Online-Innovatorentreffen zum Thema „Intelligent Mobility“

A dial-a-ride problem integrating public transport for autonomous driving

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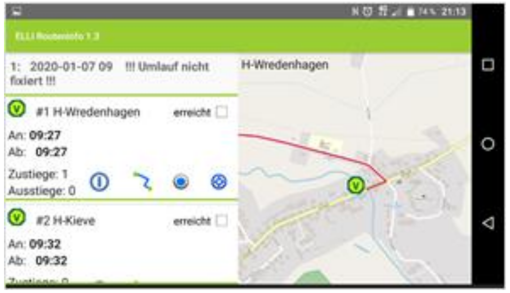
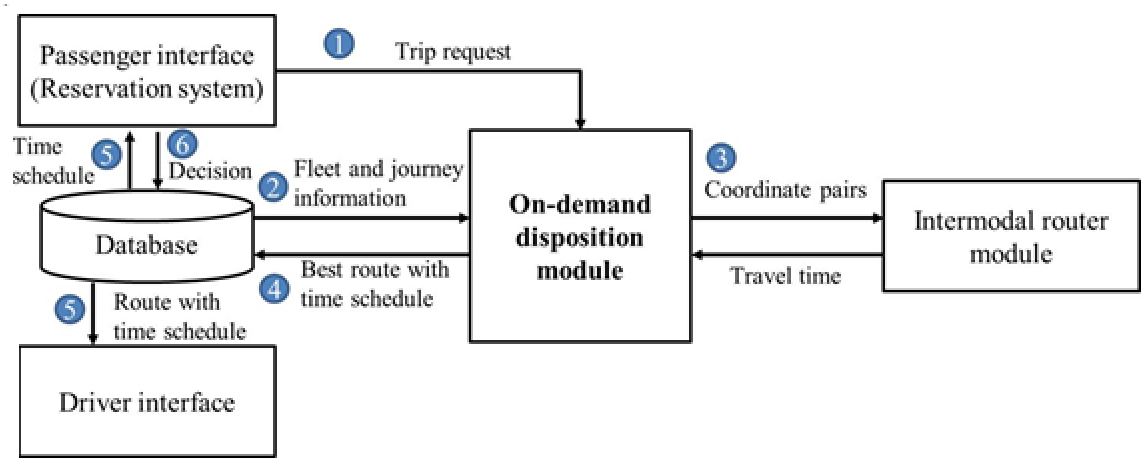
On-demand transportation system

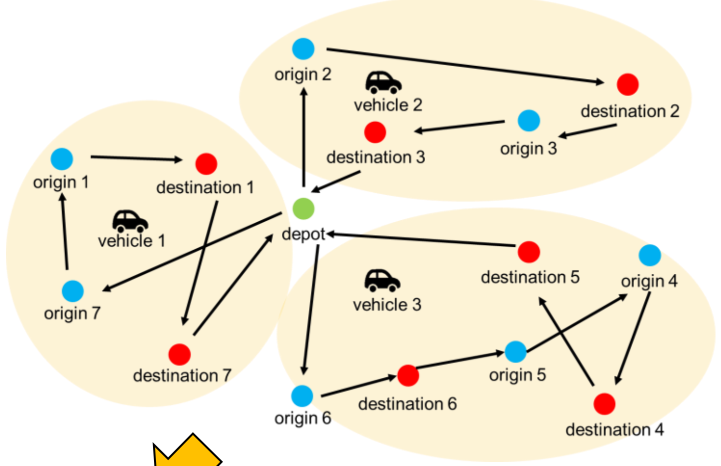
- Passengers send customized trip requests to the on-demand transportation system
- The system should provide vehicles with a suitable route while meeting passenger preferences
- Applied area:
    - in rural areas due to low frequent public transport
    - In urban areas to solve the last-mile problem
    - Especially good for elder people and the disables

