Journal of Theoretical and Applied Information Technology
15th March 2025. Vol.103. No.5

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

THE INTELLIGENT COLLABORATIVE SUPPLY CHAIN MANAGEMENT WITH LARGE LANGUAGE MODELS

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ABSTRACT

This research explores the development of an Intelligent Collaborative Supply Chain Management (iCSCM) system, driven by Large Language Models (LLMs), to enhance operational efficiency and facilitate collaboration among academic, governmental, and private sectors in advancing University Holding Companies (UHCs). Despite significant progress in AI-driven supply chain management, challenges remain in effectively aligning academic research with industry demands, resulting in suboptimal resource utilization and missed opportunities for commercialization. This study seeks to address these issues by proposing an AI-driven framework to optimize collaboration within this ecosystem. Employing system design frameworks, architectural evaluation matrices, and expert surveys, the study evaluates the proposed system's effectiveness, demonstrating a high level of suitability (Mean = 4.73, SD = 0.30). The findings underscore the transformative potential of large language models in enhancing collaborative supply chain processes, equipping universities to serve as key innovation hubs that bridge the gap between research and industry applications.

Keywords: *Intelligent Collaborative Supply Chain Management, Large Language Models, Artificial Intelligence, University Holding Company*

1. INTRODUCTION

Universities are transforming into University Holding Companies (UHCs), serving as a bridge between academic research and industry collaboration to generate economic value. However, conventional supply chain mechanisms face challenges in efficiently aligning research projects with suitable industry partners and funding sources. The incorporation of Artificial Intelligence (AI) into Collaborative Supply Chain Management (CSCM) presents substantial benefits, including enhanced project matching and optimized resource allocation. While prior research has investigated AI applications in supply chain management, there remains a significant gap in studies addressing AI-driven collaborative frameworks specifically designed for University Holding Companies [1], [2].

Despite the growing implementation of AI in supply chain management, the absence of an integrated AI-driven framework customized for university-industry collaboration constrains opportunities for commercialization and innovation. Existing research predominantly focuses on general supply chain optimization but lacks a structured framework that leverages Large Language Models (LLMs) to facilitate seamless collaboration within university-driven ecosystems [3], [4].

This study seeks to address this gap by developing an Intelligent Collaborative Supply Chain Management (iCSCM) system tailored to the needs of University Holding Companies. By integrating LLMs and AI-driven mechanisms, the proposed framework aims to enhance coordination, improve decision-making, and accelerate the commercialization of academic research, thereby strengthening the role of University Holding Companies in fostering innovation and industry engagement [5], [6].

2. OBJECTIVES OF RESEARCH

This research aims to explore the integration of Large Language Models (LLMs) into the architecture of Intelligent Collaborative Supply Chain Management (iCSCM) systems to enhance efficiency and collaboration. The study adopts a descriptive research methodology, combining literature review, analysis, synthesis, and system

Journal of Theoretical and Applied Information Technology
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ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

evaluation to achieve the following specific objectives:

- To review trends, research, and literature related to the systems architecture of Intelligent Collaborative Supply Chain Management with Large Language Models to drive University Holding Companies.
- To analyze and synthesize related research.
- To design the system architecture of Intelligent Collaborative Supply Chain Management with Large Language Models.
- To evaluate the system architecture of Intelligent Collaborative Supply Chain Management with Large Language Models.

3. RESEARCH HYPOTHESIS

H1: The integration of Large Language Models into Intelligent Collaborative Supply Chain Management will significantly improve the suitability of project matching and resource allocation within University Holding Companies.

4. RESEARCH METHODOLOGY

The research methodology was designed to systematically address the objectives of integrating Large Language Models (LLMs) into the architecture of Intelligent Collaborative Supply Chain Management (iCSCM) systems. This methodology involved a multi-stage approach, encompassing a comprehensive literature review, analytical synthesis, architectural design, and system evaluation. The details of each stage are as follows:

4.1 Review of Trends and Literature

The first stage involved an extensive review of academic research, industry reports, and case studies related to the system architecture of Intelligent Collaborative Supply Chain Management and the applications of Large Language Models. Sources were selected based on their relevance, credibility, and publication recency to ensure the incorporation of the latest advancements. Key research databases and journals, in Scopus, were consulted to gather data on trends, technologies, and methodologies.

