A decision support system for coordinated disaster relief distribution

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Sections

- Section 1-Introduction
- Section 2-Overview of related work
- Section 3-Description of problem and corresponding mathematical formulation
- Section 4-Developed DSS is introduced
- Section 5-Computational experiments
- Section 6-Conclusion

1. Introduction

- Availability of transportation infrastructure.
- Demand uncertainty
- Unmanned aerial vehicles(UAVs).

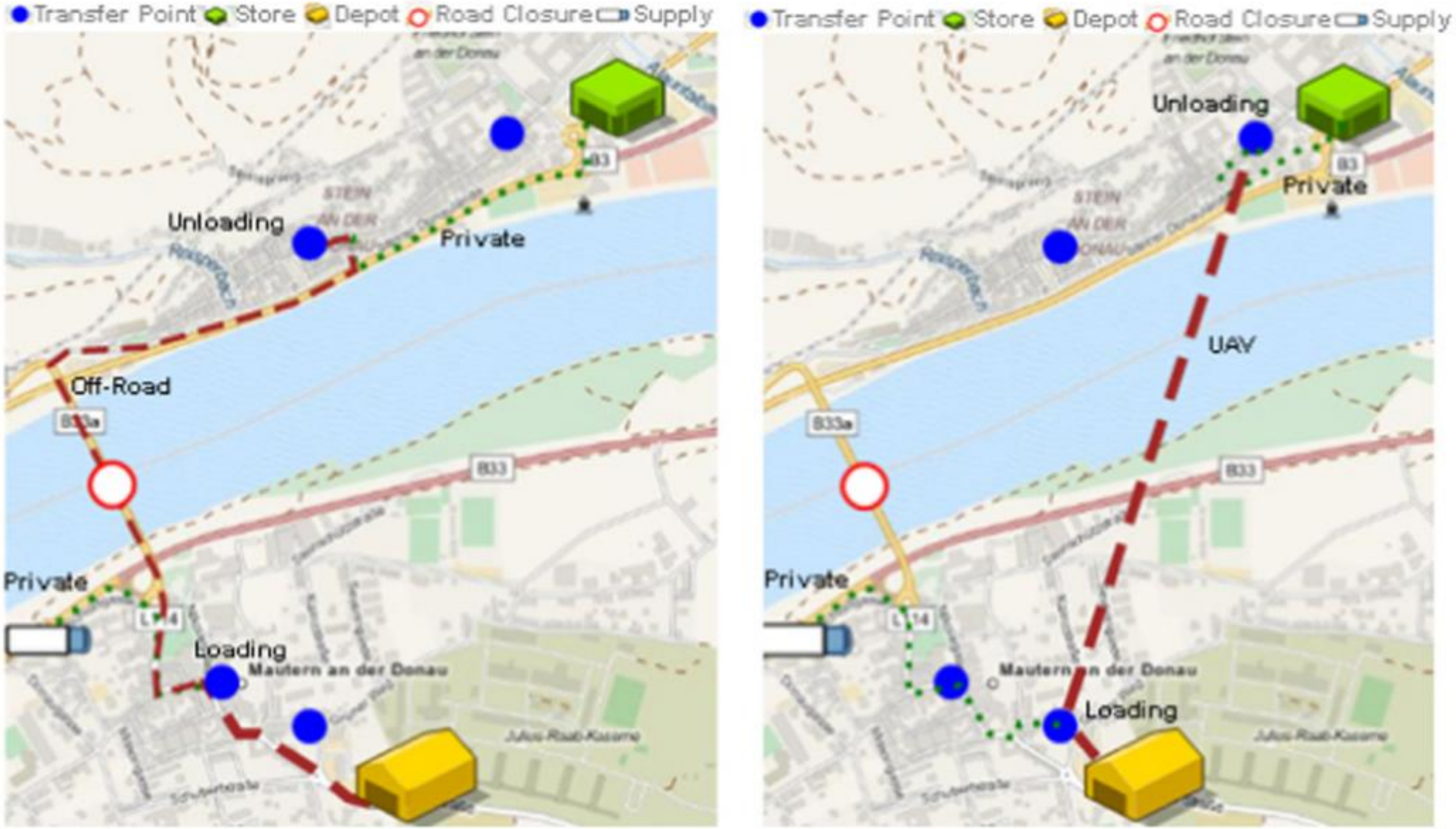


Fig. 1. Shipment coordination with off-road vehicles (left) and UAVs (right).

2. Related Work

- Optimization of facility locations
- Coordinate shipments

3. Problem Description

Assumptions:

- Each vehicle is indicated by a traveling speed and the duration required for loading and unloading.
- Full truckloads are assumed.
- A direct delivery by relief forces to a demand point is not allowed
- Our aim is to minimize average lead time and we do not take the demand in the locations into consideration. Our aim is just to decrease the time between a request is occurred and the goods are delivered.

