Applications of Multi-Agent Systems in Logistics

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Applications of Multi-Agent Systems in Logistics

Overview

- Transportation Domain
- Agent-Based Optimization
  - Agent-Design
  - Allocation
  - Reallocation
  - User-Interaction
- Optimization Results
- Conclusion
Freight Logistics

- Task: Create a plan to transport all orders
- Challenges
  - Complexity
    - Mergers
    - Higher volumes
    - Constraints
  - Dynamics
    - Ever shorter notice in advance
    - Unforeseen events
    - User interaction
Freight Logistics

Today's Solution
- Division into (regional) businesses

Problems
- Visibility
- Communication
- Missed synergetic effects
Spot-Market

- Trucks are ordered on the Spot-Market just in time
  - Assumption: truck is always available everywhere
  - We do not have to care for successor routes
- Dispatchers have to find a truck for each route (by phone)
- System has to suggest the routes

Objective
- Minimum cost

Pickup and delivery has to obey
- Load constraints
- Time constraints
Cost Calculation

☐ Spot-Market
  - Variable costs depending on
    - Distance
    - Load
    - Relation (Start – Destination)
    - Discount
  - Minimum costs
Load Constraints

- Precedence (pickup before delivery)
- Pairing (pickup and delivery by the same truck)
- LIFO (last in first out loading of orders)
- Capacity limitation (dependent on truck type)
- Weight limitation (dependent on truck type)
- Order – truck compatibility (Type, Equipment)
- Order – order compatibility (Dangerous goods)
Transportation Domain

Time Constraints

- Order dependent load and unload durations
- Earliest and latest pickup (Soft constraints)
- Earliest and latest delivery (Soft constraints)
- Opening hours for pickup and delivery
- Legal drive time restrictions
- Lead time for ordering spot market trucks
- Maximum Tour duration
Traditional Optimization (top-down)

- Batch optimizers using Linear Programming
- Complexity
  - Not able to deal with number of orders and trucks of big logistics companies
  - Harder to model and change constraints
- Dynamics
  - Need to know all orders in advance
  - Batch optimization, no real-time capabilities, no user interaction
- Advantages
  - Closer to optimum (for those domains they are able to solve and if time allows)
Each truck is represented by an autonomous agent

- Maximal scalability
- Overhead (messaging, memory, other resources)
Agent Design

- Regional cluster of trucks represented by an agent
  - Agents use almost same solution generation and optimization

- Solution generation
  - Start in the most promising cluster

- Optimization
  - Exchange request for tours running across multiple clusters
Allocation

- Contract Net
  - Coordinator agent asks each truck agent for a quote
  - Each truck able to transport the order sends back a bid representing the cost increase when transporting the order
  - Coordinator awards order to lowest bidding agent

- Example
  - Order1 is assigned to truck1, it is closer to the pickup location
Example

- Order2 is also assigned to truck1
- Additional distance for truck1 is less than additional distance for truck2
- truck1 is now fully loaded when order2 and order1 are picked up
Example

- Order3 is assigned to truck2
- truck1 does not bid, because
  - it is overloaded when picking it up together with order1 and order2
  - it is late at pickup location of order2 when picking it up before picking up order1 and order2
  - it is late at pickup location of order3 when picking it up after delivering order1 and order2
Example

- Order4 is also assigned to truck2

Optimality

- Contract net protocol produces sub-optimal results
- Quality depends on the order in which transport orders arrive
Mutual negotiation

- Agent with changed route sends request for checking order exchanges to other agents
- Other agent checks potential and sends back request for order exchange if exchange creates a better solution
- Agent accepts if exchange creates a better solution

Better solution
- win-win for inter-company systems (self-interested agents)
- win-loose for intra-company systems if win > loose
Agent-Based Optimization

Reallocation

- Example
  - agent2 sends agent1 request for checking order exchanges
  - agent1 sends back request for exchanging order2 and order3 to save costs
  - agent2 accepts exchange, because it also saves costs

- b-cyclic k-transfer
  - b: number of involved trucks
  - k: number of involved orders

- Distributed Hill-climbing
Agent-Based Optimization

User Interaction

- Agents and Users have to work together

- Performance
  - Users expect feedback within seconds (real-time optimization)

- Control
  - Full control to agents
    - Not feasible (can not know all constraints, spot market, ..)
  - Full control to dispatchers (all the time)
    - Slows down the system
  - Solution: different phases with handover of control
Agent-Based Optimization

User Interaction

- Planning phase
  - Until \( n \) hours before route starts
  - Trucks under full control of the agents
  - Allocation and Reallocation without restrictions
  - Dispatcher observes
Agent-Based Optimization

User Interaction

- Todo phase
  - Trucks under control of agents, but dispatcher can take over
  - Find alternatives to transport an order
  - Add (1), Remove (2) or exchange (3) orders
  - Change schedule (4)
  - Agents may not change manually edited routes
  - Dispatchers may violate some constraints
Agent-Based Optimization

