# Lives Saving Logistics for Emergency Services

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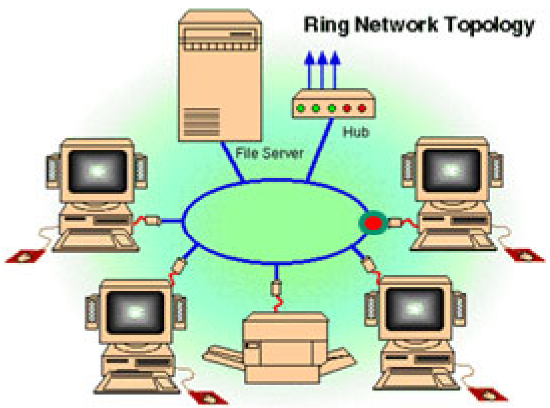
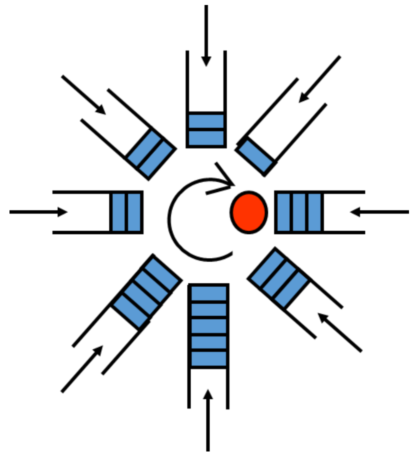
**Thanks to:** Karen Aardal, Caroline Jagtenberg, Pieter van den Berg, Thije van Barneveld, Theresia van Essen, Martin van Buuren, Sandjai Bhulai, Coen Huibers, Lisette Sloof, Guido Legemaate

IARIA DataSys congress, Porto, June 28, 2022

# 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

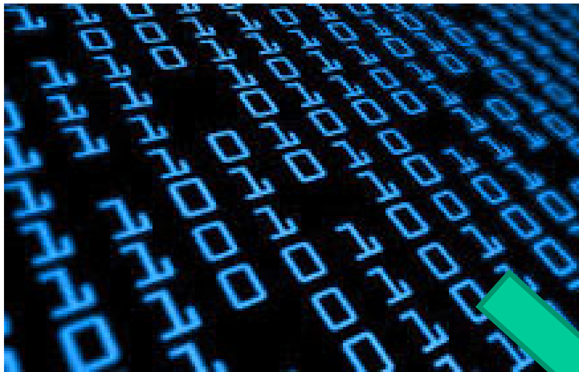
# Huibregtsen Award 2021



- **“Mathematics for a Safer and Healthier World”**
- **Review report:** **“This is really on-street Mathematics”**

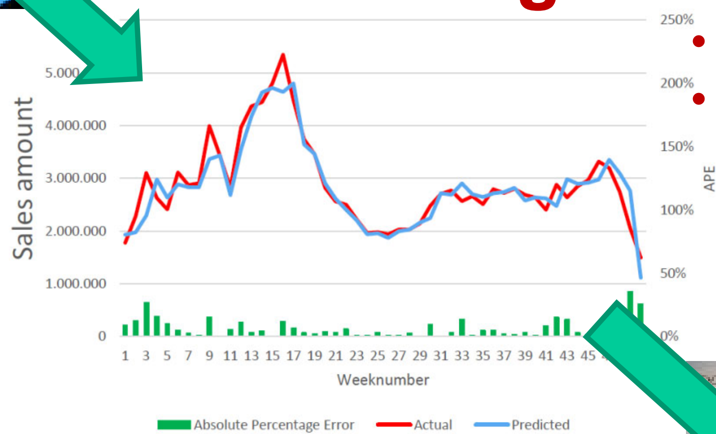
# Data, Forecasting and Optimization

## data



## insights and forecasting

**data analytics**




- Operations Research
- Stochastic Optimization

## optimization

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

**optimization models**

# 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**


Pictures from veiligheidsregio Noord-Holland Noord

# Ambulance Care in NL

**A1-calls: Urgent and life threatening** **< 15 min**

- severe incident

**A2-calls: Urgent but not life-threatening**

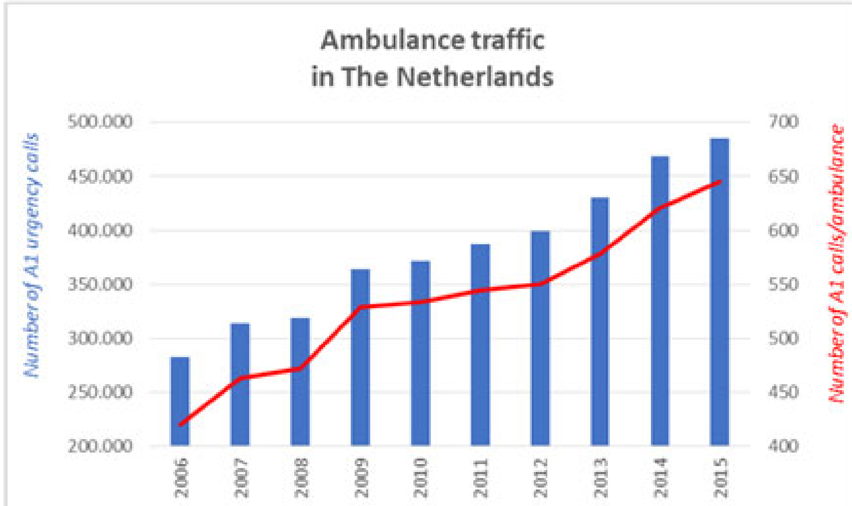
- broken leg **< 30 min**

**B-calls: Planned transport**

- 'taxi' transport between hospital and care center or home

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

# Ambulance Care in NL



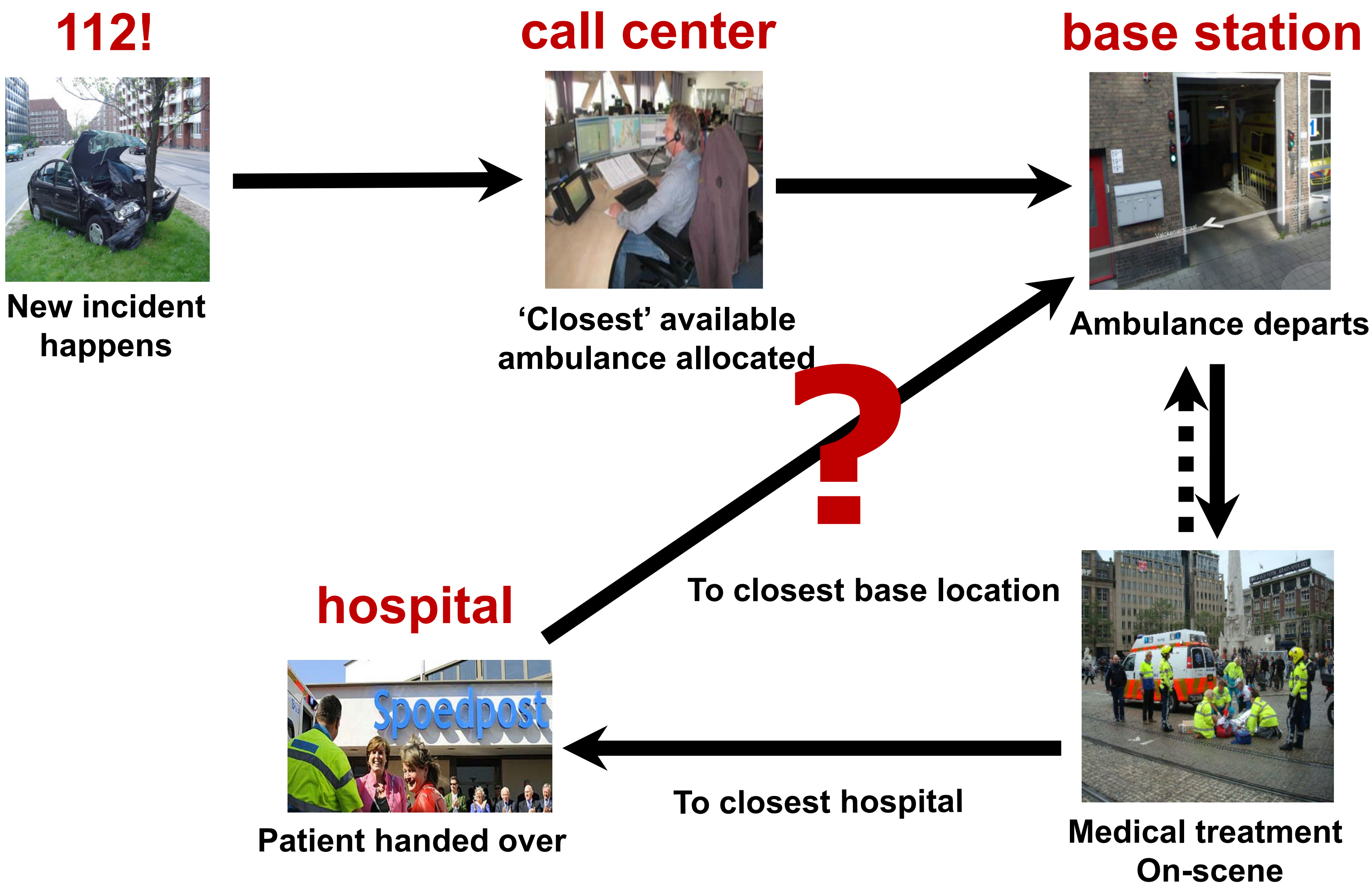

**Facts:**

- **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 ('groeiende zorgvraag')**