Constants

M	sufficiently large number (set to latest possible departure time)
K	number of vehicles
F	number of transfer point candidates
R	number of shipment requests
V	number of vehicle depots
$\mathcal{K} = \{1, \ldots, K\}$	set of vehicles
$\mathcal{F} = \{1, \ldots, F\}$	set of transfer points
$\mathcal{R} = \{1, \ldots, R\}$	set of shipment requests
$\mathcal{R}_0 = \{0, \ldots, R+1\}$	set of shipment requests including start (0) and end depot (R+1)
s_l	l (request); start time of l
c_{ijk}	i,j (location), k (vehicle); duration from i to j on k
q_k	k (vehicle); (un)loading time of k for each request
N	max. number of operated transfer points
Z_k	k (vehicle); home depot of k
P_l	l (request); supply point of l

Decision Variables:

1. $f_i = 1$ if a transfer point is operated at location i
   $f_i = 0$ otherwise

2. $x_{ijlk} = 1$ if for request l, transfer points at i and j and vehicle k is used
   $x_{ijlk} = 0$ otherwise

3. $y_{lmk} = 1$ if k performs m after l (m and l are requests)

4. z_{lmk} auxiliary variable for time from l to m on vehicle k

5. u_l departure time of request l at supply or transfer point

6. e_l arrival time of request l at demand time

Mixed Integer Programming Model

$$\text{minimize: } \frac{1}{R}\sum_{l\in\mathcal{R}}(e_l - s_l) \qquad (1)$$

subject to:

$$e_l = u_l + c_{P_lD_l0}\Big(1 - \sum_{i,j\in\mathcal{F}}\sum_{k\in\mathcal{K}} x_{ijlk}\Big)$$

$$+ \sum_{i,j\in\mathcal{F}}\sum_{k\in\mathcal{K}}(c_{jD_l0} + c_{ijk} + q_k)x_{ijlk} \qquad \forall l\in\mathcal{R} \qquad (2)$$

$$u_l \geq s_l + \sum_{i,j\in\mathcal{F}}\sum_{k\in\mathcal{K}}(c_{P_li0} + q_k)x_{ijlk} \qquad \forall l\in\mathcal{R} \qquad (3)$$

$$\sum_{i\in\mathcal{F}} f_i \leq N \qquad (4)$$

$$\sum_{j\in\mathcal{F}}\sum_{l\in\mathcal{R}}\sum_{k\in\mathcal{K}}(x_{ijlk}+x_{jilk})\le 2Rf_i \qquad \forall i\in\mathcal{F} \tag{5}$$

$$\sum_{i,j\in\mathcal{F}}\sum_{k\in\mathcal{K}}x_{ijlk}\le 1 \qquad \forall l\in\mathcal{R} \tag{6}$$

$$\sum_{m\in\mathcal{R}_0\setminus\{R+1\}} y_{mlk}=\sum_{i,j\in\mathcal{F}}x_{ijlk} \qquad \forall l\in\mathcal{R}, k\in\mathcal{K} \tag{7}$$

$$u_l+\sum_{i,j\in\mathcal{F}}c_{ijk}x_{ijlk}+2q_k+z_{lmk} \le u_m+(1-y_{lmk})M \qquad \forall l,m\in\mathcal{R}, k\in\mathcal{K} \tag{8}$$

$$\sum_{m\in\mathcal{R}_0}(y_{lmk}-y_{mlk})=0 \qquad \forall k\in\mathcal{K}, l\in\mathcal{R} \tag{9}$$

$$z_{lmk}\le \max_{i,j\in\mathcal{F}} c_{ijk}y_{lmk} \qquad \forall l,m\in\mathcal{R}, k\in\mathcal{K} \tag{10}$$

$$z_{lmk}\ge c_{jhk}y_{lmk}-c_{jhk}\Big(2-\sum_{i\in\mathcal{F}}x_{ijlk}-\sum_{g\in\mathcal{F}}x_{hgmk}\Big) \qquad \forall j,h\in\mathcal{F}, k\in\mathcal{K} \quad \forall l,m\in\mathcal{R} \tag{11}$$

$$c_{Z_k P_l k} + y_k \leq u_l + (1 - y_{0lk})M \qquad \forall l \in \mathcal{R}, k \in \mathcal{K} \qquad (12)$$

$$\sum_{m \in \mathcal{R}_0 \setminus \{0\}} y_{0mk} = 1 \qquad \forall k \in \mathcal{K} \qquad (13)$$

$$\sum_{l \in \mathcal{R}_0} y_{l0k} = 0 \qquad \forall k \in \mathcal{K} \qquad (14)$$

$$\sum_{l \in \mathcal{R}_0 \setminus \{R+1\}} y_{l(R+1)k} = 1 \qquad \forall k \in \mathcal{K} \qquad (15)$$

$$\sum_{m \in \mathcal{R}_0} y_{(R+1)mk} = 0 \qquad \forall k \in \mathcal{K} \qquad (16)$$

$$x_{ijl} \in \{0, 1\} \qquad \forall i, j \in \mathcal{F}, l \in \mathcal{R} \qquad (17)$$

$$s_i \in \{0, 1\} \qquad \forall i \in \mathcal{F} \qquad (18)$$

$$y_{lmk} \in \{0, 1\} \qquad \forall l, m \in \mathcal{R}, k \in \mathcal{K} \qquad (19)$$