A systematic literature search was conducted in Scopus databases following the PRISMA flow. In this search, only English-language papers published in the last five years, between January 2020 and December 2024 were considered. The keywords and search operators used were To search for relevant articles in Scopus, you can use the following ("Collaborative" OR "Supply Chain" OR "Supply Chain Management") AND ("Artificial Intelligence" OR "AI") AND ("Large Language Models" OR "LLMs") AND ("University Holding Companies" OR "Science Park" OR "Techno Park" OR "Start up" OR "Spinoff") AND ("OpenAI" OR "ChatGPT") AND ("Components" OR "Processes" OR "Flows") AND ("IoT" OR "Blockchain") shown in Figure 1.

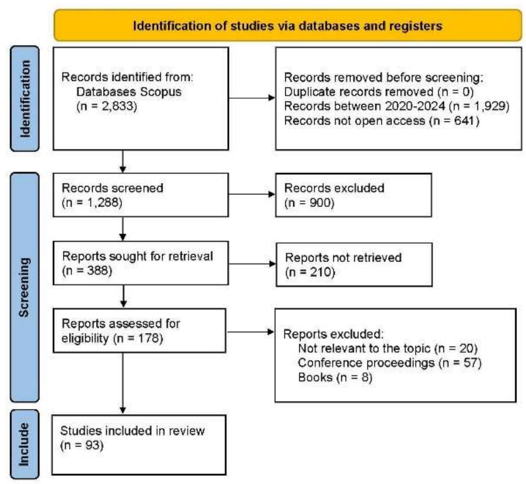

Figure 1. The Systematic reviews and Meta-Analyses (PRISMA) of Intelligent Collaborative Supply Chain Management with Large Language Models

4.2 Analysis and Synthesis of Research Findings

In this stage, the findings from the literature review were critically analyzed and synthesized to develop a conceptual framework for the Intelligent Collaborative Supply Chain Management. Comparative analysis techniques were employed to evaluate different Large Language Models applications and their suitability for collaborative supply chain environments. The synthesis process involved identifying core functionalities, such as natural language processing, predictive analytics, and decision-making support, that Large Language Models could contribute to the Intelligent Collaborative Supply Chain Management system.

4.3 Design of Intelligent Collaborative Supply Chain Management System Architecture

Based on the insights gained, the Intelligent Collaborative Supply Chain Management system architecture was designed with a focus on scalability, interoperability, and intelligent capabilities. The architecture design followed the Software Development Life Cycle (SDLC) methodology, starting with requirement analysis, followed by design and prototyping.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

4.4 Evaluation of the System Architecture

The proposed Intelligent Collaborative Supply Chain Management system architecture was evaluated for its efficiency, usability, and effectiveness. A structured evaluation was conducted with 9 domain experts, each possessing over five years of experience in system development, ICT, and supply chain management. Experts assessed the system using suitability evaluation matrices, with scores based on specific metrics. Quantitative data, including mean scores and standard deviations, were calculated to measure the system's overall suitability. Qualitative feedback was also collected to identify areas for refinement. The interpretation of results based on the range of average scores is presented in Table 1.

Table 1: Range of average scores and interpretation of results

Range of Average Score	Interpretation of Appropriateness
4.50 - 5.00	Highest level of suitability
3.50 - 4.49	High level of suitability
2.50 - 3.49	Moderate level of suitability
1.50 - 2.49	Low level of suitability
0.00 - 1.49	Lowest level of suitability

5. RESULT

5.1 Review of Trends and Literature

- The Role of Intelligent Collaborative Supply Chain Management in University Holding Companies

University holding companies (UHCs) act as vital intermediaries between academia and industry, facilitating the transfer of knowledge, commercialization of research, and development of innovative partnerships. In this context, Intelligent Collaborative Supply Chain Management (iCSCM) systems serve as pivotal tools to enhance their operational capacity. By leveraging these systems, UHCs can efficiently manage intellectual property, align academic research outputs with industry needs, and foster strategic collaborations that drive economic growth. The integration of Intelligent Collaborative Supply Chain Management with Large Language Models (LLMs) further empowers University holding companies by providing advanced data processing capabilities, real-time communication tools, and actionable insights for decision-making. These features collectively enable University holding companies to optimize resource allocation, streamline project execution, and strengthen their role in bridging the gap between academic institutions and external stakeholders [7], [8].

