

RGC Ref. No.: UGC/FDS14/E06/20 (please insert ref. above)

**RESEARCH GRANTS COUNCIL
COMPETITIVE RESEARCH FUNDING SCHEMES FOR
THE LOCAL SELF-FINANCING DEGREE SECTOR**

FACULTY DEVELOPMENT SCHEME (FDS)

Completion Report
(for completed projects only)

Submission Deadlines: 1. Auditor's report with unspent balance, if any: within **six** months of the approved project completion date.
2. Completion report: within **12** months of the approved project completion date.

Part A: The Project and Investigator(s)

1. Project Title

A blockchain-enabled IoT system for pallet-pooling management

2. Investigator(s) and Academic Department(s) / Unit(s) Involved

Research Team	Name / Post	Unit / Department / Institution
Principal Investigator	Dr WU, Chun-ho / Associate Professor	Department of Supply Chain and Information Management, The Hang Seng University of Hong Kong
Co-Investigator(s)	Dr YUEN, Sheung-man Simon / Senior Lecturer	Division of Business and Hospitality Management, SPEED, The Hong Kong Polytechnic University
Co-Investigator(s)	Prof. CHING, Wai-ki / Professor	Department of Mathematics, The University of Hong Kong

3. Project Duration

	Original	Revised	Date of RGC / Institution Approval (must be quoted)
Project Start Date	2021-01-01	N/A	N/A
Project Completion Date	2023-06-30	N/A	N/A
Duration (in month)	30	N/A	N/A
Deadline for Submission of Completion Report	2024-06-30	N/A	N/A

- 4.4 Please attach photo(s) of acknowledgement of RGC-funded facilities / equipment.
N/A

Part B: The Final Report

5. Project Objectives

5.1 Objectives as per original application

1. To develop an effective deployment scheme for the integration of blockchain and IoT technologies in the logistics industry, to facilitate information exchange and management for a pallet-pooling management strategy.
2. To formulate the pallet-pooling management strategy as the core element of the closed-loop logistics network by making use of the developed blockchain-enabled IoT system, to achieve better performance in terms of transparency, security, traceability, efficiency, and cost reduction.
3. To evaluate the performance and feasibility of the proposed pallet-pooling strategies through the adoption of a blockchain-enabled IoT system.

5.2 Revised objectives

Date of approval from the RGC: N/A

Reasons for the change: N/A

5.3 Realisation of the objectives

(Maximum 1 page; please state how and to what extent the project objectives have been achieved; give reasons for under-achievements and outline attempts to overcome problems, if any)

The project objectives have been fully fulfilled, demonstrating significant achievements in integrating blockchain and IoT technologies in the logistics industry for pallet-pooling management. An effective deployment scheme was developed, enabling seamless information exchange and management through the blockchain-enabled IoT system. This integration improved transparency, security, traceability, efficiency, and cost reduction. Secondly, the pallet-pooling management strategy was successfully formulated as the core element of a closed-loop logistics network, leveraging the developed blockchain-enabled IoT system. This strategy demonstrated enhanced performance in terms of the identified metrics. Lastly, the proposed pallet-pooling strategies were thoroughly evaluated, validating their feasibility and performance by adopting the blockchain-enabled IoT system. Overall, the project has achieved all its objectives, leading to a comprehensive understanding and practical utilisation of blockchain and IoT technologies for efficient and sustainable pallet management in the logistics industry.

5.4 Summary of objectives addressed to date

Objectives <i>(as per 5.1/5.2 above)</i>	Addressed <i>(please tick)</i>	Percentage Achieved <i>(please estimate)</i>
1. To develop an effective deployment scheme for the integration of blockchain and IoT technologies in the logistics industry, to facilitate information exchange and management for a pallet-pooling management strategy.	<input checked="" type="checkbox"/>	100%
2. To formulate the pallet-pooling management strategy as the core element of the closed-loop logistics network by making use of the developed blockchain-enabled IoT system, to achieve better performance in terms of transparency, security, traceability, efficiency, and cost reduction.	<input checked="" type="checkbox"/>	100%
3. To evaluate the performance and feasibility of the proposed pallet-pooling strategies through the adoption of a blockchain-enabled IoT system.	<input checked="" type="checkbox"/>	100%

6. Research Outcome

6.1 Major findings and research outcome

(Maximum 1 page; please make reference to Part C where necessary)

The research project has successfully met all its objectives, leading to an enhanced understanding and utilisation of blockchain and IoT technologies within the logistics sector. Key findings from the study have underscored the transformative potential of these technologies in pallet-pooling management systems.