4.Decision Support System

1. Agent based simulation
2. Route selection and improvement
3. Optimization of facility locations
4. User Interface

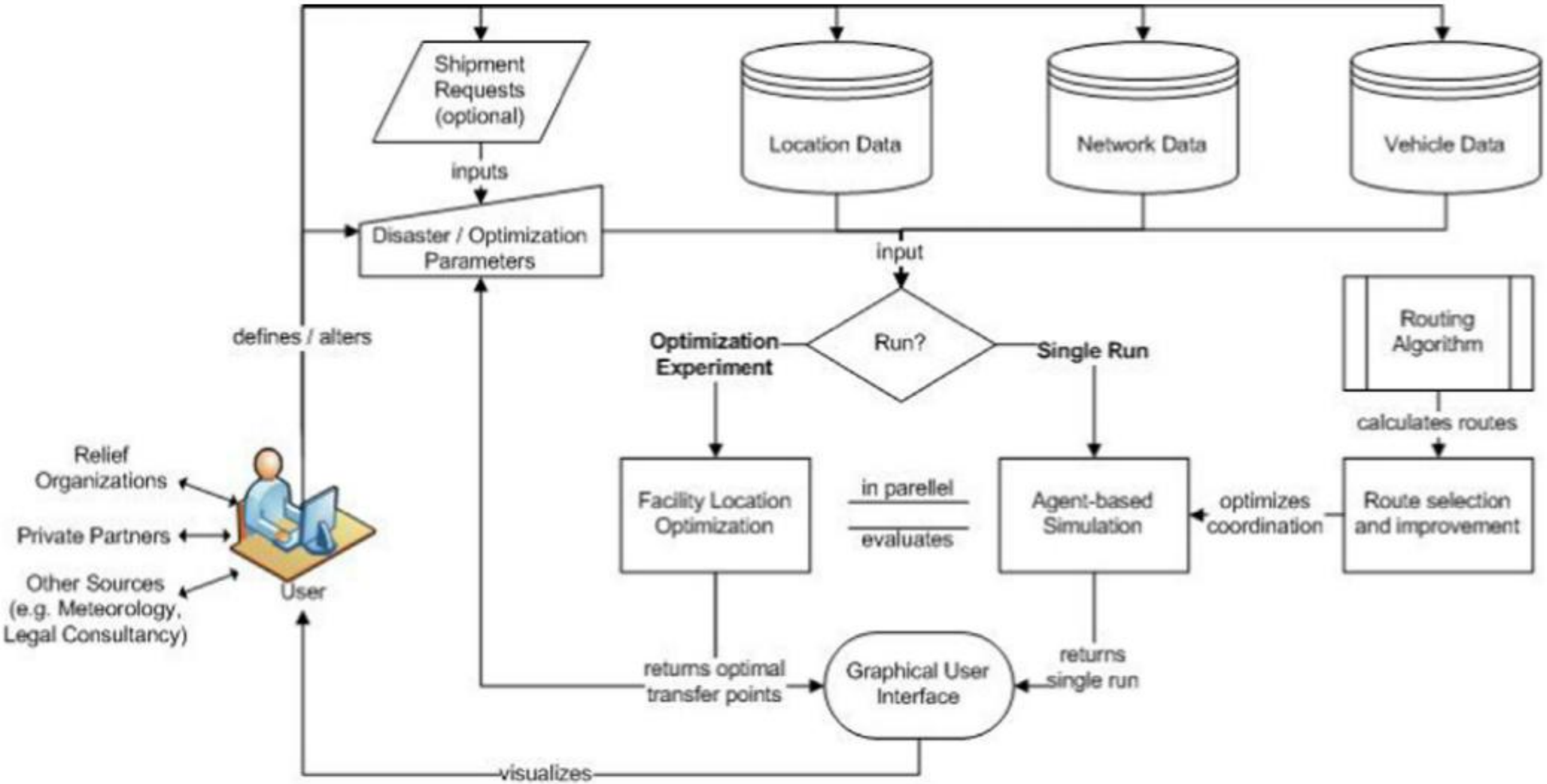


Fig. 2. A DSS for coordinated disaster relief distribution.

Assumptions

- If a demand point is not reached due to closed roads, all requests delivered to the nearest accessible request point.
- Private trucks travel with a speed which changes based on road condition and relief trucks travel at an average speed regardless of road condition.
- In case of an event which causes a vehicle to be unavailable, the vehicle completes its trip and will not be used until the conditions are available.
- Relief vehicles return to depot if no other demand is planned.

