benefit supply chain management and many corporations are expected to employ HMI by 2023 (Gartner, 2019b). However, according to a report produced by the IDC, at least 50% of HMI projects fail for one in every four companies. HMI is different from the previous technology; in fact, it is highly dynamic owing to the inclination of AI and Humans.

The chemical industry uses Human-Machine Interaction (HMI) to improve a range of tasks such as risk assessment, identifying and mitigating potential hazards; and inventory management, which can operate at improved levels of efficiency, safety, and precision by integrating HMI. HMI can improve supply chain management by allowing managers to see what is in their inventories, forecast manufacturing demands, and maximize output at all levels. Chemical manufacturers deal with issues such as a lack of visibility, quality assurance requirements, production scheduling, coordinating material deliveries, and inventory management for cost-effectiveness. HMI have the potential to improve a variety of business processes, including contract negotiations, route selection, and truck loading.

3. Problem Statement

Recent developments in AI have led to the evolution of intelligence systems' roles into those of teammates as they become more complex and capable of working with humans on cognitive tasks, that do not always function well. Encouraging an efficient human-machine interface (HMI) is therefore essential for the success of AI projects and attaining the desired enhancement results. These findings raise the question of what skills are necessary for human-machine collaboration to be successful.

4. Present Theories and Models on Human-Machine Teaming

Teammates play complementary roles in human teams. A teammate is a free individual with limited autonomy who works within social structures and situational limitations and joins forces for a particular task or activity. By sharing knowledge and acknowledging one another's strengths and weaknesses, teammates can grow and change together. Positive engagement histories have helped teammates build trust, and their combined experiences will enhance their mutual capacities and advance the team's objectives (Brill et al., 2018).

With the long history of studying human teams, numerous sophisticated models for creating and analyzing productive teams have been developed. Wageman, Hackman, and Lehman's "Five Conditions That Foster Team Effectiveness" (2005) model is one of the most well-known. They contend that to promote a culture of learning and collaborative problem-solving, a company's organizational framework must be supportive of effective team interactions in addition to the skills necessary to drive them.

A team needs leadership, or a "compelling direction," to succeed, as covered in Wageman, Hackman, and Lehman's "effective team framework" (Wageman et al., 2005). With the aid of information and communication technologies, leaders in contemporary cultures can make prompt and well-informed judgments (Daggett & Hurley, 2019). With the development of AI technology, choices are now frequently influenced by computers or, in certain cases, are made solely by them. Artificial intelligence (AI) can assist, supplement, and replace human judgment (Jarrahi, 2018). According to Jarrahi, the optimal method to make decisions is to collaborate between human intuition and computer logic.

5. HMT Capabilities

In psychology research publications, human teams have been the focus of numerous investigations; however, there has not been much research on human teams working with AI-driven cognitive machine partners.

The authors' first major finding is the significance placed on a "human-centric" strategy for interactions between humans and machines. According to John and Vera (2019, p. 18), "the growth of sophistication in machine capabilities must go hand in hand with the growth of sophistication in human-machine interaction capabilities." They go on: "Teaming must be built as an add-on to systems; it is not an isolatable, unitary capacity." According to Johnson and Vera (2019), "it should be viewed as an approach to what AI capabilities should be built to enable intelligent systems with teaming competence."

Early in the field of HMT research, "Controllability" received a lot of attention. According to Urlings and Jain (2002), a human-machine team has a relationship similar to that of a "pilot" and "co-pilot," with the human leading the team and the machine acting as a subordinate associate or assistant, sharing authority, accountability, and autonomy over tasks. Accordingly, controlled, practical, and useable AI systems are required (Urlings & Jain, 2002).

Stanford University, UC Berkeley, and MIT collaborated in Human-centered AI (HAI) research in response to concerns about the risks that AI poses to human life. The humanistic and ethical side of AI-that is, the idea that technology should complement humans rather than replace them-is emphasized in their HAI research initiatives (Stanford, 2013).