Moreover, the adoption of Intelligent Collaborative Supply Chain Management systems within University holding companies addresses the growing complexity of supply chain networks that involve diverse stakeholders, including universities, government agencies, and private enterprises. The advanced capabilities of Large Language Models, such as natural language understanding and predictive analytics, enable University holding companies to navigate these complexities by enhancing collaboration and reducing inefficiencies. For example, Large Language Models can analyze vast datasets to identify emerging trends, facilitate contract negotiations, and ensure the seamless exchange of information across organizational boundaries. As a result, the role of University holding companies extends beyond traditional knowledge transfer to becoming catalysts for innovation ecosystems, fostering sustainable development and competitive advantage in the global marketplace. University holding companies serve as bridges between academic institutions and external partners. AI-driven systems can help these entities manage intellectual property, foster partnerships, and commercialize research effectively [9], [10].

Table 2: Components of the role of Intelligent Collaborative Supply Chain Management in University Holding Companies

Components	[11]	[12]	[13]	[14]	[15]	[16]	[17]
UHCs as Intermediaries	✓	✓		✓	✓	✓	✓
iCSCM Systems	✓	✓	✓	✓	✓	✓	✓
Integration with LLMs	✓	✓	✓		✓	✓	✓
Addressing Supply Chain Complexities	✓	✓	✓	✓	✓	✓	✓
Extended Role of UHCs	✓	✓		✓	✓	✓	✓
Conclude	✓	✓	✓	✓	✓	✓	✓

- Integration of Large Language Models in Intelligent Collaborative Supply Chain Management

The integration of Large Language Models (LLMs) into Intelligent Collaborative Supply Chain Management (iCSCM) has revolutionized the way organizations manage and optimize their supply chains. LLMs, with their advanced natural language understanding and predictive capabilities, facilitate seamless communication among stakeholders, automate data-intensive tasks, and generate actionable insights. By leveraging Large Language Models, organizations can enhance operational efficiency, improve decision-making, and foster collaboration across the supply chain. For instance, Large Language Models can analyze vast amounts of unstructured data from various sources, such as emails, reports, and social media, to provide real-time insights and recommendations. This capability enables organizations to anticipate demand fluctuations, optimize inventory levels, and respond proactively to dynamic supply chain challenges [18], [19].

Moreover, Large Language Models play a crucial role in enhancing supply chain visibility and transparency. By integrating data from multiple sources, Large Language Models provide a unified view of the entire supply chain, enabling real-time tracking of products from production to delivery. This visibility helps organizations monitor the performance of their supply chain, identify bottlenecks, and ensure compliance with regulations. Additionally, Large Language Models facilitate intelligent collaboration by enabling seamless communication and data sharing among supply chain partners. Natural Language Processing (NLP) and Large Language Models enhance communication by understanding and generating human-like text, making interactions more efficient and effective. This intelligent collaboration leads to better coordination and alignment of supply chain activities, ultimately driving innovation and improving overall supply chain performance [20], [21].

Table 3: Components of the integration of Large Language Models in Intelligent Collaborative Supply Chain Management

Components	[22]	[23]	[24]	[25]	[26]	[27]	[28]
Advanced Capabilities of LLMs	✓	✓	✓	✓		✓	✓
Operational Efficiency and Decision-Making	✓	✓	✓	✓	✓	✓	✓
Data Analysis and Insights	✓		✓	✓	✓	✓	✓
Supply Chain Visibility and Transparency	✓	✓	✓	✓	✓	✓	✓
Intelligent Collaboration	✓	✓	✓	✓	✓		✓
Innovation and Performance Improvement	✓	✓	✓		✓	✓	✓
Conclude	✓	✓	✓	✓	✓	✓	✓

- Collaborative Frameworks and Multi-Stakeholder Coordination in Intelligent Collaborative Supply Chain Management

Collaborative frameworks and multi-stakeholder coordination are essential components of Intelligent Collaborative Supply Chain Management (iCSCM). These frameworks facilitate the integration of various stakeholders, including suppliers, manufacturers, distributors, and customers, into a cohesive and efficient supply chain network. By fostering collaboration, organizations can achieve greater alignment between internal processes and external demands, leading to improved operational efficiency and resilience. Effective collaboration requires the establishment of trust, transparency, and open communication among all parties involved. Information sharing and joint decision-making are critical elements that enable stakeholders to respond swiftly to market changes and disruptions. For instance, public-private partnerships and multi-stakeholder initiatives have been shown to enhance supply chain resilience by promoting coordinated actions and resource sharing [29], [30].