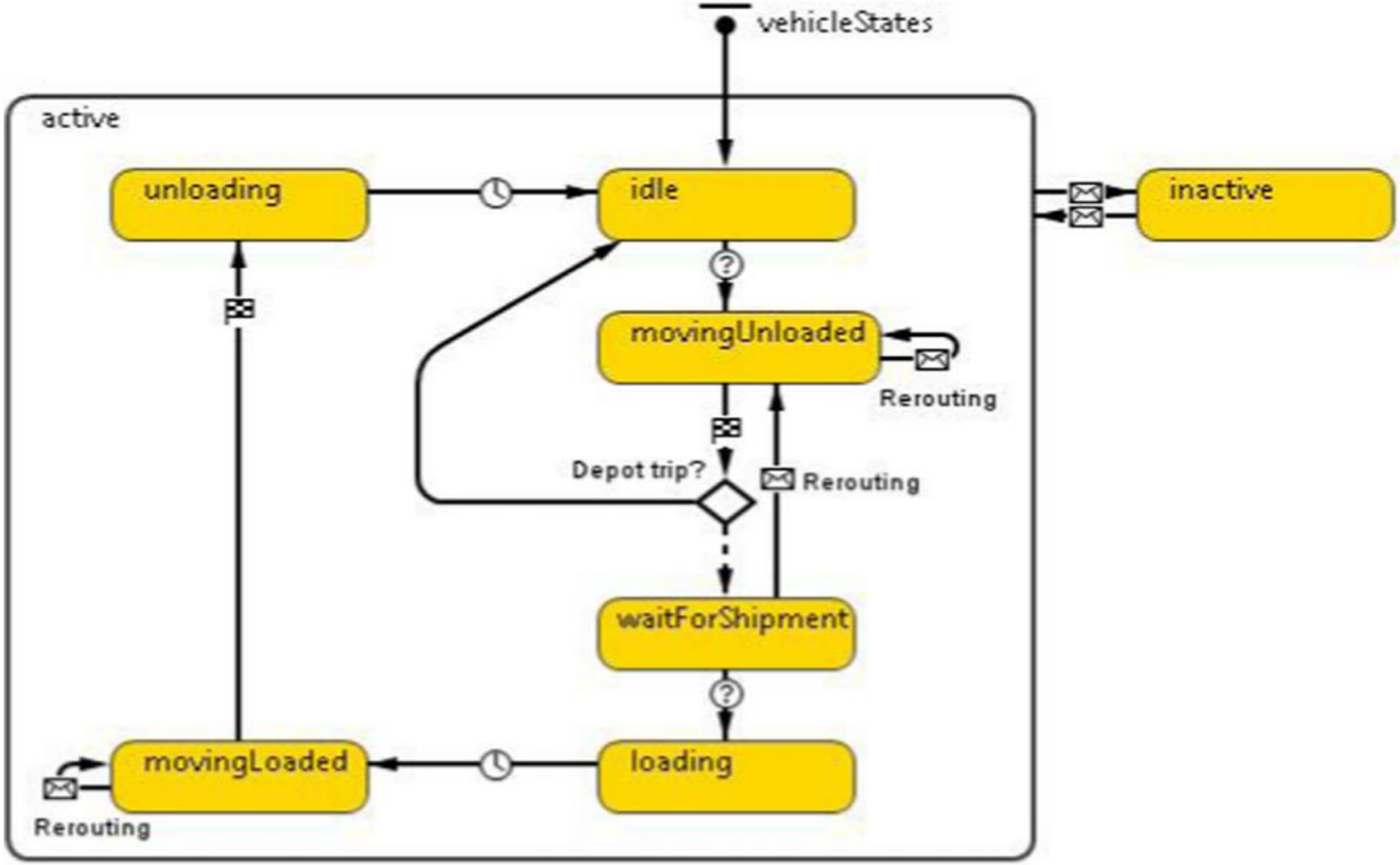
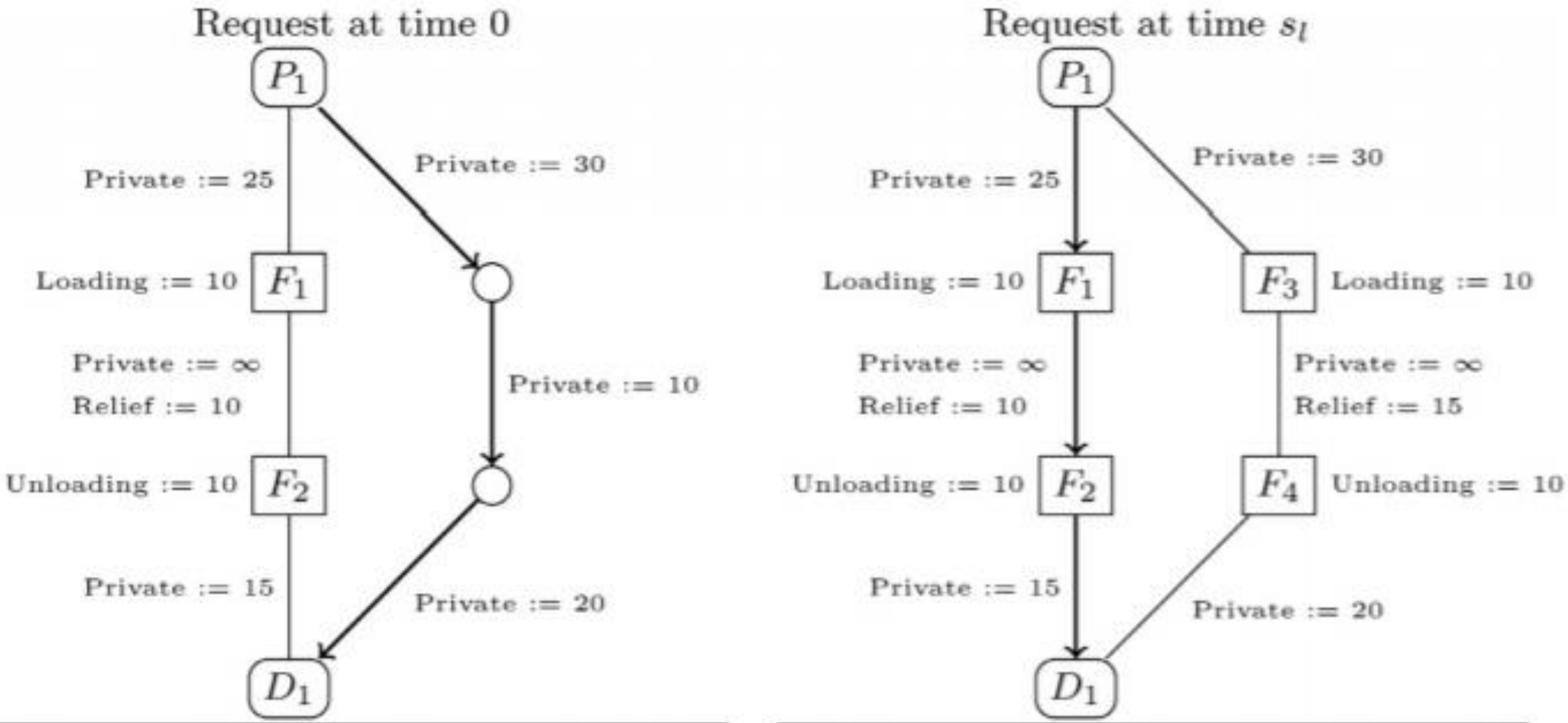


