Designing Urban Omni-Channel Distribution Networks
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Introduction

RESEARCH CONTEXT
We consider urban last-mile distribution from two complimentary perspectives

**Better logistics for cities.**

**Better cities for logistics.**
Our research will focus on three major building blocks

**Distribution Network Design**
- Multi-tier urban distribution network design
- Multi-/omni-channel distribution
- Mixed integer programming
- Continuous approximation
- Stochastic optimization
- Optimization heuristics
- Simulation

**Urban Freight Policy**
- Freight policy and regulation
- Infrastructure investments
- Public Private Partnerships
- Best practices for urban freight
- Analysis of socio-economic, infrastructural, operational data
- Data visualization
- Simulation

**Data & Technology**
- Low-cost sensor technologies
- Big Data
- Robotics and automation
- Alternative vehicle technologies
- Augmented reality
- Analysis of socio-economic, infrastructural, operational data
- Data visualization
- Machine learning
- Simulation, optimization

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Motivation
We support companies in implementing multi-channel distribution strategies.

- **Traditional Retail Location**
- **Convenience Store / Nanostore**
- **Automated Package Station**
- **Home Delivery**

**Manufacturer**

**Customers**
Modeling approach

MULTI-TIER, MULTI-CHANNEL DISTRIBUTION NETWORK DESIGN
We model competition among distribution channels to inform network design

**Concentration point (CP):**
- delivery facility in which part of the surrounding demand is concentrated
- various CP-levels: retail store, convenience store, package station, ...

**Scenario-specific data preprocessing**

- Home-delivery failure rate
- Base end-customer demand density
- Concentration point (CP) levels and locations
- CP service areas
- Demand density “balancing”
- Effective home-delivery demand density
- CP specific cumulated demand volume
- Service area specific CP densities and CP demand volumes
- Generalized 2E-CLRP with routing cost estimation (ARCE)
- Optimization
We model channel competition using a capacity-constrained gravity model.

CP demand attraction rate

Customer distance from CP

CP #1  CP #2
If CPs have sufficient capacity, customers choose closest preference

Customer distance from CP

CP demand attraction rate

CP #1  CP #2
Capacity limitations of the CPs let customers choose less preferred channels.

CP demand attraction rate

Customer distance from CP

Optimization: Attract as much demand as possible while respecting all CP capacities.
We aim at modeling network designs and physical delivery processes closer to reality.

Most existing approaches

**Single-echelon system**

- CDC: City Distribution Center
- POD: Point of Demand

**Two-echelon system**

- CDC: City Distribution Center
- ID: Intermediate Depot
- POD: Point of Demand

More realistic approach

**Mixed multi-echelon system with multiple CDCs**

- CDC: City Distribution Center
- ID: Intermediate Depot
- POD: Point of Demand

We model multi-tier distribution networks using mixed-integer linear programming

**Decision variables**
- active CDC locations
- active ID locations
- facility influence areas: assignment of city segments to CDCs / IDs
- modal choice: assignment of city segments to vehicle types

**Constraints**
- feasibility of solution
- limited vehicle carrying capacities
- limited ID capacities
- limited CDC capacity
- enforced active facilities (brownfield optimization)
- bounds to number of IDs

**Optimization objective**
Minimization of total cost of operation
- routing cost
  - closed-form approximation required for tractability
- vehicle / equipment cost
- facility capacity cost
- facility fixed cost
- handling cost

We use industrial solver algorithms to find an optimum network design.

**Decision variables**

\[ a^C = \{a^C_c\} \]
\[ a^{C,H} = \{a^{C,H}_{c,b}\} \]
\[ a^D = \{a^D_d\} \]
\[ S^L = \{S^L_{c,i,l}\} \]
\[ S^S = \{S^S_{d,i,s}\} \]
\[ S^D_{d,i,s}, S^L_{c,i,l}, a^D_d, a^C_c, a^{C,H}_{c,b} \in \{0,1\} \]

**Optimization objective**

\[
K^T \left( a^C, a^{C,H}, a^D, S^L, S^S \right) \\
= K^{R,S}(S^S) \\
+ K^{H,S}(a^{C,H}) \\
+ K^{R,L}(S^L) \\
+ K^{S,R,L}(S^S) \\
+ K^{S,H,L}(a^{C,H}) \\
+ K^L(S^L) \\
+ K^I(a^C, a^D) \\
+ K^h
\]

