Rural Logistic Facilities

Subjects: Transportation
Contributor: Qianli Zhang

Transport has long been considered a concern for rural residents around the world. Rural express logistics, one of the transport topics, is associated with rural residents' convenience as well as e-commerce development. As key nodes in the network, logistic centers need to be properly located to improve the delivery efficiency. In general, existing studies on rural logistics are mostly conducted qualitatively. Most studies focus on policy suggestions on the development of rural e-commerce, while geographic, economic, and population data are not exploited enough. Although some issues such as route design and rural e-commerce are getting attention, there are still very few studies on site selection of rural logistic centers. Much uncertainty still exists about balancing the coverage rates with the operational cost when evaluating the optimal locations for logistic centers in remote rural areas with low population density. Quantitative methods are urgently needed for solving the logistic center locating problem, especially in areas at the early stages of building a rural logistic network.

Keywords: logistics network design ; rural logistics ; Holt–Winters model

1. Introduction

Transport has long been considered a concern for rural residents around the world, under the topic of rural transport [1], rural mobility [2], rural accessibility [3], etc. Researchers have found that transport, especially public transport, strongly influences the economy and livability of a region. In the U.S., the American Public Transportation Association reported that transport services are seriously lacking in many rural areas, which is a key concern for rural residents' well-being [4]. In New Zealand, the Public Transport 2045 study was commissioned, finding that public transport services are important in any scenario, including rural transport, and will need to become more flexible, more frequent, and more responsive to travelers' needs [5]. In Cambodia, Lao's Republic, and the Philippines, transport needs of rural people are associated with basic needs such as water, food, and firewood, social welfare aspects of rural life such as health and education, and with economic aspects of rural life such as agriculture, livestock, and home industries [6].

Rural e-commerce turns out to be a new economic growth point in China. Rural online retail sales reached CNY 2.05 million in 2021, with an increase of 11.3% over the previous year, and is more than twice as much as that of 2016. The rapid growth of rural e-commerce is supported by an express network, which is promoted by the government as a kind of "new infrastructure". According to the government plan, the rural express service network should reach all administrative villages by 2025, and it is suggested that logistic centers are built in every town.

Although rural e-commerce has made great progress in China, the last-mile delivery has become an obstacle and bottleneck of rural ecommerce and economic development. One of the key problems in enhancing last-mile express delivery service in rural areas is how to properly place logistics centers, which carry out logistics activities (e.g., transportation, forwarding, distribution of goods, etc.). Compared with urban areas, the rural areas have a relatively low population scattered in a wide area, which significantly increases last-mile logistics costs. Most rural areas, especially in West China such as Tibet, suffer from great challenges in operating rural logistic centers. Some rural logistic centers used to charge extra high fees for delivery but stopped doing so under the pressure of superior local departments. As a result, most end-to-end logistic enterprises stop at counties or towns, providing no service for villagers. These problems lead to a low service level of last-mile delivery, as well as reduction in rural e-commerce users' enthusiasm.

2. Rural Logistics

Existing research on rural logistics mostly stays at the qualitative level, putting forward general suggestions and introducing new logistic modes. Brovarone and Cotella proposed a multitiered policy system, recommending demand responsive services [7]. Fu and Li proposed to guide rural residents to change their transaction patterns and consumption habits [8]. Jin called for the integration of joint distribution resources [9]. Wang and Chen emphasized the influence of resident factors on urban–rural distribution [10]. Li suggested that run-resistant vehicles should be used to improve service [11].

As for rural e-commerce logistics, Song suggested adopting the joint distribution mode, setting up rural e-commerce logistic centers [12]. Jin proposed to adopt the “X + 1” rural e-commerce business model [9]. Wang and Chen suggested the establishment of a rural logistics distribution alliance to build branches [10]. Xie and Zhou introduced an agreement between Chongqing government and Cainiao to build rural logistics network and to achieve coverage goals [13]. Joint distribution and crowdsourcing are recommended to improve service levels.

