Lives Saving Logistics for Emergency Services

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Short Resume

1991  M.Sc. in Mathematics and Econometrics VU A’dam
1995  Ph.D. in Queueing Theory
1996-2000  AT&T Bell Labs USA
2000-2002  KPN Research
2002-2004  TNO ICT
Since 2003  Full Professor in Applied Mathematics at VU A’dam
Since 2004  Centrum Wiskunde & Informatica
Over the Past 25 Years...

Over the years:
100+ consultancy projects, 100+ R&D projects, 60+ Ph.D. students, 100+ M.Sc. students

Topics of interest: emergency logistics, healthcare logistics, RM & pricing, telecommunication networks, mobility, AI for suicide prevention, defense
Huibregtsen Award 2021

• “Mathematics for a Safer and Healthier World”

• Review report: “This is really on-street Mathematics”
Data, Forecasting and Optimization

- Data mining
- Machine learning
- Neural networks
- Artificial intelligence
- Pattern recognition
- Predictive analytics
- Statistics

optimization models

- Operations Research
- Stochastic Optimization

insights and forecasting

data analytics

data
Lives Saving Logistics for Emergency Services

Plan for today:
1. Examples of success stories
   - When every second counts: ambulance, firefighters
   - Predictive policing
   - Waiting times in acute elderly care
   - Real-Time reporter
2. Questions and discussion
Ambulance Care in NL

**A1-calls:** Urgent and life threatening
• severe incident  

**A2-calls:** Urgent but not life-threatening
• broken leg  

**B-calls:** Planned transport
• ‘taxi’ transport between hospital and care center or home

**Requirement:** 95% within response-time deadline

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Ambulance Care in NL

Facts:
- 1 million calls per year, out of which 500,000 A1-calls
- 35,000 times (7%) the 15-minute target is not met
- Growing demand (‘groeiente zorgvraag’)

New and powerful concept:
Dynamic Ambulance Management: proactive planning
Wiskunde redt levens
Kansberekening en modelering moeten ambulanceplanning in Amsterdam verbeteren

Ambulance is vaker op tijd dankzij de wiskunde.

Ambulances kunnen veel tijdwinst boeken
De licht van ambulances kan veel beter worden genomen en de dienstverlening kan worden verbeterd.

‘Big Data’ helpt politie
Big Data is een krachtige tool voor de politie.

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Ambulance Service Process

112!

New incident happens

call center

‘Closest’ available ambulance allocated

base station

Ambulance departs

hospital

To closest base location

To closest hospital

Patient handed over

Medical treatment On-scene
Operations Research in Action
Playing Chess
Chess for Dummies
Chess for Professionals
Basic situation
(no incidents)
Proactive relocations after incidents in Almere (2) and Lelystad (1)
Simple Model

- Region subdivided in $N$ nodes (postal areas)
- Base locations
- Locations of hospitals
- **Next incident**: at node $i$ with probability $p_i$
- **Arrivals**: Poisson
- All incidents of highest urgency
- Travel distance matrix $R$ (fixed)
Simple Model

Phase 0
idle
at BS or relocating

Phase 1
travel
decision: where to send?

Phase 2
treatment

Phase 3
transport
to hospital

Phase 4
transfer

Relocation decision moments:

1: when ambulance is dispatched to newly incoming incident
2: when ambulance becomes idle → where to go?

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In Time or Not in Time..

Target: 12 minutes = 15 minus ‘time to finish coffee’

Based on expert opinion

\[
f(t) = \begin{cases} 
\frac{1}{5e^{-0.008(t-720)+5}} & 0 \leq t \leq 720, \\
\frac{4}{5} + \frac{1}{5e^{-0.008(t-720)+5}} & t > 720.
\end{cases}
\]
Single-Coverage Heuristic

**Basic idea:** minimize ‘unpreparedness’

- **System state:**
  for each ambu: (location/destination, phase)

- **Unpreparedness:**

  \[ U(s) := \sum_{i=1}^{N} f(\min\{r_i^0(s), r_i^4(s)\}) p_i \]

  - driving time from destination of closest phase-0 ambu to node i
  - expected time till closest phase-4 ambu is present at node i

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Single-Coverage Heuristic

“Coverage” of zipcode area:

- Time till closest ambulance present = 276 seconds
- Probability that next call is in that area = 0.033

\[ \text{‘Unpreparedness’} = f(276) \times 0.033 = 0.006 \times 0.033 = 0.00018 \]
Single-Coverage Heuristic (ct’d)