**New and powerful concept:**
**Dynamic Ambulance Management: proactive planning**

# REPRO : from Reactive to Proactive

# Ambulance Service Process



# Operations Research in Action

# Playing Chess

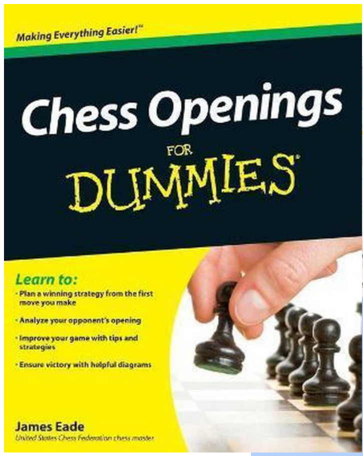

CWI

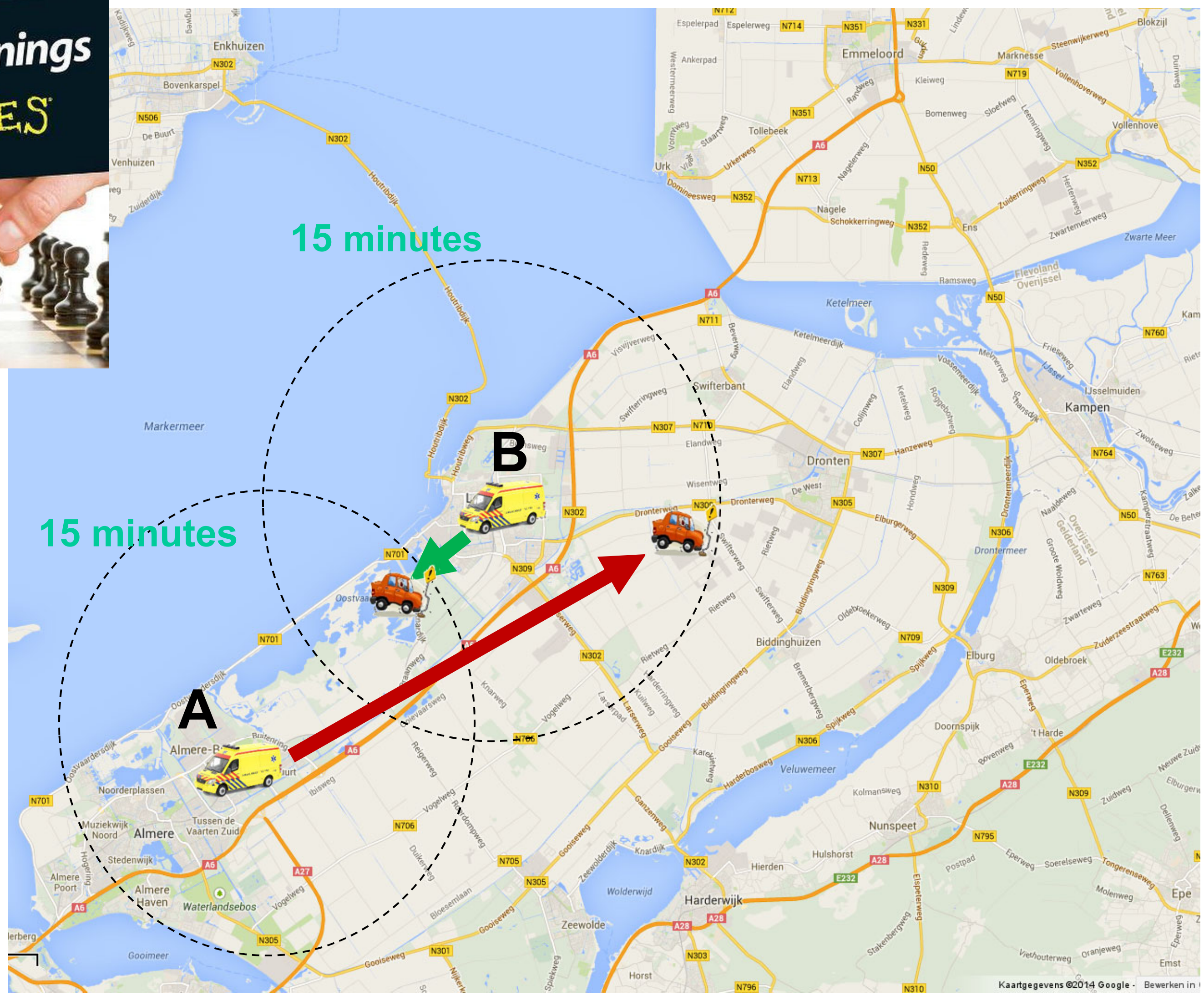
connexxion

Flevoland

rivm

# Chess for Dummies

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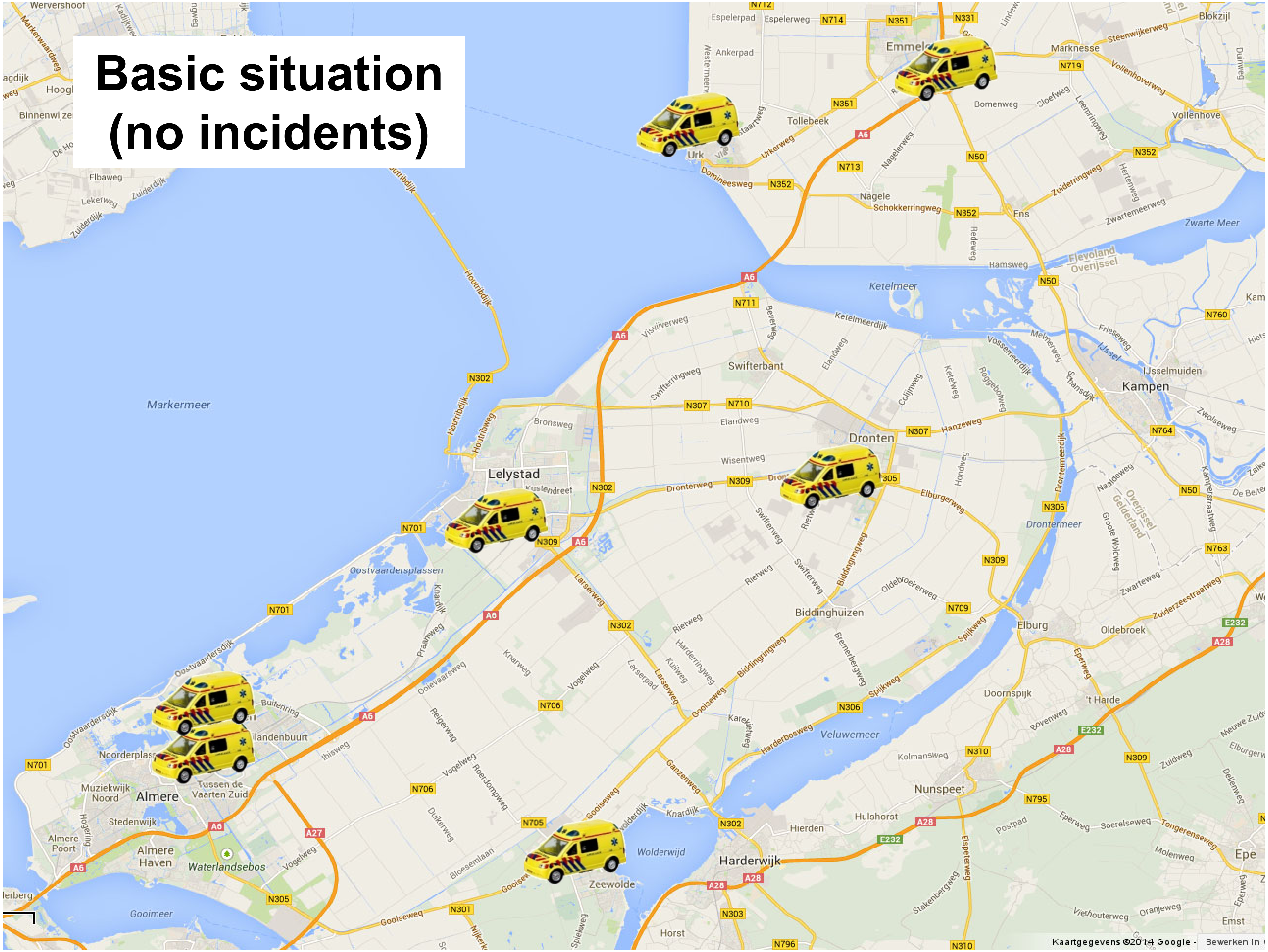
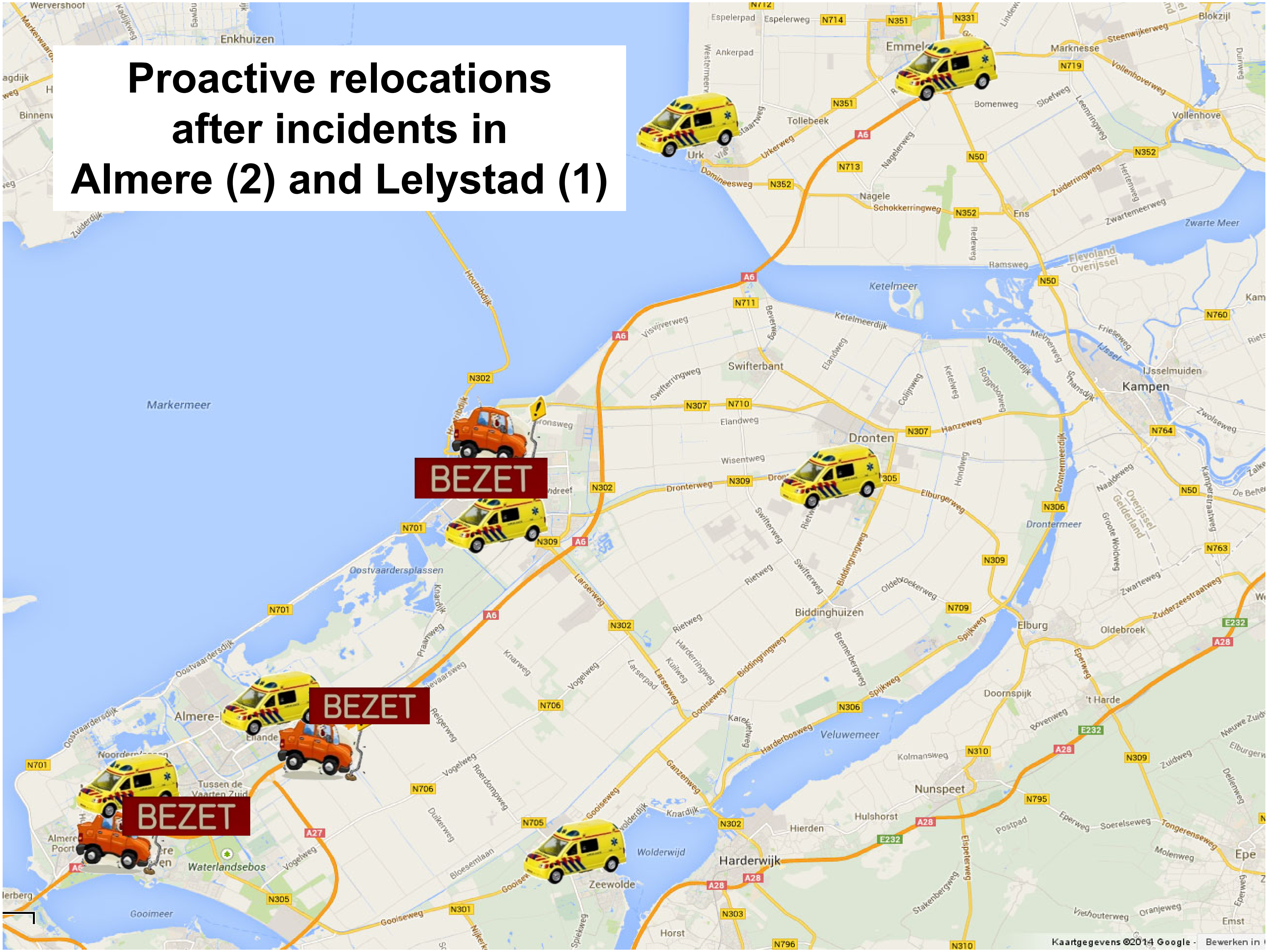
# Chess for Professionals

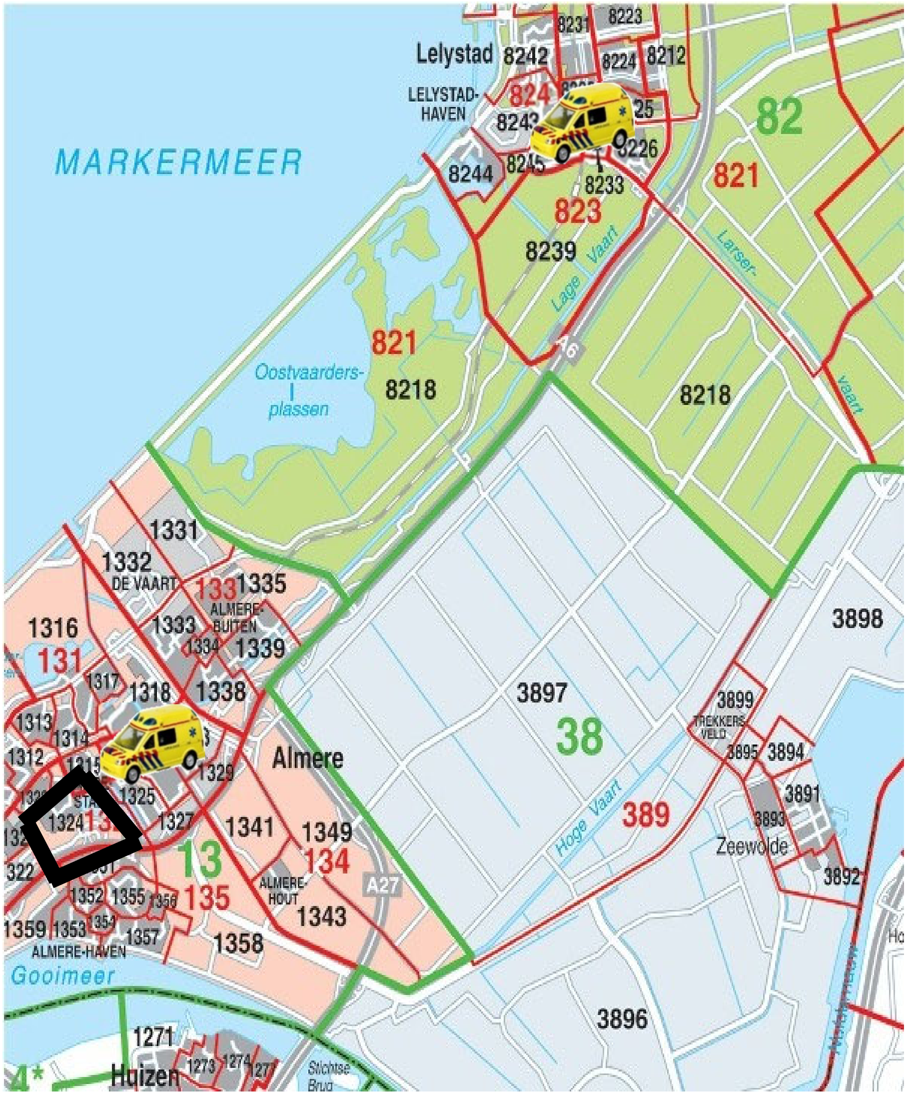
# Basic situation (no incidents)



