Last-mile logistics optimization in the on-demand economy

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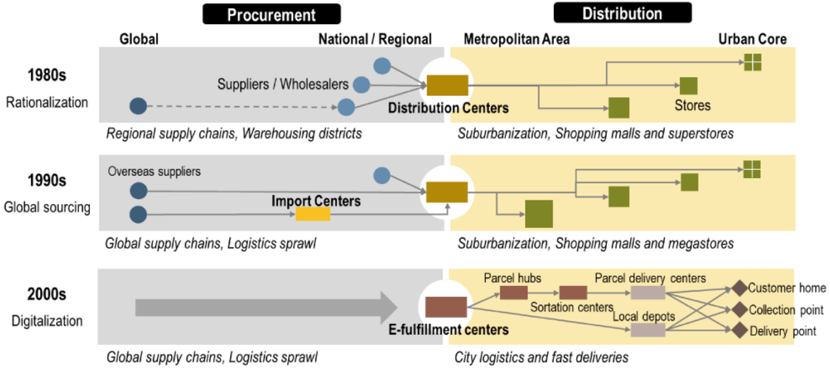
Outlines

1. Urban freight transportation and last-mile logistics
2. A managerial analysis of urban parcel delivery
3. On-demand parcel delivery in sharing economy
4. Time-dependent green vehicle routing problem with time windows
5. Conclusions

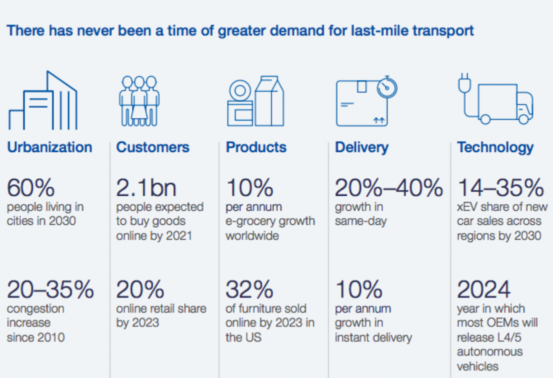
What is urban freight transportation?
Find appropriate strategies that can improve the overall efficiency of freight distribution in urban areas while mitigating congestion and environmental externalities.

The evolution of urban freight transportation



source:The Geography of Transport Systems FIFTH EDITION Jean-Paul Rodrigue (2020)

Last-mile logistics



source:Urban Logistics as a Service (ULaaS): the Next Frontier of Last Mile Logistics (2020)

State-of-the-art in last-mile delivery

Themes addressed in last-mile logistics research

Themes	Representative References	Count
Emerging trends and technologies		51
Goods reception solutions	Liu et al. (2019); Cardenas, I.D et al. (2017)	22
Innovative vehicle solutions	de Mello Bandeira et al.(2019)	15
Emerging business models	Perboli, G. et al. (2019); Devari, A.et al.(2017)	7
New perspectives on collaboration	Allen, J. et al. (2017)	7
Operational optimization		45
Routing	Zhou, L. et al.(2018); Stenger, A. et al. (2013)	23
Transport planning	Florio, A.M. et al. (2018)	12
Scheduling	Boysen, N. et al. (2018)	6
Facility location	Zhou, L. et al.(2019)	4
Supply chain structures		35
Logistics and supply chain design	Weber, A.N. et al. (2018); Faccio, M. et al. (2015)	15
Urban freight terminals	Marujo, L.G. et al. (2018)	9
Urban planning	Allen, J. et al. (2018)	5
Urban freight structures	Ewedairo, K. et al. (2018)	3
Networks design	Wygonik, E. et al. (2018)	3
Performance measurement		22
Environmental performance	Brown, J.R. et al. (2014)	9
Customer focused performance	Carlsson, J.G. et al. (2016)	9
Economic performance	Seebauer, S. et al. (2016)	4
Policy	Aljohani, K. et al. (2018)	2
Total		155