Example: unpreparedness in given situation = 0.49201

Sending an ambulance from Zeewolde to Lelystad reduces unpreparedness by from 0.49 to 0.29
Effectiveness of Relocations

**Good news:**
1. Only a **few relocations** really do matter
2. Doing ‘at least something’ already makes the difference (‘80/20-rule’)

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Real-Time Decision Making

weather circumstances

mass events

real-time traffic information
How to get to desired configuration?
Simultaneous Relocations

Idea: Move to ‘optimal’ configuration as quickly as possible

Tradeoff: Short time to ‘optimum’ versus number of movements

Solution: Linear Bottleneck Assignment Problem (LBAP)
Two Threshold Parameters

M: Maximum number of simultaneous relocations
Q: Minimum relative gain in unpreparedness

\[
q := \frac{U(s_{static}) - U(s_{opt})}{U(s_{static})} \times 100\% \quad (0 \leq q \leq 1)
\]

Here, ‘static’ means ‘no move’ (for phase 0) or ‘move to closest base location after incident’ (for phase 2 or 4)
Acceptance in Practice?

Acceptance of new concept only if

1. not too many relocations!
2. only at specific time epochs (e.g., departure from hospital)
3. performance is really better than ‘static’ solution
Proof of the Pudding...

Pilot with tool implementation

1. Our algorithms are well accepted and really used
2. More reliable / predictable performance
3. Strong reduction in late arrivals, while many more 112-calls!

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Operational Setting

Computer zet ambulances slimmer in
Our Seconds Application calculates the coverage of emergency services so that future incidents are reached within the set response time.
What Made the Difference?

Computer zet ambulances slimmer in Flevoland 2 juli 2017

Zo moeten ze sneller ter plaatse zijn

Martin van Buuren

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Lessons Learned

1. Not every researcher is a good entrepreneur!
2. Include software engineering expertise from the beginning
3. Presence of the research team during pilot phase crucial
Demand Changing over Time

Amsterdam in 1600

Amsterdam in 2020

Service region Amsterdam/Amstelland

- 21 incidents per day
- Duration 1 hour

Response time target: 5, 6, 8 or 10 minutes

Question: are base locations still properly located?
Mathematical Model

Assumptions

• set of demand locations (DL’s)
• multiple vehicle types k
• relative demand $d_{i,k}$ for DL i for type-k vehicles
• distance matrix
• set of potential locations for base stations
• number of available vehicles per type
• professional or volunteer stations
• response time targets: 5, 6, 8, 10
• option to ‘veto’ relocation at specific stations

• Repositioning of base locations
Optimization Model

Goal: Maximize expected coverage subject to constraints

Decision variables:
\[ x_{jk} = \text{#type-k vehicles at location } j \]

\[
\begin{align*}
\text{max } & \left\{ \sum_{i \in N} \sum_{k \in K} d_{ik} y_{ik} - \beta \sum_{j \in M} z_j \right\} \\
\text{subject to } & \sum_{j \in M_{ik}} x_{jk} \geq y_{ik} \quad \forall \ i \in N, \ k \in K \\
& \sum_{j \in M} x_{jk} \leq c_k \quad \forall \ k \in K \\
& x_{jk} \leq z_j \quad \forall \ j \in M, \ k \in K \\
& y_{ik}, z_j, x_{jk} \in \{0, 1\} \quad \forall \ i \in N, \ j \in M, \ k \in K.
\end{align*}
\]

Easy extension: inclusion volunteering stations

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Optimization Results

Coverage

<table>
<thead>
<tr>
<th># wijzigingen</th>
<th>TS</th>
<th>RV</th>
<th>HV</th>
<th>WO</th>
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<td>98.62</td>
<td>99.86</td>
<td>98.10</td>
<td>93.37</td>
<td>98.93</td>
</tr>
</tbody>
</table>

Observation

% late arrivals can be reduced by > 50% by relocating only 4 stations!

Letter by Commander in Chief:

"The results convincingly show that—and how—significant improvements of our service quality can be realized by easily implementable re-allocation of our resources. While pro-actively re-allocating current base stations is costly and time-consuming, we recognize the benefits improved coverage provides. We have successfully integrated results from the model into our decision making process, and will continue to do so.

