Solving Real-World Vehicle Scheduling and Routing Problems

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Vehicle Routing @ SAP

- SAP offers two products covering transportation planning functionality:
  - Since 2001: SAP Supply Chain Management, APO TP/VS
    (Advanced Planner and Optimizer, Transportation Planning / Vehicle Scheduling)
  - Since 2007: SAP Transportation Management

- SAP offers one product for service management and technician scheduling:
  - SAP Multi Resource Scheduling

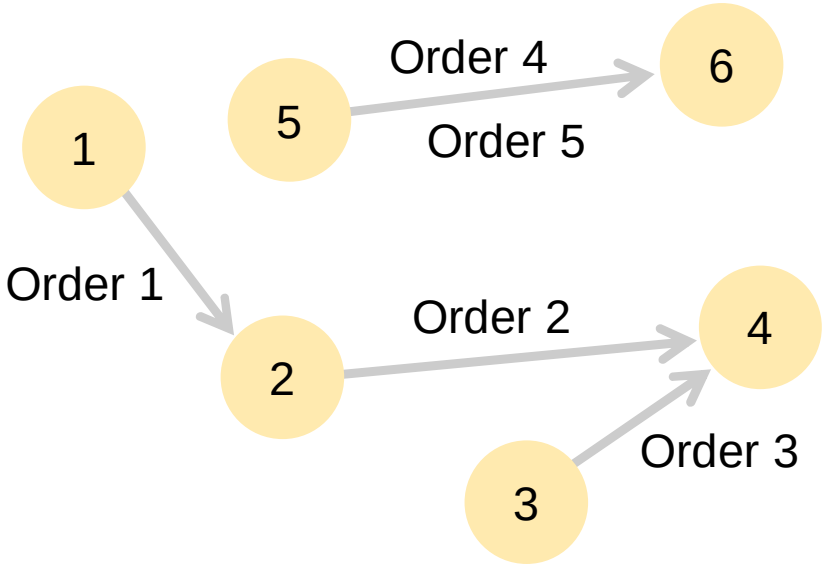
- Since 2001, SAP has developed and continuously improved an optimization algorithm for the vehicle scheduling and routing problem, which is the planning engine in above products

Agenda

1. **The vehicle scheduling and routing problem**
2. Solution approach
3. Selected scenarios
4. Conclusion

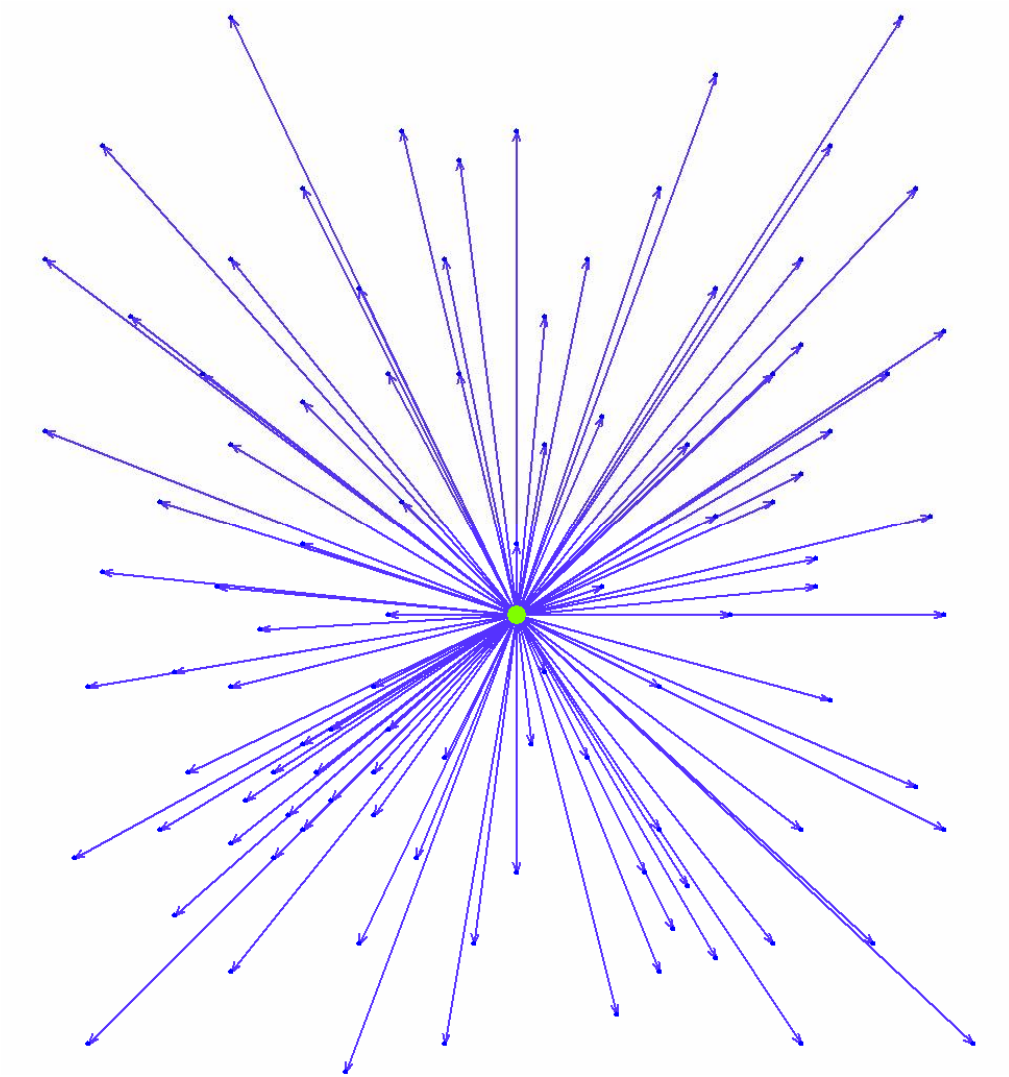
The vehicle scheduling and routing problem: Orders