Fig. 3. Vehicle start-chart.



Route	Lead Time
Private $P_1 \to D_1$	60 min
Coordinated $P_1 \to F_1 \to F_2 \to D_1$	70 min

Route	Lead Time
Private $P_1 \to D_1$	∞
Coordinated $P_1 \to T_1 \to T_2 \to D_1$	70 min
Coordinated $P_1 \to T_3 \to T_4 \to D_1$	85 min

Fig. 4. Simplified example with loading delays of 10 minutes.

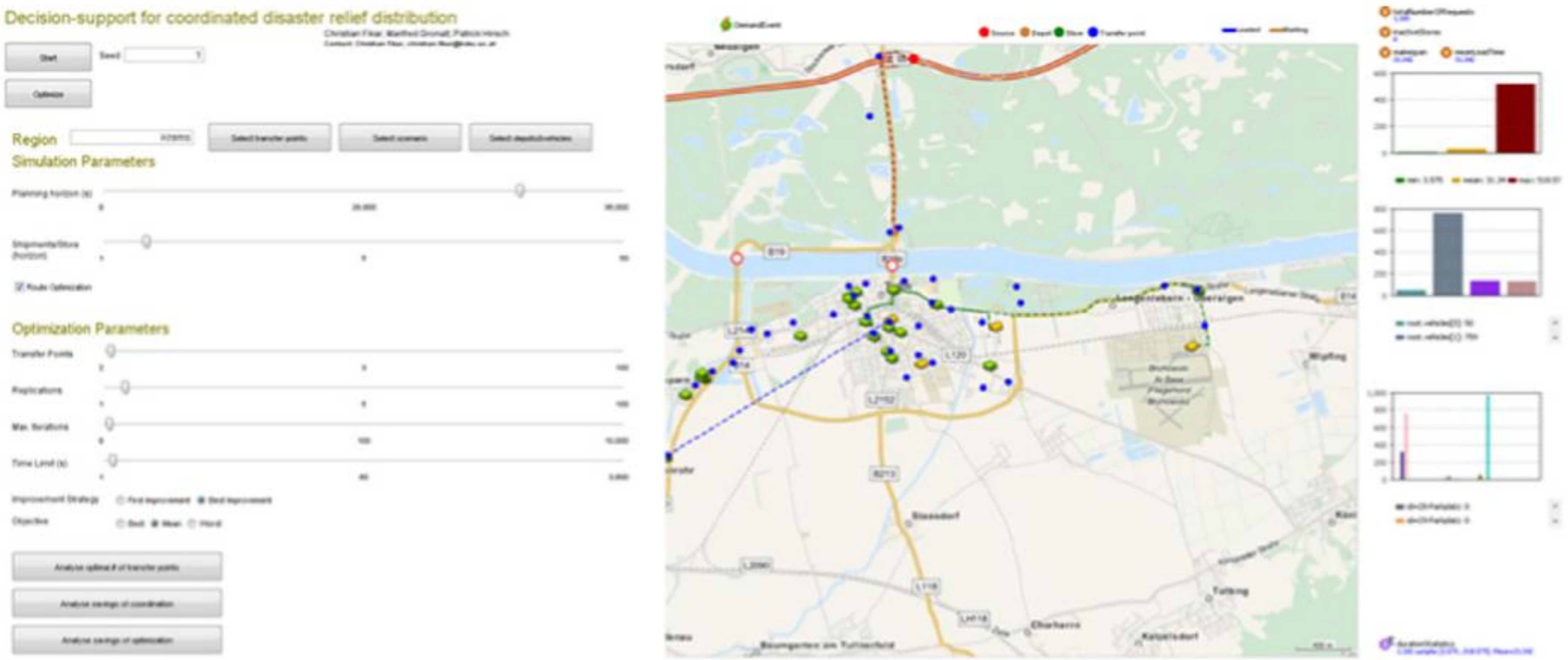


Fig. 5. Decision support for disaster relief distribution: user menu (left), animation (right).