In recent years, researchers began to use the cost optimization model to study rural logistics and explore issues such as route design and distribution mode. Ren and Shi applied the milkrun model in urban–rural distribution route design [14]. Jiang established an optimization model to pursue the lowest total system cost (including customer time penalty cost) for joint distribution center locating and vehicle routing [15]. Liu designed three codistribution modes for distribution enterprises, recommending alliance operation mode, and gave a route calculation method for cargo mixed vehicles considering customer satisfaction [16]. Xiahou constructed a multiobjective and multicenter vehicle routing optimization model [17]. Wang and Zhou proposed an optimization strategy of multicenter joint distribution alliance based on vehicle sharing [18].

3. Facility Location Problems

Proper placement of rural logistic facilities plays an important role in improving distribution efficiency and lowering cost, which in general falls into the facility location problem. The facility location problem is a widely discussed topic in transportation and logistics [19][20] and involves the selection of specific locations of [21][22][23]: warehouses, distribution centers, transportation hubs, passenger and cargo terminals, etc.

The location problem is one of the classical problems in operational research and has been extensively studied in the literature [24]. Study of the location problem began in 1909, when Alfred Weber described a 1-median problem (the famous Weber problem) in Euclidean space in order to decide how to locate a single warehouse [25]. So far, three basic types of location problems have been put forward, including the P-median problem (PMP), P-center problem (PCP), and covering problem (CP).

(1)PMP is a “MinSum” problem, which aims to select P facilities from a given set to serve all demand points while minimizing the total weighted distance from demand points to their nearest facilities [26]. PMP is proven to be a NP-hard problem [27]. Both heuristic and optimal algorithms are provided [28]. PMP is still a research hotspot, with various extensions studied by modern researchers, including capacitated PMP [29], simplified PMP [30], and uncertain PMP [31].

(2)PCP is a “MinMax” problem, which aims to select P facilities from a given set to serve all demand points while minimizing the maximal distance from any demand point to its nearest facility [26]. PCP is proven a NP-hard problem as well, with heuristic and optimal algorithms provided [32].

(3)CP, including set covering problem (SCP) and maximal covering problem (MCP), introduces the constraint of service radius, which means a facility cannot serve a demand point beyond a given distance. First raised by Toregas, SCP is a “Min” problem, aiming to serve all demand points with as few facilities as possible [33]. MCP is a “Max” problem, aiming to serve as many demand points as possible with a given number of facilities, and was first proposed by Church and ReVelle [34]. The problem is further discussed by Daskin, Hogan, Berman, Krass, and many other researchers [35][36][37].

In recent years, the maximal covering problem (MCP) and maximal covering model (MCM) have been widely applied in describing and solving location problems. Yu proposed the capacitated reliable fixed-charge location problem and provided solving algorithms [24]. Tian used the flow capture location model to solve the charging pile point layout problem, which is essentially a flow-based maximal covering problem [38]. Li, Sylvia, and Xue also took advantage of MCM [11][39][40].

(4)In addition to the above methods, a number of other locating methods have emerged in recent studies, considering facility capacity, road capacity, dynamic decision process, competitive situation, and many other factors. Kulakova described a locating model based on geographic coordinates [41]. Muravev used the Dematel–Marica method and applied the multicriteria decision model to locate China Railway Express International Logistics Centers [42]. Stienen developed a single deterministic optimization model for locating disaster relief warehouses [43]. Rabe combined the system dynamics simulation model with the multicycle capacity-limited facility locating problem to locate automated parcel lockers [44].