# 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** → Phase 1: **travel** → Phase 2: **treatment** → Phase 3: **transport** → Phase 4: **transfer**

idle: at BS or relocating

transport: to hospital

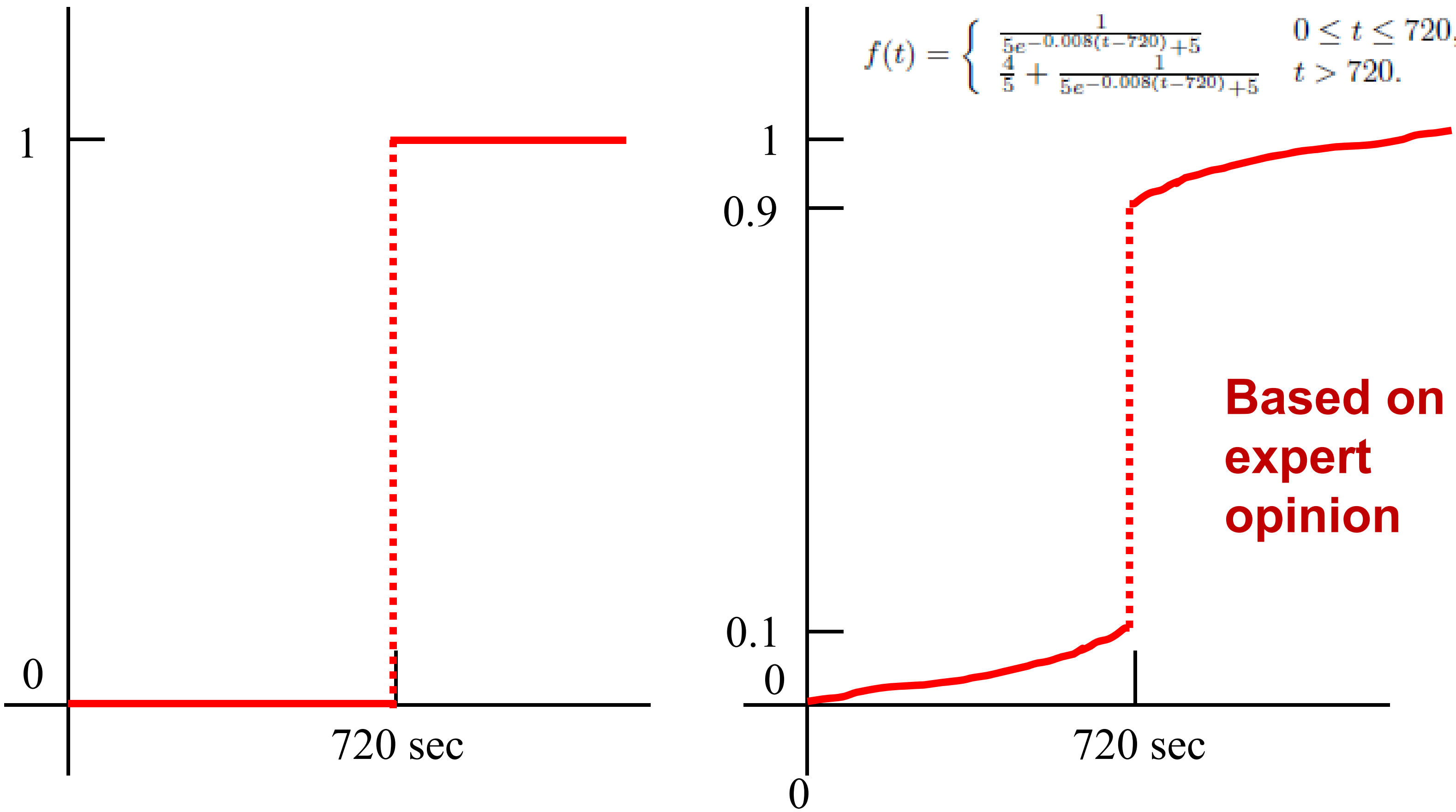
decision: where to send?



## Relocation decision moments:

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

# In Time or Not in Time..




$$f(t) = \begin{cases} \frac{1}{5e^{-0.008(t-720)}+5} & 0 \le t \le 720, \\ \frac{4}{5} + \frac{1}{5e^{-0.008(t-720)}+5} & t > 720. \end{cases}$$

**Target: 12 minutes = 15 minus 'time to finish coffee'**

# Single-Coverage Heuristic

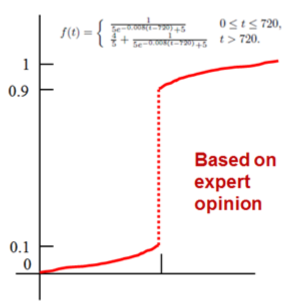
**Basic idea: minimize ‘unpreparedness’**

- **System state:**

  for each ambu: (location/destination, phase)

- **Unpreparedess:**

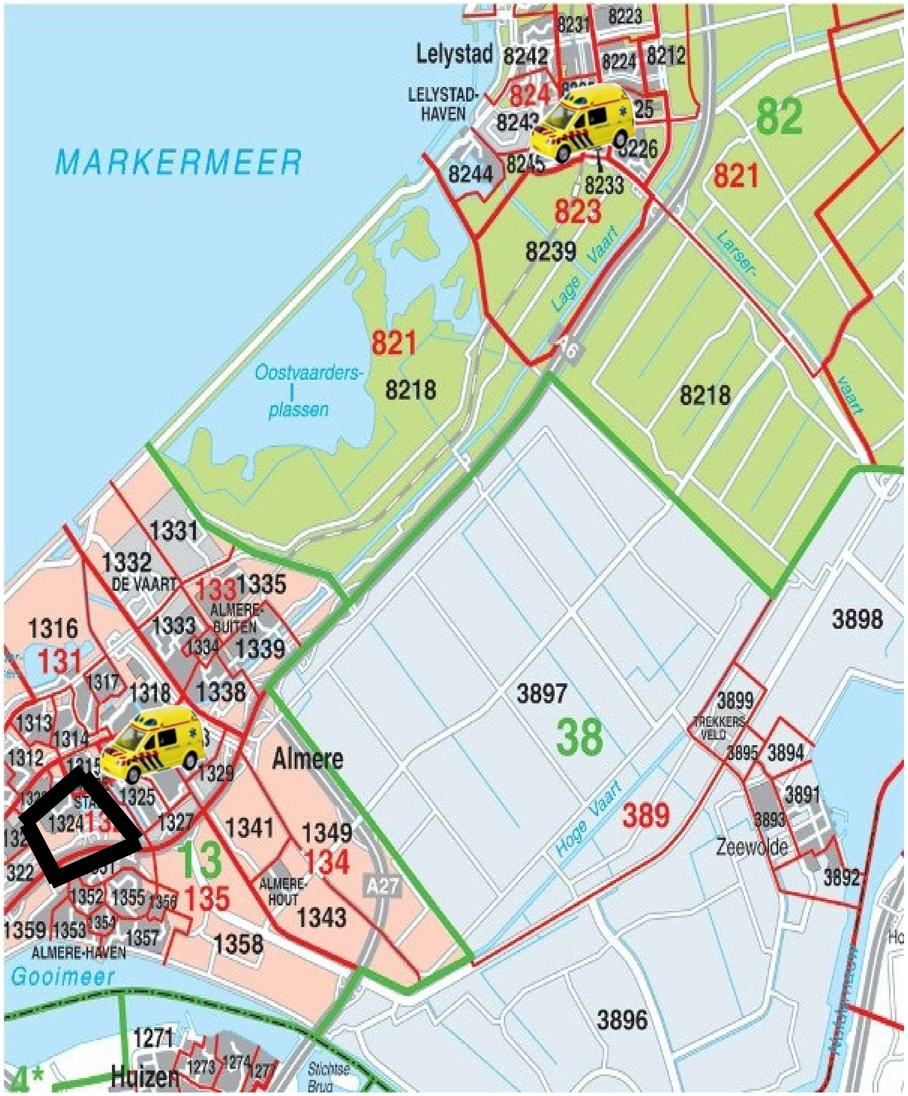
$$U(s) := \sum_{i=1}^{N} f\left(\min\{r_i^0(s), r_i^4(s)\}\right) p_i$$




**driving time from destination of closest phase-0 ambu to node i**

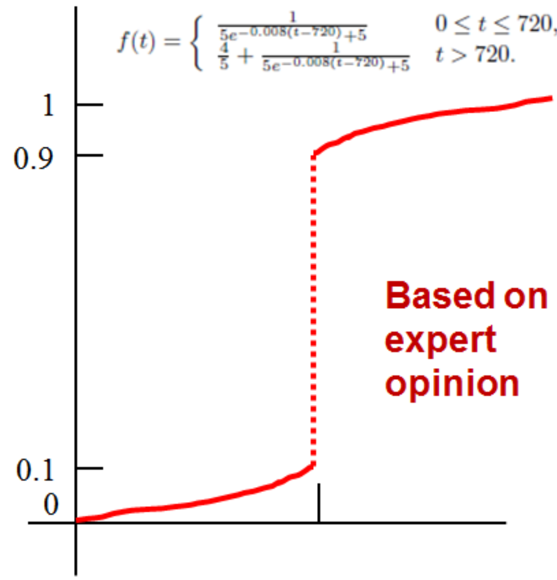
**expected time till closest phase-4 ambu is present at node i**

# Single-Coverage Heuristic




**"Coverage" of zipcode area:**

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




'Unpreparedness' = f(276) x 0.033
= 0.006 x 0.033 = 0.00018

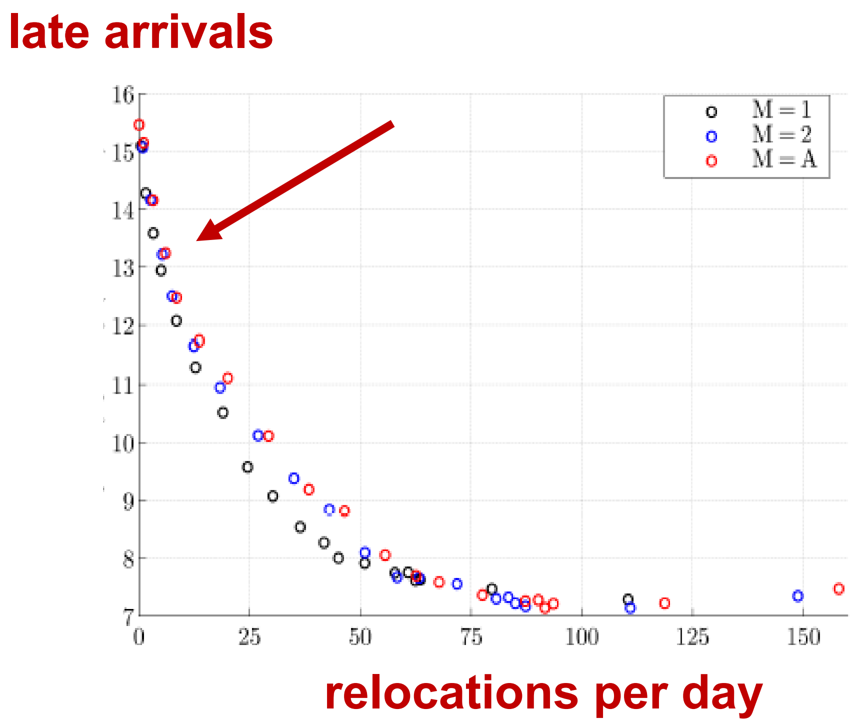
# Single-Coverage Heuristic (ct'd)


| | A | L | Z | D | E | U |
|---|---|---|---|---|---|---|
| A | 0.49201 | 0.71491 | 0.95077 | 0.8746 | 0.80672 | 0.82788 |
| Z | 0.52587 | 0.29001 | 0.49201 | 0.44969 | 0.38181 | 0.40297 |