5-Computational Experiments

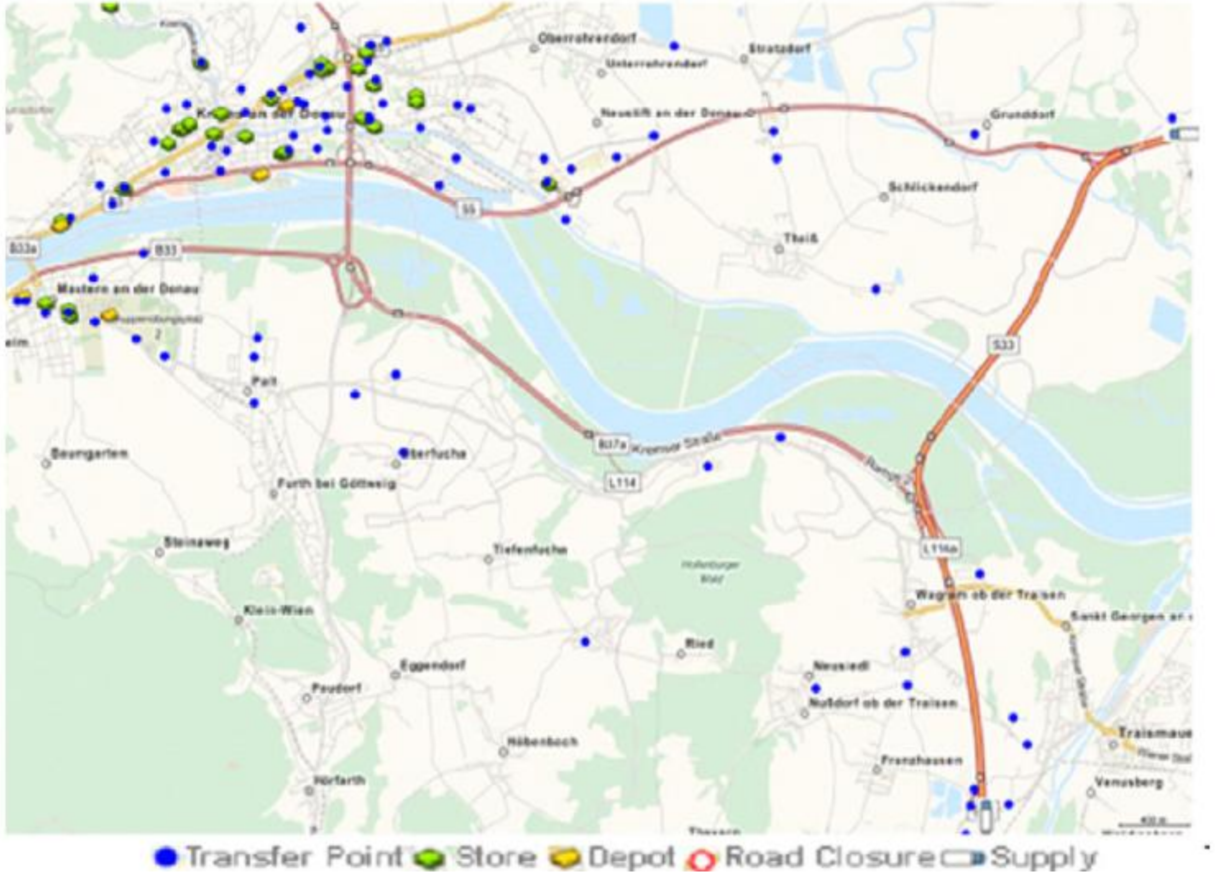
1. Test settings
2. Impacts of coordination and the fleet configurations
3. Interdependencies
4. Limitations

Test settings

- Krems and Tulln
- 8 am - 4 pm shipment requests
- Transfer points →large parking lots, sport fields, military, industrial areas
- Demand points →stores, pharmacies
- Supply points → major road exits