Moreover, collaborative frameworks support the development of innovative solutions to common supply chain challenges. Techniques such as crowd shipping, gainsharing, and the sharing economy can be leveraged to optimize resource utilization and reduce costs. These approaches not only improve efficiency but also contribute to sustainability by minimizing waste and reducing the environmental impact of supply chain operations. Additionally, multi-stakeholder coordination helps in aligning incentives and ensuring that all parties benefit from collaborative efforts. This alignment is crucial for maintaining long-term partnerships and achieving mutual goals. By integrating intelligent systems and technologies, such as AI and IoT, organizations can further enhance collaboration and coordination, leading to more agile and responsive supply chains [31], [32].

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 4: Components of collaborative frameworks and Multi-Stakeholder Coordination in Intelligent Collaborative Supply Chain Management

Components	[33]	[34]	[35]	[36]	[37]	[38]	[39]
Integration of Stakeholders	✓	✓	✓	✓	✓	✓	
Fostering Collaboration	✓	✓		✓	✓	✓	✓
Information Sharing and Joint Decision-Making	✓	✓	✓	✓	✓	✓	✓
Development of Innovative Solutions	✓	✓		✓	✓	✓	✓
Alignment of Incentives	✓	✓	✓	✓	✓	✓	✓
Integration of Intelligent Systems and Technologies	✓	✓		✓	✓	✓	✓
Conclude	✓	✓	✓	✓	✓	✓	✓

5.2 The conceptual framework for the Intelligent Collaborative Supply Chain Management with Large Language Models

The Intelligent Collaborative Supply Chain Management (iCSCM) system, enhanced with Large Language Models (LLMs), is designed to optimize collaboration, streamline operations, and drive efficiency in university-industry partnerships. This conceptual framework outlines the integration of advanced technologies, including LLMs, Artificial Intelligence (AI), and Machine Learning (ML), to support the complex processes involved in collaborative supply chain management. The framework is structured around four key components, as illustrated in Figure 2.

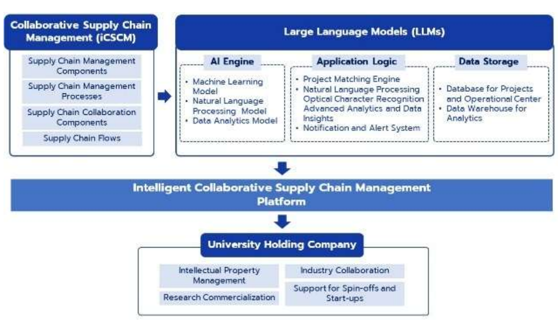

Figure 2. The conceptual framework of Intelligent Collaborative Supply Chain Management

From Figure 2, this framework demonstrates the integration of Intelligent Collaborative Supply Chain Management (iCSCM) with Large Language Models (LLMs) to enhance the operational efficiency and strategic capabilities of universities transitioning into University Holding Companies (UHCs). The design leverages the advanced functionalities of Large Language Models to address challenges in supply chain coordination, data-driven decision-making, and multi-stakeholder collaboration. The framework consists of the following four parts:

Part 1: Collaborative Supply Chain Management (CSCM)

The framework begins with the foundational components of Collaborative Supply Chain Management (CSCM), which include:

1) Supply Chain Management Components: The core elements necessary for effective supply chain operations, including suppliers, manufacturers, and distributors.

2) Supply Chain Management Processes: Key processes such as procurement, production, logistics, and delivery that drive supply chain efficiency.

3) Supply Chain Collaboration Components: Tools and mechanisms that enable seamless coordination among diverse stakeholders in the supply chain.