State-of-the-art in last-mile delivery

Methodologies used in last mile logistics research

Methodology	Representative References	Count
Modeling and simulation		73
Modeliing	Breunig, U. et al. (2019); Boysen, N. et al. (2018)	59
Simulation	Fikar, C. (2018); Perboli, G. and Rosano, M.(2019)	14
Case studies and interviews		39
Case Study	Allen, J. et al. (2018); Malik, L. et al. (2017)	36
Interviews	Hübner, A. et al. (2016)	3
Surveys		13
	Wang, X. et al. (2018); Otter, C. et al. (2017)	
Theoretical and conceptual papers		12
	Butrina, P. et al. (2017); Cardenas, I. et al. (2017)	
Total		137

Critical issues in the application of city logistics

- Dynamic and uncertain setting
- Large scale problems with uncertainty
- Short-time horizons for decision-making process

Contribution of this thesis

- Demonstrate the potential value of integrating business and operational models in city logistics
- Investigate last mile optimization of supply chain, considering the integration of crowdsourced delivery and multiple delivery options in urban parcel delivery with large scale and uncertainty settings
- Investigate the possibility to reduce carbon emissions in parcel delivery application

A managerial analysis of urban parcel delivery*

- Environmental impact
  congestion, noise, climate change and air pollution
- Non-motorized transport tools
  bikes and cargo bikes
- New delivery options
  lockers and postal box
- Collaborative business models
  crowdsourced delivery and Third-party delivery

*: Brotcorne, L., Perboli, G., Rosano, M., **Wei, Q**. (2019). A managerial analysis of urban parcel delivery: A lean business approach. Sustainability, 11(12), 3439.(JCR Q2)

Managerial and strategic analysis for urban parcel delivery

- Business models, cost and revenue structures, and policies
- Traditional vehicles and green carriers
- A Lean Business methodology: GUEST*

*Osterwalder, Alexander, and Yves Pigneur. Business model generation: a handbook for visionaries, game changers, and challengers. Vol. 1. John Wiley Sons, 2010.
*Perboli G. The GUEST methodology[J]. 2017.

Methodology-GUEST

- Go: data, stakeholders' profiles
- Uniform: standard form, value proposition
- Evaluate: cost and revenue structures, assessment and comparison
- Solve: managerial analyses, simulation-optimisation tool
- Test: monte carlo simulation, design policies

Cost and Revenue Analysis of multiple Delivery system

Estimate the Operating Costs per Kilometre (OCK) related to each type of vehicle

$$OCK = (FC + VC)/TK = ((v + tx + i + p) + (f + t + mr))/TK$$

where:

- FC is the total annual fixed costs;
- VC is the total annual variable costs;
- TK is the total annual traveled kilometres.

The components of fixed and variable costs

- Purchase cost of vehicle (v)
- Vehicle taxes (tx)
- Insurance (i)
- Personnel costs (p)
- Vehicle fuelling (f)
- Tyres costs (t)
- Maintenance and repair costs (mr)

Cost and Revenue Analysis of multiple Delivery system

Environmental Costs Analysis

- the carbon footprint of the last-mile deliveries, as the total direct and indirect greenhouses gas emitted by logistics activities
- social costs paid by the courier due to its environmental impact

Cost and Revenue Analysis of multiple Delivery system

Cost analysis results

Costs	Tariffs Carbon Tax [€/tons]	Fossil Fuel Vehicle	Diesel Fuel Vehicle	Electric Vehicle	Bike
TCK [€/km]					
Annual kilometre cost		2.70	2.68	2.66	1.50
Environmental costs [€]					
Direct CO_2 Emissions [tons]		4.15	3.38		
Indirect CO_2 Emissions [tons]		4.15	3.38		
Equivalent CO_2 Emissions [tons]		8.46	5.52		
Total Emissions [tons]		16.76	12.28		
Carbon Tax [€]	17.00	284.92	208.63		
	30.00	502.80	368.18		
	90.00	1508.40	1104.53		
	150.00	2514.00	1840.88		
Electric Battery Emissions [tons]				3.08	
Carbon Tax [€]	17.00			52.31	
	30.00			92.31	
	90.00			276.94	
	150.00			461.56	
Direct CO_2 Emissions [tons]					0.00

On-demand parcel delivery in sharing economy*

Why the last-mile delivery is so important?

