RGC Ref. No.:
UGC/FDS14/E06/21
(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

Dynamic Pick Face Replenishment & Pallet Consolidation Model for Landing in the Next E-Fulfilment Normal

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

Research Team	Name / Post	Unit / Department / Institution
Principal Investigator	Dr. HO To Sum / Associate Professor	Department of Supply Chain and Information Management, The Hang Seng University of Hong Kong
Co-Investigator(s)	Dr. CHUNG Sai-Ho, Nick / Associate Professor	Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University
	Dr. TSE Ying Kei, Mike / Professor	Cardiff Business School, Cardiff University
	Dr. LEUNG Ka Ho / Lecturer	The University of Liverpool Management School, University of Liverpool
Others	N/A	N/A

3. Project Duration

	Original	Revised	Date of RGC / Institution Approval *(must be quoted)*
Project Start Date	1/1/2022	1/1/2022	
Project Completion Date	31/12/2023	30/06/2024	16/05/2023 (HSUHK)
Duration *(in month)*	24	30	16/05/2023 (HSUHK)
Deadline for Submission of Completion Report	30/12/2024	30/6/2025	16/05/2023 (HSUHK)

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 examine the practice of the e-fulfilment process in the industry through case studies from the perspectives of Logistics Service Providers.
2. To establish an enterprise-wide model for small and medium enterprises (SMEs) in designing the optimal pick face replenishment strategy for facing the next e-fulfilment normal through the adoption of Federated Learning.
3. To enhance SMEs' operational excellence through the optimization of put-away and order picking processes jointly under the pick face replenishment strategy in e-fulfilment operations.

5.2 Revised objectives

Date of approval from the RGC: N/A

Reasons for the change: N/A

1. N/A

2. N/A

3. 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 objectives 1 to 3 of this project have been fully achieved, as shown in part 5.1. The accomplishments of project objectives 1 to 3 inspired three research publications, including two journal publications and one conference publication:

[1] Ho, G. T. S., Tang, V., Tong, P. H., & Tam, M. M. F. (2025). Demand-driven storage allocation for optimizing order picking processes. Expert Systems with Applications, 126812.

[2] Lam, H. Y., Ho, G. T. S., Mo, D. Y., & Tang, V. (2023). Responsive pick face replenishment strategy for stock allocation to fulfil e-commerce order. International Journal of Production Economics, 264, 108976.

Conference publication:

[3] Ho, G. T., Lam, H. Y., & Tang, V. (2023, December). An AI-based forecasting model for intelligent pick face replenishment. In 2023 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM) (pp. 0178-0182). IEEE.

The first objective was fully achieved through an in-depth examination of e-fulfilment practices within the logistics industry, primarily informed by a case study approach. Publication [2] details a pilot case study conducted with a medium-sized third-party logistics (3PL) distribution centre in Hong Kong. This investigation provided critical insights into the operational realities, challenges, and prevailing e-fulfilment strategies, particularly concerning pick-face replenishment and order picking in response to e-commerce demands. The findings from this case study highlighted the practical issues faced by LSPs, such as handling fluctuating order demands with limited resources and the need for more dynamic replenishment strategies. This hands-on industry engagement was crucial in understanding the specific needs of LSPs, especially Small and Medium Enterprises (SMEs). Further contextual understanding of LSP challenges, particularly for SMEs in Hong Kong, was also incorporated into the problem definitions and solution frameworks proposed in publications [1] and [3], ensuring the research remained grounded in real-world applicability.

The second objective was also fully achieved by developing and conceptualizing advanced models for optimal pick-face replenishment strategies for SMEs, with a specific focus on Federated Learning (FL). The Intelligent Forecasting for Order Picking Optimization (IFOPO) model [1] is central, using FL for demand forecasting to enable dynamic, data-privacy-conscious pick-face replenishment responsive to e-commerce volatility. This was complemented by an AI-based forecasting model [3] demonstrating AI's efficacy in predicting demand for pick-face strategies, and the Responsive Pick Face Replenishment (RPFR) system [2], which exemplified a practical system for dynamic stock allocation based on predicted demand. Together, these works establish a comprehensive approach for SMEs to adopt advanced replenishment techniques.

Finally, the third objective was fully achieved by developing and validating integrated solutions that jointly optimize put-away (storage allocation) and order picking processes within a pick-face replenishment strategy, demonstrating significant enhancements in operational excellence for SMEs. The IFOPO model [1] directly addressed this by using demand forecasts to optimize storage allocation for both pick-face and bulk storage and subsequently optimizing order picking routes for holistic warehouse improvement. Strong empirical evidence was provided by the RPFR system [2], which showed a 63.28% reduction in average order picking time through optimized put-away based on predicted demand. The AI forecasting model [3] further supported this by enabling more effective put-away decisions, leading to simplified and accelerated order picking.

5.4 Summary of objectives addressed to date

Objectives *(as per 5.1/5.2 above)*	**Addressed** *(please tick)*	**Percentage Achieved** *(please estimate)*
1.To examine the practice of the e-fulfilment process in the industry through case studies from the perspectives of Logistics Service Providers.	✓	100%
2.To establish an enterprise-wide model for small and medium enterprises (SMEs) in designing the optimal pick face replenishment strategy for facing the next e-fulfilment normal through the adoption of Federated Learning.	✓	100%
3.To enhance SMEs' operational excellence through the optimization of put-away and order picking processes jointly under the pick face replenishment strategy in e-fulfilment operations.	✓	100%

6. Research Outcome

6.1 Major findings and research outcome
(Maximum 1 page; please make reference to Part C where necessary)

This project has yielded significant findings and research outcomes that advance the understanding and practice of e-fulfilment operations, particularly for Small and Medium Enterprises (SMEs). The major findings are encapsulated in the development and validation of intelligent, data-driven models designed to optimize critical warehouse processes.