4) Supply Chain Flows: The structured movement of goods, information, and financial resources across supply chain networks.

These components form the foundation for introducing advanced intelligence through Large Language Models.

Part 2: Role of Large Language Models (LLMs)

Large Language Models serve as the core enabler of intelligent functionalities within the Intelligent Collaborative Supply Chain Management system. Their integration is categorized into three main areas:

1) AI Engine:

- Machine Learning Models: Provide predictive insights to optimize supply chain operations.

- Natural Language Processing (NLP) Models: Facilitate effective communication and understanding among stakeholders by processing unstructured text data.

- Data Analytics Models: Analyze large datasets to detect trends and allocate resources effectively.

2) Application Logic:

- Project Matching Engine: Identifies optimal resources and stakeholders for collaborative projects.

- Natural Language Processing and Optical Character Recognition (OCR): Automate the extraction and analysis of unstructured data.

- Advanced Analytics and Insights: Generate actionable recommendations for stakeholders.

- Notification and Alert Systems: Ensure real-time updates to mitigate risks and enhance decision-making.

3) Data Storage:

- Database for Projects and Operations: Provides a centralized repository for managing supply chain activities.

- Data Warehouse for Analytics: Enables advanced data processing and trend analysis to support strategic planning.

Part 3: The Intelligent Collaborative Supply Chain Management Platform

The integration of Collaborative Supply Chain Management components with Large Language Models functionalities results in an intelligent platform. This platform serves as a unified solution for managing supply chain processes, automating routine tasks, and enabling data-driven decision-making. It ensures real-time operational transparency and effective collaboration among all supply chain stakeholders.

Part 4: Driving University Holding Companies (UHCs)

The ultimate objective of this framework is to enhance the capabilities of universities transitioning into University Holding Companies, which play a critical role in bridging academia and industry. By leveraging the intelligent platform, University Holding Companies can:

- Manage Intellectual Property (IP): Ensure robust protection and commercialization of innovations.

- Foster Industry Collaboration: Build partnerships with private and government sectors.

- Accelerate Research Commercialization: Transform academic research into market-ready solutions.

- Support Spin-offs and Start-ups: Empower entrepreneurial ventures through resource allocation and strategic guidance.

5.3 Intelligent Collaborative Supply Chain Management System Architecture

The Intelligent Collaborative Supply Chain Management (iCSCM) system architecture is designed to enhance the management of research collaborations and commercialization efforts between universities and industry. By leveraging Large Language Model (LLM) technologies, the Intelligent Collaborative Supply Chain Management system optimizes project matching, resource allocation, and communication within university-industry partnerships, aligning with the strategic goals of the University Holding Company (UHC) framework. This section outlines the architecture and key components that enable the efficient and intelligent management of the university's collaborative supply chain, as illustrated in Figure 3.

As illustrated in Figure 3, the Intelligent Collaborative Supply Chain Management (iCSCM) system architecture is organized into six main components that manage user interactions, core system operations, data management, and security. The six components are as follows:

1) Users: The system categorizes users into different groups with specific access rights based on their roles and responsibilities. These groups are divided into three categories:

- Staff: Responsible for coordinating and inputting information regarding academic services or potential project topics of interest.

- Head of Operational Center: Approves academic service work on the platform, focusing on the development of research, inventions, and innovations with commercial potential.

- Administrator: Oversees the platform, coordinates with users, and ensures the system's development and operational efficiency to achieve optimal performance.

2) Devices: Devices connected to the platform include smartphones, tablets, and personal computers, which are used to access information and services through the user interface on the web application.

3) User Interface: The user interface serves as the interaction point for various stakeholders within the university's collaborative ecosystem. It is responsible for collecting project data and providing status updates, accessible through a web application.

4) Collaborative Supply Chain Management Processes: These consist of four main elements:

4.1) Supply Chain Management Components: Categorized into two groups:

- Structural Management Components: Include Planning and Control Methods, Workflow Activity Structure, Organizational Structure, Communication and Information, Flow Facility Structure, and Knowledge Management.

Journal of Theoretical and Applied Information Technology
15th March 2025. Vol.103. No.5

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

- Behavioral Management Components: Comprise Management Methods, Power and Leadership, Risk and Reward, Culture and Attitude, and Trust and Commitment.

