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A human-robot collaborative delivery model for instant orders in metropolitan areas

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ABSTRACT

In metropolitan instant delivery systems, rising operational costs and poor delivery timeliness pose significant challenges. This study addresses these issues by investigating optimal order allocation and route optimization in a hybrid delivery system that integrates autonomous delivery vehicles (ADVs) with human riders. Analysis of historical order data indicates that inefficient order assignment between ADVs and riders is a major operational bottleneck. To address this problem, a collaborative human-ADV delivery model is formulated with the objective of minimizing total logistics costs under constraints related to delivery time windows, vehicle capacity, and routing requirements. The proposed model is applied to a real-world case involving QX Fresh Supermarket, comprising 80 orders and 16 community transfer points. An improved genetic algorithm is developed to solve the optimization problem efficiently. Empirical results for off-peak, normal, and peak periods show that the collaborative delivery approach significantly improves ADV utilization and reduces total delivery costs by more than 30 % without compromising timeliness. These findings provide both a sound theoretical basis and practical guidance for the advancement of human-machine collaborative logistics.

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References

[1] Alirezazadeh, S., Alexandre, L.A. (2022). Dynamic task scheduling for human-robot collaboration, *IEEE Robotics and Automation Letters*, Vol. 7, No. 4, 8699-8704, doi: 10.1109/LRA.2022.3188906.
[2] Wu, B., Hu, B., Lin, H. (2017). Toward efficient manufacturing systems: A trust based human robot collaboration, In: *Proceedings of 2017 American Control Conference (ACC)*, Seattle, USA, 1536-1541, doi: 10.23919/ACC.2017.7963171.
[3] Ranz, F., Hummel, V., Sihn, W. (2017). Capability-based task allocation in human-robot collaboration, *Procedia Manufacturing*, Vol. 9, 182-189, doi: 10.1016/j.promfg.2017.04.011.
[4] Cai, H., Mostofi, Y. (2019). Human-robot collaborative site inspection under resource constraints, *IEEE Transactions on Robotics*, Vol. 35, No. 1, 200-215, doi: 10.1109/TRO.2018.2875389.
[5] Yao, B., Li, X., Ji, Z., Xiao, K., Xu, W. (2024). Task reallocation of human-robot collaborative production workshop based on a dynamic human fatigue model, *Computers & Industrial Engineering*, Vol. 189, Article No. 109855, doi: 10.1016/j.cie.2023.109855.
[6] Faccio, M., Granata, I., Minto, R. (2024). Task allocation model for human-robot collaboration with variable cobot speed, *Journal of Intelligent Manufacturing*, Vol. 35, No. 2, 793-806, doi: 10.1007/s10845-023-02073-9.