- Order-based model
- Source and destination location per order

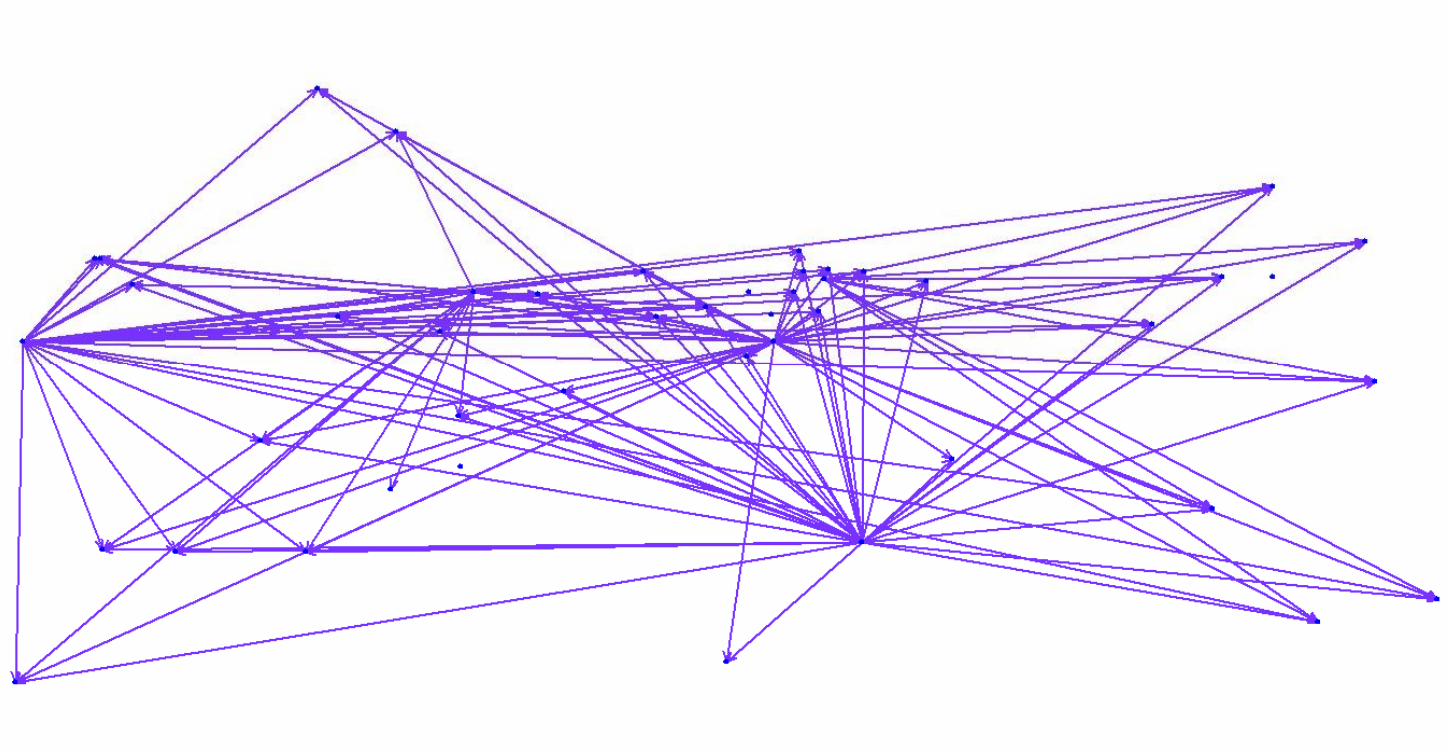


- Priority (Non-delivery costs)
- Loading dimensions (weight, volume, ...)
- Characteristics (hazardous goods, frozen, ...)
- Loading/unloading durations (depending on vehicle)