Table 1: Overview of HMT Capabilities and Conceptual Concepts from Key Authors

Capabilities	Authors	Definition/Key Concepts
Directability, Controllability, Accountability	Urlings et al, 2002 McDermott et al. 2017 Azad et al. 2018 Smith 2019	• The system needs to be under human control and human and machine authority can be assigned depending on situations • Provide for appropriate levels of human intervention in real-time machine processes to help resolve these situations not encompassed within the designed performance envelope of the human-machine system • Humans supporting the ability to redirect resources, reassign tasks, change workflow parameters, or reorder & reprioritize tasks

Explanation	Smith 2019 Cruz, 2019 Xu, 2019	• Machine learning needs to be "interpretable by design" • Humans understand when and why AI acts including when AI makes decisions. • Allowing users to understand the logic angles of the algorithm and parameters used
Observability, Directing Attention, Predictability	Urlings et al, 2002 McDermott et al. 2017 Smith 2019	• Some states or parameters of the system and its environment The AI system should be capable of being explained - in a timely manner - to humans, who should be able to check what the system is doing, and why. • Human-machine team members can guide each other on important issues or alerts • Human-machine team has the ability to predict the future intentions of its human and machine counterpart; • The ability of the Machine to understand how the situation may change to help the user predict future states. • Information is provided in a manner that assists brevity and comprehensibility
Ethical, Honest	Smith 2019 Xu, 2019	• Humans can recognize that they are interacting with AI, not humans
Learning	McDermott et al. 2017 Smith 2019	• Human-machine teams can flexibly alter, and reconfigure to react to novel events • Machine is impelled to be perfected periodically to fit human desires and technical requirements
Shared Decision Making	McDermott et al. 2017 Azad et al. 2018	• Collaborative human-machine decision making and gets rid of human oversight slips and has reduced human error • Multi-view, knowledge and solution, human-machine partners joint understanding of the problem space
Transparency	Azad et al. 2018 Cruz, 2019	• Understand the mistakes and biases from the ML models and correct them • For humans, evidence is provided for the decision-making

Shared Knowledge of State; Shared Context; Common Ground	McDermott et al. 2017 Azad et al. 2018	• Shared Knowledge and Awareness: The human is aware of the information that the machine uses to perform the tasks, whereas the machine is aware of the Human cognitive, physical and emotional state • Team members share relevant beliefs and assumptions • Team members maintain a constantly updated shared picture of what is happening and the status of the overall plan
Usable, Useful	Smith 2019 Xu, 2019	• The AI solution includes some of the functionalities that users would require to meet their needs in these valid usage scenarios.
Cognitive Load Balance	Azad et al. 2018	• Maintain a workable human workload — change the distribution between (chart) headers human and machine as context changes
Interoperability	Azad et al. 2018	• Connect the human-machine team into larger systems
Security	Smith 2019	• Generate Explainable Security Techniques from AI that are, in fact, Robust, Validated and Reliable • Prevent unintentional/unauthorized entry into and use of purposefully intending to lay out lines of demarcation cleaning of HMT processes, mechanisms, physical elements, data, and services mining.

According to Xu (2019), the AI design should preserve fairness in addition to not replacing humans. He persisted in arguing that in order for AI technology to fully replicate human intellect, it must continue to advance and that any answers should be explicable (Xu, 2019).
"Transparency," which fosters human-machine trust, is another important issue in current HMT research. According to McDermott (2017), machines must act in a way that gains human trust as autonomy technology advances and the need for continual human supervision decreases. As a result, the HMT requires situational awareness to recognize changes in conditions, bidirectional human-machine interaction, and transparency in machine processes. Humans must be able to step in at various points throughout machine operations to adjust their objectives or reallocate resources. (Dermott, 2017).

