Trends in Transportation and Logistics and the Role of Optimization

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Optimization in transportation and logistics

1960's and 70's
“Transportation science” emerged
“Transportation” meant traffic and public transportation
“Logistics” referred to physical distribution and inventory management
The contributions

- Vehicle routing
- Facility location
- Warehouse management
- Network design
- Supply chain management
- Inventory management
- Optimization: trains and aircrafts
- Traffic assignment
- Crew management
- Bus scheduling
- Production planning and scheduling

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The contributions: efficiency

Efficient use of scarce resources

**Scarcity** is a fact of life.
While people’s desire for goods is unlimited, the resources to produce them are limited.
The contributions: systemic approach
The contributions: looking ahead

Anticipation of consequences
The contributions: in one word

Intelligence
Technology

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Trends in transportation
Trends in logistics
Moreover...

Meeting the needs of the present without compromising the ability of future generations to meet their needs

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Technology and optimization

Intelligence is needed
Transportation (freight and people)

**Freight**-empty returns:
31% for companies
23% for logistic companies

**People**-use of personal cars:
70-75%

Waste of capacity

Unnecessary emissions
Directions in research

Systemic

Collaborative

Data-driven

Dynamic

Technology-driven
Freight
Coordination of pick-up and delivery over time

Archetti, Christiansen, Speranza, EJOR, 2018

Pick-up
Delivery
Coordination of pick-up and delivery over time
Coordination of pick-up and delivery over time
Coordination of pick-up and delivery over time

- Sequential policy: each customer independent
- Coordinated policy

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<tbody>
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<td>% total cost (average)</td>
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<td>% total cost (max)</td>
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<tr>
<td>Low inventory cost</td>
<td>36.36</td>
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<tr>
<td>High inventory cost</td>
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<tr>
<td>All</td>
<td>35.54</td>
<td>63.19</td>
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Reduction of emissions: 35.54%
Coordination of operations over time

In

Sorting

Out

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Coordination of operations over time

Arrival times

Release dates

Archetti, Feillet, Mor, Speranza, EJOR, 2020
Archetti, Feillet, Mor, Speranza, COR, 2018
Coordination of operations over time
Coordination of operations over time
Coordination of operations over time
Coordination of operations over time

Iterated local search

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<td>Avg.</td>
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<td>1.16</td>
<td>2.14</td>
<td>2.09</td>
<td>1.88</td>
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Reduction of emissions: 13%
Loading/unloading areas
Loading/unloading areas
Loading/unloading areas

Causes of double parking:

• Scarcity of L/U areas
• Need to deliver
• Individual routes and schedules

Consequences of double parking:

• One less lane available
• Queues of vehicles
• Emissions
Loading/unloading areas
Loading/unloading areas

A vehicle makes a booking of the L/U areas

Windows of (un)availability for the following vehicles

Mor, Speranza, Viegas, TR E, 2020
Loading/unloading areas

L/U area with 2 parking spots
Loading/unloading areas

Problem to solve:
A new variant of the TSP (with multiple soft time windows)

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Fixed and flexible starting time

Fixed starting time of the route: $T_0 = q$

(the vehicle decides the starting time of the route)

Routing only

Flexible starting time of the route: $T_0 \geq q$ and $T_0 \leq q+f$

(the starting time of the vehicle is between $q$ and $q+f$)

Routing + Scheduling
Computational experiments

Lisbon: 560m x 260m
Tests

Independent vehicles: TSP for each vehicle (Lin-Kernighan heuristic)

Sequential booking with fixed starting time (formulation solved with CPLEX 12.6)

Sequential booking with flexible starting time (formulation solved with CPLEX 12.6)

Trade-off between routing time and number of double parked vehicles
Results (up to 50 vehicles)

- **Fixed starting times**
  - No double parking

- **Flexible starting times**
  - No double parking

- **Independent vehicles**
  - Double parking
People
Shared taxi

Emissions and occupation of space
Shared taxi

- Public transportation

- Personal car

  - Shared taxi
Shared taxi

A simulation/optimization model

Input:
- Origins
- Destinations
- Request time
- Desired departure time
- Flexibility factor

Archetti, Speranza, Weyland, ITOR, 2018
Shared taxi

Reduction of emissions: more than 50%

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Fair collaboration

Shared taxi service (reservation-based)