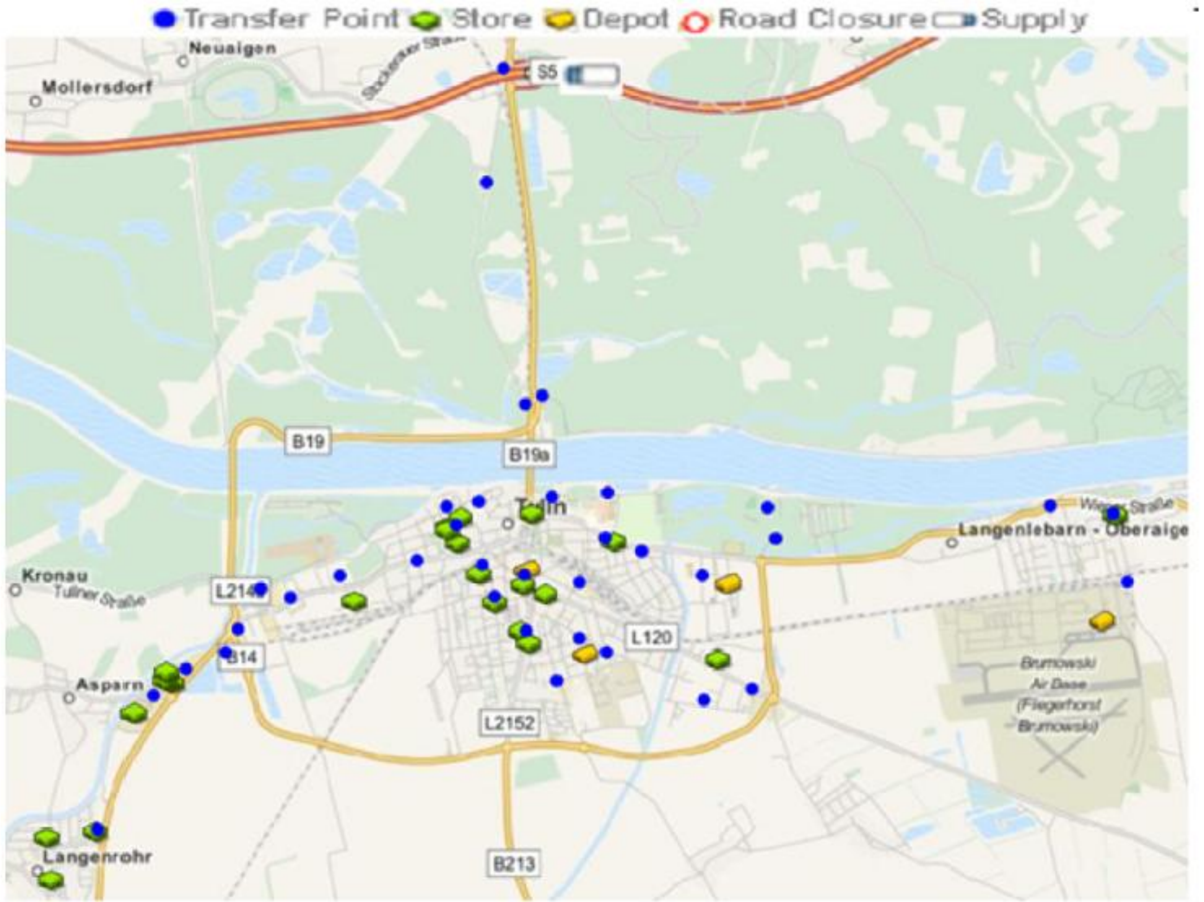
- Arrival times → uniformly distributed
- Each demand point → specified number of shipments
- Supply points → uniformly randomly selected

- UAV → **1** at hospital and military area (**135 km/h** - **6 minutes** for loading and unloading operations)
- Off-road vehicle → **1** at firefighter station (**45 km/h** - **3 minutes** for loading and unloading operations)


Transfer Point
Store
Depot
Road Closure
Supply
Oberrohrendorf
Stratzdorf
Unterrohrendorf
Neustift an der Donau
Grunddorf
Schlickendorf
Theiß
Mautern an der Donau
Palt
Baumgarten
Furth bei Göttweig
Steinaweg
Tiefenfucha
Klein-Wien
Eggendorf
Paudorf
Höbenbach
Hörfarth
Ried
Neusiedl
Nußdorf ob der Traisen
Franzhausen
Wagram ob der Traisen
Traismauer
Venusberg
S5
S33
B33
B33a
L114
L116a