**Example:** unpreparedness in given situation = 0.49201

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

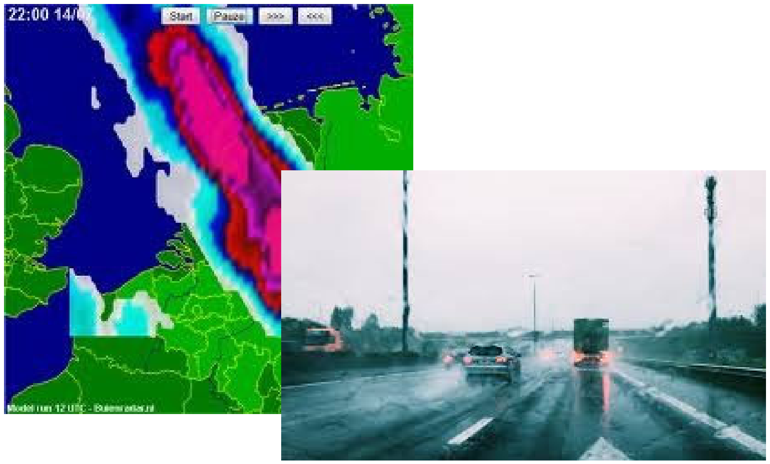
# Effectiveness of Relocations



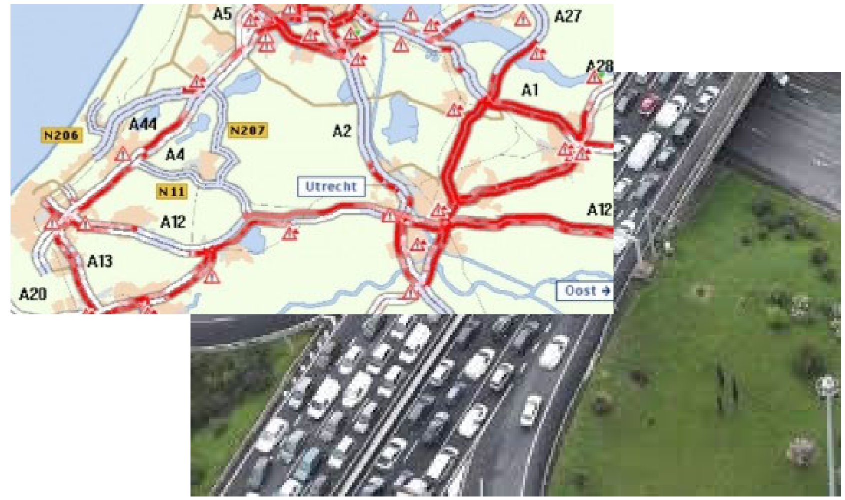

**Good news:**

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

# Real-Time Decision Making




**weather circumstances**

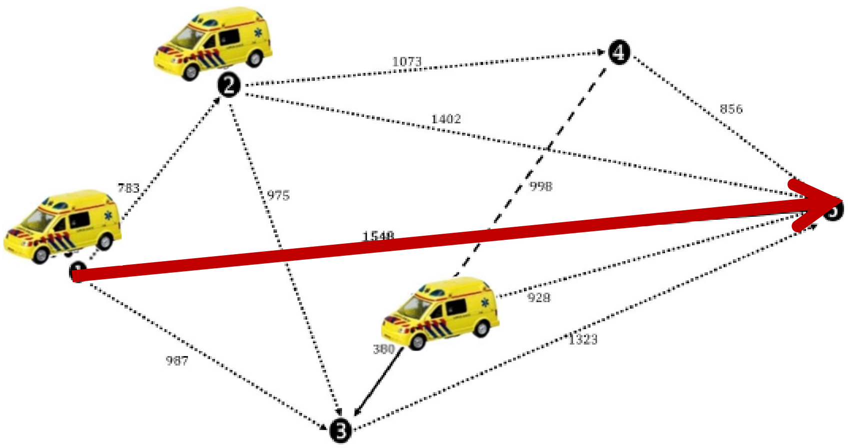


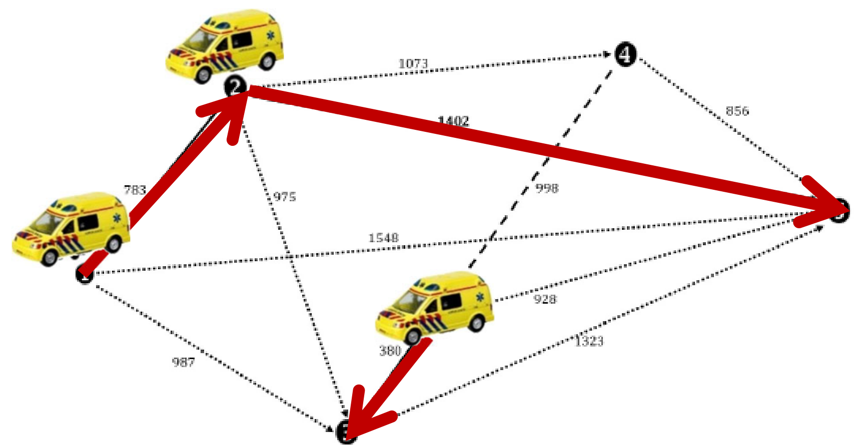

**real-time traffic information**

**mass events**

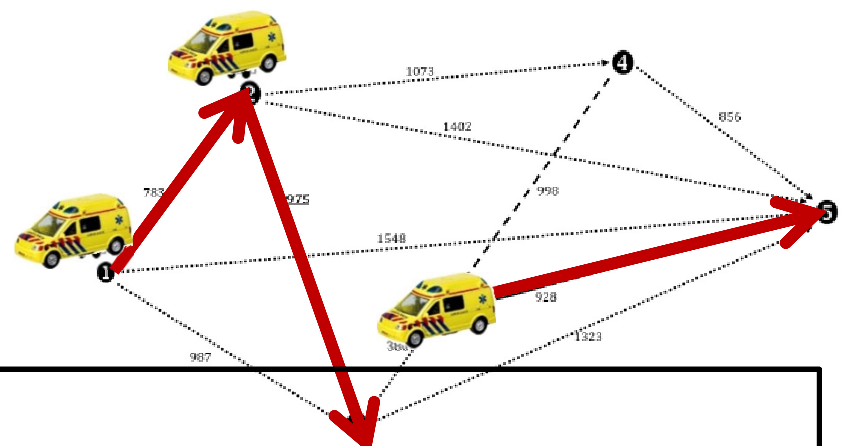
# How to get to desired configuration?

# Simultaneous Relocations




**Idea: Move to 'optimal' configuration as quickly as possible**

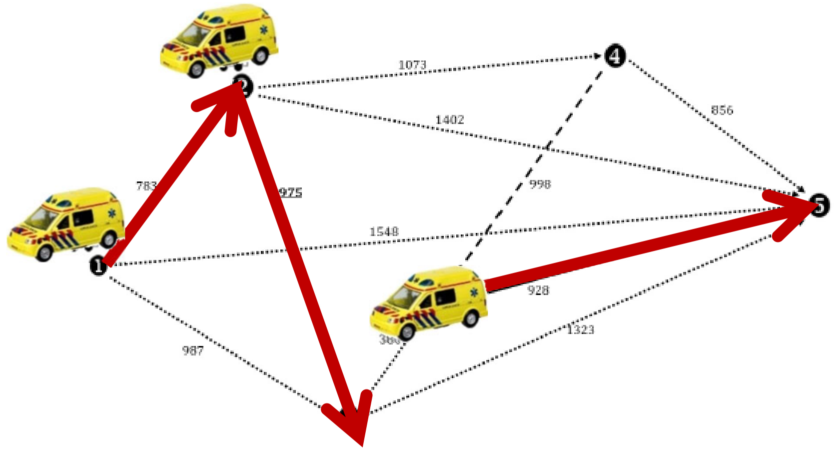



**Tradeoff:**

**Short time to 'optimum' versus number of movements**

**Solution: Linear Bottleneck Assignment Problem (LBAP)**

# Two Threshold Parameters





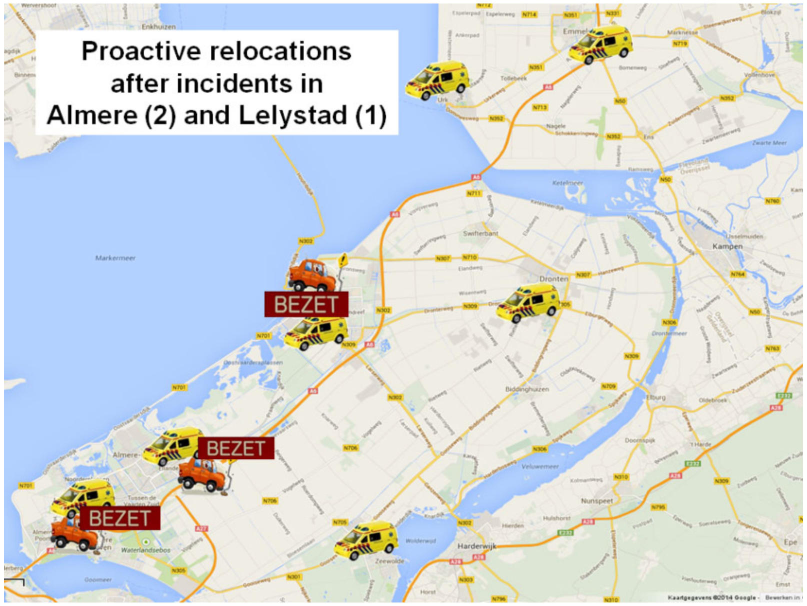
**M: Maximum number of simultaneous relocations**

**Q: Minimum relative gain in unpreparedness**

$$q := \frac{U(s^{static}) - U(s^{opt})}{U(s^{static})} \times 100\% \quad (0 \le q \le 1)$$

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

# Acceptance in Practice?

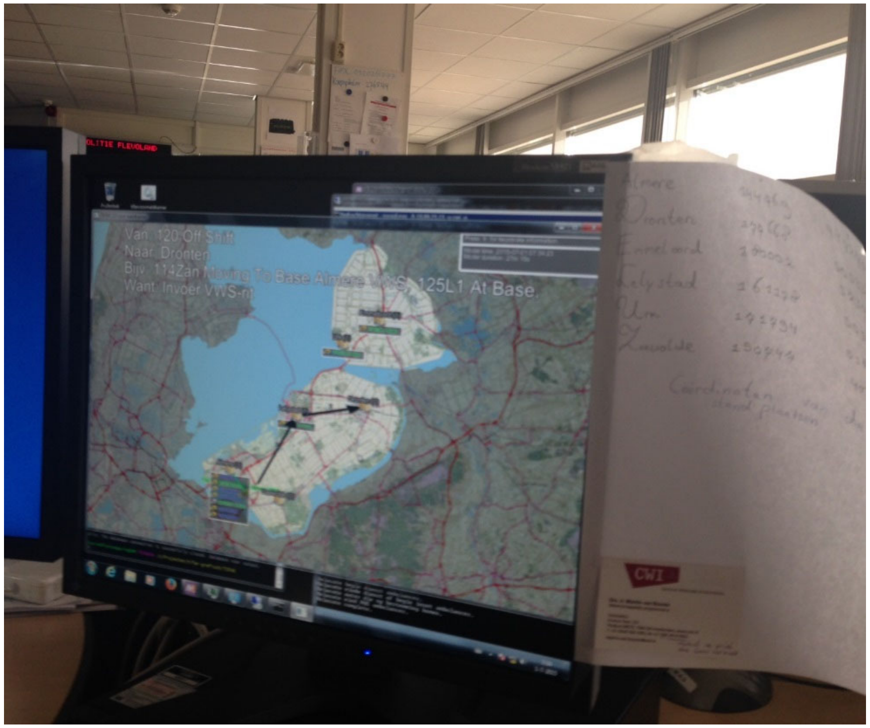




**Acceptance of new concept only if**

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…



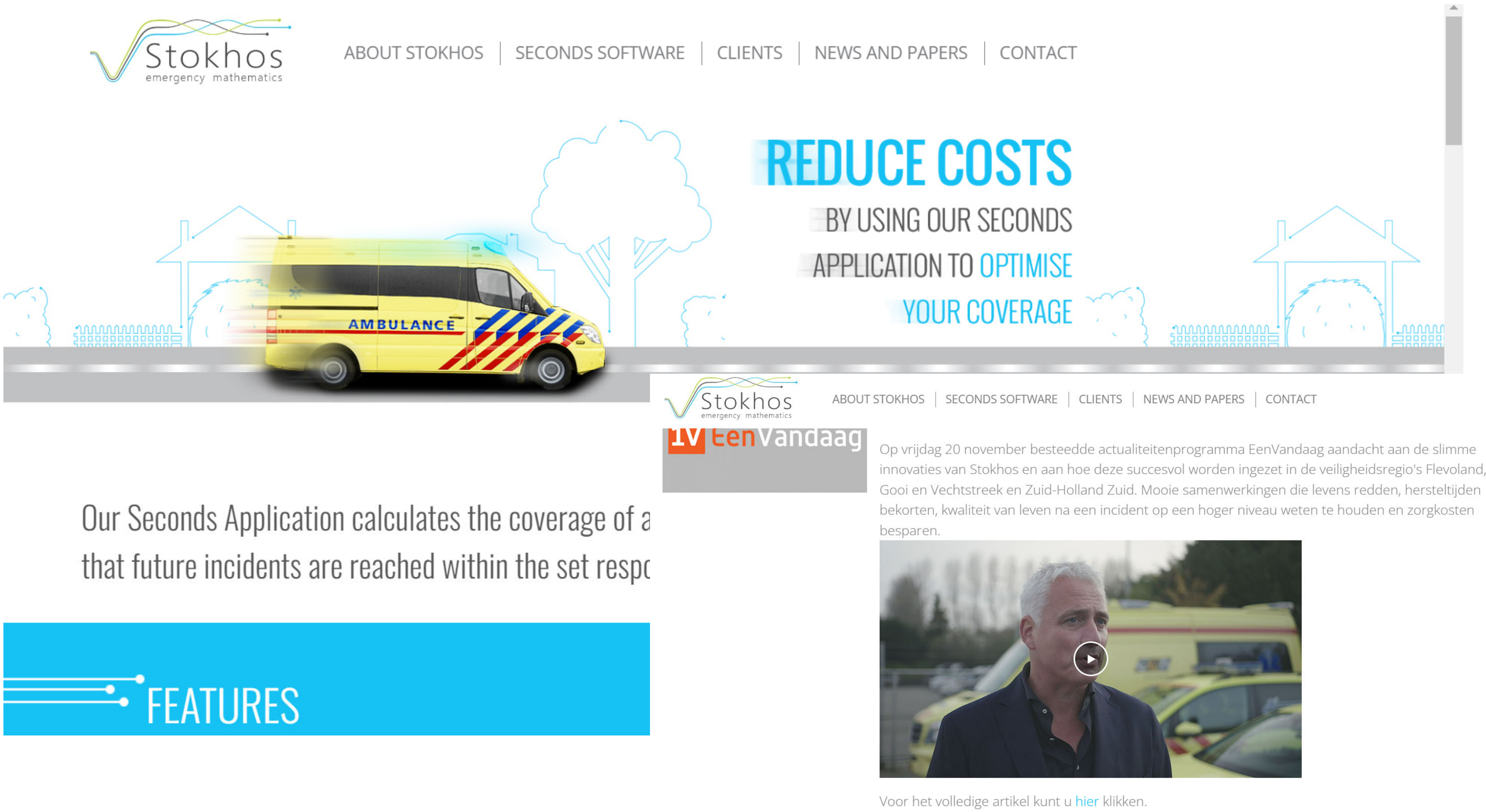

## Pilot with tool implementation

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!**

# Operational Setting

## Computer zet ambulances slimmer in

# Stokhos Emergency Mathematics




IARIA DataSys congress, Porto, June 28, 2022

# What Made the Difference?


Martin van Buuren

IARIA DataSys congress, Porto, June 28, 2022

# Lessons Learned

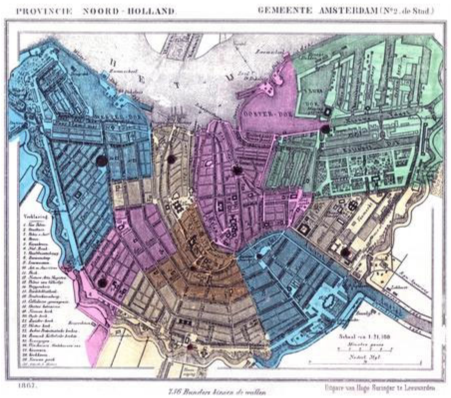


1. Not every researcher is a good entrepreneur!
2. Include software engineering expertise from the beginning
3. **Presence of the research team during pilot phase** crucial