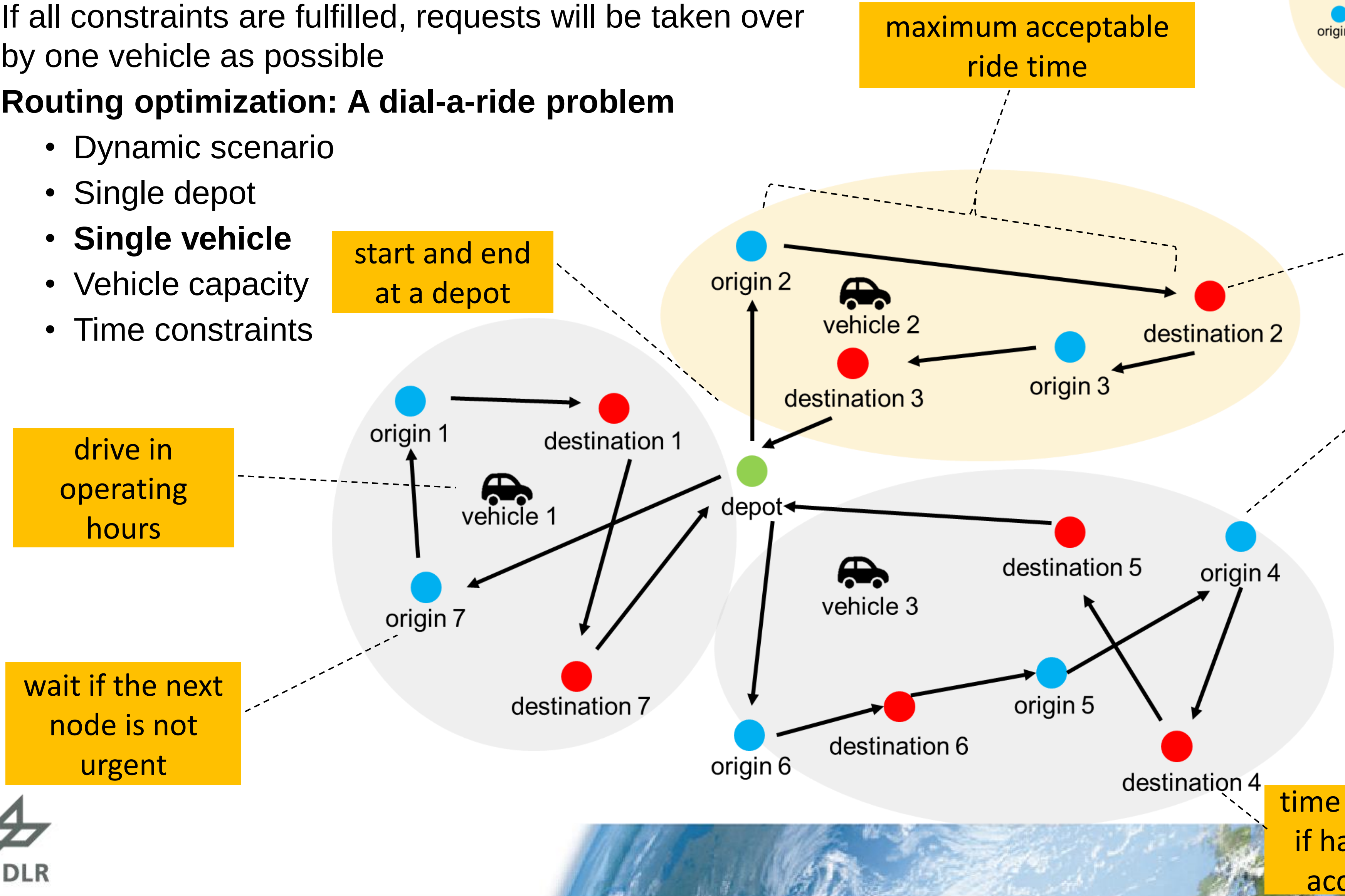


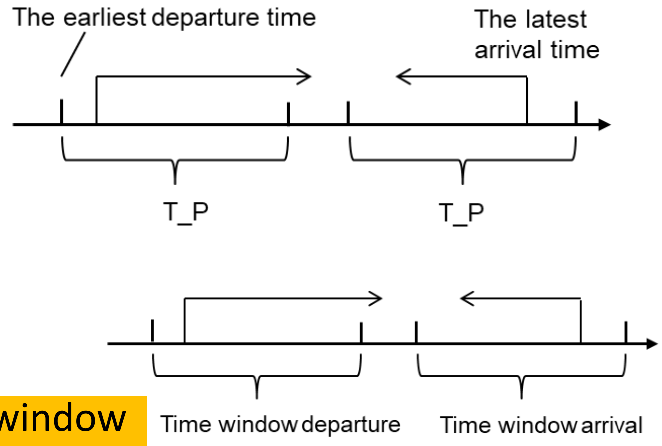


Problem statement

- If all constraints are fulfilled, requests will be taken over by one vehicle as possible
- **Routing optimization: A dial-a-ride problem**
  - Dynamic scenario
  - Single depot
  - **Single vehicle**
  - Vehicle capacity
  - Time constraints