- most time-consuming and expensive element in the shipping process
- boost customer loyalty and benefit overall business operations
- help businesses make their last-mile delivery more profitable

*Perboli, G., Rosano , M., **Wei, Q** (2021). A Simulation Optimization Approach for the Management of the On Demand Parcel Delivery in Sharing Economy. IEEE Transactions on Intelligent Transportation Systems.

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Difference between traditional and on-demand parcel delivery

Traditional parcel delivery

- deterministic
- offline decision
- low efficiency

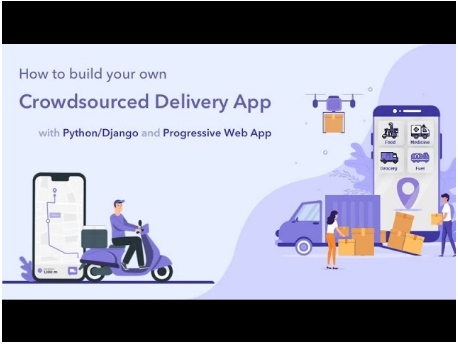
On-demand parcel delivery

- dynamic and stochastic
- online or real-time decision
- same-day or two-hour delivery

Crowdsourced delivery

Crowdsourced delivery

- non-professional couriers
- tech-heavy and asset-light
- flexibility



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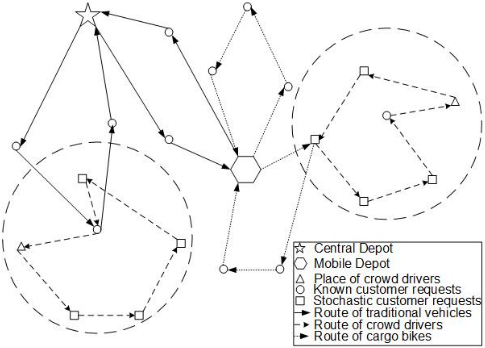
Problem statement

Stochastic and dynamic vehicle routing problem

- multiple couriers (van, bike, crowd-driver)
- stochastic and dynamic orders
- constraints (time windows, capacity, synchromodality)



Mathematical formulation and objective function

$$min \ E_{\tilde{\xi}} \left[\sum_{i \in N} \sum_{j \in N} \sum_{k \in K} c_{ijk} \, x_{ijk} + Q(x, p, s, \tilde{\xi}) \right]$$

$$Q(x, p, s, \tilde{\xi}) = \sum_{i \in N'} \sum_{j \in N'} \sum_{k \in K} c_{ijk} \left(x_{ijk}^{+} - x_{ijk}^{-} \right) + H_i \sum_{i \in C'} \sum_{v \in V} y_{iv} + P \sum_{j \in C'} p_j$$

Minimizes the expected value of total travel costs

- cost for adjusting the routing
- reward for crowd drivers
- a penalty paid for the customer rejection

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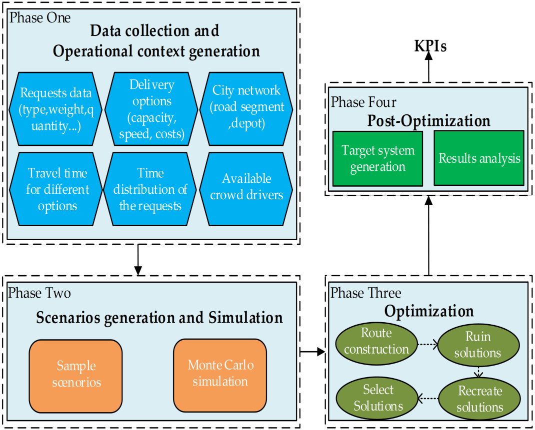
Simulation-optimization framework

Monte Carlo Simulation

- sample scenarios
- statistical analysis

Variable Neighborhood Search

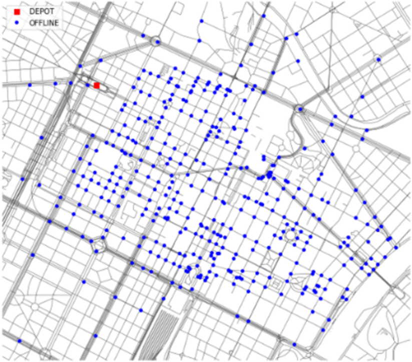
- ruin operator
- recreate operator



Case study and experiment settings

A real case study related to urban logistics in Turin (Italy)