[7] Zhao, R.H., Tao, S.C., Li, P.Z. (2025). Safety-efficiency integrated assembly: The next-stage adaptive task allocation and planning framework for human-robot collaboration, *Robotics and Computer-Integrated Manufacturing*, Vol. 94, Article No. 102942, doi: 10.1016/j.rcim.2024.102942.
[8] Bruno, G., Antonelli, D. (2018). Dynamic task classification and assignment for the management of human-robot collaborative teams in workcells, *The International Journal of Advanced Manufacturing Technology*, Vol. 98, No. 9, 2415-2427, doi: 10.1007/s00170-018-2400-4.
[9] Vahedi-Nouri, B., Tavakkoli-Moghaddam, R., Hanzálek, Z., Dolgui, A. (2024). Production scheduling in a reconfigurable manufacturing system benefiting from human-robot collaboration, *International Journal of Production Research*, Vol. 62, No. 3, 767-783, doi: 10.1080/00207543.2023.2173503.
[10] Xu, W., Xu, S., Liu, D.Y., Awaga, A.L., Rabia, A.C., Zhang, Y.Y. (2024). Impact of fairness concerns on resource-sharing decisions: A comparative analysis using evolutionary game models in manufacturing enterprises, *Advances in Production Engineering & Management*, Vol. 19, No. 2, 223-238, doi: 10.14743/apem2024.2.503.
[11] Sodenkamp, M.A., Tavana, M., Di Caprio, D. (2016). Modeling synergies in multi-criteria supplier selection and order allocation: An application to commodity trading, *European Journal of Operational Research*, Vol. 254, No. 3, 859-874, doi: 10.1016/j.ejor.2016.04.015.
[12] Xiang, W., Song, F.S., Ye, F.F. (2014). Order allocation for multiple supply-demand networks within a cluster, *Journal of Intelligent Manufacturing*, Vol. 25, No. 6, 1367-1376, doi: 10.1007/s10845-013-0735-0.
[13] Zhang, Z.Z., Zhang, L., Li, W.C. (2025). An improved adaptive variable neighborhood search algorithm for stochastic order allocation problem, *Scientific Reports*, Vol. 15, Article No. 481, doi: 10.1038/s41598-024-84663-y.
[14] Huq, F., Sultana, N., Roy, P., Razzaque, M.A., Huda, S., Hassan, M.M. (2025). Cross regional online food delivery: Service quality optimization and real-time order assignment, *Computers & Operations Research*, Vol. 173, Article No. 106877, doi: 10.1016/j.cor.2024.106877.
[15] Silva, K.O.A.N., Lima, R.S., Alves, R. (2024). The impacts of the pandemic on urban freight deliveries: A case study in a Brazilian carrier, *International Journal of Simulation Modelling*, Vol. 23, No. 1, 65-76, doi: 10.2507/IJSIMM23-1-672.
[16] Seghezzi, A., Mangiaracina, R. (2021). Investigating multi-parcel crowdsourcing logistics for B2C e-commerce last-mile deliveries, *International Journal of Logistics Research and Applications*, Vol. 25, No. 3, 260-277, doi: 10.1080/13675567.2021.1882411.
[17] Seghezzi, A., Mangiaracina, R., Tumino, A., Perego, A. (2021). 'Pony express' crowdsourcing logistics for last-mile delivery in B2C e-commerce: An economic analysis, *International Journal of Logistics Research and Applications*, Vol. 24, No. 5, 456-472, doi: 10.1080/13675567.2020.1766428.
[18] Errico, F., Desaulniers, G., Gendreau, M., Rei, W., Rousseau, L.M. (2016). A priori optimization with recourse for the vehicle routing problem with hard time windows and stochastic service times, *European Journal of Operational Research*, Vol. 249, No. 1, 55-66, doi: 10.1016/j.ejor.2015.07.027.
[19] Ghannadpour, S.F., Noori, S., Tavakkoli-Moghaddam, R., Ghoseiri, K. (2014). A multi-objective dynamic vehicle routing problem with fuzzy time windows: Model, solution and application, *Applied Soft Computing*, Vol. 14, 504-527, doi: 10.1016/j.asoc.2013.08.015.
[20] Wang, Y., Assogba, K., Liu, Y., Ma, X.L., Xu, M.Z., Wang, Y.H. (2018). Two-echelon location-routing optimization with time windows based on customer clustering, *Expert Systems with Applications*, Vol. 104, 244-260, doi: 10.1016/j.eswa.2018.03.018.
[21] Jiao, Z.H., Duan, H.W., Zhou, Y.J., Xiang, X. (2025). Low-carbon multimodal vehicle logistics route optimization with timetable limit using Particle Swarm Optimization, *Advances in Production Engineering & Management*, Vol. 20, No. 2, 173-190, doi: 10.14743/apem2025.2.534.
[22] Xiao, N., Lan, H. (2025). Two-echelon drone–truck collaborative TSP-based routing for humanitarian logistics with time windows and stochastic demand, *Advances in Production Engineering & Management*, Vol. 20, No. 3, 351-368, doi: 10.14743/apem2025.3.545.
[23] Mohammed, M.A., Abd Ghani, M.K., Hamed, R.I., Mostafa, S.A., Ahmad, M.S., Ibrahim, D.A. (2017). Solving vehicle routing problem by using improved genetic algorithm for optimal solution, *Journal of Computational Science*, Vol. 21, 255-262, doi: 10.1016/j.jocs.2017.04.003.
[24] Huang, W., Zhang, T. (2016). An improved genetic algorithm for vehicle routing problem with simultaneous pickups and deliveries and time windows, In: *Proceedings of 2016 35th Chinese Control Conference (CCC)*, Chengdu, China, 9639-9643, doi: 10.1109/ChiCC.2016.7554885.
[25] Zhang, D.F., Cai, S.F., Ye, F.R., Si, Y.-W., Nguyen, T.T. (2017). A hybrid algorithm for a vehicle routing problem with realistic constraints, *Information Sciences*, Vol. 394-395, 167-182, doi: 10.1016/j.ins.2017.02.028.
[26] Zhang, H.K., Zheng, Q.M., Yang, S., Ojsteršek, R. (2025). Bare-bones particle swarm optimization for emergency scheduling in public events, *International Journal of Simulation Modelling*, Vol. 24, No. 2, 273-284, doi: 10.2507/IJSIMM24-2-726.
[27] Li, Y., Liu, M., Hu, H., Jiang, X. (2025). A cost analysis of the collaborative delivery mode of drones and riders in food delivery scenarios, *International Journal of Logistics Research and Applications*, 1-30, doi: 10.1080/13675567.2025.2480636.
[28] Li, J., Li, J., Fang, H., Jiang, J. (2024). Dynamic energy-efficient path planning for electric vehicles using an enhanced Ant Colony Algorithm, *Tehnički Vjesnik – Technical Gazette*, Vol. 31, No. 2, 434-441, doi: 10.17559/TV-20230510000618.
[29] Zhang, Y., Chen, Y., Yu, P., Li, X., Wang, Y., Zhang, J., Pang, J. (2024). Optimization of multi-temperature joint distribution paths for convenience store chains, *Tehnički Vjesnik – Technical Gazette*, Vol. 31, No. 5, 1734-1746, doi: 10.17559/TV-20230812000875.