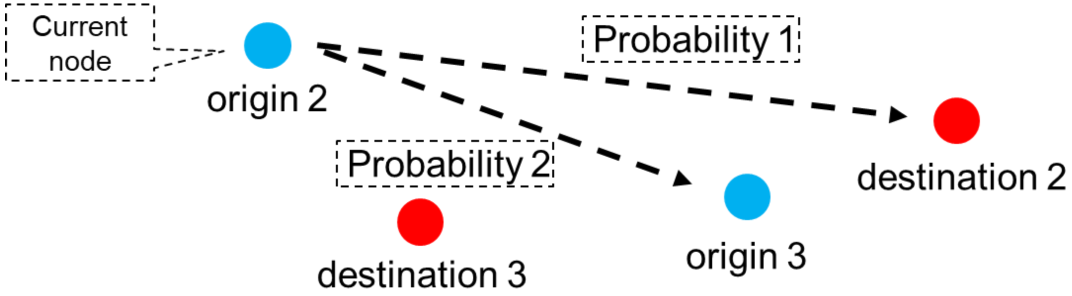
Routing optimization – ant colony optimization with penalties (ACOP)

- Objective function of the ant colony algorithm: total travel time + service time + **penalty**

1. *State transition rule*

   Calculate the selection probabilities of **node candidates**

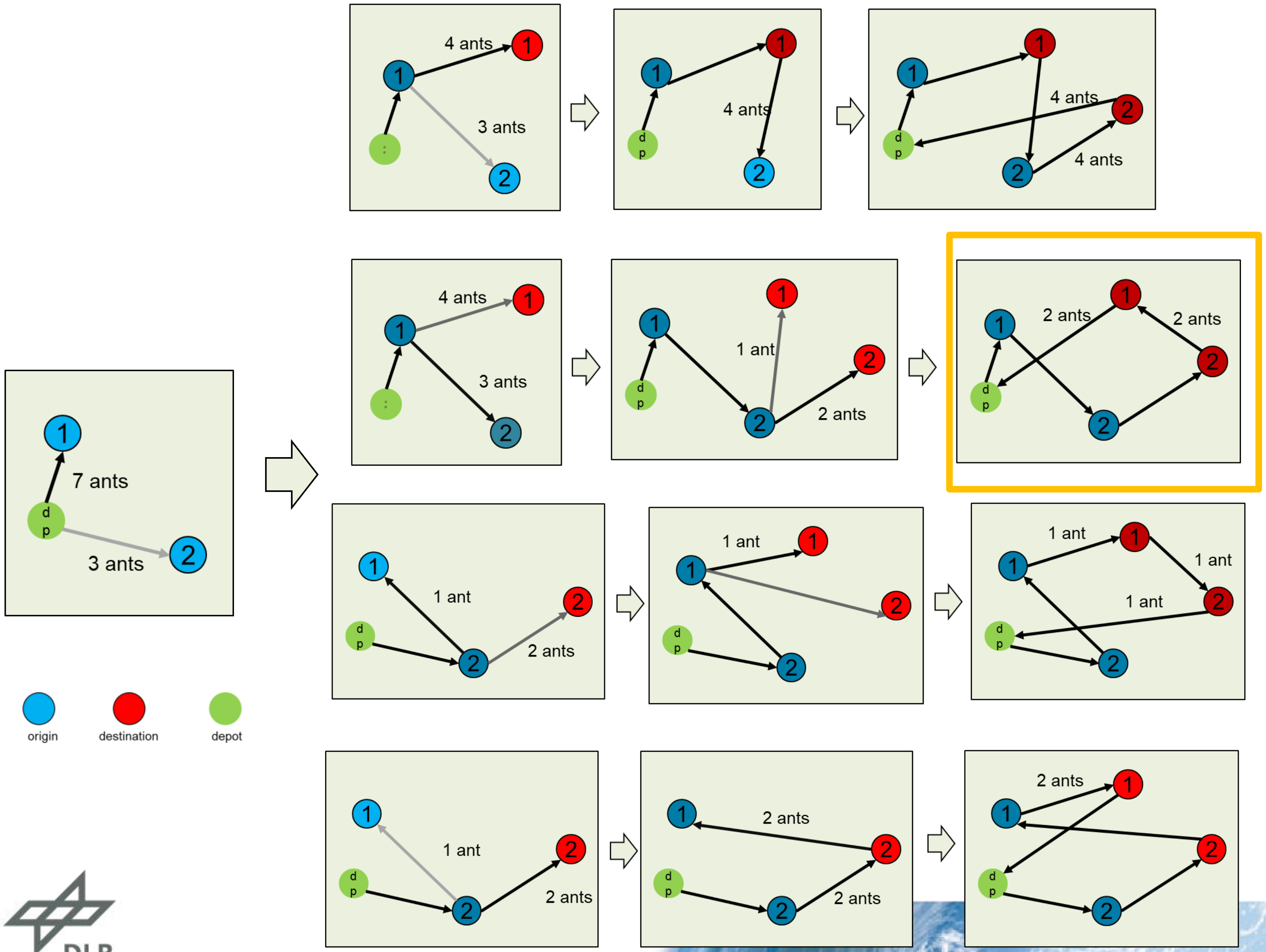
   The selection probability is the function of **travel cost (= travel time +service time + penalty) + weight of pheromone**