"Furthermore, we have identified another process which can greatly benefit from optimizations the model provides. When during a large scale incident multiple base stations are being called upon, we are now able to re-allocate remaining resources (vehicles) to better positions to regain optimal overall coverage. Results from this project are to be implemented in the Spring of 2016."

→ next step: relocations during major incidents
Fighting Crime with Maths!
Predictive Policing

• **Goal**: reduction of *high-impact crimes*

• **Idea**: Allocation of man-power at ‘hot’ places

  • Cross-correlation with demo- and geographic factors

  • ‘Near-repeat’ phenomenon
Waiting Lists for Nursing Homes

Kamer ontevreden: wachtlijsten verpleeghuizen flink langer dan verwacht
NOS, 15-01-2020

'Druk op mantelzorgers'
Nu.nl, 14-12-2019

Maanden wachten op de juiste zorg: 'Mijn patiënt overleed op de wachtlijst'
Nieuwsuur, 26-11-2019
"DOLCE VITA": Challenges in Acute Elderly Care

DE UITDAGINGEN IN ACUTE OUDERENZORG IN DE KOMENDE 10 JAAR

1.300.000 ouderen van 75+ 2018
Op elke oudere 4 werkenden
800.000 ouderen bezoeken jaarlijks de SEH
280.000 ouderen jaarlijks acuut opgenomen

2.100.000 ouderen van 75+ 2030
Op elke oudere 2 werkenden
1.100.000 ouderen bezoeken jaarlijks de SEH
390.000 ouderen jaarlijks acuut opgenomen

+60%
-50%
+40%

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Patient Journey

Patient journey through care supply system

Legend:
- = no significant bottlenecks in transfer
- = some concerns in transfer
- = significant bottlenecks in transfer

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Excessive Waiting Times

1. High fractions of older people in need of institutional care that are currently on a waiting list
   - 16% in the Netherlands
   - 30% in Slovakia
   - 47% in Lithuania

2. 16% of older adults in Spain die on the waiting list

3. Regional shortages: Copenhagen, waiting time > 3.5 years

Cause for long waiting times: preferences for nursing homes
Balancing Trade-off

+ include personal preferences
- inefficient use of beds

+ efficient use of beds
- no individual preferences

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Current Way of Working

• Older adults typically apply for **one nursing home**

• They **wait at home** until a bed becomes available → probably placed in a **temporary** nursing home

• Hardly any coordination!

• **Our approach:** centralized approach using allocation model
Toy Example

(1) Preferences of patients

![Diagram showing preferences of patients with rooms and availability]

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(2) Transitions between care centers

Toy Example
(2) Transitions between care centers

Toy Example
Toy Example

(3) Increase in urgency

Day 1

Day 90

NORTH
WEST
- EAST

NORTH
WEST
+ EAST

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Toy Example

(4) Transition to preferred nursing home
Allocation Model

- Patient preferences are defined as **utility functions**
- **Allocation model** maximizes the utility of all patients
- Simulation model to test quality of outcomes

**Optimization model**

\[
\max \sum_{p \in P} \sum_{n \in N} u_{pn}(l_p, w_p) x_{pn}
\]

subject to

\[
\sum_{p \in P} x_{pn} \leq c_n \quad \forall n \in N
\]

\[
\sum_{n \in N} x_{pn} = 1 \quad \forall p \in P
\]

\[
x_{pn} \in \{0, 1\} \quad \forall p \in P, n \in N.
\]
Results for Amsterdam

- **Current practice:**
  - Waiting time till placement 211 days (232 till preferred)

- **Assignment model with 1 preferred care center:**
  - Waiting time till placement 51 days (177 till preferred)

- **Assignment model with 2 preferred care centers:**
  - Waiting time till placement 33 days (105 till preferred)

**Centralized approach:**
1. Includes individual preferences
2. Dramatic reduction in waiting time
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Incident Management on our Railways
Balancing preventive and corrective maintenance tasks

bad coverage

good coverage
Application

- Given set of employees and tasks

- **Calculate schedule** with the optimal (weighted expected) response time

- Combines ambulance coverage models and *travelling salesman problem*

**Currently:** operational in whole Netherlands

**Result:** 31% more preventive tasks and 14% less waiting times
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Real-Time News

Jānis Krūms @jkrums

http://twilpic.com/135xa - There's a plane in the Hudson. I'm on the ferry going to pick up the people. Crazy.
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