As Tsang et al. (2021) reported, the first significant finding involved an in-depth exploration of the theoretical underpinnings of blockchain and IoT integration. The study outlined the importance of data privacy, security models, system deployment frameworks, and the establishment of trust in the blockchain-IoT (BLoT) ecosystem. This foundational work paved the way for developing a service-oriented architecture to streamline the design and deployment of these technologies within logistics systems.

The second outcome was the design of a BLoT platform for smart pallet pooling management based on this theoretical groundwork, as detailed by Wu et al. (2021). A layered architecture encompassed perception, network, decentralisation, service, and application layers. This architecture facilitated the creation of a closed-loop Pallet as a Service (PalletaaS) mechanism, which structured the material and information flows between logistics service providers and pallet pooling operators. This integration was instrumental in embedding sustainable practices into the logistics and supply chain operations through four main business activities: pallet sourcing, repair and maintenance, quality compliance, and stock management.

The third outcome, as developed by Long et al. (2021), was the creation of an end-to-end bidirectional authentication protocol. This protocol was designed to ensure the authenticity of pallets within the logistics network by considering tag-based, location-based, and object-specific features, which significantly improved the efficiency of pallet traceability and allocation processes.

A fourth notable outcome of the project concerns the intersection of human interaction with the cyber-physical logistics system. Tsang et al. (2022) discussed using extended reality (XR) as an interface for workers to engage with the cyber-physical system, which has further implications for future research and development in this field.

In the final major research outcome, Yang et al. (2023) successfully developed an XR application that facilitates smart palletisation. This application uses deep reinforcement learning to provide optimal loading instructions and is equipped with an online optimisation feature that requires minimal prior knowledge of item dimensions and sequence. This advancement is expected to be an invaluable addition to the PalletaaS, enhancing the efficiency and sustainability of pallet utilisation within the industry.

In summary, the project outcomes have significantly advanced the pallet pooling management strategy's development and introduced a novel PalletaaS to logistics service providers. The additional capabilities, such as the XR-enabled optimal pallet loading instructions, can potentially revolutionise the industry's approach to pallet usage. The research has led to reduced industrial waste and optimised space utilisation, thus contributing to the overarching goal of sustainable pallet management.

6.2 Potential for further development of the research and the proposed course of action (Maximum half a page)

The project anticipates two critical areas of development that will further refine and enhance the efficiency of the logistics network. The first area centres on advancing operations research related to pallet delivery and pickup operations. This potential involves deploying sophisticated analytical models and simulations to optimise routing, scheduling, and utilising assets and resources within the pallet-pooling ecosystem. The goal is to minimise downtime and ensure that pallets are transported most efficiently, thereby reducing costs and environmental impact. The research will likely leverage the existing blockchain-enabled IoT (BIIoT) infrastructure to gather real-time data, which will inform dynamic decision-making processes and predictive analytics to anticipate logistical challenges before they arise.

The second development area seeks to broaden the scope of the current pallet-pooling management system to include a more comprehensive array of palletisation materials and sensors, such as pallet covers and temperature sensors. This extension aims to enhance the quality control aspects of logistics, ensuring that goods are tracked and maintained in their optimal condition throughout their journey. By integrating sensors that can monitor conditions such as temperature, humidity, and shock, the system can provide immediate alerts and actionable insights to prevent damage and ensure the integrity of sensitive products. This holistic approach to palletisation material and sensor integration will necessitate the development of new protocols and standards for sensor data management and analysis within the BIIoT framework, ensuring seamless interoperability and maximum reliability.

7. Layman's Summary

(Describe in layman's language the nature, significance and value of the research project, in no more than 200 words)

Our research project has met its objectives, transforming pallet management in the logistics sector through blockchain and IoT integration. The investigation delved into these technologies' core principles, establishing a framework that prioritises data privacy, security, and trust. Building on this foundation, a sophisticated, layered blockchain-IoT platform for smart pallet pooling is designed. This platform enabled a Pallet as a Service (PalletaaS) model, optimising the flow of materials and information and embedding sustainable practices into logistics operations. A key innovation was the development of an authentication protocol that improved the traceability and allocation of pallets, ensuring their authenticity across the logistics network. Besides, an XR application that utilises deep reinforcement learning for efficient pallet loading is designed in the PalletaaS. This application optimises the loading process, making it more efficient and less dependent on prior knowledge of cargo. Consequently, our research has significantly advanced pallet pooling management strategies, introducing a novel PalletaaS to the industry. These advancements are set to revolutionise pallet usage, reduce waste, and improve spatial efficiency, contributing to the overarching aim of sustainable pallet management.