2. *Local updating rule*
3. *Global updating rule*

Enhancing the pheromone of best next node and best route

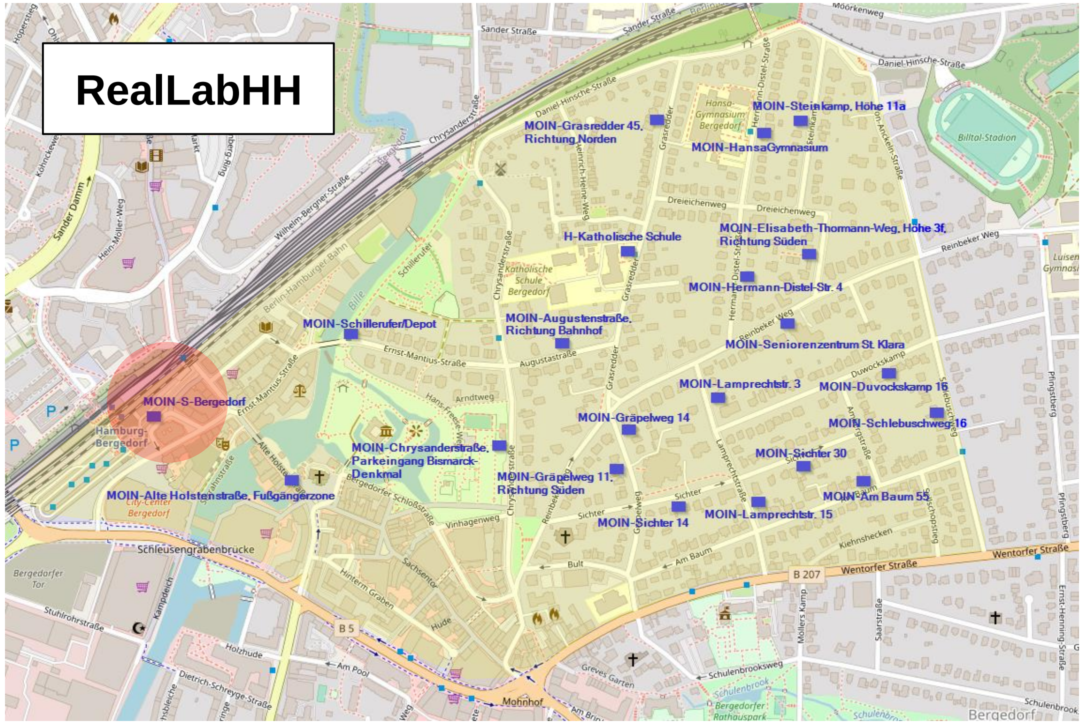
Routing optimization – ant colony optimization with penalties (ACOP)



- Stop combination if they have space similarity and temporal overlapping
- Special cases in reality:
  - Multiple origins link to one destination
    - A -> B
    - C -> B
    - D -> B
  - A stop is both an origin and a destination
    - A -> B
    - B -> C
  - Origin and destination are reversed
    - A -> B
    - B -> A (= A')