References

1. George, B.; Henry, G.; John, R. Rural Transport: Improving Its Contribution to Growth and Poverty Reduction in Sub-Saharan Africa; Sub-Saharan Africa Transport Policy Program (SSATP) Working Paper no. 93; World Bank: Washington, DC, USA, 2012; Available online: https://openknowledge.worldbank.org/handle/10986/17807 (accessed on 1 May 2022).
2. Paul, S.; Simon, E.; John, H.; Anna, T. Improving Rural Mobility: Options for Developing Motorized and Nonmotorized Transport in Rural Areas; World Bank Technical Paper No. 525; World Bank: Washington, DC, USA, 2002; Available online: https://openknowledge.worldbank.org/handle/10986/15230 (accessed on 1 May 2022).
3. Peter, R.; Shyam, K.C.; Cordula, R. Rural Access Index: A Key Development Indicator; Transport Paper Series; No. TP-10; World Bank: Washington, DC, USA, 2006; Available online: https://openknowledge.worldbank.org/handle/10986/17414 (accessed on 1 May 2022).
4. American Public Transportation Association. Rural Communities Expanding Horizons: The Benefits of Public Transportation; American Public Transportation Association: Washington, DC, USA, 2012.
5. Enoch, M.P.; Cross, R.; Potter, N.; Davidson, C.; Taylor, S.; Brown, R.; Huang, H.; Parsons, J.; Tucker, S.; Wynne, E.; et al. Future local passenger transport system scenarios and implications for policy and practice. Transp. Policy 2020, 90, 52–67.
6. Donnges, C. Rural Transport and Local Government Units: How to Improve Rural Transport for the Rural Poor; Transport and Communications Bulletin for Asia and the Pacific, No.71; Economic and Social Commission for Asia and the Pacific: Bangkok, Thailand, 2001.
7. Vitale Brovarone, E.; Cotella, G. Improving rural accessibility: A multilayer approach. Sustainability 2022, 12, 2876.
8. Fu, H.; Li, H. Research on the Optimization of Rural Logistics Development in Henan Province. Int. J. Soc. Sci. Educ. Res. 2020, 3, 181–185.
9. Jin, E.T. Research on Innovation of Agricultural Products Circulation System under Digital Rural Strategy; Nanchang University: Nanchang, China, 2020.
10. Wang, M.; Chen, X. Analysis of influencing factors of urban and rural logistics distribution in Hainan province based on AHP. China Tequ Econ. 2020, 11, 81–86.
11. Li, X.; Ramshani, M.; Huang, Y. Cooperative maximal covering models for humanitarian relief chain management. Comput. Ind. Eng. 2018, 119, 301–308.
12. Song, G.; Zhao, Z.; Tian, C.; Yi, Y.; Song, T. Research on Joint Distribution of Rural Logistics. In IOP Conference Series: Materials Science and Engineering; IOP Publishing: Bristol, UK, 2019; Volume 631, p. 052003.
13. Xie, L.; Zhou, L. Regional differentiation of service quality of rural E-commerce logistics terminal distribution: A case study of four districts and counties in Chongqing. Logist. Technol. 2020, 39, 73–77.
14. Ren, X.; Shi, X. Research on Milk Run Model of Rural Logistics Based on “Internet +”; International Informatization and Engineering Associations: Qinhuangdao, China, 2019.
15. Jiang, L.J. Research on LRP Optimization of Urban and Rural Joint Distribution Network Based on Two-Way Logistics; Beijing Jiaotong University: Beijing, China, 2019.
16. Liu, Y.H. Study on the Join Distribution Mode Design and Vehicle Route Planning of Urban Trade Logistics; Chongqing Technology and Business University: Chongqing, China, 2020.
17. Xiahou, J. Study on Site Selection and Distribution Optimization of Joint Distribution Network at the End of E-Commerce Logistics; Beijing Jiaotong University: Beijing, China, 2020.
18. Wang, Y.; Zhou, X. Optimization of multi-center joint distribution alliance based on vehicle sharing. Comput. Integr. Manuf. Syst. 2021, 27, 1820–1832.
19. Chen, X. Study on Location Selection of Urban Distribution Center Using Multi-Level Inventory Management; Changsha University of Science and Technology: Changsha, China, 2007.
20. Özcan, O.; Reeves, K.A. The Impact of Sustainability-Focused Strategies on Sourcing Decisions. In Green Finance and Sustainability: Environmentally-Aware Business Models and Technologies 2011; IGI Global: Hershey, PA, USA, 2011; pp. 358–386.
21. Berman, O.; Drezner, Z. The multiple server location problem. J. Oper. Res. Soc. 2007, 58, 91–99.