- source data given by an international delivery company
- road information provided by the local public authority
- travel time is calculated by using Google Earth application programming interfaces (APIs)



City network in the case study

Case study and experiment settings

Problem size and degree of dynamism

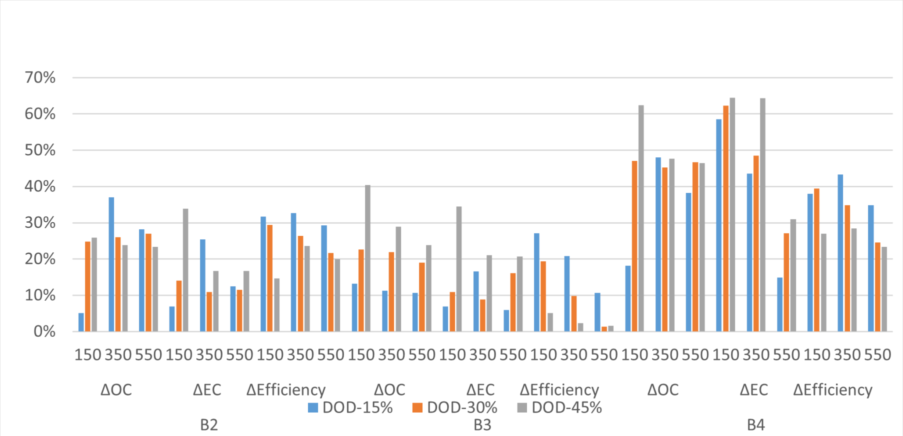
- 360 instances in total
- 150, 350 and 550 customers
- DOD-15%, DOD-30% and DOD-45%

Four Benchmarks

- B1: only van
- B2: van and cargo bike
- B3: van and crowd driver
- B4: all delivery options

Delivery Options	Maximum parcel size(kg)	Capacity	Coverage (km)	Speed (km/h)	Service time(min)		
					Mailers	small parcels	large parcels
Van	70	700kg	NA	40	4	4	5
Cargo Bike	15	70kg	NA	20	2	2	—
Crowd Driver	6	4 Parcels	2	15	2	—	—

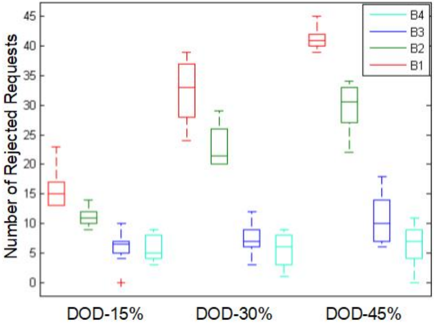
Performance comparison of different benchmarks



Analyze the impact of crowd drivers for on-demand parcel delivery

Green carriers and crowd drivers are promising delivery options

- stable low rejection in B4
- dynamism has no influence on B3 and B4



Summary

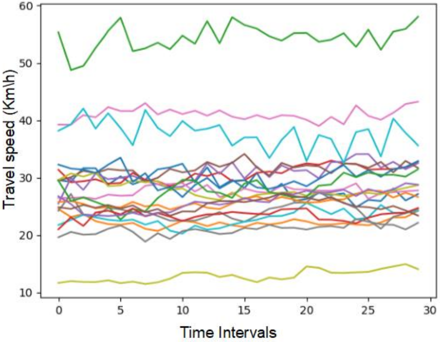
- Multiple delivery options are considered into this problem together with crowd drivers
- A new simulation-optimization framework, enabling decision-makers to combine different sources of data, conduct simulation and optimization
- Combining crowd drivers and green carriers into traditional van delivery is beneficial to economic and environmental cost-saving

Last-mile logistics optimization in the on-demand economy

Time-dependent green vehicle routing with time windows*

What is Time-dependent travel time?