Example 1:
Orders in classical CVRP scenario

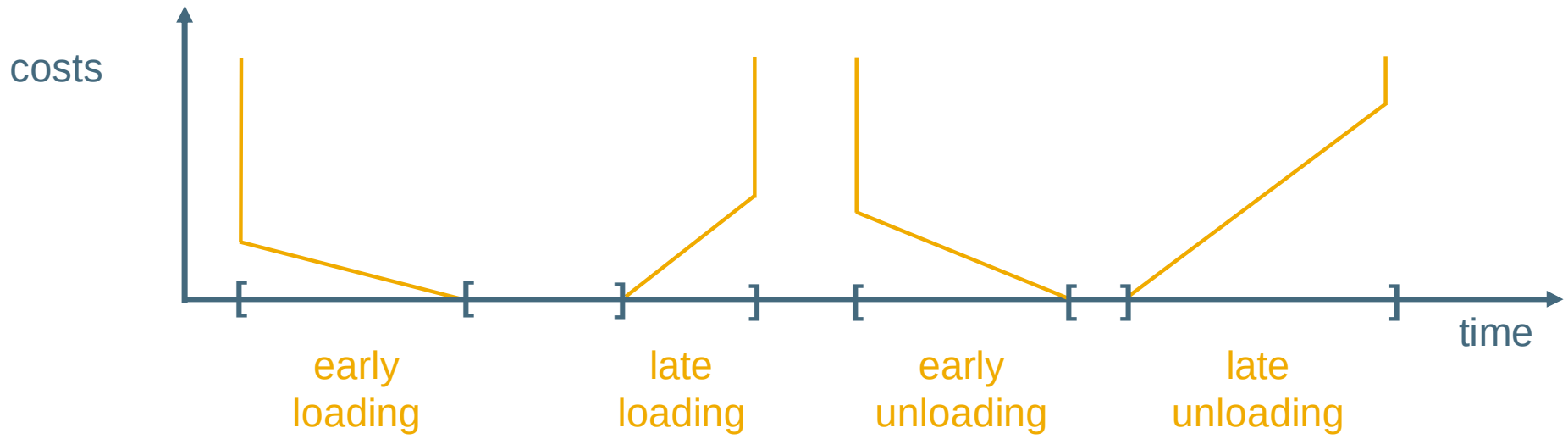


Example 2:
Orders in selected customer scenario



The vehicle scheduling and routing problem: Time restrictions per order

- Time windows per order (hard and soft) for loading and unloading