4.2) Supply Chain Management Processes: Include Customer Relationship Management, Customer Service Management, Demand Management, Order Fulfillment, Manufacturing Flow Management, Supplier Relationship Management, Product Development and Commercialization, and Return Management.

4.3) Supply Chain Collaboration Components: Focus on Joint Knowledge Creation, Collaborative Communication, Resource Sharing, Information Sharing, and Decision Synchronization.

4.4) Supply Chain Flows: Consist of seven distinct flows: Material Flow, Finished Products Flow, Services Flow, Information Flow, Knowledge Flow, Financial Resources Flow, and Return Flow.

5) Large Language Models (LLMs): Designed to enhance the management of research collaboration and commercialization processes by leveraging Large Language Models, Machine Learning (ML), and Artificial Intelligence (AI) technologies. It comprises the following key components:

5.1) Large Language Model-Driven Project Matching Engine: Matches research projects with university labs and resources based on project requirements and lab capabilities. The engine uses ML algorithms and Natural Language Processing (NLP) to analyze data from multiple sources and recommend the most suitable operational center for each project. The process includes:

- Input Data: Processes data from research proposals, operational center profiles including expertise, available equipment, and past performance, and industry requirements.

- Matching Algorithm: Identifies patterns in the data, such as matching keywords in project descriptions with operational center expertise, or analyzing previous successful collaborations. The system continuously improves its recommendations based on feedback and past outcomes.

- Outcome: Generates a ranked list of recommended operational centers for each project, based on the likelihood of successful collaboration. This enhances the speed and accuracy of the project-matching process, reducing manual effort and minimizing the risk of mismatches.

5.2) Collaborative Management Module: Facilitates real-time communication, coordination, and tracking between researchers, university administrators, and industry partners. It ensures that all stakeholders remain aligned throughout the project lifecycle by offering tools for managing timelines, resources, and deliverables. Features include:

- Collaboration Tools: Includes features for creating project workspaces, sharing documents, and setting project milestones. Integrates with email and messaging systems to send automatic updates and reminders.

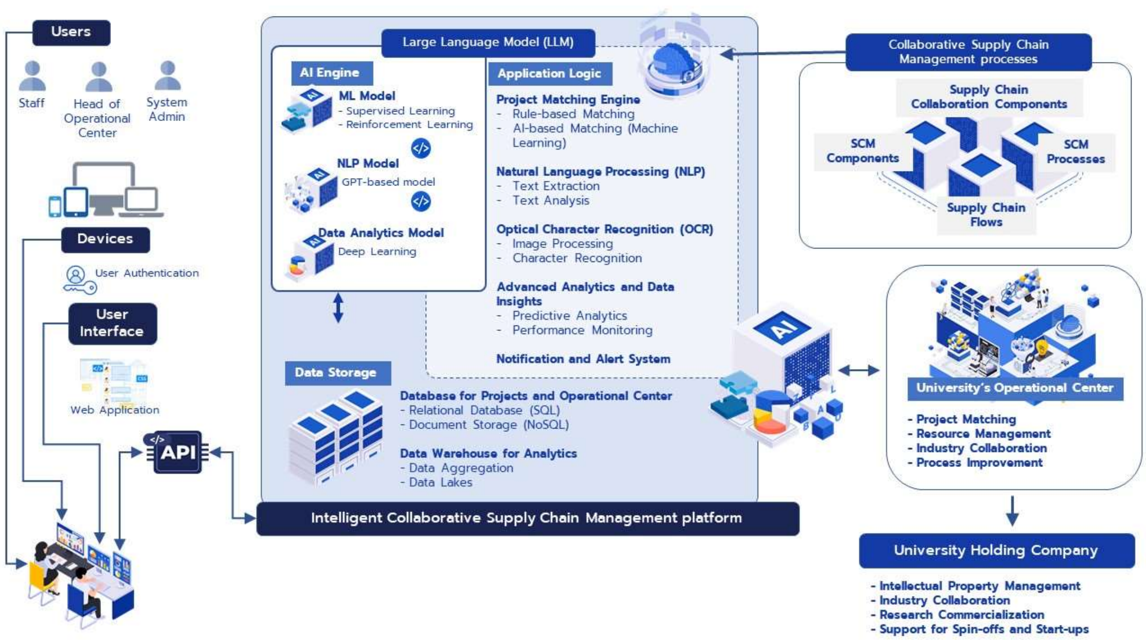

Figure 3. The Intelligent Collaborative Supply Chain Management (iCSCM) system architecture