Experimental study: Hamburg, Germany

- Project “RealLabHH” funded by Federal Ministry of Transport and Digital Infrastructure
- Single depot at S-bahnhof Bergedorf
- Pre-defined 20 stops
- To observe how requests are accepted



Parameters	Values
Vehicle capacity	6 seats
Max ride time	5 times
Start of operation	07:00:00
End of operation	20:00:00
Time window departure	10 mins
Time window arrival	10 mins
Max time variation at planned stop	20 mins
Service time at each stop	2 mins
Max waiting time at each stop	180 mins

Plan	Number of passengers	Origin	Destination	Earliest Departure time	Latest arrival time
1	1	Hansa-Gymnasium	S-Bergedorf	09:00:00	
	2	S-Bergedorf	Gräpelweg 14		12:00:00
2	2	Grasredder 45	Seniorenzentrum St. Klara	09:00:00	
	2	Lamprechtstr. 3	Seniorenzentrum St. Klara	09:10:00	
3	2	Sichter 30	Katholische Schule	14:00:00	
	2	Augustenst. 4	Am Baum 55	14:30:00	
	3	Augustenst. 4	Steinkamp 11a		14:20:00

Results: Hamburg, Germany

Plan	Number of passengers	Origin	Destination	Earliest Departure time	Latest arrival time
1	1	Hansa-Gymnasium	S-Bergedorf	09:00:00	
	2	S-Bergedorf	Gräpelweg 14		12:00:00
2	2	Grasredder 45	Seniorenzentrum St. Klara	09:00:00	
	2	Lamprechtstr. 3	Seniorenzentrum St. Klara	09:10:00	
3	2	Sichter 30	Katholische Schule	14:00:00	
	2	Augustenst. 4	Am Baum 55	14:30:00	
	3	Augustenst. 4	Steinkamp 11a		14:20:00

- The time schedule works as expected.

Plan	Vehicle	Stop	Arrival time	Departure time	Waiting time (s)	Pickup (passengers)	Delivery (passengers)
1	1	Depot	08:56:13	08:56:13	0s	0	0
		Hansa-Gymnasium	08:58:00	**09:00:00**	0	2	0
		S-Bergedorf	09:02:36	11:55:57	10281	0	2
		S-Bergedorf	11:55:57	11:55:57	0	1	0
		Gräpelweg 14	**12:00:00**	12:02:00	0	0	1
		Depot	12:02:58	12:02:58	0	0	0
2	1	Depot	08:56:32	08:56:32	0	0	0
		Grasredder 45	08:58:00	**09:06:50**	410	2	0
		Lamprechtstr. 3	09:08:00	**09:10:00**	0	2	0
		Seniorenzentrum	09:10:26	09:12:26	0	0	4
		Depot	09:14:13	09:14:13	0	0	0
3	1	Depot	13:55:41	13:55:41	0	0	0
		Sichter 30	13:58:00	**14:00:00**	0	2	0
		Katholische Schule	14:02:11	14:15:50	699	0	2
		Augustenst. 4	14:16:23	14:18:23	0	3	0
		Steinkamp 11a	**14:20:00**	14:26:17	257	0	3
		Augustenst. 4	14:28:00	**14:30:00**	0	2	0
		Am Baum 55	14:32:29	14:34:29	0	0	2
		Depot	14:37:40	14:37:40	0	0	0

