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Agent-based Modelling and Simulation of Tour Planning in Urban Freight Traffic

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1. Introduction

Freight traffic has grown in the last years and decades, and it is expected to grow further (see Schmiele et al. 2011; Stiegeler 2012). Especially in major cities, increasing levels of online-trade cause a shift toward smaller individual deliveries directly to the consumer (see Cerwenka et al. 2007). Supplying their own shops is of existential importance for classic retail groups. The creation of good or optimal tours is complicated significantly in areas with many destinations. Therefore, the aspect of tour planning is becoming more important for freight carriers. They strive to offer the highest possible service quality while at the same time keeping costs as low as possible (see Ehmke 2012).

2. Vehicle Routing Problem (VRP)

The decisions regarding optimal vehicle routing made by transport companies depend on various factors. Internal restrictions influencing the carrier(s) can include the location of depot(s) and the available vehicle fleet at the depot(s). Each vehicle type has its own properties, e.g. capacity, fixed and variable costs, fuel consumption and, depending on

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this, the CO2-emissions per distance travelled (see jsprit 2018). Additionally, environmentally-motivated measures to increase the quality of life are being discussed in society and politics (see SenUVK 2018).

External restrictions and specifications offer a framework in which carrier(s) have to operate. Customer demand (quantity, type and location to bring goods) is one very important specification for generating tours; e.g. time windows for delivery are one kind of restriction given by customers (see jsprit 2018). For our purposes we simply call this demand a “service”. Further constraints such as driving restrictions and tolls exist due to politics, either directly or indirectly because of court decisions. These constraints can be valid for certain areas, selected vehicle types, e.g. large trucks or vehicles with diesel engines, and/or certain times (see Cerwenka et al. 2007).

The (expected) traffic situation has a direct impact on travel times. These lead to an important indirect impact on the optimal organization of the tours regarding both interdependent main subproblems of vehicle routing problems (VRP) (see Prockl 2010; Scheuerer 2004):

- Assigning services to tours (clustering).
- Determining the optimal order and directions in which the services are served within a tour (routing).

As a consequence, congestion can decrease service quality and can increase the costs of delivery for the carrier(s). Nevertheless, congestion is usually not considered in urban tour planning (see Ehmke 2012).

For more information about different types for vehicle routing problems, see e.g. Scheuerer (2004) or jsprit (2013).

3. Agent-based freight traffic simulation

Freight traffic in agent-based traffic simulations is often simulated similar to usual passenger traffic, with fixed plans. The individual agents are the drivers. They typically can only optimize their own route between the various destinations. An adjustment of the sequence within the tour is rarely performed, and moving pickups or deliveries from one agent/vehicle to another is not possible (see Zilske/Joubert 2016).

3.1. MATSim & jsprit

Jsprit is a freely available open source toolkit for solving VRPs. It is a well-integrated but separate tool from the existing MATSim project. With this integration, tour planning takes place separately from the traffic simulation in upstream processes (see Zilske et al. 2012).

3.2. New functionality: Additional Hubs between Depot and Customer

Jsprit can solve VRPs with one or more depots and a large number of pickups or deliveries. Jsprit, however, cannot add one or more additional hub(s) between the depots and the customers – often called Urban Consolidation Centers (UCC) in the urban context. For modeling such supply chains, the present investigation creates a new carrier. Fig. 1 shows how the supply chains change by adding a UCC.

When the assignment of customers to a UCC is fixed, then from the perspective of the original depots a UCC is simply an additional customer; the UCC just has to solve its own tour planning problem. Thus UCC(s) are represented by a new carrier agent. A new UCC supplies the demand given by the assigned customers. For the case that a UCC-Carrier operates more than one UCC, the upper level assignment does not know which service is executed from which UCC until the VRP for the UCC-Carrier is solved. Therefore, it is necessary to solve the VRP for the UCC-Carrier(s) first. After that it is clear what quantity of goods needs to be transported from the main depot(s) to each UCC-Depot. This demand can be simply added as service for the existing carrier. After this, the VRP for the non-UCC carrier can be solved.