- Resource Management: Enables heads of operational centers to allocate resources (such as personnel, lab space, and equipment) to specific projects based on current availability. The system dynamically tracks resource usage to prevent overallocation

5.3) Predictive Analytics and Machine Learning Integration: Key to enabling continuous improvement in the Intelligent Collaborative Supply Chain Management system. By analyzing historical project data, these tools provide valuable insights into future project outcomes, resource needs, and collaboration success factors. Features include:

- Historical Data Analysis: Learns from past projects, identifying factors contributing to successful collaborations. This data is used to refine project matching and resource planning.

- Forecasting: Uses predictive models to estimate the likelihood of project success, project completion times, and potential challenges. These forecasts help heads of operational centers and university administrators make informed decisions regarding resource allocation and project timelines.

- Continuous Learning: Machine learning models continuously update based on new data from ongoing and completed projects, ensuring the system adapts to changing needs and trends in research and industry

5.4) Secure Data Management Layer: Ensures that sensitive research data, intellectual property, and collaboration agreements are protected from unauthorized access or data breaches. Features include:

- Data Encryption: All data stored in the Intelligent Collaborative Supply Chain Management system is encrypted using advanced encryption standards (AES) both at rest and in transit, ensuring that confidential research data remains secure throughout its lifecycle.

- Access Control: Uses Role-Based Access Control (RBAC) to manage permissions, ensuring that only authorized users can access or modify sensitive information.

6) University Holding Company (UHC): An entity established by a university to manage and commercialize its intellectual property, innovations, and research outputs. It typically acts as a bridge between academia and industry, facilitating technology transfer, the creation of spin-offs and startups, and partnerships with external organizations. The UHC's goal is to generate revenue for the university through licensing agreements, equity in ventures, and product commercialization while supporting the broader mission of driving innovation and societal impact.

Table 5: the system architecture of Intelligent Collaborative Supply Chain Management with Large Language Models.

List of Evaluation		$\bar{X}$	S.D.	Rating Scales
1. Users	1.1 Staff	5.00	0.00	Highest
	1.2 Head of Operational Center	4.53	0.51	Highest
	1.3 Administrator	5.00	0.00	Highest
	Total	4.84	0.17	Highest
2. Devices	2.1 Smartphones	5.00	0.00	Highest
	2.2 Tablets	5.00	0.00	Highest
	2.3 Personal computers	5.00	0.00	Highest
	Total	5.00	0.00	Highest
3. User Interface	Web application	4.82	0.39	Highest
4. CSCM processes	4.1 Supply Chain Management Components	4.47	0.51	Highest
	4.2 Supply Chain Management Processes	4.76	0.44	Highest
	4.3 Supply Chain Collaboration Components	4.82	0.93	Highest
	4.4 Supply Chain Flows	4.59	0.51	Highest
	Total	4.66	0.46	Highest
5. Large Language Models	5.1 LLM-Driven Project Matching Engine	4.82	0.39	Highest
	5.2 Collaborative Management Module	5.00	0.00	Highest
	5.3 Predictive Analytics and ML Integration	4.53	0.51	Highest
	5.4 Secure Data Management Layer	4.47	0.51	Highest
	Total	4.71	0.36	Highest
6. University Holding Company	6.1 Total Commercialization Revenue	4.29	0.47	Highest
	6.2 Intellectual Property Value	4.24	0.44	Highest
	6.3 Spin-off Success	4.06	0.43	High
	6.4 Industry Collaboration	4.76	0.44	Highest
	Total	4.34	0.44	Highest
Total		**4.73**	**0.30**	**Highest**

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

5.4 Evaluation of the System Architecture

The assessment results of the Intelligent Collaborative Supply Chain Management (iCSCM) with Large Language Models (LLMs) system architecture for driving University Holding Companies are summarized in Table 5. The overall evaluation of the system architecture indicated the highest level of suitability (Mean = 4.73, S.D. = 0.30). When considering individual components, most items were rated as having the highest level of suitability.