User Interaction

- Tracking phase
  - Trucks under full control of dispatcher
  - Agents can make suggestions to add orders
  - Telematics system keeps schedule updated
- Reactive alerting
- Proactive alerting
Case study with 3500 real orders

Objectives
- Reduce cost
- Reduce distance

Measures to ensure comparability with manual solution
- Same geo-coding
- Same cost parameterization
- No soft time constraints
- Result checked by dispatchers
Optimization Results

Solution Quality

- Comparison to manual dispatching plan

<table>
<thead>
<tr>
<th>Objective</th>
<th>Reduce Cost</th>
<th>Reduce Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>11.7%</td>
<td>not comparable</td>
</tr>
<tr>
<td>Kilometer</td>
<td>4.2%</td>
<td>13.4%</td>
</tr>
<tr>
<td>Vehicles</td>
<td>25.5%</td>
<td>40.4%</td>
</tr>
</tbody>
</table>

- Cost savings
  - 4.2% by reducing driven kilometers
  - 2.2% by increasing cost-saving tramp routes (reuse of trucks)
  - 5.3% by hiring trucks in cheaper regions
Solution Quality

- w/o ATN: Dispatchers (manual) solution
- ATN 1: Significant reduction of driven kilometers at same service level
- ATN 2: Reduced kilometers with significant higher service level
- ATN 3: Minimal additional kilometers while meeting all restrictions

Optimization Results

<table>
<thead>
<tr>
<th>ATN</th>
<th>Empty KM</th>
<th>Constraints broken &lt; 6 hours</th>
<th>Constraints broken &gt; 6 hours</th>
<th>Total KM</th>
</tr>
</thead>
<tbody>
<tr>
<td>w/o ATN</td>
<td>18.0%</td>
<td>55.5%</td>
<td>1.0%</td>
<td>87.157 km</td>
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<tr>
<td>ATN 1</td>
<td>10%</td>
<td>65%</td>
<td>25%</td>
<td>79.890 km</td>
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<tr>
<td>ATN 2</td>
<td>15.5%</td>
<td>78.0%</td>
<td>4.0%</td>
<td>86.471 km</td>
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<td>ATN 3</td>
<td>15.0%</td>
<td>85.0%</td>
<td>2.5%</td>
<td>88.636 km</td>
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</tbody>
</table>
Optimization Results

Soft Time Windows

- Optimization results with increased soft time windows

![Graph showing optimization results with increased soft time windows. The x-axis represents max allowed delay (in hours), the y-axis represents costs (in 1000s of units), and the graph includes lines for total costs and broken constraints.]}
Optimization Results

k-transfers

- Optimization results with increasing k (number of orders exchanged)

![Graph showing costs and runtime vs. k-transfers]

- Total Costs
- Runtime
Clustering

- Cluster sizes can be varied
- Compared 4 clusters against 1 on a 4 CPU machine

<table>
<thead>
<tr>
<th></th>
<th>4 Clusters compared to 1</th>
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</thead>
<tbody>
<tr>
<td>Cost</td>
<td>+1.2%</td>
</tr>
<tr>
<td>Runtime</td>
<td>11%</td>
</tr>
</tbody>
</table>

- Cost
  - Higher costs due to distribution of trucks into clusters

- Runtime
  - Factor 3 by having computation distributed to 4 CPUs
  - Factor 3 by having less trucks in one cluster
Tracking Feedback

- It is common to have feedback at pickup/delivery locations
- Truck positions are not known in between
- Knowing the position more precisely has advantages
  - Can suggest to add very short time notice orders
  - May detect late trucks earlier and replan
  - May make use of truck ahead of schedule

<table>
<thead>
<tr>
<th>Real time tracking</th>
<th>Cost</th>
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<tbody>
<tr>
<td></td>
<td>-3%</td>
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Conclusion

Software Agents

- Help our customers to reduce their costs
- Support the dispatchers in working in a
  - Complex,
  - Distributed and
  - Dynamic domain
- Help us to sell ATN
- Accounted for roughly 10% of the effort to create the system (assuming having an agent runtime available)
Questions?

Thank you for your attention!
Heterogeneous Vehicles (FTL)

- Decision for which truck to choose matters
- Example
  - Order 5 (24 tons) cannot be transported by truck 17t
  - Routes in a have too many empty km
  - Simple Reallocation does not work
Network Optimization

- Transport orders between network of hubs
- Orders may be relayed at hubs
- Create a transport plan for all relations between hubs
Network Optimization

- Distance optimal solution
  - 352 km
  - 3 trucks

- How does a cost optimal solution look like?
  - Distance costs
  - Fix costs for trucks
  - Costs for drivers not at home
Setup

- 175 orders
- 33 hubs
- 16 paths on average per relation for each order
- 61233 order kilometers

<table>
<thead>
<tr>
<th>Approach</th>
<th>Result</th>
<th>Result</th>
<th>Runtime</th>
<th>Result</th>
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<tbody>
<tr>
<td></td>
<td>(avg) (km)</td>
<td>(best) (km)</td>
<td>(avg) (sec)</td>
<td>(best known)</td>
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