- the travel times (speeds) on a road link are different in different time periods



*Working paper: **Qu Wei** , Feng Guo, Mariangela Rosano, Zhaoxia Guo*, Perboli Guido. A branch and price algorithm for time dependent green vehicle routing problem.

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Time-dependent green vehicle routing with time windows

Why time-dependent travel time is important?

- improve the accuracy of candidate solution evaluations
- generate reliable final routing solutions

Difference between previous study and our work

Previous TDVRPs

- consider less than 10 time periods
- rare to use real road network

Our Work

- 30 time periods using real travel speed
- real road network with up to 4641 road segments and 1502 nodes

Problem description

Objective and features

- determine a set of routes for a fleet of vehicles to serve a given set of customers
- large-scale urban road networks
- frequently changing travel speeds in real road networks

Set partitioning model

$$\text{Min} \sum_{r\in\Omega} f_r y_r$$

subject to

$$\sum_{r\in\Omega} \Upsilon_i^r y_r = 1, \qquad \forall i \in C$$

$$y_r \in \{0,1\}, \qquad \forall i \in C$$

- minimize the total fuel consumption
- constraints

Reduced cost of the route

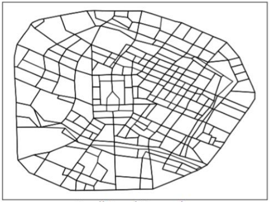
$$\bar{f_r} = f_r - \sum_{r\in\Omega} \Upsilon_i^r \pi_i, \qquad \forall i \in C$$

- dual variables
- negative reduced cost routes
- column generation process is terminated

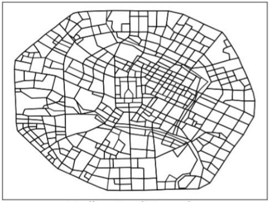
Real road network

Information of three different road network

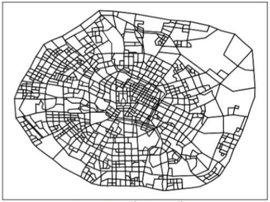
Road network	# Road segments	# Nodes
Small	1250	408
Medium	2233	835
Large	4641	1502



Small Road Network



Medium Road Network

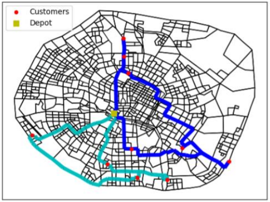


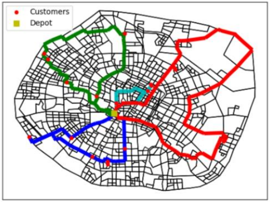
Large Road Network

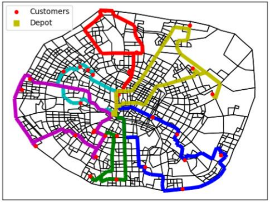
Example of solutions

Detailed solution of a problem instance

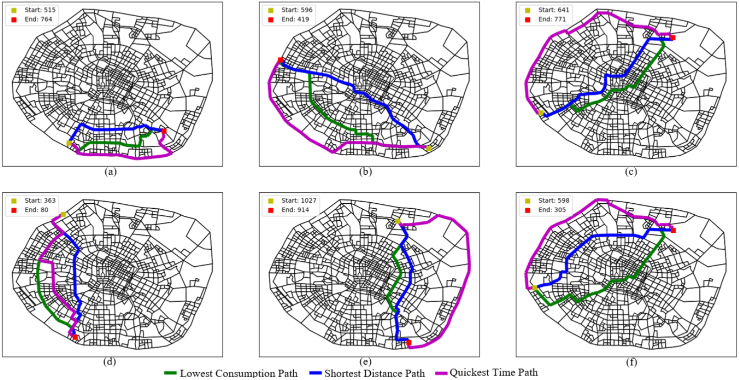
Vehicle Routes	Distance (km)	Fuel (Liter)	CO_2 Emissions (kg)	Travel Times (min)
0-13-17-3-18-0	9.48	0.56	1.47	21.5
0-5-10-16-1-9-20-0	21.43	1.16	3.08	43.8
0-2-14-6-19-12-0	25.66	1.51	4.00	57.9
0-8-15-11-4-7-0	40.09	2.14	5.67	79.1
Total	96.65	5.37	14.23	202.3