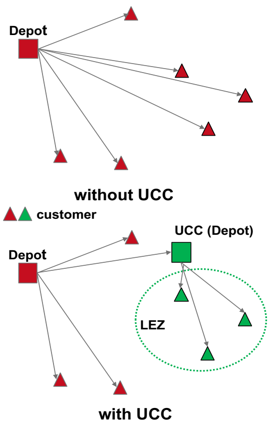

Fig. 1 Transport chain without and with an Urban Consolidation Centre (UCC) between depot and customer.

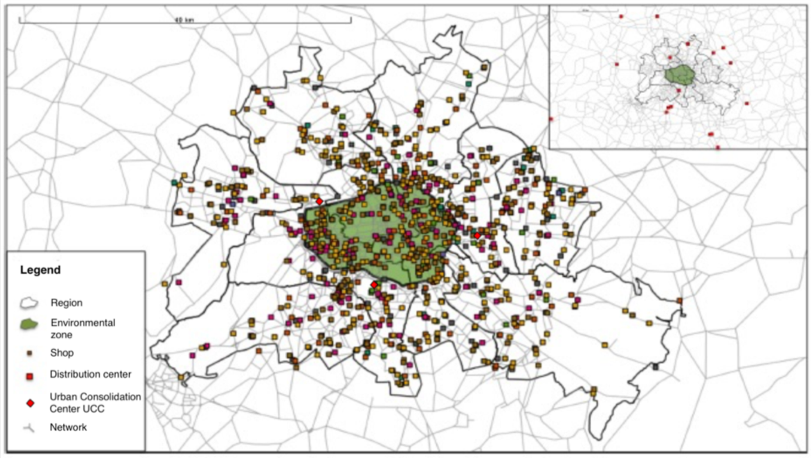

Fig. 2 Berlin food retailing scenario (Schröder/Liedtke, 2014) with location of the Urban Consolidation Centers (UCC)

4. Case: Berlin-Scenario

The Berlin Scenario (see Fig. 2) is based on the real-world scenario of food retailers in the city of Berlin by Schröder/Liedtke (2014). It is a freight traffic simulation scenario for urban food distribution in Berlin. “This case study picks up the concept of distribution centers and models the ‘last mile’ in food retailer's transport chains” (Schröder/Liedtke 2014). The goods are transported from 17 distribution centers (depots) located outside the urban area to 1,040 shops located inside. Each of the eleven retailers employs its own depots and vehicle fleet (see Schröder/Liedtke 2014).

Several scenarios are investigated, which in part reinvestigate and deepen the results by Schröder and Liedtke (2014), and in part go beyond. Policy measures are implemented using the existing environmental zone of Berlin (LEZ) which essentially contains the inner city (see Fig. 2). The investigated policy measures with respect to that zone include:

- **(A1) Cordon toll** (20 €) for heavy diesel trucks (26t or 40t)
- **(A2) Cordon toll** (20 €) for heavy diesel trucks, e-trucks available at depots
- **(B) Prohibition of diesel** trucks inside the LEZ, e-trucks available at depots
- **(C) Prohibition of diesel** trucks inside the LEZ, e-trucks available at depots, and **UCC** inserted to supply the shops within the LEZ with e-trucks. Therefore, three UCCs were generated around and nearby the environmental zone (see Fig. 2).

This scenario assumes carbon-free energy generation. The available vehicle types can be found in

.

5. Results and limitations

5.1. Results

The tool jsprit solves the VRP of freight transportation well. Congestion can be included in the VRP by using time-dependent networks. Tolls are also handled by jsprit. Tours generated by jsprit can be directly used as input for the traffic simulation with MATSim. It is possible to simulate the freight vehicle agents together with other agents, e.g. cars.