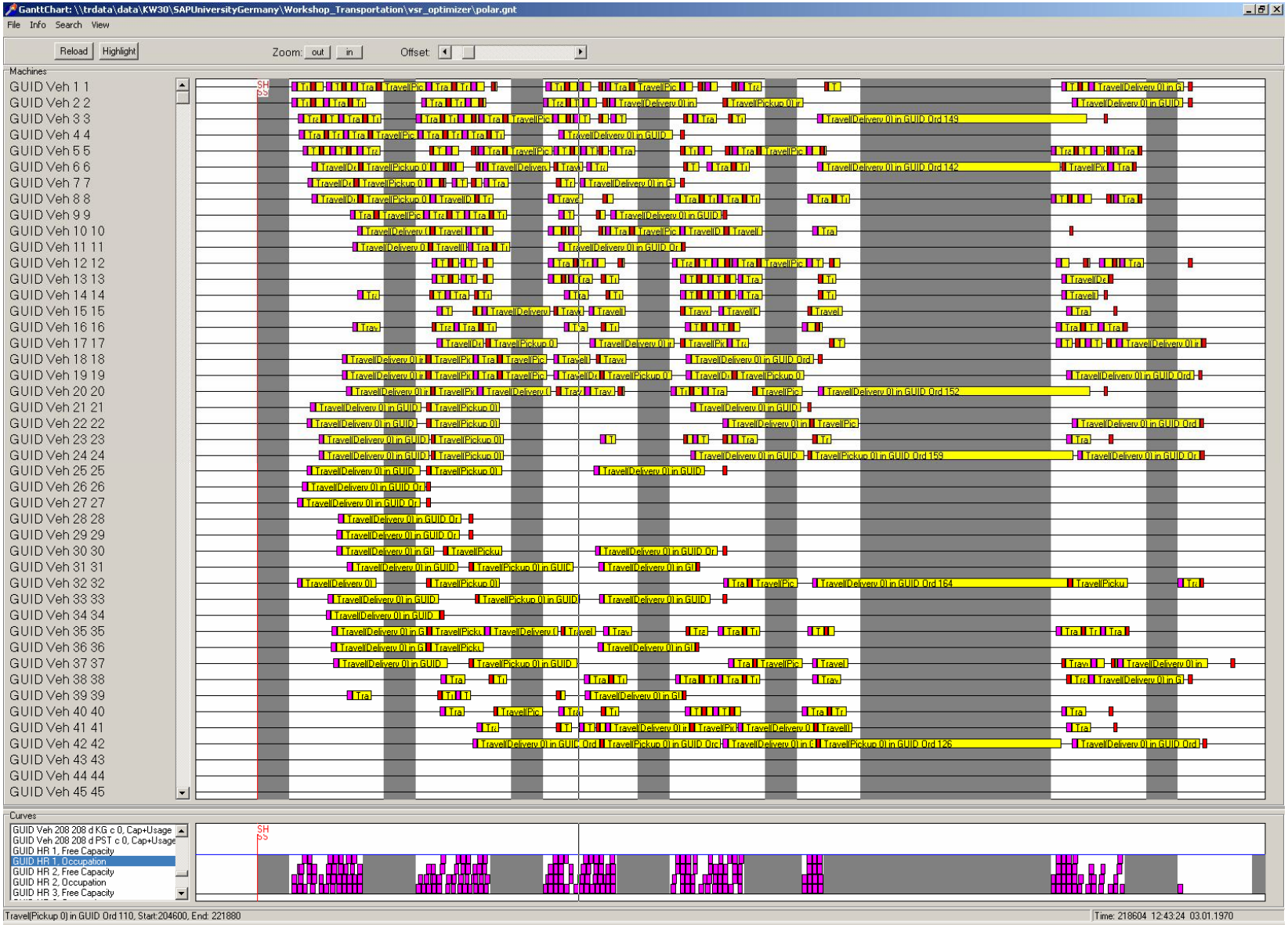


- Loading requires outbound handling resource at source location
  - Business hours
  - Capacities
- Unloading requires inbound handling resource at destination location
  - Business hours
  - Capacities