According to Smith (2019), human-machine teams function best when users can rely on AI systems to act in a predictable, safe, secure, and comprehensible manner. According to Cruz (2019), gaining human confidence requires developing intelligent systems that are visible, explainable, and as accurate as possible while also combating algorithmic prejudice (Cruz, 2019). Based on the interaction capabilities of AI system design, Azad et al. (2018) suggested that the HMT should be flexible. Human-machine joint performance, task allocation based on human cognitive load balance, knowledge sharing, interoperability, shared decision-making,

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and protecting human-machine teaming processes are among the crucial elements that must be considered in adaptive HMT (Azad M. Madni & Carla C. Madni, 2018). Table 1 lists the capabilities and definitions covered in the above-mentioned studies.

6. Conceptual Framework

Some HMT-related theoretical approaches were analyzed based on which, we developed and proposed a conceptual HMT framework, as illustrated in **Figure 1**. The conceptual framework diagram illustrates the future chemical supply chain utilizing patterns of human-machine interaction (HMI). It presents a linear flow of seven key stages in the chemical supply chain, each of which is paired with a corresponding HMI component. The process begins with Raw Material Procurement, supported by a Smart Sourcing Interface. This is followed by Chemical Manufacturing, which incorporates collaborative robot control. Quality Control & Testing are enhanced by an AR Inspection Panel, while Packaging & Storage employ automated Monitoring. The Customer Delivery & Feedback stages are aided by a smart logistics planner. Data Analytics and Continuous Improvement, appearing twice in the diagram, is supported by a Feedback Collection Portal. The framework demonstrates how HMI technologies are integrated at each stage to optimize and modernize the chemical supply chain process, emphasizing the synergy between human expertise and machine capabilities throughout the entire workflow.

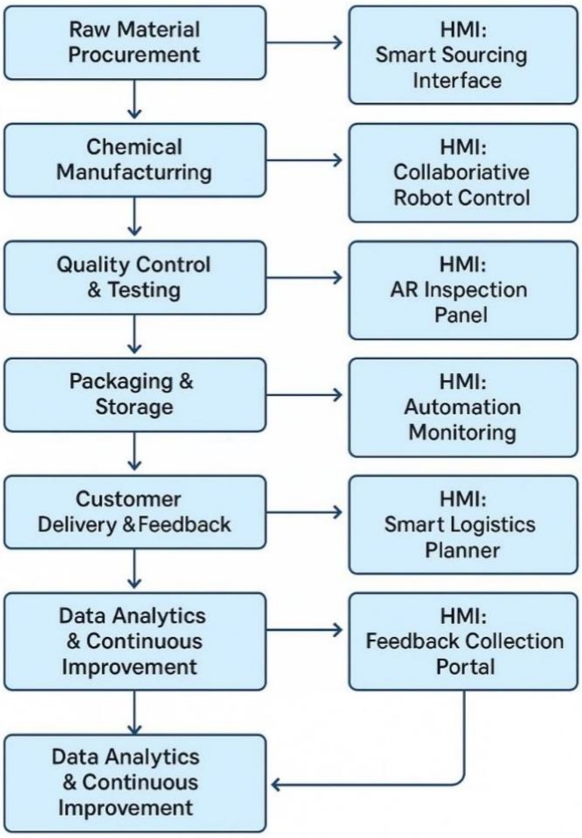

Figure 1: Integration of Human-Machine Interfaces (HMI) across the Chemical Manufacturing Lifecycle

7. Conclusions

The integration of Human-Machine Interaction (HMI) into the chemical supply chain presents significant opportunities for optimization and efficiency. As the chemical industry continues to evolve, leveraging HMI can address critical challenges such as inventory management, risk assessment, and production optimization. The conceptual framework proposed for Human-Machine Teaming (HMT) emphasizes key capabilities such as controllability, transparency, and adaptability. These elements are crucial in promoting trust and effective collaboration between humans and AI systems. As the chemical industry embraces these technologies, it is essential to maintain a human-centric approach, ensuring that AI complements human decision-making rather than replacing it. The successful implementation of HMI in chemical supply chains has the potential to revolutionize operations, enhance safety, and drive sustainable growth in this vital sector of the global economy.

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