Urban Consolidation Centers (UCC) as additional hubs were successfully implemented as explained above. As stated, the transport chain and therefore the VRP from the depot to the customer gets divided into two parts: supplying the UCC, and delivering to the customer from the UCC. The UCC usage is successfully applied to a food retailing case study in the Berlin area.

Table 1: Overview of the capabilities of the available vehicle types (Schröder/Liedtke, 2014)

vehicle type	Electric vehicle	capacity [units]	Cost rates [€]			Diesel consumption [l/km]	CO_2-emissions [kg/km]
			fix	per km	per hour		
heavy40t	no	33	140	0.86		35	0.917
heavy26t	no	24	130	0.77		30	0.786
medium18t	no	16	107	0.61		25	0.655
light8t	no	10	80	0.47		20	0.524
heavy26t_frozen	no	160	130	0.77	28.8	30	0.786
light8t_frozen	no	70	89	0.47		20	0.524
medium18telectro	yes	16	112	0.55		0	0
light8telectro	yes	10	89	0.5		0	0
light8telectro_frozen	yes	70	89	0.5		0	0

The results for the policy measures compared to the base case are as follows (see Fig. 4 and Fig. 3):

- Cordon toll for heavy diesel trucks increases costs, distance and therefore diesel consumption and CO2 emissions (A1)
- Cordon toll with introducing small and medium e-trucks decreases diesel consumption and CO2 emissions by 8% (A2)
- Prohibition of diesel trucks within the LEZ increases the distance driven; decrease of diesel consumption and CO2 emissions by 11% (B)
- Number of employed vehicles increases significantly when using UCCs, due to the need of reloading; reduction of diesel consumption and CO2 emissions by 7% (C)

5.2. Limitations

The services (customer demand) are strictly bound to one carrier. There is no instance or intelligence which can move services from one carrier to another, or organize which carrier would be the best one to execute a service. As a consequence, decisions like using UCC for a service vs. transporting directly, or moving a service from one UCC to another, are not part of the optimization. The assumptions regarding the strict assignment of customers which will be delivered directly from the depot or via UCC have a high impact. Future development will include agent-based organizer(s) of the transport chain, called Logistic Service Providers (LSP). It is expected that the overall distance in scenario (C) will decrease from this.

Vehicles drive one tour and return to the depot. As a result, there are many more vehicles, each having fixed costs, on the road than needed if trucks were to drive several tours. Using vehicles for more than one tour is planned for the future. This should in particular reduce the number of necessary vehicles and thus the costs, while the overall distance is expected to remain similar.

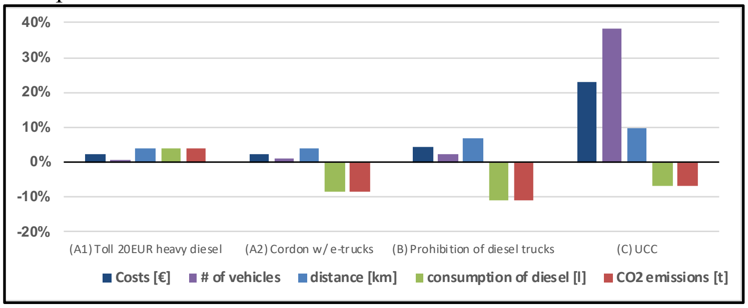

Fig. 4 Relative changes compared to the base scenario.

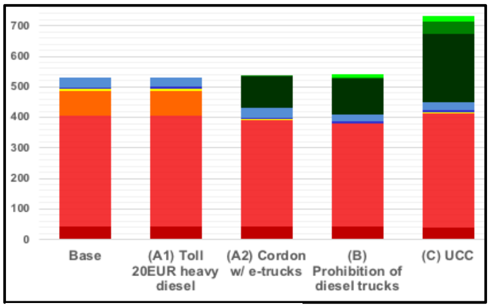

Fig. 3 Number of vehicles used.

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