[30] Zhao, Y., Cattaruzza, D., Kang, N., Roberti, R. (2024). Synchronized deliveries with a bike and a self-driving robot, *Transportation Science*, Vol. 58, No. 1, 219-239, doi: 10.1287/trsc.2023.0169.
[31] Wang, W., Huang, Q. (2023). Research on urban end-delivery paths considering the consumer's delivery time demand, *Tehnički Vjesnik – Technical Gazette*, Vol. 30, No. 4, 1209-1216, doi: 10.17559/TV-20221212144331.
[32] Zhao, S., Li, P., Li, Q. (2024). The vehicle routing problem considering customers' multiple preferences in last-mile delivery, *Tehnički Vjesnik – Technical Gazette*, Vol. 31, No. 3, 734-743, doi: 10.17559/TV-20230717000807.
[33] Ji, X., Xu, W., Aslam, R., Yin , Y. (2024). The influence of government on automobile enterprise's production methods: An evolutionary game based study, *Economic Computation and Economic Cybernetics Studies and Research*, Vol. 58, No. 4, 223-240, doi: 10.24818/18423264/58.4.24.14.
[34] Ostermeier, M., Huf, T. (2026). The truck-and-robot routing problem with pickups and deliveries, *European Journal of Operational Research*, Vol 333, No. 1, 174-191, doi: 10.1016/j.ejor.2025.11.034.
[35] Han, Y., Song, T. (2024). Path planning for shop-floor material transfer robots incorporating particle swarm and ant colony algorithms, *Studies in Informatics and Control*, Vol. 33, No. 3, 49-59, doi: 10.24846/v33i3y202405.
[36] Păun, M.-A., Coandă, H.-G., Mincă, E., Iliescu, S.S., Duca, O.G., Stamatescu, G. (2024). Improved multi-objective genetic algorithm used to optimizing power consumption of an integrated system for flexible manufacturing, *Studies in Informatics and Control*, Vol. 33, No. 1, 27-36, doi: 10.24846/v33i1y202403.
[37] Zhang, X.R., Zhou, J.N. (2025). Simulation of AIGC-enhanced congestion management in factory autonomous driving, *International Journal of Simulation Modelling*, Vol. 24, No. 4, 718-729, doi: 10.2507/IJSIMM24-4-CO19.