**Constraints**

\[
\sum_d S^S_{d,i,s} = 1, \quad \sum_c S^L_{c,i,l} = 1 \quad \forall i
\]
\[
S^S_{d,i,s} - a^D_d \leq 0, \quad S^L_{c,i,l} - a^C_c \leq 0 \quad \forall d, c, i, s, l
\]
\[
\sum_b a^{C,H}_{c,b} - a^C_c = 0 \quad \forall c
\]
\[
a^D_d \geq \tau^D_d, \quad a^C_c \geq \tau^C_c \quad \forall d, c
\]
\[
\sum_d a^D_d \geq b^{D,l}, \quad \sum_d a^D_d \leq b^{D, i,b} \quad \forall d
\]
\[
\sum_i S^S_{d,i,s} S^S_{c,i,s} \zeta^v_d \leq \zeta^C_d \quad \forall i,\forall s
\]
\[
\sum_i \sum_l S^L_{c,i,l} q_{c,i,l} \zeta^l_i + \sum_b \max \left[ q_{c,b}^{H,S,D}, q_{c,b}^{H,S,P} \right] a^{C,H}_{c,b} \zeta^v_b \leq \zeta^C_c \quad \forall c
\]


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Real-world application

THE CASE OF ZARA IN MADRID
We apply our model to the case of ZARA’s fashion retail business in Madrid

ZARA
- Leading INDITEX brand in Spain
- 323 stores across Spain in a total of 1822 INDITEX brand stores

Madrid City
- 3.5M inhabitants
- 444 city segments of 1 square kilometer

Distribution channels
- Retail stores: ZARA (21 CPs), other INDITEX stores (97 CPs)
- Convenience stores: REPSOL stations (14 CPs)
- Automatic Post Stations: CORREOS (112 CPs)
- Home deliver: Madrid city divided in km² (444 segments)

CDC and Depots locations
- CORREOS network
- Use of Google street view to analyze the location feasibility
We parameterize our model using publicly available data and reports

- Transport cost (ACOTRAM)
- Facilities cost (adapted from a real-world case study)
- Demand (2014) estimation based on daily online sales (Euromonitor report)
- 5 years online estimation (2019) based on Euromonitor report predictions
- Creation of 2 scenarios:
  a) only ZARA stores for pick ups
  b) all INDITEX stores for pick ups
- Both scenarios were run for:
  c) 2014, online retail share of 4.1%
  d) 2019, online retail share of 20%

Euromonitor 2014 in EUR (Retail + online retail)

<table>
<thead>
<tr>
<th>Spain retail ONLINE sales</th>
<th>Spain retail sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 696M</td>
<td>3.1%</td>
</tr>
<tr>
<td>x0.012</td>
<td>182 700M</td>
</tr>
<tr>
<td>68M</td>
<td>4.1%</td>
</tr>
<tr>
<td>6.54% Pop Spain</td>
<td>1 644M</td>
</tr>
<tr>
<td>4.4M Zara online Madrid</td>
<td>109M Zara Madrid</td>
</tr>
</tbody>
</table>

Average online shop = 50€
52 weeks and 5 week day

338 items/day
Visualization of model results: most preferred distribution channel by area

a) Only ZARA stores (20)
b) all INDITEX network of stores (118)
Visualization of model results: all four channels served by separated networks

- When the number of retail stores increase, a 2-echelon system is preferred (more bikes are used)
- When the number of retail stores increase, the preference for conv. store decrease. The network remain stable
- When the number of retail stores increase, the capacity of capturing demand by the APS decreases, the network change from 2-echelon to 1-echelon system
- Same network facility, only more number of vehicles are needed when demand increased
RESULTS: Omni-channel solution – all four channels within an unique network

- **Scenario 1**: Only ZARA stores
  - 2014 estimation: $4,606
  - 2019 estimation: $8,985

- **Scenario 2**: All INDITEX stores
  - 2014 estimation: $4,869
  - 2019 estimation: $9,208

- Same number of facilities in the 4 scenarios
- The location of the CDC and ID change when demand increase (moves close to centers of demand).
- CDC moves to a more centric area
- When the number of retail stores increase, more segments are reached using a 2-echelon network
Conclusions

- A multi-echelon location-routing model is a useful tool to design omnichannel distribution networks
  - To support companies in choosing which channel offer to their customers
  - To support companies in choosing their distribution strategy

- Omnichannel solution reduce the total network cost more than 50% in 2014 scenario, and around a 40% in 2019 scenario.
  - A better use of resources (e.g. sharing facilities among different channels)
  - Regarding vehicles:
    » A reduction of 20% on the number of Vans
    » An increase of 33% of the number of bikes

- Demand attraction: once the number of retail stores increase (scenario 2), attraction to convenience stores and APS decrease.

- For future networks, with higher demand (20% vs. 4%):
  - An increase of 5 times in demand, only increase 2 times the total omnichannel network cost.
  - Facility and vehicles capacity constraints explains a smaller cost reductions when using the omnichannel network.
Thank you.

Questions?

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