22. Church, R.L.; Murray, A.T. Business Site Selection, location Analysis and GIS; John Wiley & Sons Incorporated: Hoboken, NJ, USA, 2009.

23. Farahani, R.Z.; Hekmatfar, M. (Eds.) Facility Location: Concepts, Models, Algorithms and Case Studies; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2009.

24. Yu, R. The Capacitated Reliable Fixed-Charge Location Problem: Model and Algorithm. Dissertations Thesis, Lehigh University, Bethlehem, PA, USA, 2015.

25. Weber, A. Theory of the Location of Industries; University of Chicago Press: Chicago, IL, USA, 1957.

26. Hakimi, S.L. P-median theorems for competitive location. Ann. Oper. Res. 1986, 6, 75–98.

27. Garey, M.R.; Johnson, D.S. Computers and Intractability: A Guide to NP-Completeness; W. H. Freeman: New York, NY, USA, 1979.

28. Rosing, K.E.; Hillsman, E.L.; Rosing-Vogelaar, H. A note comparing optimal and heuristic solutions to the p-median problem. Geogr. Anal. 2010, 11, 86–89.

29. Lorena, L.A.N.; Senne, E.L.F. Local search heuristics for capacitated p-median problems. Netw. Spat. Econ. 2003, 3, 407–441.

30. Church, R.L. Cobra: A new formulation of the classic p-median location problem. Ann. Oper. Res. 2003, 122, 103–120.

31. Berman, O.; Drezner, Z. The p-median problem under uncertainty. Eur. J. Oper. Res. 2008, 189, 19–30.

32. Levin, Y.; Ben-Israel, A. A Heuristic Method for Multifacility Location Problems. Comput. Oper. Res. 2004, 31, 257–272.

33. Toregas, C.; Revelle, C.; Bergman, L. The location of emergency services. Oper. Res. 1971, 19, 93–95.

34. Church, R.L.; Revelle, C. The Maximal Covering Location Problem. Pap. Reg. Sci. Assoc. 1974, 32, 101–118.

35. Daskin, M.S. A maximum expected covering location model: Formulation, properties and heuristic solution. Transp. Sci. 1983, 17, 48–70.

36. ReVelle, C.; Hogan, K. The maximum availability location problem. Transp. Sci. 1989, 23, 192–200.

37. Berman, O.; Krass, D. The generalized maximal covering location problem. Comput. Oper. Res. 2002, 29, 563–581.

38. Tian, S.; Hua, G.; Cheng, T.C.E. Optimal Deployment of Charging Piles for Electric Vehicles Under the Indirect Network Effects. Asia-Pac. J. Oper. Res. 2019, 36, 1950007.

39. He, S.; Kuo, Y.H.; Wu, D. Incorporating institutional and spatial factors in the selection of the optimal locations of public electric vehicle charging facilities: A case study of Beijing, China. Transp. Res. Part C 2016, 67, 131–148.

40. Xue, Y.; Wen, Z.; Ji, X.; Bressers, H.T.A.; Zhang, C. Location optimization of urban mining facilities with maximal covering model in GIS: A case of China. J. Ind. Ecol. 2017, 21, 913–923.

41. Kulakova, I.M.; Lebedeva, O.A.; Poltavskaya, J.O. Solving the problem of determining the optimal location of the logistics center, taking into account cost minimization. In IOP Conference Series: Materials Science and Engineering; IOP Publishing: Bristol, UK, 2020; Volume 971, p. 052009.

42. Muravev, D.; Hu, H.; Zhou, H.; Pamucar, D. Location optimization of CR express international logistics centers. Symmetry 2020, 12, 143.

43. Stienen, V.F.; Wagenaar, J.C.; den Hertog, D.; Fleuren, H.A. Optimal depot locations for humanitarian logistics service providers using robust optimization. Omega 2021, 104, 102494.

44. Rabe, M.; Gonzalez-Feliu, J.; Chicaiza-Vaca, J.; Tordecilla, R.D. Simulation-Optimization Approach for Multi-Period Facility Location Problems with Forecasted and Random Demands in a Last-Mile Logistics Application. Algorithms 2021, 14, 41.