Multiple companies

Collaboration initiative

Angelelli, Morandi, Speranza, TR C, 2022
Fair collaboration

Routes without collaboration
Fair collaboration

Routes with full/unconstrained collaboration

Routes with fair/constrained collaboration

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The problem: basic formulation

\[
\min z = \sum_{i \in V} \sum_{j \in V} \sum_{k \in K} c_{ij} x_{ij}^k \\
+ \text{Routing constraints} \\
+ \text{Time windows and maximum time on board constraints} \\
+ \text{Capacity constraints}
\]

\[
y_c^k \in \{0, 1\} \hspace{2cm} k \in K \hspace{0.5cm} c \in C \\
x_{ij}^k \in \{0, 1\} \hspace{2cm} k \in K \hspace{0.5cm} i \in V \hspace{0.5cm} j \in V \\
w_i^k \in \mathbb{N} \hspace{4cm} k \in K \hspace{0.5cm} i \in V \\
u_i^k \geq 0 \hspace{4cm} k \in K \hspace{0.5cm} i \in V \\
r_c \geq 0 \hspace{11cm} c \in C.
\]

Unconstrained optimization
The problem: time balance

the difference between the total travel time (direct transfer) acquired and conceded by company $m$

\[
S_m = \sum_{k \in K_m} \sum_{c \in C \setminus C_m} t_c y_c^k - \sum_{k \in K \setminus K_m} \sum_{c \in C_m} t_c y_c^k
\]

\[
- \tilde{S}_m \leq S_m + S'_m \leq \tilde{S}_m
\]

Time credit (+) or debit (-)

Without memory if =0
With memory if >0

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The problem: customer balance

the difference between the number of customers acquired and conceded by company $m$

$$U_m = \sum_{k \in K_m} \sum_{c \in C \setminus C_m} p_c y_c^k - \sum_{k \in K \setminus K_m} \sum_{c \in C_m} p_c y_c^k$$

$$-\tilde{U}_m \leq U_m + \tilde{U}'_m \leq \tilde{U}_m$$

Customer credit (+) or debit (-)

Without memory if $=0$
With memory if $>0$
Adaptive large neighborhood search

while $T_{\text{max}} > 1$ do
  - $q := \text{resizeNeighborhood}(E, w, q, q_{\text{min}}, q_{\text{max}}, p)$;
  - Draw a destroy and a repair operator;
  - Destroy the current solution $x$;
  - Repair the destroyed solution and obtain $x'$;
  - if $\text{cost}(x') \geq \text{cost}(x^*)$ then
    - $w = w + 1$;
    - $u$ randomly drawn in $U(0, 1)$;
  - if $u < e^{\frac{\text{cost}(x^*) - \text{cost}(x')}{T_{\text{max}}}}$ then
    - $x = x'$;
    - if $\text{cost}(x') < \text{cost}(x^*)$ then
      - $x^* = x'$;
      - if $r > R$ then
        - $r = 0$;
        - Set destroy and repair operators’ scores to initial values;
      else
        - Update destroy and repair operators’ scores
      - $r = r + 1$;
    - $T_{\text{max}} = T_{\text{max}} \cdot \gamma$;
  - return $x^*$;

A worse solution may be accepted (with decreasing probability)
Instances

Map-based 142 instances (real travel time with Graphhopper)

112 instances (2 to 10 companies, 4 to 10 customers)
  4 sizes
  7 demand scenarios per city

30 instances - Paris only – 5 different demand scenarios for:
  E1: 6 companies, 50 customers
  E2: 3 companies, 100 customers
  E3: 2 companies, 150 customers
  E4: 1 company with 150 customers, 3 with 50
  E5: 1 company with 150 customers, 1 with 100, 1 with 50
  E6: 1 company with 200 customers, 2 with 50
Savings on large instances

Acceptable % of more or less time or customers

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<th>$\alpha$ (%)</th>
<th>Group E</th>
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Reduction of emissions: 15%

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Coordination of sat-navs
Coordination of sat-navs
Coordination of sat-navs
Traffic assignment

Long paths for some drivers vs Minimum total travel time

User-equilibrium vs System-optimum

Selfish behaviour (Nash equilibrium, no one can switch to a path of smaller cost) vs Congestion
Coordination of sat-navs

\[ t^{FF}_{ij} \left[ 1 + 0.15 \left( \frac{x_{ij}}{u_{ij}} \right)^4 \right] \]

Travel time on arc \((i,j)\) with flow \(x_{ij}\)

Min Total travel time

on paths of limited length

Non linear optimization problem

on an exponential number of paths
Coordination of sat-navs

Min Total travel time (piecewise approximation)

LP and MILP with exponential number of binary variables
(FP-UC-SO and L-UC-SO)

Angelelli, Morandi, Savelsbergh, Speranza, EJOR, 2021
Angelelli, Morandi, Speranza, COR, 2019 and 2020
Coordination of sat-navs

Reduction of emissions: 20%
The future

Ridesharing in the sky
The future