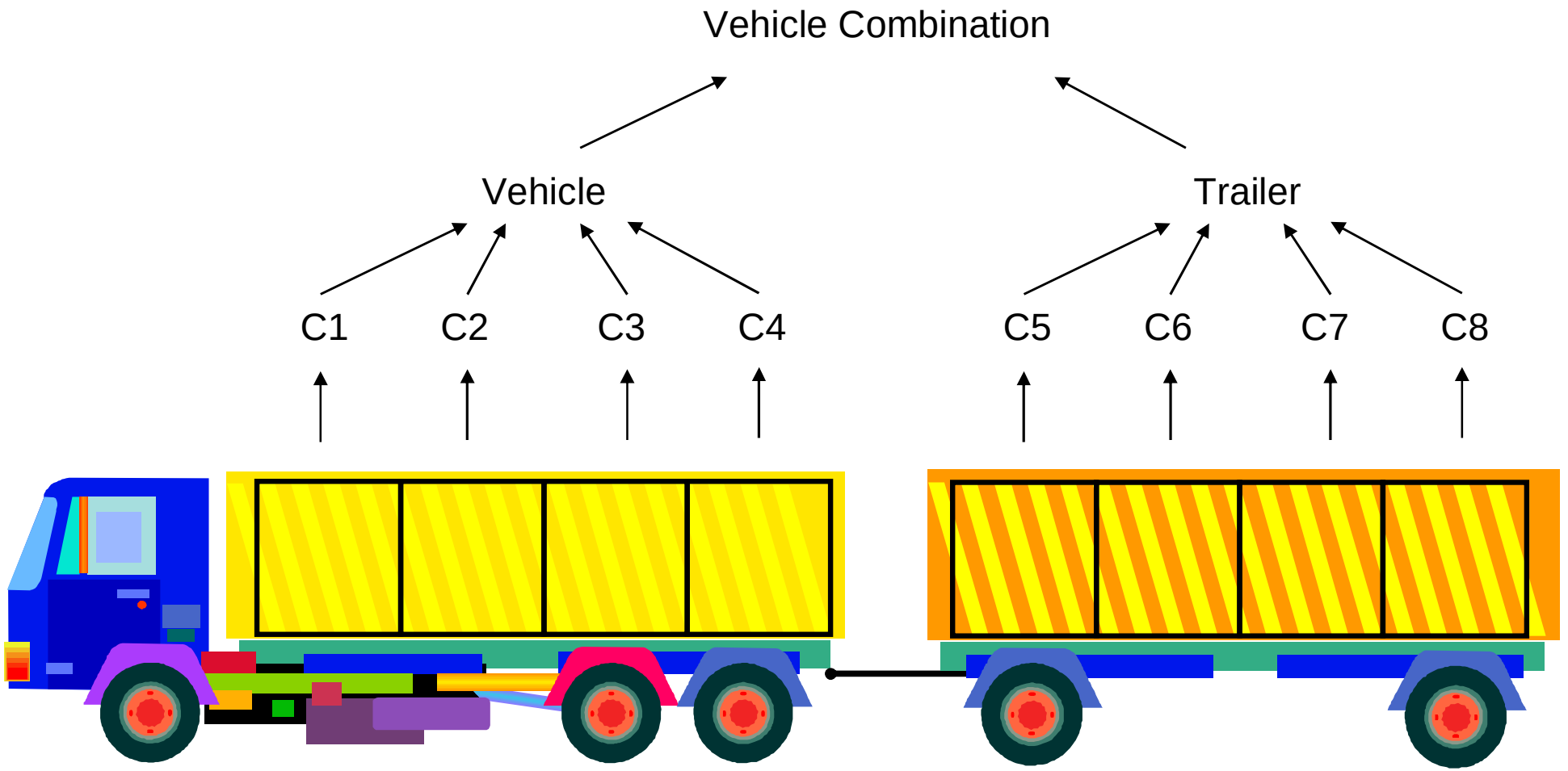
The vehicle scheduling and routing problem: Vehicles

- Travel capabilities (duration, distance, distance cost per lane)
- Characteristics (cooled, available for hazardous goods, …)
- Break calendar
- Constraints:
  - Start location, end location
  - Duration
  - Distance
  - Number of stops
  - Load capacity (weight, volume, …), may depend on number of stops
- Costs:
  - Fixed costs
  - Duration
  - Distance
  - Number of stops
  - Quantity costs (distance x load)

Example:
Schedule for a selected customer scenario



The vehicle scheduling and routing problem: Trailers and compartments (1)