BRANDWEER
VOLVO

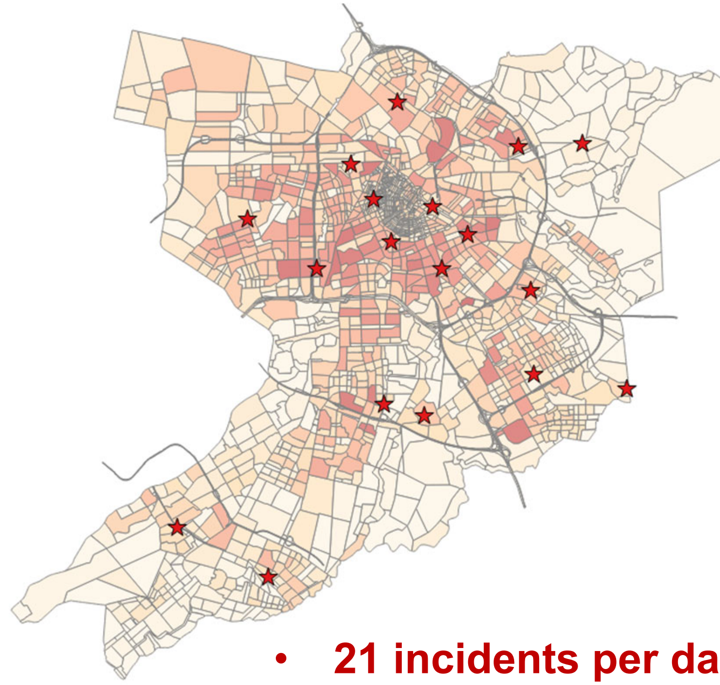
# Demand Changing over Time

**Amsterdam in 1600**



**Amsterdam in 2020**

**Service region Amsterdam/Amstelland**

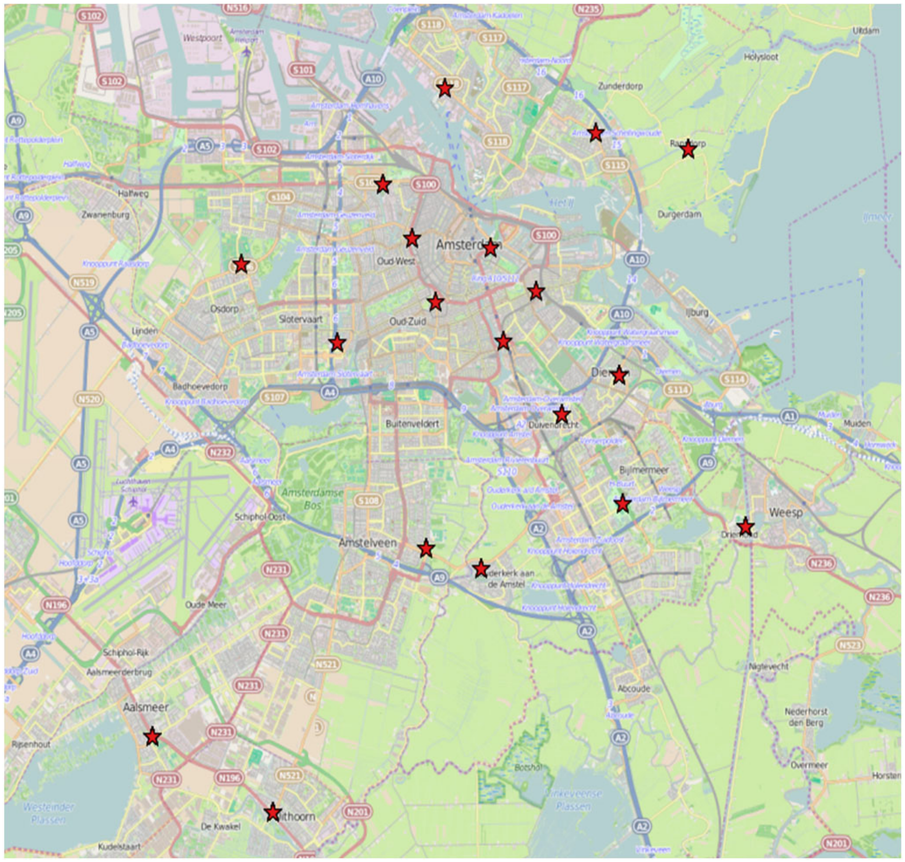


- **21 incidents per day**
- **duration 1 hour**

**<u>Response time target</u>:** 5, 6, 8 or 10 minutes

**<u>Question</u>:** 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

demand at demand point i for vehicle type k

1 if demand point i is covered by vehicle of type k

1 if at least 1 vehicle located at location j

$$\max \left\{ \sum_{i \in N} \sum_{k \in K} d_{ik} y_{ik} - \beta \sum_{j \in M} z_j \right\}$$

**Decision variables:**
$x_{jk}$ = #type-k vehicles at location j

$$\sum_{j \in M_{ik}} x_{jk} \geq y_{ik} \quad \forall i \in N, k \in K$$

coverage constraint for demand point i for type-k vehicles

$$\sum_{j \in M} x_{jk} \leq c_k \quad \forall k \in K$$

capacity constraint of type-k vehicles

$$x_{jk} \leq z_j \quad \forall j \in M, k \in K$$

no vehicles at unused station j

$$y_{ik}, z_j, x_{jk} \in \{0,1\} \quad \forall i \in N, j \in M, k \in K.$$

**Goal: Maximize expected coverage subject to constraints**

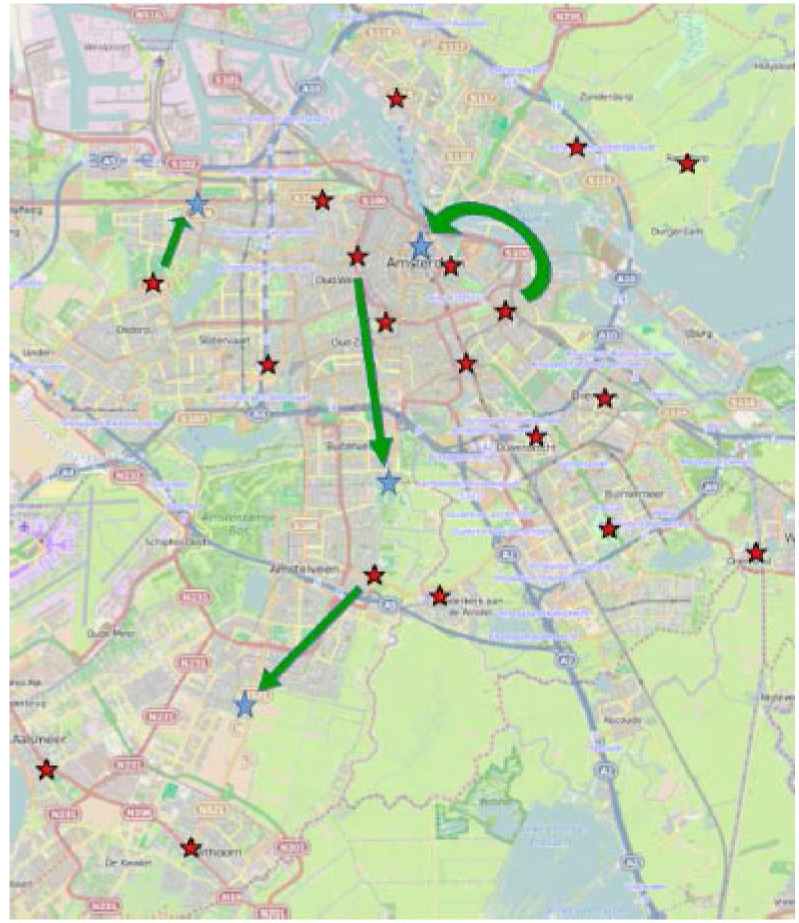
**Easy extension: inclusion volunteering stations**

# Optimization Results

## coverage

| | Dekking | | | | |
|---|---|---|---|---|---|
| # wijzigingen | TS | RV | HV | WO | Totaal |
| 0 | 87,68 | 98,23 | 96,84 | 88,64 | 90,83 |
| 1 | 89,99 | 98,23 | 96,84 | 88,64 | 92,29 |
| 2 | 91,76 | 99,64 | 96,84 | 88,64 | 93,74 |
| 3 | 93,20 | 99,64 | 97,27 | 89,78 | 94,70 |
| 4 | 94,38 | 99,64 | 96,84 | 90,68 | 95,53 |
| Ongelimiteerd | 98,62 | 99,86 | 98,10 | 93,37 | 98,53 |

## 4 modifications



### Observation

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

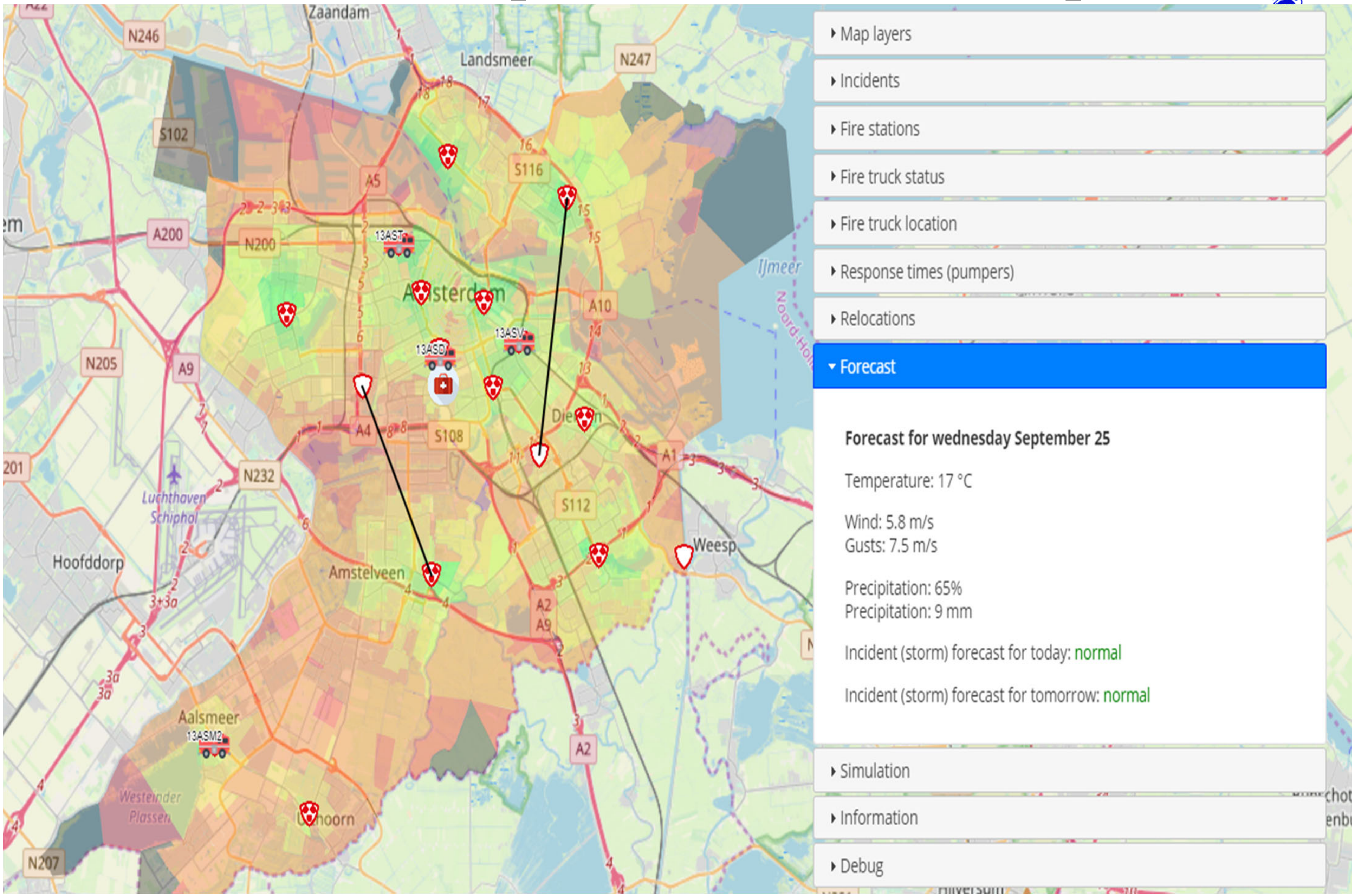
### Letter by Commander in Chief:

"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

# Tool (“fireSCore”)



# Fighting Crime with Maths!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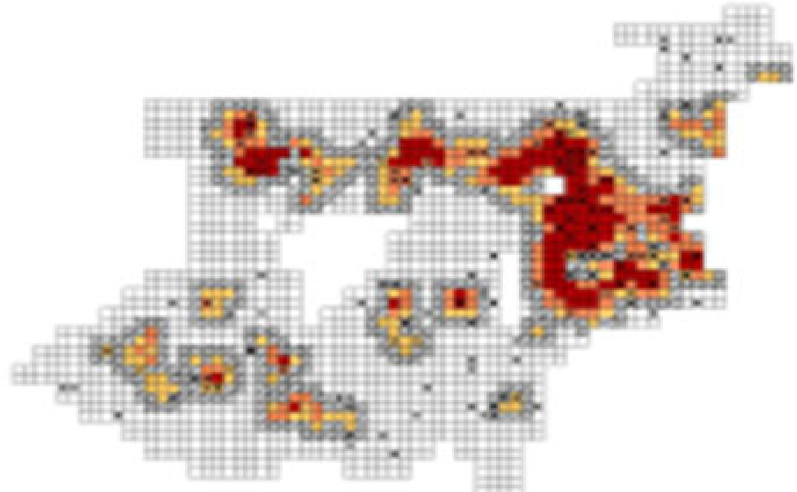
# Predictive Policing


- **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

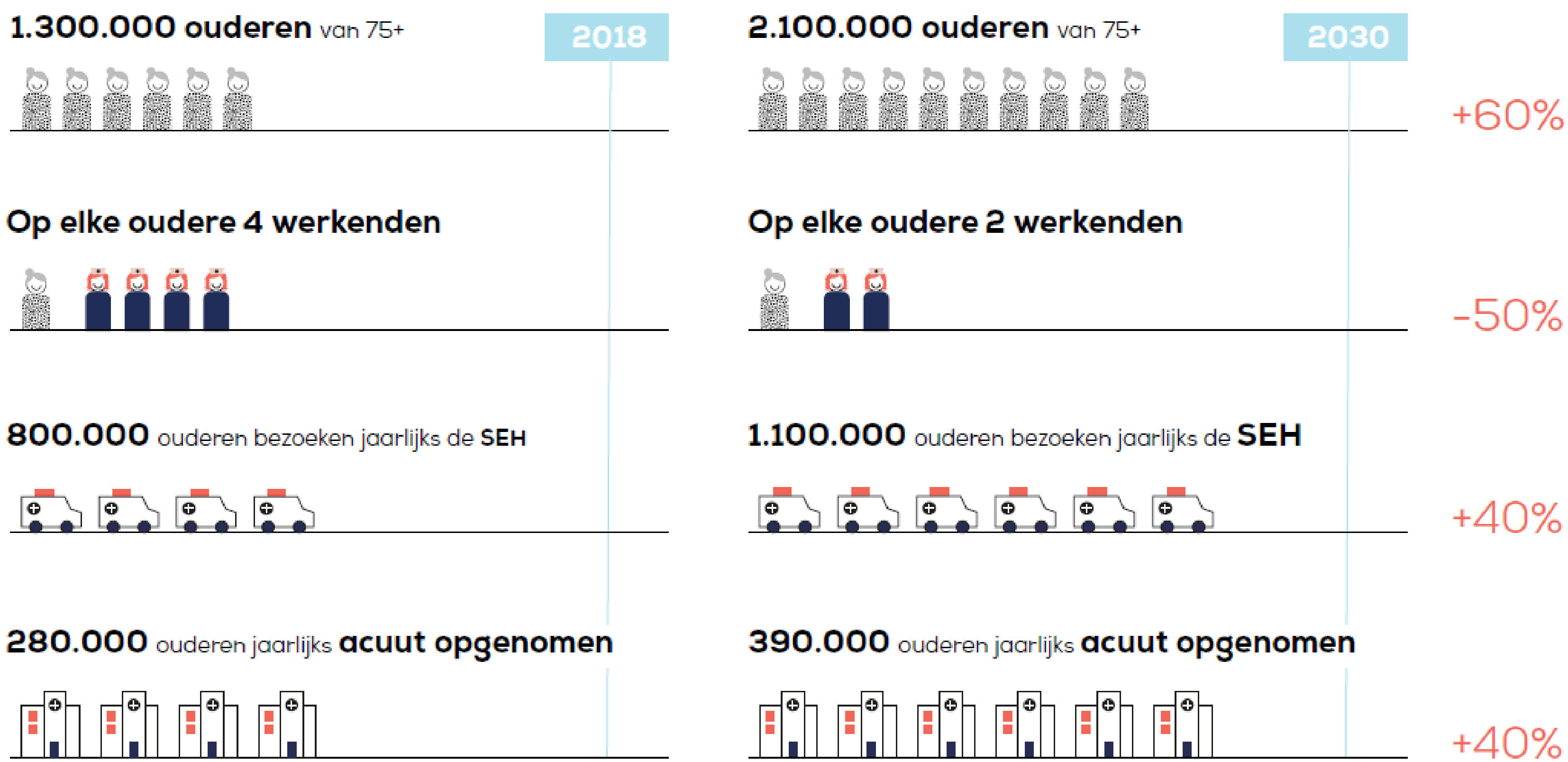
CWI Centrum Wiskunde & Informatica

Amsterdam UMC Universitair Medische Centra

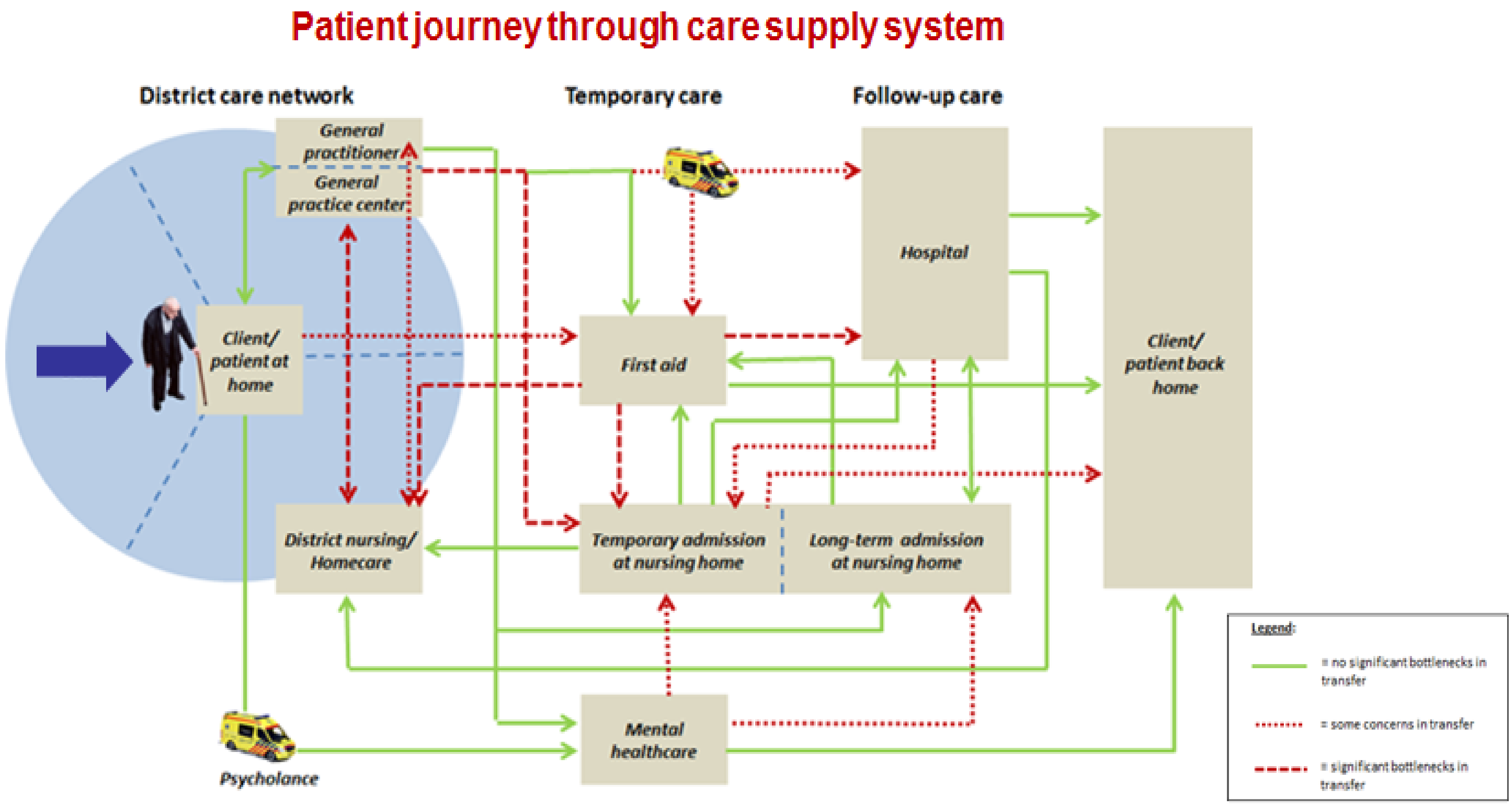
VU

# “DOLCE VITA”: Challenges in Acute Elderly Care

DE UITDAGINGEN IN ACUTE OUDERENZORG IN DE KOMENDE 10 JAAR



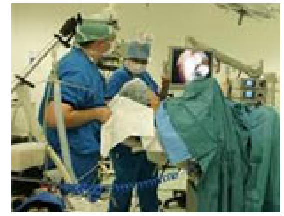
# Patient Journey



# Excessive Waiting Times


incident


overload

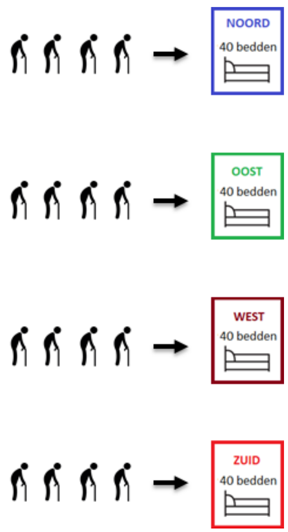

surgery (after 14 days)

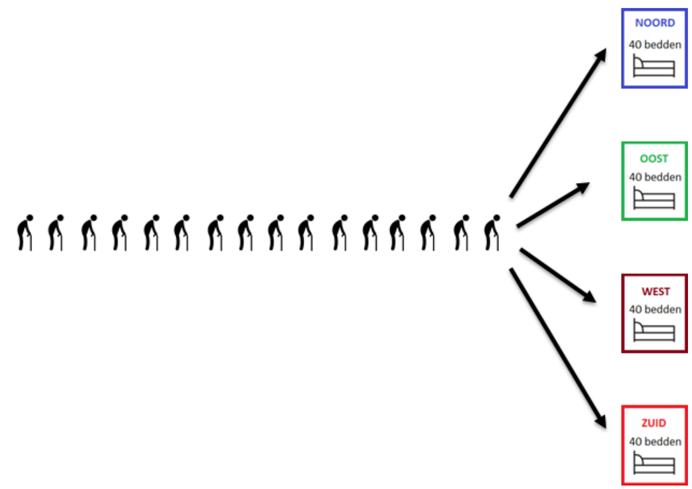

nursing home

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

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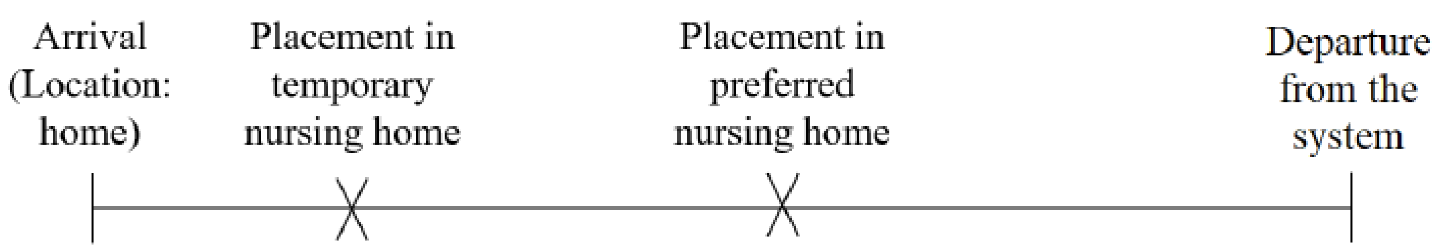
individual preferences ⟷ efficient use of beds