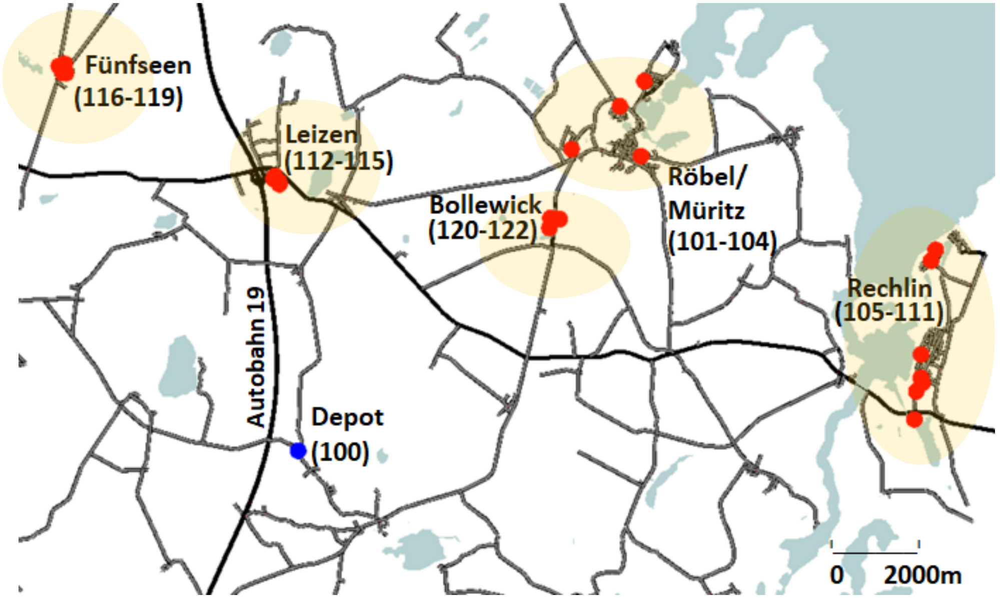
A -> B
B -> C
No stop combination

A -> C
B -> C
Stop combination

A -> B
A -> C
No stop combination

Experimental study: Elde region, Germany

- Project “HubChain” funded by Federal Ministry for Economic Affairs and Energy, Germany
- Single-depot
- 22 nodes (in red) are randomly generated in this road network
- Travel times between nodes are calculated with SUMO
- 10 requests are randomly generated from all these 22 nodes
- To compare with optimal results



Parameters	Values
Vehicle capacity	10 seats
Max ride time	4 times
Start of operation	07:00:00
End of operation	11:30:00
Time window departure	30 mins
Time window arrival	30 mins
Max time variation at planned stop	30 mins
Service time at each stop	1 mins
Max waiting time at each stop	180 mins

N°.	Number of passengers	Start node	End node	Earliest departure	Latest arrival
1	2	109	106	07:30:00	
2	2	102	113	08:00:00	
3	2	115	105		11:00:00
4	2	111	121	09:00:00	
5	1	112	103		09:30:00
6	2	114	117		11:00:00
7	1	120	116		08:00:00
8	1	119	108	07:40:00	
9	2	110	118		10:00:00
10	1	104	107	10:20:00	

Results: Elde region, Germany

- The same 10 requests are also simulated in SUMO, but using an exact algorithm [1]
- The routes found by the proposed ACOP-algorithm match the optimal results. Only in two steps, the proposed algorithm shows worse results but with a difference of only 5 seconds.

Request No.	Vehicle No.	Total travel time (s) by ACOP	Waiting time (s)	Optimal travel time (s)
1	1	2242	0	2242
2	1	3311	0	3311
3	1	4620	7251	4620
4	1	7119	4752	7119
5	1	7119	4752	7119
	2	1619	0	1619
6	1	7119	4752	7119
	2	2837	2576	2837
7	1	7119	4752	7119
	2	4289	7009	4289
8	1	7119	4752	7119
	2	6062	5902	6062
9	1	7119	4752	7119
	2	**7096**	4202	**7091**
10	1	7741	4469	7741
	2	**7096**	4202	**7091**

[1] M. G. Armellini, “Optimierung der buslinie 450 in braunschweig durchon-demand-zubringer,” Master’s thesis, Fachhochschule Munster, 2019.

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Results – Computing efficiency

- Running in a laptop with Intel(R) Core(TM) i7-HQ CPU 2.70GHz and 16.0 Gb memory
- As the problem size increases, the computing time increases
- Results can be found in acceptable time for real-world application

Scenario No.	Number of nodes (vehicle 1)	Number of nodes (vehicle 2)	Computing time (ms)
1	2	0	391
2	4	0	440
3	6	0	604
4	8	0	692
5	10	2	859
6	10	4	967
7	10	6	1093
8	10	8	1437
9	10	10	1405
10	12	12	1406

Conclusions

- An ant colony algorithm with penalties was proposed to solve a dynamic DARP with time windows and capacity constraints
- The algorithm can handle special cases in reality
- The proposed ACOP algorithm was able to find almost the same routes as the optimal ones with acceptable computing time

- Limitations and further work
  - In some cases, passengers have to wait a long time inside the vehicle for the next passenger to be picked up
  - Fleet management
  - To be evaluated in scenarios with more complex networks and higher demand