"Success Stories of Mathematics in Real Life"

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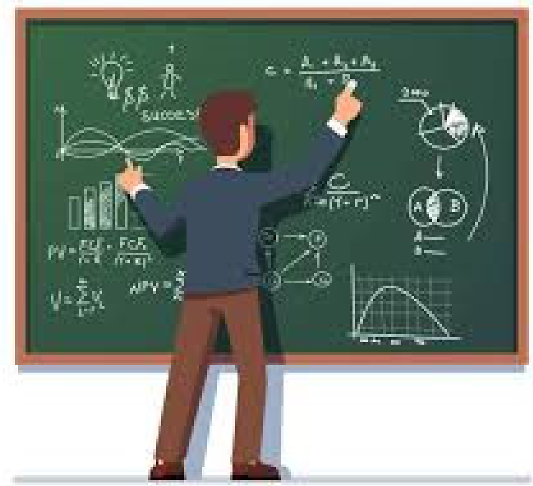
IARIA Congress, Nice, July 24-28, 2022

Problem: Applied Mathematics too often Not Applied…

“practice”

“theory”

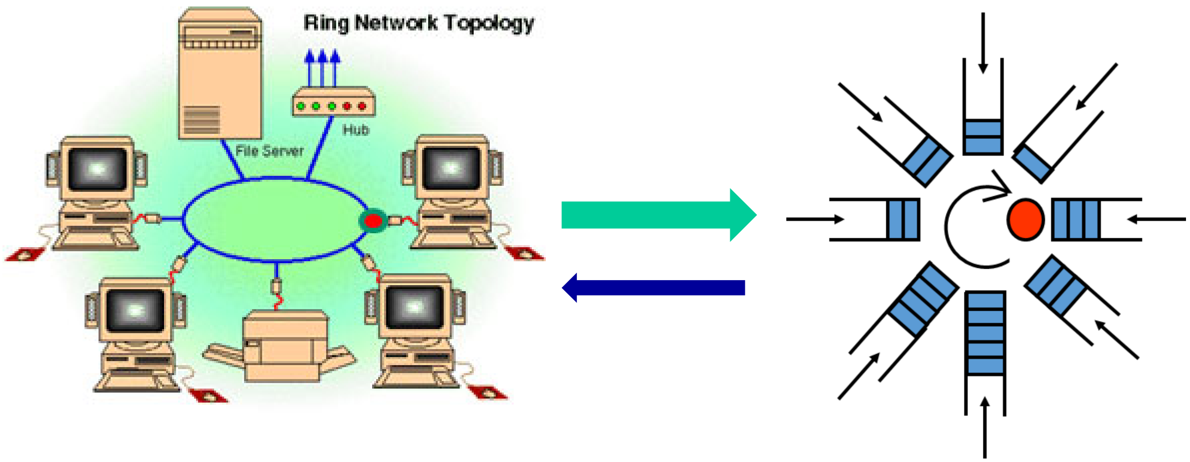


Success Stories of Mathematics in Real Life

Plan for today:

1. **Examples of success stories**
   - Ambulance
   - Firefighters
   - Predictive policing
   - Reducing waiting times in acute elderly care
2. **Lessons learned and discussion**

Short Resume



1991	M.Sc. in Mathematics and Econometrics
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 years: shift from theory to application

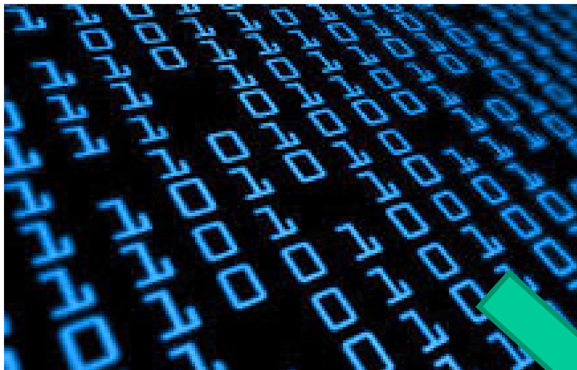
Over the Past 25 Years…

Over the years:
100+ consultancy projects, 100+ R&D projects, 60+ Ph.D. students, 130+ M.Sc. students