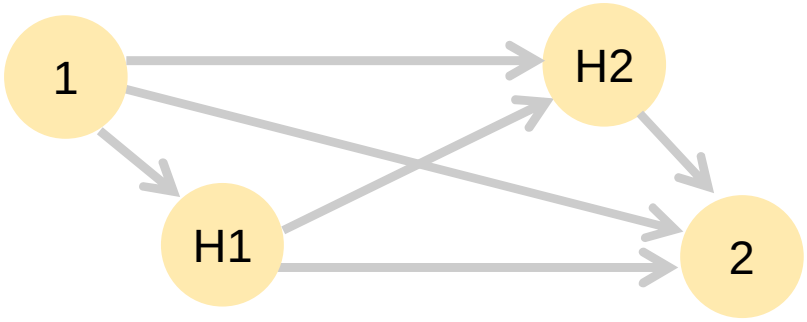


The vehicle scheduling and routing problem: Trailers and compartments (2)

- Trailers cannot move without vehicle
- Coupling/uncoupling activities
- Constraints for trailers like for vehicles
  - Start location, end location
  - Duration, distance, number of stops, load (weight, volume, …)
- Costs for trailers like for vehicles
  - Fixed costs, duration, distance, number of stops
  - Quantity costs (distance x load)
- Constraint for vehicle combinations: load (weight, volume, …)
- Compartments
  - Each vehicle/trailer has fixed number of compartments
  - Load capacity per compartment (weight, volume, …)
  - Fixed versus flexible load capacity

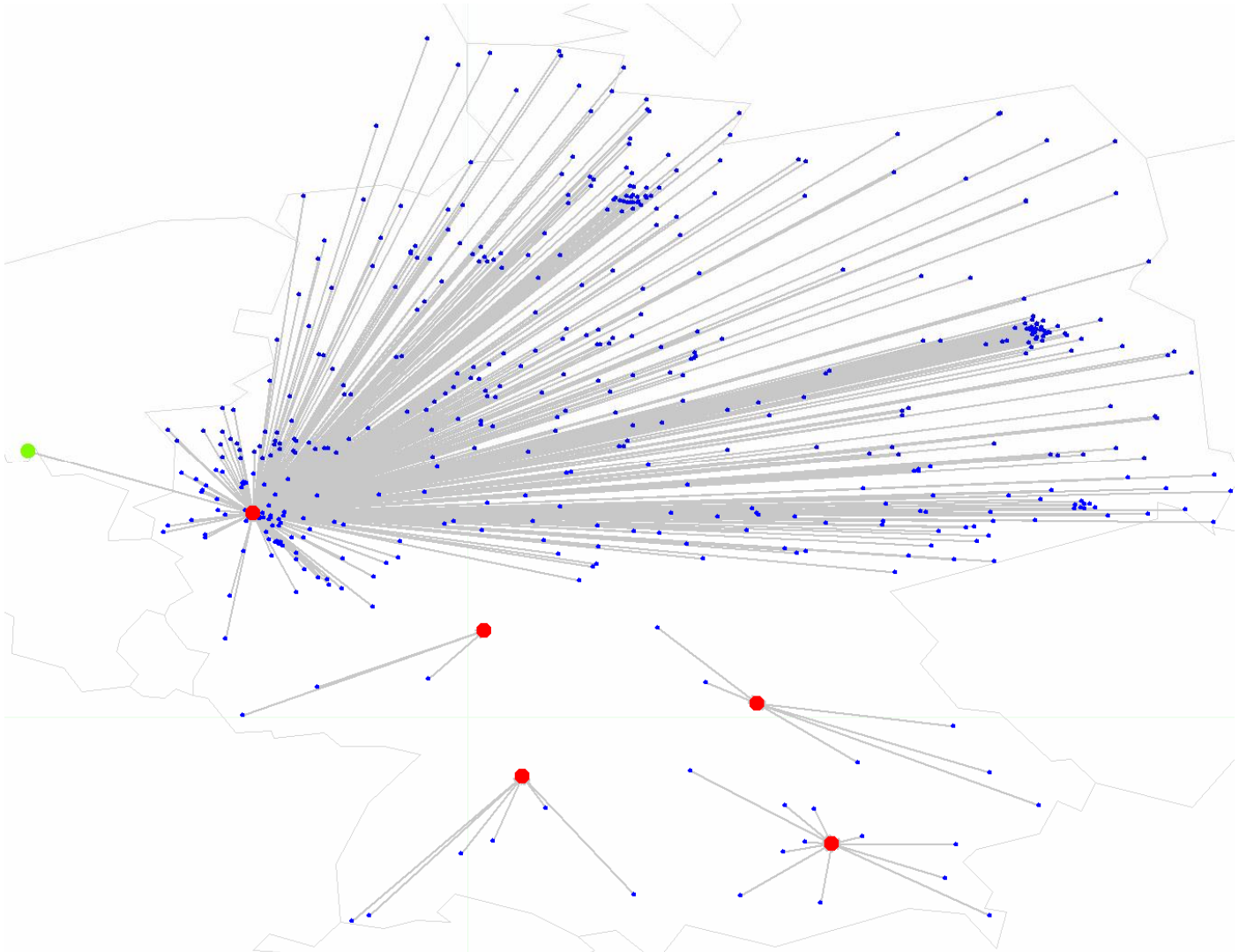
The Vehicle Scheduling and Routing Problem: Hubs