A key research outcome is the **establishment of integrated frameworks that jointly optimize historically siloed operations such as demand forecasting, storage allocation (put-away), and order picking.** The **Intelligent Forecasting for Order Picking Optimization (IFOPO) model** [1] stands as a central achievement. This model innovatively employs **Federated Learning (FL)** for demand forecasting, enabling SMEs to collaboratively build robust predictive models without compromising data privacy. The IFOPO model then leverages these forecasts to dynamically optimize storage allocation in both pick-face and bulk storage areas, and subsequently determines optimal order picking routes. This holistic approach was shown through simulation to enhance overall warehouse efficiency and responsiveness to volatile e-commerce demands.

Another major finding, empirically validated through a case study with a Hong Kong 3PL provider, is the significant operational improvement achievable with responsive pick-face replenishment strategies. The **Responsive Pick Face Replenishment (RPFR) system** [2] demonstrated that by integrating predictive analytics (using ANFIS and Genetic Algorithms) to dynamically adjust the type and quantity of SKUs in pick-face forward areas, SMEs can achieve substantial gains. Notably, the case study reported a **63.28% reduction in average order picking time**, showcasing the tangible benefits of such intelligent systems in real-world settings. This highlights the finding that targeted, AI-driven replenishment can drastically reduce unproductive time in warehousing.

Furthermore, the project successfully developed and demonstrated the efficacy of a dedicated **AI-based forecasting model (using Artificial Neural Networks)** specifically for intelligent pick-face replenishment [3]. This research found that even without extensive infrastructure changes, LSPs can significantly improve their ability to handle fluctuating e-orders and optimize resource utilization by adopting AI for demand prediction to inform pick-face strategies. This outcome also underscores the potential for such technologies to contribute to broader goals like sustainable industrialization (SDG 9) and decent work and economic growth (SDG 8) by enhancing operational capabilities of SMEs.

In essence, the project's major findings confirm that:

- Integrated, AI-driven approaches significantly outperform traditional methods in e-fulfilment.
- Federated Learning offers a viable and effective solution for SMEs to leverage advanced forecasting.
- Optimizing put-away and order picking processes jointly, guided by intelligent pick-face replenishment, leads to substantial improvements in operational excellence.

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

This project's success lays the groundwork for impactful future research. Key development areas include: **validating the IFOPO model [1] in real-world SME pilots**, particularly its Federated Learning aspects; **exploring advanced ML techniques** (e.g., LSTMs, reinforcement learning) for enhanced forecasting and optimization [1]; **extending models to address operational uncertainties** like stockouts and varied lead times [2, 3]; **adapting solutions for diverse warehouse layouts and picking strategies** [2]; investigating **human-AI collaboration and XAI** for better adoption; and conducting deeper **sustainability and economic impact analyses** [3].

The proposed course of action involves **securing funding for real-world pilot studies**; **establishing strong industry collaborations** with LSPs and SMEs for co-development; **expanding the research team's expertise** in advanced ML and operations research; **developing open-source components** or demonstrators to foster wider adoption; and **continuing active dissemination** through high-impact publications and conferences. Pursuing these steps will further develop robust, adaptable solutions for SMEs in the evolving e-fulfilment sector.

7. Layman's Summary

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

Imagine online shopping is booming, and small businesses need to get orders out faster than ever. This research helps them do just that. We've created smart computer models that act as an expert assistant for warehouses. These models use artificial intelligence to predict what customers will buy. This helps businesses store popular items in easy-to-reach spots (the 'pick-face') and plan the quickest routes for staff to collect items for orders. A key feature is 'Federated Learning,' which lets businesses learn from each other's data without sharing private information. The significance is that even small companies can greatly improve their speed and reduce costs – one of our systems cut order picking time by over 60%. This makes businesses more competitive, keeps customers happy with faster deliveries, and supports overall economic growth.

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)*						
2025	-	-	-	Ho, G. T. S., Tang, V., Tong, P. H., & Tam, M. M. F.	Demand-driven storage allocation for optimizing order picking processes. *Expert Systems with Applications*, 126812.	**N/A**	Yes (Annex I)	Yes	Yes **https://scholars.hsu.edu.hk/en/publications/demand-driven-storage-allocation-for-optimizing-order-picking-pro**
2023	-	-	-	Lam, H. Y., Ho, G. T. S., Mo, D. Y., & Tang, V.	Responsive pick face replenishment strategy for stock allocation to fulfil e-commerce order. *International Journal of Production Economics*, *264*, 108976.	2022	Yes (Annex II)	Yes	Yes **https://scholars.hsu.edu.hk/en/publications/responsive-pick-face-replenishment-strategy-for-stock-allocation-**

9. Recognized 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)*
Dec/2023/ Marina Bay Sands, Singapore	An AI-based forecasting model for intelligent pick face replenishment	IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)	N/A	Yes (Annex III)	Yes	Yes https://scholars.hsu.edu.hk/en/publications/an-ai-based-forecasting-model-for-intelligent-pick-face-replenish

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

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	2	1	N/A	N/A	Type	No.
					N/A	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