+ include personal preferences
– inefficient use of beds

+ efficient of use beds
– no individual preferences

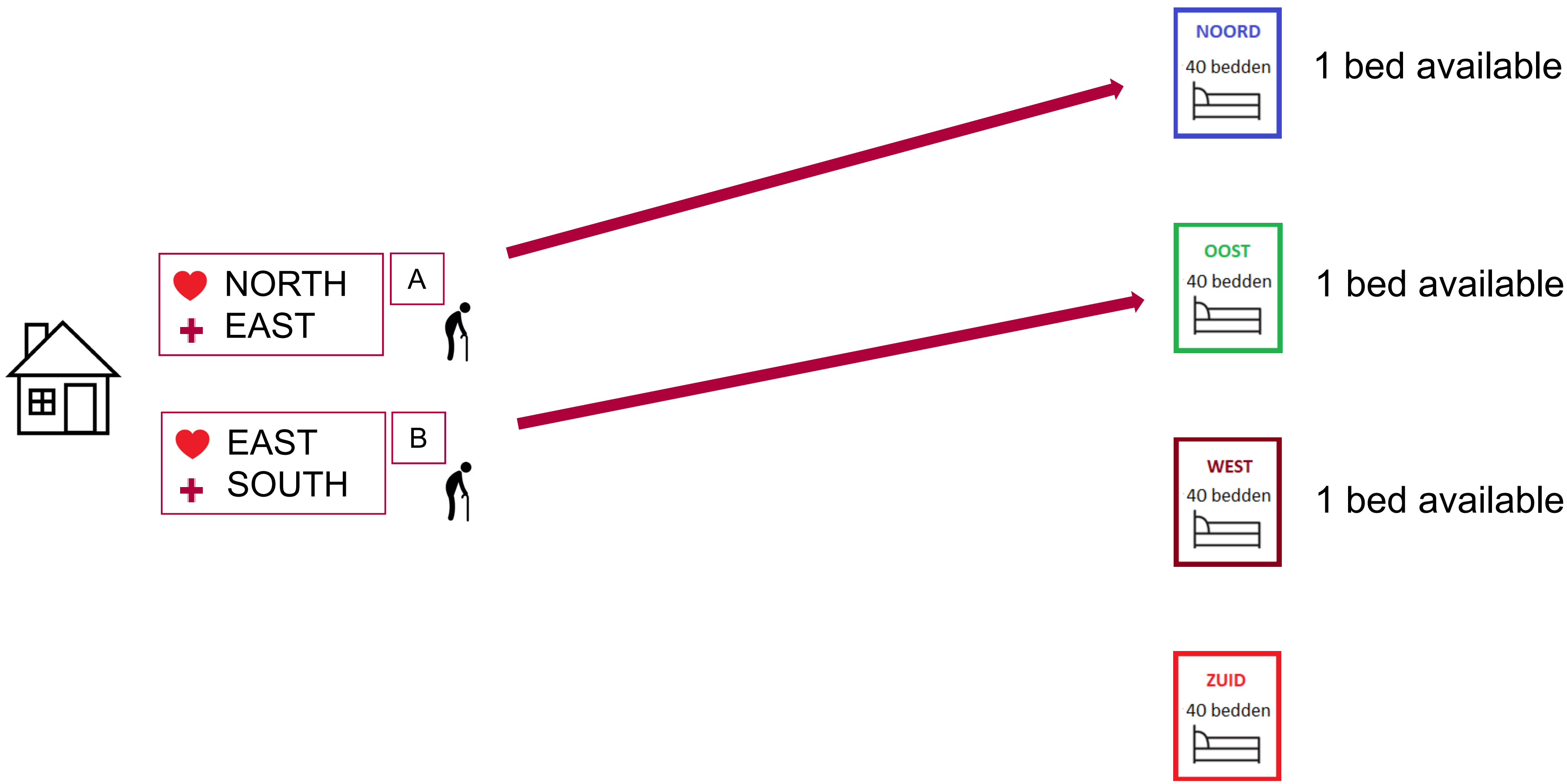
# Current Way of Working

- 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



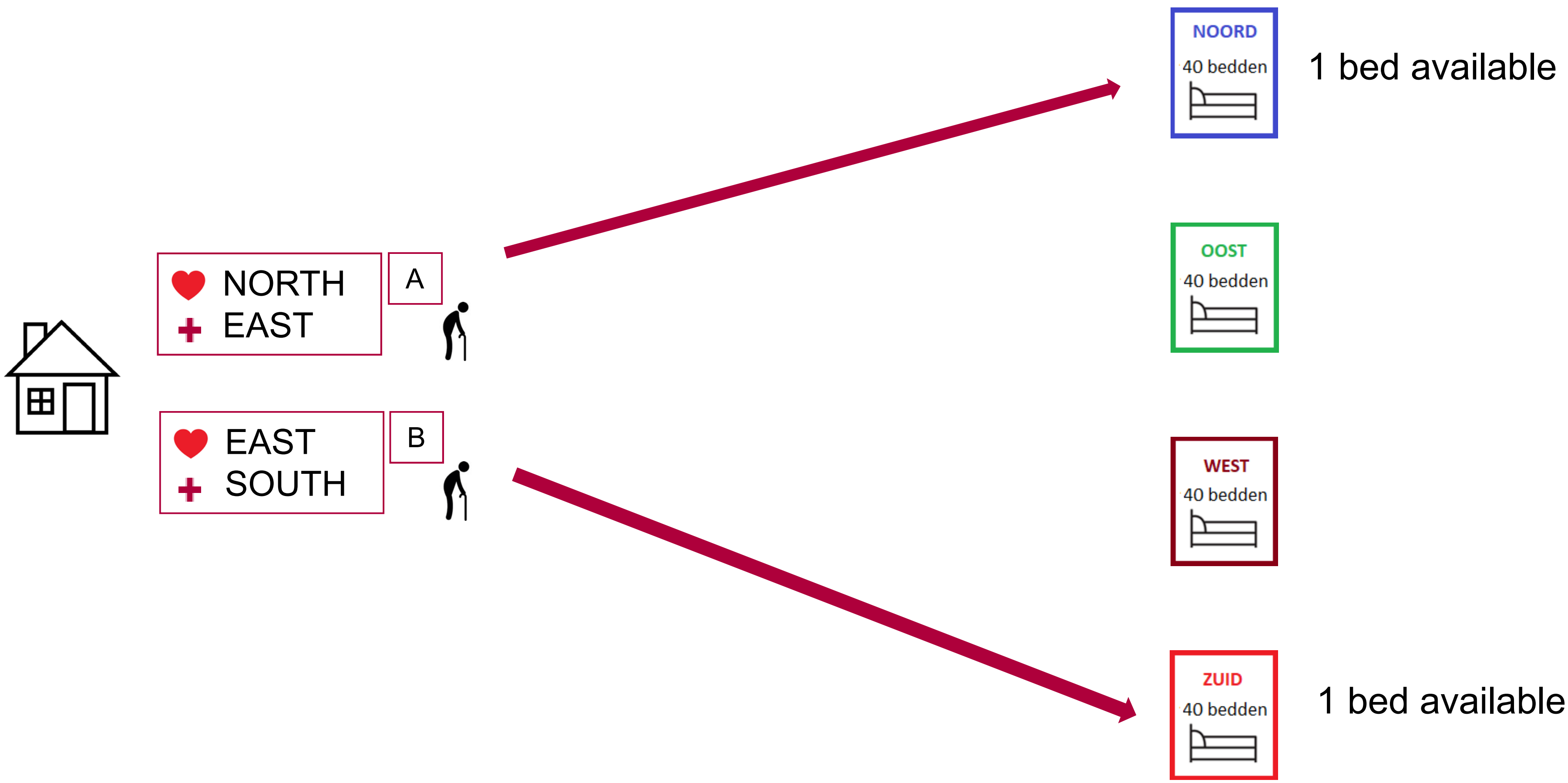
# Toy Example

(1) Preferences of patients



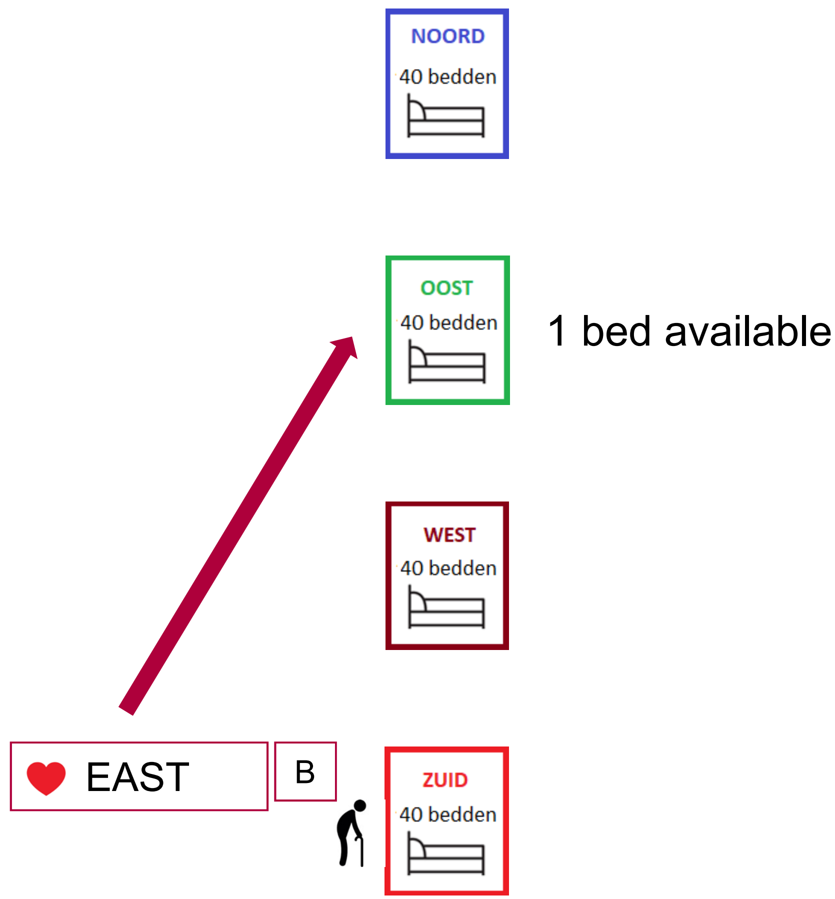
# Toy Example

(2) Transitions between care centers



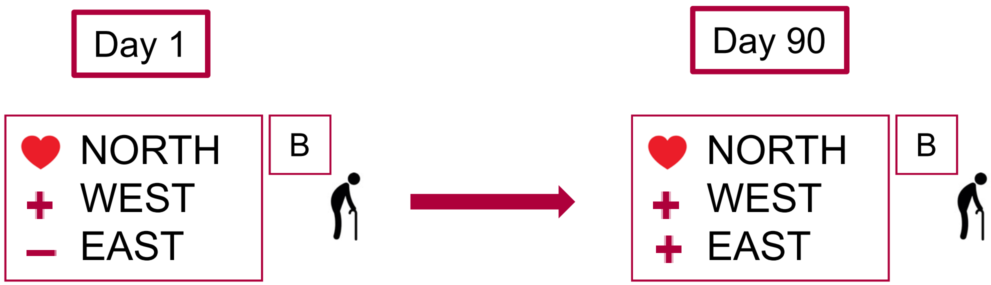
# Toy Example

(2) Transitions between care centers



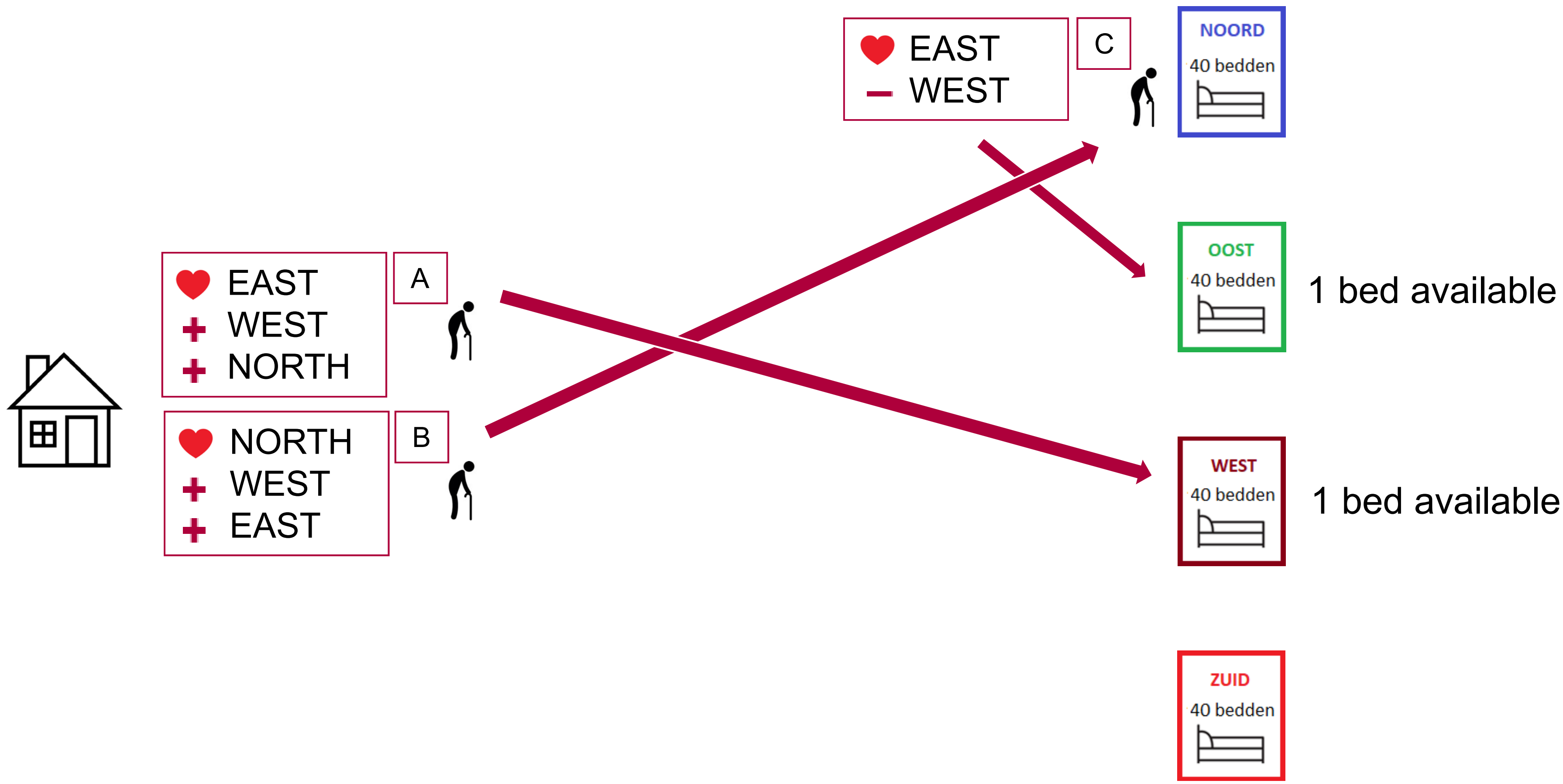
# Toy Example

(3) Increase in urgency



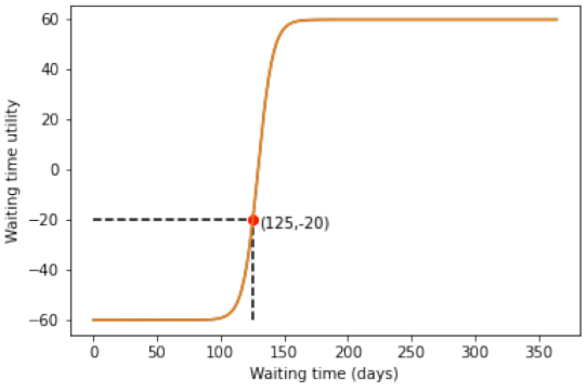
# Toy Example

(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

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

**maximize utility**

$$\text{s.t.} \sum_{p \in P} x_{pn} \leq c_n \qquad \forall n \in N$$

$$\sum_{n \in N} x_{pn} = 1 \qquad \forall p \in P$$

$$x_{pn} \in \{0, 1\} \qquad \forall p \in P, n \in N.$$

# 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

**also psychiatry, youth care,…**

# Lives Saving Logistics for Emergency Services


Rob van der Mei

Contact: mei@cwi.nl



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# Incident Management on our Railways


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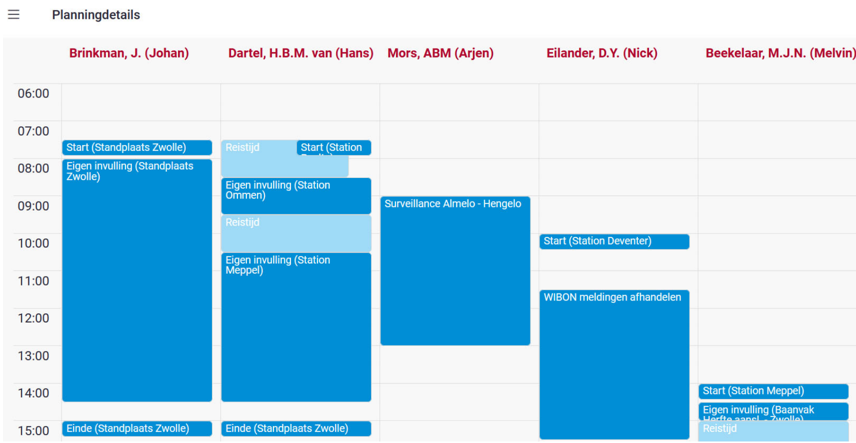
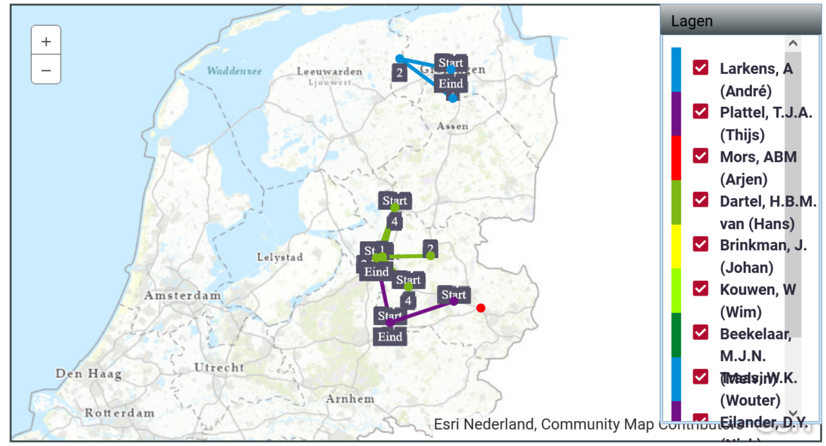
# Balancing preventive and corrective maintenance tasks

**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 15 Jan 09

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

Collapse Reply Retweet Favorite More