- Hub locations (= transshipment locations):
  - Indirect shipment via hub(s) versus direct shipment



  - Minimum and maximum waiting time at hub

Example:
Selected customer scenario involving 5 hubs



The vehicle scheduling and routing problem: Incompatibilities and schedule vehicles

- Incompatibility constraints:
  - Between order characteristics
  - Between vehicle characteristics and order characteristics
  - Between trailer characteristics and order characteristics
  - Between compartment characteristics and order characteristics
  - Between vehicle characteristics and trailer characteristics
  - Between order characteristics and hubs
  - Between vehicle characteristics and hubs
  - Between trailer characteristics and hubs

- Schedule vehicles:
  - Route is fixed a priori
  - Schedule is fixed a priori

The vehicle scheduling and routing problem: Summary

- Goal:
  Determine transportation plan that minimizes total costs and satisfies all constraints.

- A transportation plan is characterized by the following decisions:
  - per order: deliver or not?
  - per delivered order: select legs (= path through hub network)
  - per selected leg: select vehicle/trailer and compartment
  - per vehicle/trailer:
    - select relative ordering of activities (= routing)
    - assign start time to each activity (= scheduling)

- Total costs = weighted sum of costs for
  - orders (non-delivery, earliness, lateness), and
  - vehicles and trailers (fixed, duration, distance, stops, quantity)

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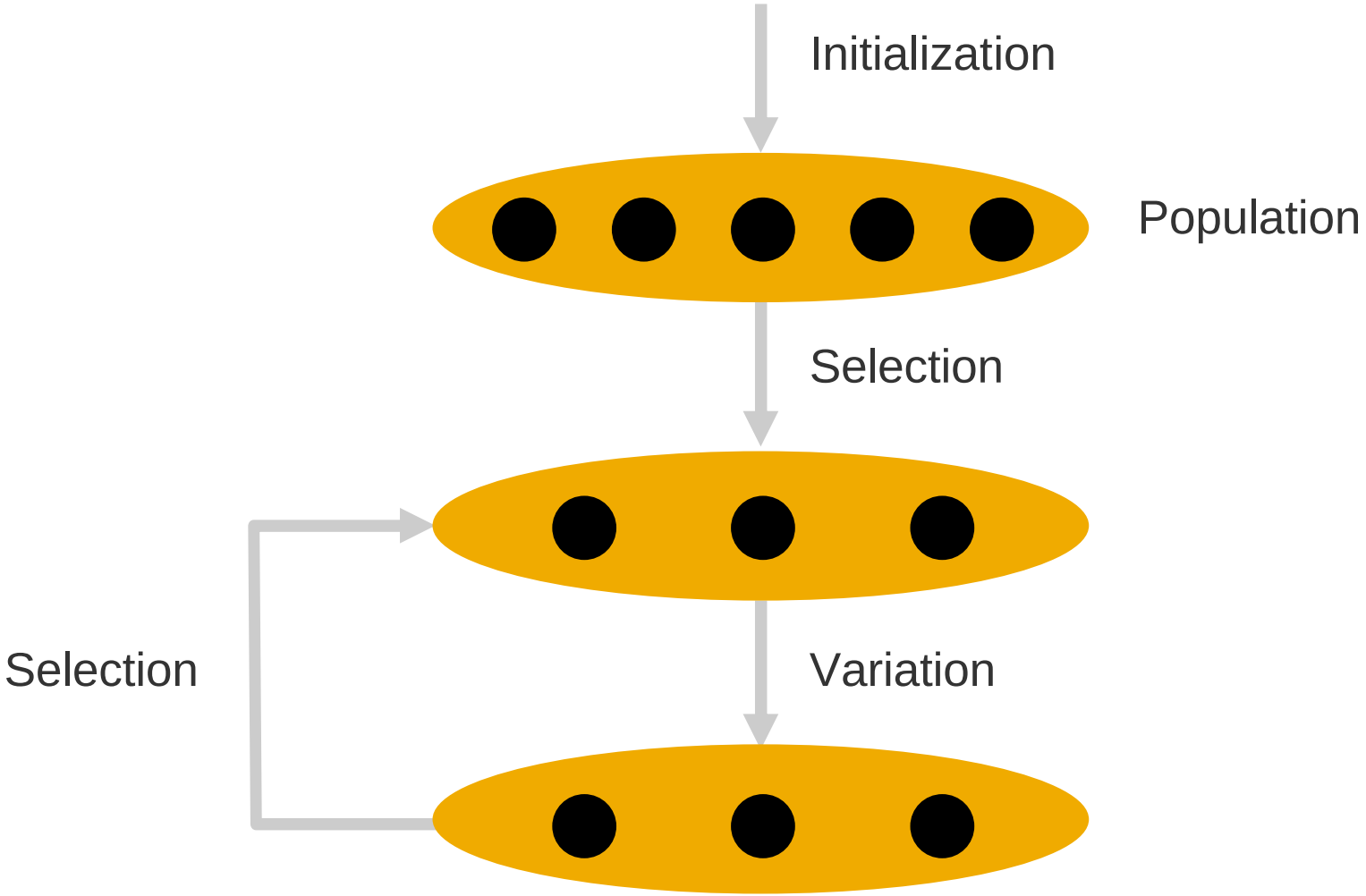
Solution approach: Evolutionary local search