Krems

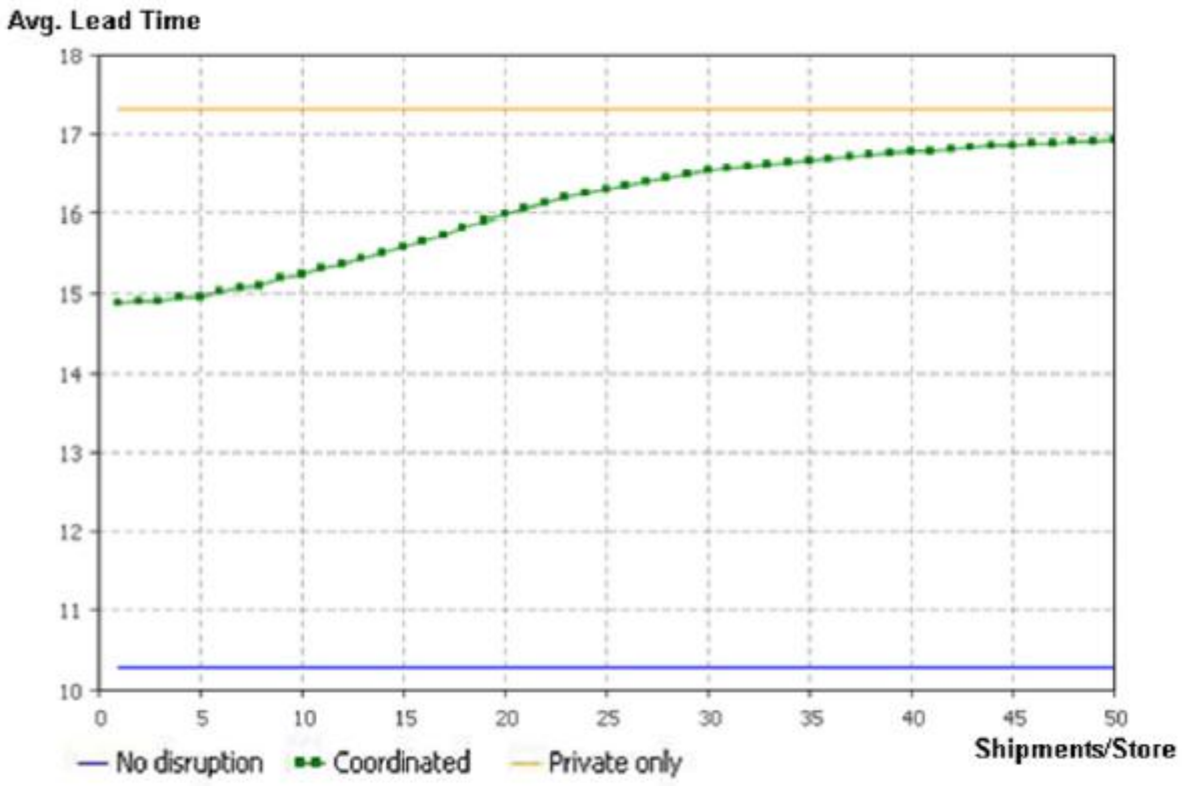
Tulln

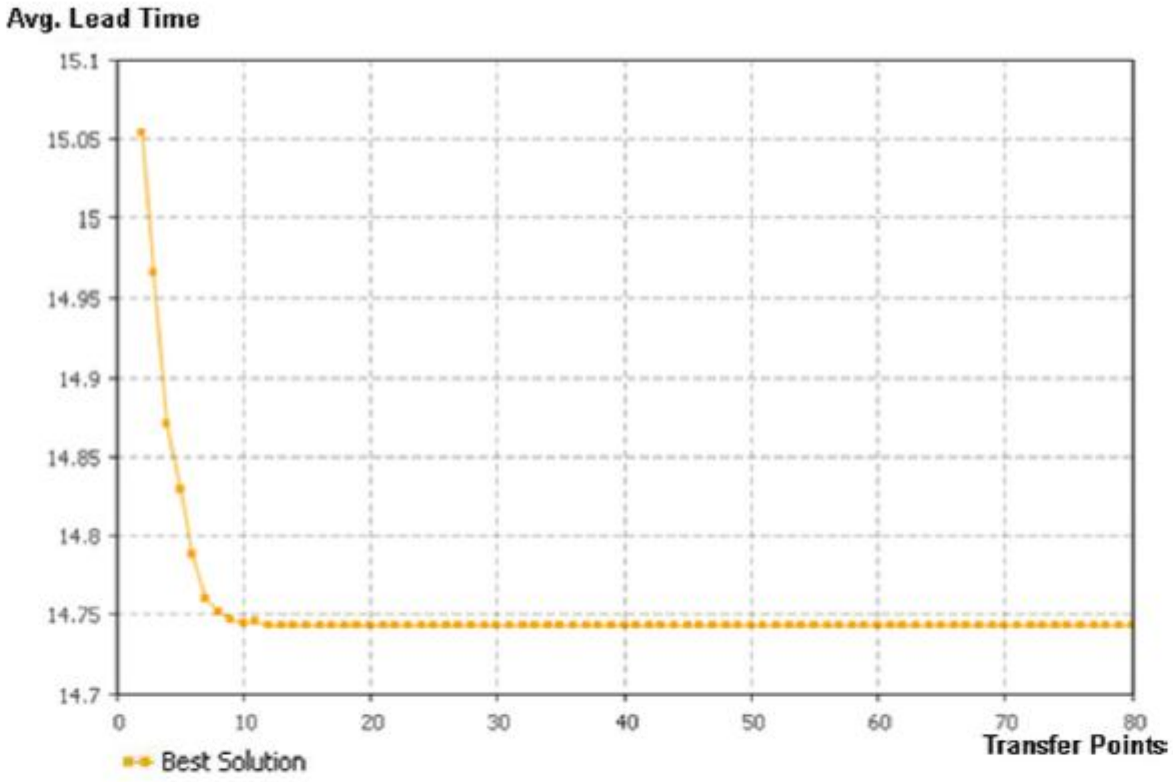

Transfer Point
Store
Depot
Road Closure
Supply
Neuaigen
Mollersdorf
S5
B19
B19a
Tulln
Kronau
Tullner Straße
L2148
B14
L120
L2152
B213
Asparn
Langenrohr
Langenlebarn - Oberaigen
Brumowski Air Base (Fliegerhorst Brumowski)

Instance characteristics of the test regions.

Instance	Transfer Points	Demand Points	Supply Points	Depots	UAVs	Off-road	Avg. lead time w/o coordination
K-Regular	–	29	2	5	–	–	10.2896 min
K-HQ30	80	29	2	5	3	2	17.3438 min
K-HQ100	80	29	2	5	3	2	17.4697 min
K-070613	80	29	2	5	3	2	17.3056 min
K-noBridge	80	29	2	5	3	2	28.0049 min
T-Regular	–	22	1	4	–	–	5.9331 min
T-noBridge	36	22	1	4	2	2	48.7298 min

Impacts of coordination and the fleet configurations





Interdependencies

- The system performs best if a high number of transfer points and vehicles are operated and little demand occurs.

Limitations

- Results depend on the selected test regions and further on the specified loading delays and traveling speeds of the vehicles.

6- Conclusion

Let’s Kahoot!