Part C: Research Output**8. Peer-Reviewed Journal Publication(s) Arising Directly From This Research Project**

(Please attach a copy of the publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

The Latest Status of Publications				Author(s) (denote the corresponding author with an asterisk*)	Title and Journal / Book (with the volume, pages and other necessary publishing details specified)	Submitted to RGC (indicate the year ending of the relevant progress report)	Attached to this Report (Yes or No)	Acknowledged the Support of RGC (Yes or No)	Accessible from the Institutional Repository (Yes or No)
Year of Publication	Year of Acceptance (For paper accepted but not yet published)	Under Review	Under Preparation (optional)						
2021#				Y.P. Tsang, C.H. Wu*, W.H. Ip, Wen-Lung Shiau	Exploring the intellectual cores of the blockchain–Internet of Things (BIoT), <i>Journal of Enterprise Information Management</i> , 34(5), 1287-1317.	2021	Yes (Annex I)	Yes	Yes https://researchdb.hsu.edu.hk/view/publication/202100057
2021				Chun-Ho Wu*, Yung-Po Tsang, Carman Ka-Man Lee, Wai-Ki Ching	A Blockchain-IoT Platform for the Smart Pallet Pooling management, <i>Sensors</i> , 21, 6310.	2021	Yes (Annex II)	Yes	Yes https://researchdb.hsu.edu.hk/view/publication/202100179
2021				Wen Long, C.H. Wu*, Y.P. Tsang, Qiyang Chen	An End-to-End Bidirectional Authentication System for Pallet Pooling Management Through Blockchain Internet of Things (BIoT), <i>Journal of Organizational and End User Computing</i> , 33(6), 1-25	2021	Yes (Annex III)	Yes	Yes https://researchdb.hsu.edu.hk/view/publication/202100176
2022				Tsang, Y. P., Yang, T. T., Chen, Z. S., Wu, C. H.*, & Tan, K. H.	How is extended reality bridging human and cyber-physical systems in the IoT-empowered logistics and supply chain	2022	Yes (Annex IV)	Yes	Yes https://researchdb.hsu.edu.hk/view/publication/202200357

					management?, Internet of Things, 100623.				
2023				T.T. Yang, Y. P. Tsang, C. H. Wu*, K. T. Chung, C. K. M. Lee & S. S. M. Yuen	Mixed reality-based online 3D pallet loading problem to achieve augmented intelligence in e-fulfilment processes, Operations Management Research, https://doi.org/10.1007/s12063-023-00432-6	N/A	Yes (Annex V)	Yes	Yes https://research.hdb.hsu.edu.hk/view/publication/202300293

#After submitting the proposal, PI started conducting a deeper literature review, and started a prior study in flourishing and growing areas associated with BloT after knowing this project had been approved in the late summer. All the findings supported achieving objective #1 stated in the project. Although this paper was submitted to the journal before the project start date, it is one of the research outputs achieved based on this project idea and initiation.

9. Recognised International Conference(s) In Which Paper(s) Related To This Research Project Was / Were Delivered

(Please attach a copy of each conference abstract)

Month / Year / Place	Title	Conference Name	Submitted to RGC (indicate the year ending of the relevant progress report)	Attached to this Report (Yes or No)	Acknowledged the Support of RGC (Yes or No)	Accessible from the Institutional Repository (Yes or No)
N/A	N/A	N/A	N/A	N/A	N/A	N/A

10. Whether Research Experience And New Knowledge Has Been Transferred / Has Contributed To Teaching And Learning

(Please elaborate)

N/A

11. Student(s) Trained

(Please attach a copy of the title page of the thesis)

Name	Degree Registered for	Date of Registration	Date of Thesis Submission / Graduation
N/A	N/A	N/A	N/A

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12. Other Impact

(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, teaching enhancement, etc.)

N/A

13. Statistics on Research Outputs

	Peer-reviewed Journal Publications	Conference Papers	Scholarly Books, Monographs and Chapters	Patents Awarded	Other Research Outputs (please specify)	
No. of outputs arising directly from this research project	5	N/A	N/A	N/A	Type	No.
					N/A	

14. Public Access Of Completion Report

(Please specify the information, if any, that cannot be provided for public access and give the reasons.)

Information that Cannot Be Provided for Public Access	Reasons
N/A	N/A