Solution approach: Ingredients of evolutionary local search

Initialization

- Greedy insertion heuristics + local search

Variation

- Uses > 20 different atomic variation operators, grouped into:
  - Assignment moves (e.g. insert an order, delete an order, delete a vehicle)
  - Routing moves (e.g. 2-opt, variants of Or-opt, 3-opt, 4-opt)
  - Scheduling moves
- Moves are applied subsequently and with certain probabilities, using the following concepts:
  - Local search
  - Randomness
  - Iterated local search
  - Variable neighbourhood search
  - Tabu search

Solution approach: Key features

- Direct solution representation
- Only feasible solutions
- Local search
- Small population
- Many specialized atomic move operators
- Orchestration of atomic moves in the variation step

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Using the optimizer

Input data specified by selection profile

Different operating modes

- Batch versus interactive start
- Long runs at night versus short runs during the day
- From scratch versus incrementally
- Planning horizon ranges from a few hours to several weeks

Run-time limits vary from a few minutes to several hours

Human transportation planner processes the optimizer‘s result:

- reviewing it,
- manipulating it interactively if needed, and
- releasing it to transportation execution

Side-effect of optimizer: Check input data

- Unexpected results typically indicate that input data are not clean.

Characteristics of selected customer scenarios

Scenario	1	2	3	4	5	6	7	8	9
Orders	75	255	662	778	804	1177	2029	7040	13569
Loading dimensions	1	1	2	1	3	2	5	4	3
Locations	30	199	55	8	32	565	128	1873	14
Hubs	9					5			
Sources	9	5	11	1	1	1	1	1	1
Destinations	14	194	46	7	31	559	127	1872	13
Vehicle types	4	38	9		7	3	10	10	2
Vehicles	58	93	301		281	680	2701	2011	100
Schedule vehicle types	1			6					
Schedule vehicles	38			11					
Business hours	2	196				1	29	64	
Capacitive resources			54		32				

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Conclusion

Summary

- Real-world problems are complex
- Heterogeneous instances of the same abstract problem
- One algorithm for the abstract problem, applicable to arbitrary special instances of our customers
- Metaheuristics work well in practice

Outlook

- Continuous extension of functionality
- Hub networks with several „parallel“ hubs and more than 2 „sequential“ hubs
- Different variants of trailer scenarios, depending on frequency of coupling and uncoupling

Thank you!

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