Detailed paths for three different path selections in large road network



Time consumption and gap of solving different instances

Problem Size	Road Network	CPU Time(s)			Gap(%)		
		Minimum	Maximum	Average	Minimum	Maximum	Average
10 customers	Small	0.3	1.2	0.6	0.0	0.0	0.0
	Medium	0.5	7.5	2.2	0.0	0.0	0.0
	Large	1.5	20.5	5.5	0.0	0.0	0.0
20 customers	Small	12.7	375.8	96.9	0.0	0.0	0.0
	Medium	31.6	382.4	110.6	0.0	0.0	0.0
	Large	44.2	677.8	196.4	0.0	0.0	0.0
30 customers	Small	55.3	3198.3	991.2	0.0	0.0	0.0
	Medium	85.5	5845.1	1613.7	0.0	0.0	0.0
	Large	179.0	18000.0	5158.1	0.0	0.0	0.0
40 customers	Small	772.6	18000.0	14051.3	0.0	6.9	1.6
	Medium	5098.8	18000.0	16483.2	0.0	6.6	2.5
	Large	7582.8	18000.0	16398.2	0.0	7.7	2.5

Summary

- the proposed branch and price algorithm is efficient to solve the problem up to 40 customers in the large road network with 1502 nodes and 4641 road segments
- considering time-dependent VRPs is beneficial for carrier companies in terms of fuel consumption and travel time saving

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Conclusions

- We identified the main actors involved in the City Logistics system from both business and operational perspectives and explicitly investigated these actors' behaviors, costs, and revenues structures.
- We addressed a DSVRPTW problem with crowdsourcing for on-demand parcel delivery.
- We conducted a case study in the medium-sized city of Turin (Italy) to measure the potential impact of using cargo bikes, crowdsourcing in parcel delivery.
- We investigated a time-dependent green vehicle routing problem based on real-time travel speeds in the road network of Chengdu, a megacity in western China.

List of publications

[1] Perboli, G., Rosano, M., **Wei, Q***. (2021). A Simulation-Optimization Approach for the Management of the On-Demand Parcel Delivery in Sharing Economy. IEEE Transactions on Intelligent Transportation Systems.(JCR Q1)
[2] **Wei, Q.**, Guo, Z., Lau, H. C., He, Z. (2019). An artificial bee colony-based hybrid approach for waste collection problem with midway disposal pattern. Applied Soft Computing, 76, 629-637.(JCR Q1)
[3] Zhang, Z., Guo, C., **Wei, Q.**, Guo, Z., Gao, L. (2021). A bi-objective stochastic order planning problem in make-to-order multi-site textile manufacturing. Computers Industrial Engineering, 158, 107367.(JCR Q1)
[4] He J, Ma X, **Wei Q**. Firm-level short selling and the local COVID-19 pandemic: Evidence from China[J].Economic Modelling, 2022: 105896.(JCR Q1)
[5] Brotcorne, L., Perboli, G., Rosano, M., **Wei, Q.** (2019). A managerial analysis of urban parcel delivery: A lean business approach. Sustainability, 11(12), 3439.(JCR Q2)
[6] Crainic, T. G., Perboli, G., Rosano, M., **Wei, Q.** (2019). Transportation for smart cities: a systematic review. Montreal, Canada: CIRRELT. Technical report

Working paper

[1] **Wei, Q.**, Guo, F., Rosano, M. Guo, Z.*, Perboli G. A branch and price algorithm for time dependent green vehicle routing problem. Plan to submit to Computers & Operations Research.
[2] Guo, F., **Wei, Q.**, Wang, M., Guo, Z.*. Deep Dynamic Attention Model with Gate Mechanism for Solving Time-dependent Vehicle Routing Problems. Under reviewed in INFORMS journal on computing.(UTD 24)

PhD activities

- Training activities: 115 hours hard skill and 42 hours soft skill courses
- Four virtual conferences: City Logistics 2019; ODS 2020; IFORS 2021; CSIE2022.
- 5 JCR Q1 papers and 1 JCR Q2 paper
- Best paper award in CSIE2022

Thanks for your attention!