**111** RETWEETS **673** FAVORITES

9:36 PM - 15 Jan 09 · Details

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2005
Luca Brun
2013

# RTREPORTER

Your early warning system for news, trends & events


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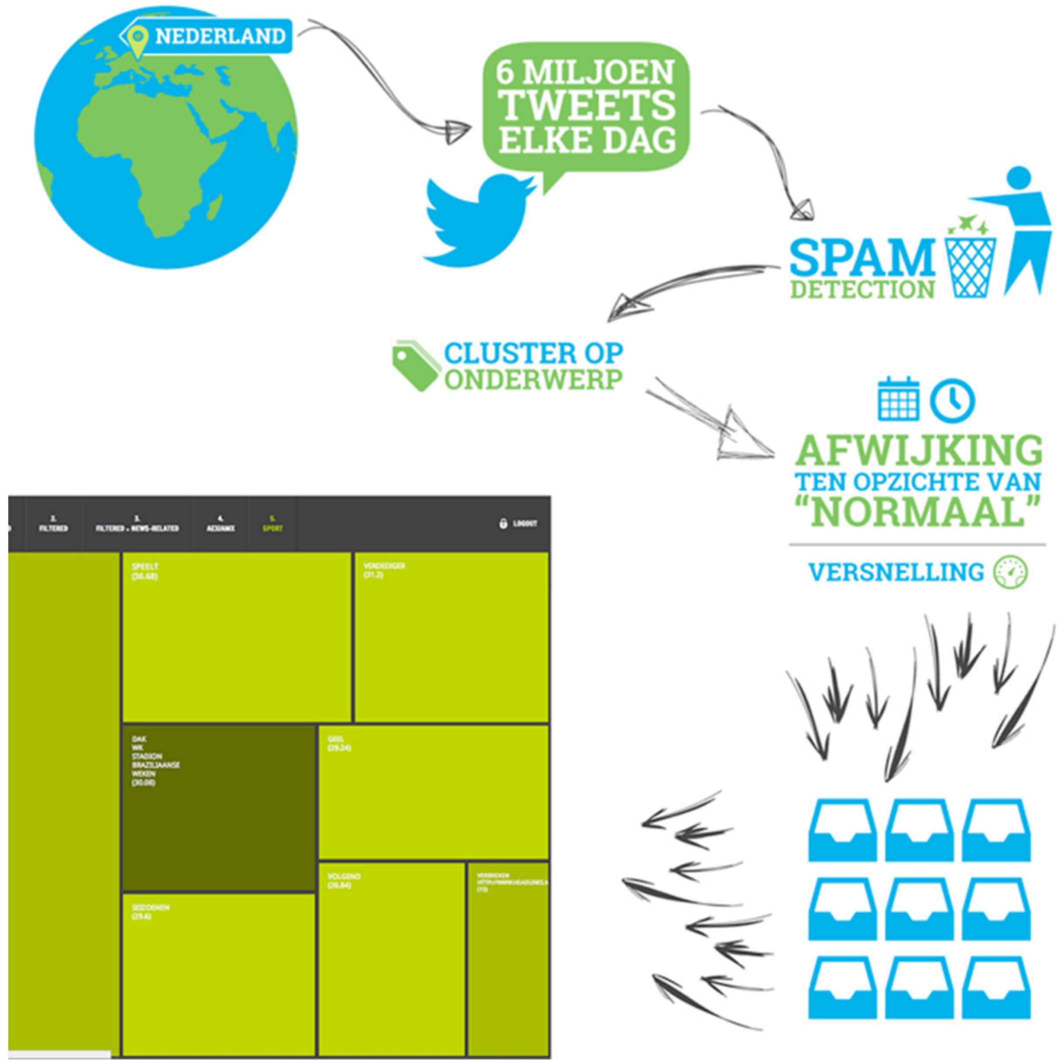
NEDERLAND
6 MILJOEN TWEETS ELKE DAG
SPAM DETECTION
CLUSTER OP ONDERWERP
AFWIJKING TEN OPZICHTE VAN “NORMAAL”
VERSNELLING


RT
reporter
SHELL
BESPAART
(6.9)
SPAART
(5)
#NIEUWSAMSTERDA
NIEUWS.NL -
'LICHT HOGERE
OPENING AEX'
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MICHAEL
(4.98)
VERZET
PLEEGKIND
YUNUS
ELSEVIER.NL - VERZET
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SHOPPEN
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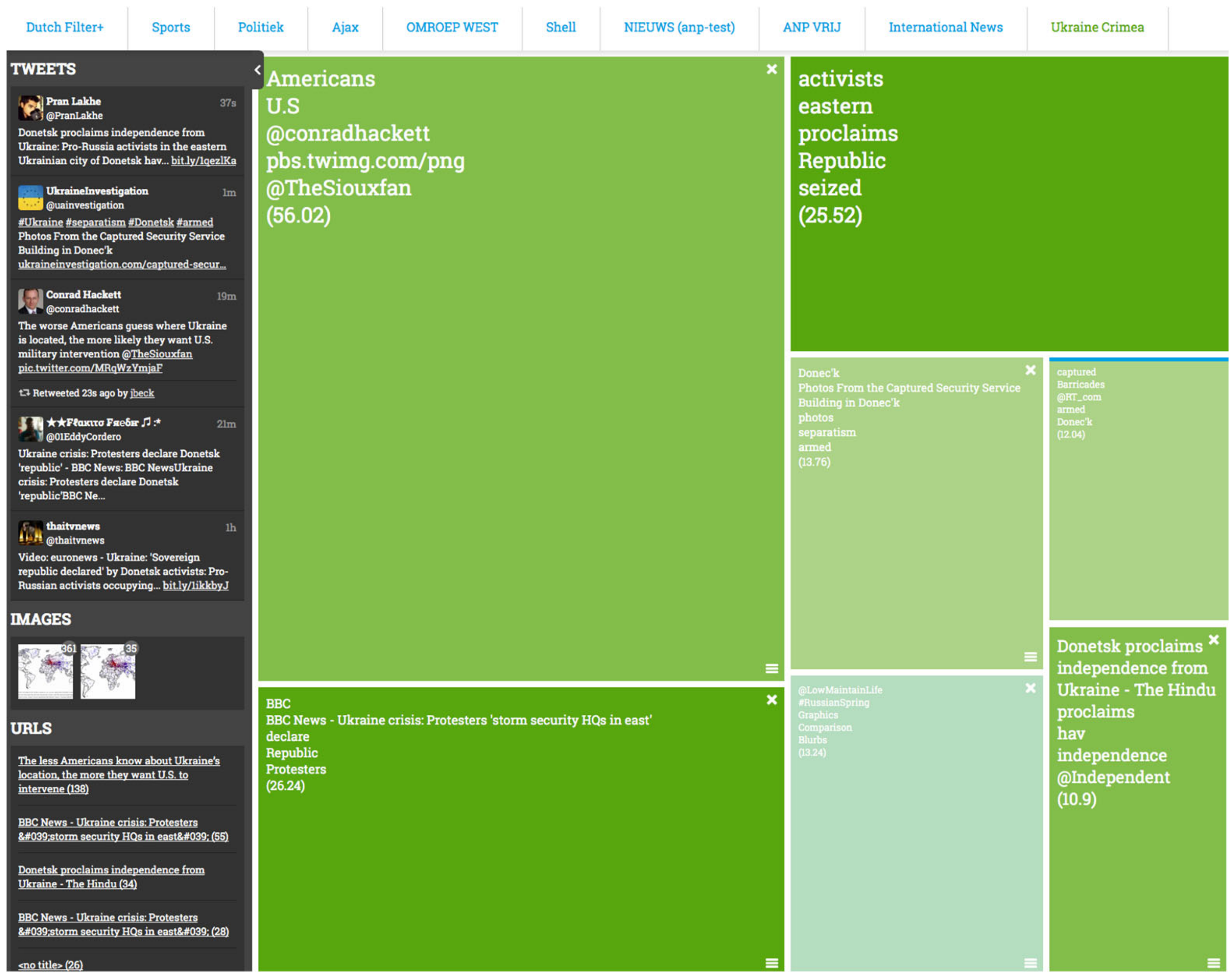
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#Ukraine #separatism #Donetsk #armed Photos From the Captured Security Service Building in Donec'k ukraineinvestigation.com/captured-secur...
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Video: euronews - Ukraine: 'Sovereign republic declared' by Donetsk activists: Pro-Russian activists occupying... bit.ly/1ikkbyJ
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Donetsk proclaims independence from Ukraine - The Hindu (34)
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<no title> (26)
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activists
eastern
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Republic
seized
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(13.76)
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