6. DISCUSSION

The Intelligent Collaborative Supply Chain Management (iCSCM) system architecture presents a transformative framework for universities transitioning into University Holding Companies (UHCs). By incorporating Artificial Intelligence (AI), Large Language Models (LLMs), and Machine Learning (ML), the system addresses critical challenges such as project matching, resource allocation, and risk mitigation, thereby enhancing research commercialization, optimizing resource utilization, and fostering stronger university-industry partnerships. These features position universities as pivotal players in innovation and economic growth [40], [41].

The findings align with other AI-driven frameworks employed by leading institutions. For instance, the University of Cambridge utilizes AI and predictive analytics for portfolio management, thereby improving commercialization outcomes, while Harvard University leverages AI tools to align research proposals with funding opportunities and collaborators, enhancing project success rates. These implementations underscore the growing role of AI in automating research workflows, aligning resources, and maximizing the impact of university research [42], [43].

The scalability and predictive capabilities of the Intelligent Collaborative Supply Chain Management system reflect the principles of European Technology Transfer and Innovation Frameworks, which emphasize robust governance, resource efficiency, and secure intellectual property management. These parallels reinforce the system's value in fostering entrepreneurial ecosystems within academic settings and promoting spin-offs and start-ups as drivers of economic growth [44].

While the current study demonstrates the suitability of the Intelligent Collaborative Supply Chain Management system architecture, it is important to acknowledge its limitations. The evaluation was conducted by a purposively selected group of 9 experts, primarily focused on assessing the system's architecture. Although these experts provided valuable insights, the findings represent a preliminary assessment limited to a small and specialized sample. Future research should aim to address this limitation by incorporating a larger and more diverse sample of users, including university administrators, researchers, industry partners, and students. This broader evaluation will provide a more comprehensive understanding of the system's usability, scalability, and real-world application.

Moreover, the full Intelligent Collaborative Supply Chain Management system should be developed and tested in operational environments to assess its performance under practical conditions. Expanding the research scope to include longitudinal studies would also be beneficial in measuring the system's long-term impact on research commercialization, resource optimization, and university-industry collaboration. Additionally, integrating emerging technologies such as Blockchain for secure contracts and the Internet of Things (IoT) for real-time resource monitoring could further enhance the system's capabilities and scalability. These future developments will ensure the Intelligent Collaborative Supply Chain Management system continues to align with the evolving needs of University Holding Companies and contributes to sustainable economic growth.

7. CONCLUSION

The Intelligent Collaborative Supply Chain Management (iCSCM) system architecture offers universities transitioning into University Holding Companies (UHCs) an effective solution for aligning academic research outputs with market demands. By enhancing research commercialization, streamlining project matching, optimizing resource allocation, and fostering collaboration, the system accelerates innovation cycles and strengthens university-industry partnerships. Predictive analytics and dynamic resource utilization within the Intelligent Collaborative Supply Chain Management system help prevent bottlenecks and ensure optimal project outcomes. Furthermore, its secure and scalable infrastructure supports the efficient management of intellectual property and large-scale collaborations, while promoting entrepreneurship through spin-offs and start-ups.

For future research, it is recommended to extend the current study by incorporating additional emerging technologies such as Blockchain for enhanced contract management and IoT for real-time resource monitoring, which could further improve the scalability and security of the system.

Additionally, it is essential to involve a larger and more diverse group of users, including global stakeholders from universities, industries, and research institutions, to assess the system's applicability and impact across varied contexts. Future studies could explore long-term system performance, addressing the evolving needs of UHCs, and further examining the system's role in advancing technological innovation and economic growth through global partnerships.

8. ACKNOWLEDGEMENTS

The authors express their heartfelt gratitude to the experts for their invaluable assistance in evaluation, validation, and insightful recommendations. Special thanks are extended to KMUTNB Techno Park and the Division of Information and Communication Technology for Education, Faculty of Technical Education, King Mongkut's University of Technology North Bangkok, Thailand, for their steadfast support throughout this research.

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