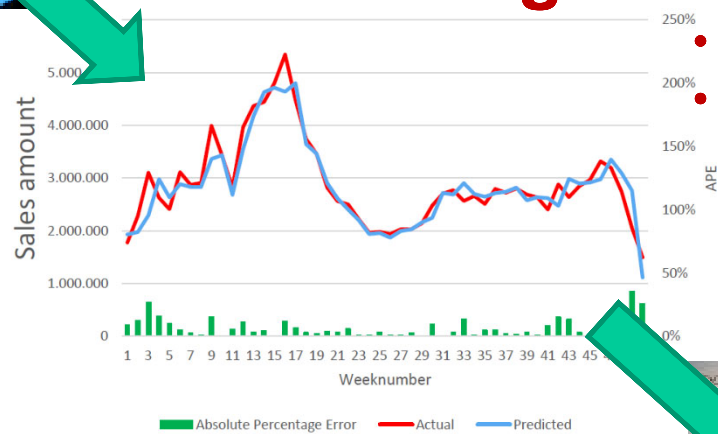
Topics of interest: emergency logistics, healthcare logistics, RM & pricing, telecommunication networks, mobility, AI for suicide prevention, AI for cyber security and intelligence, defense

Data, Forecasting and Optimization

data



insights and forecasting



- Operations Research
- Stochastic Optimization

optimization

data analytics

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

optimization models


Pictures from veiligheidsregio Noord-Holland Noord
10-101
10-101 AMBULANCE
AMBULANCE
6-KKV-28

Ambulance Care in NL

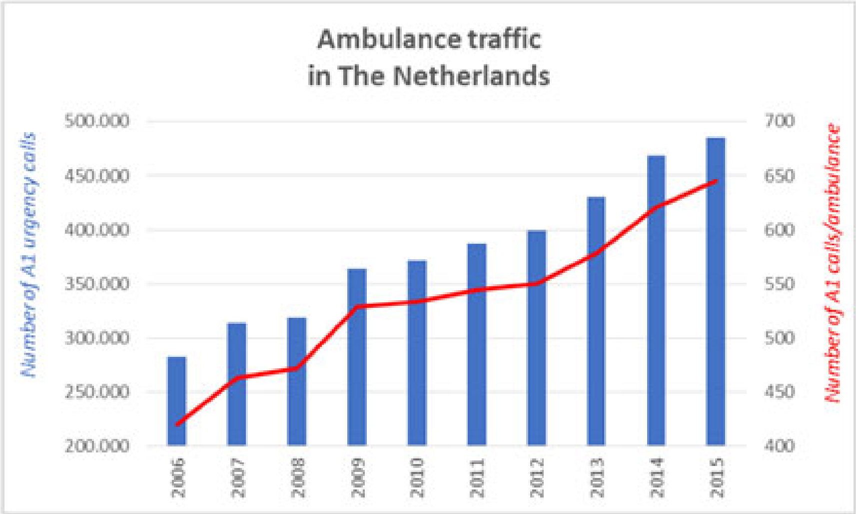
A1-calls: Urgent and life threatening **< 15 min**
- severe incident

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:

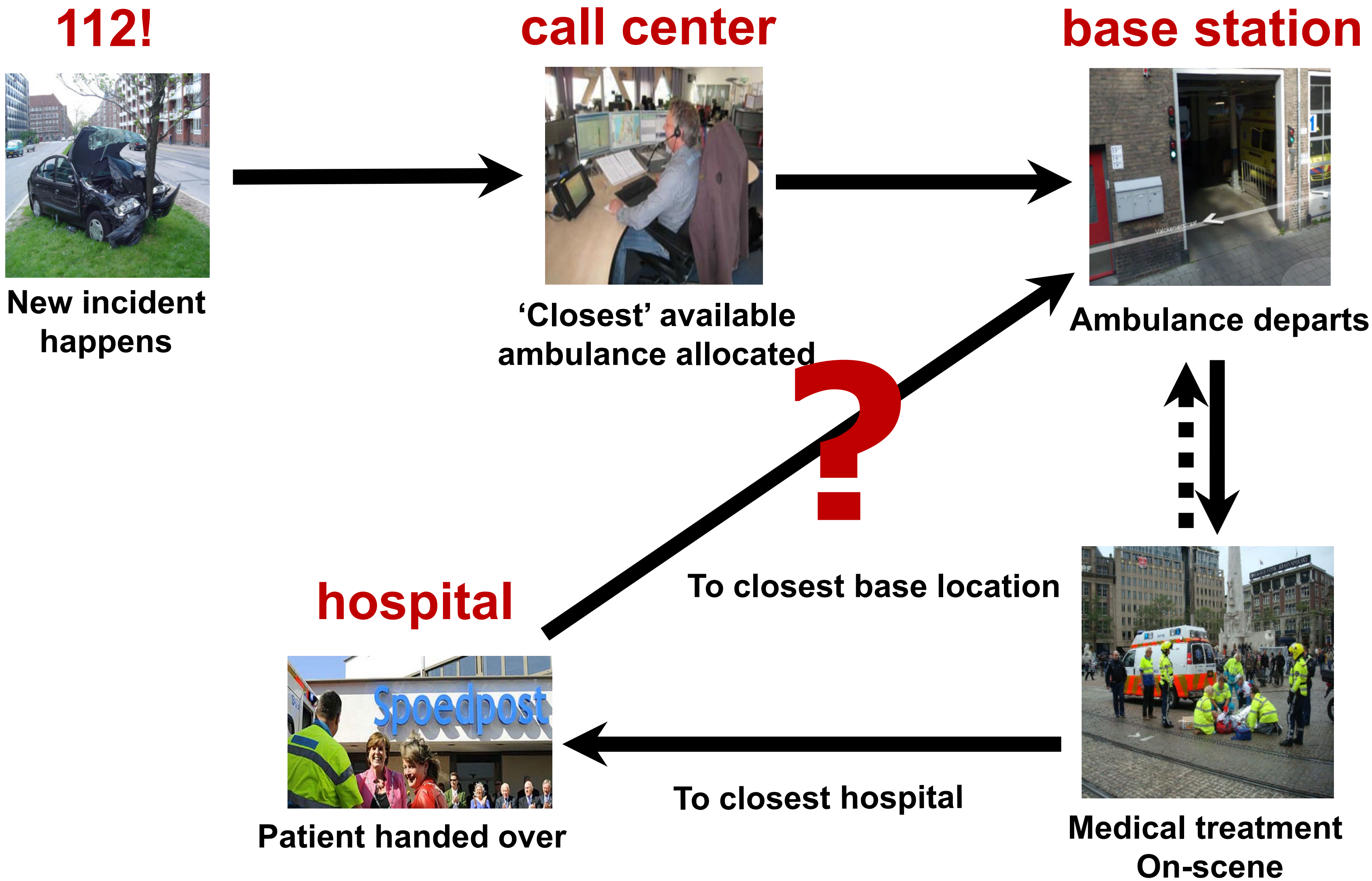
- **1 million calls per year, out of which 500,000 A1-calls**
- **35,000 times (7%) the 15-minute target is not met**
- **Growing demand ('groeiende zorgvraag')**

New and powerful concept:

Dynamic Ambulance Management: proactive planning

REPRO : from Reactive to Proactive

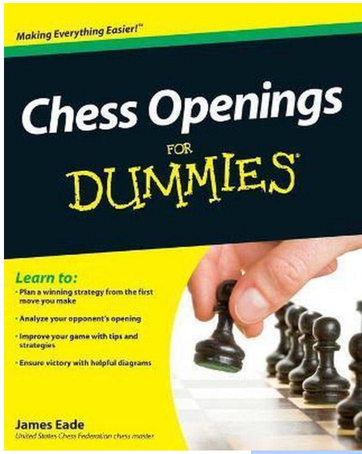
Ambulance Service Process

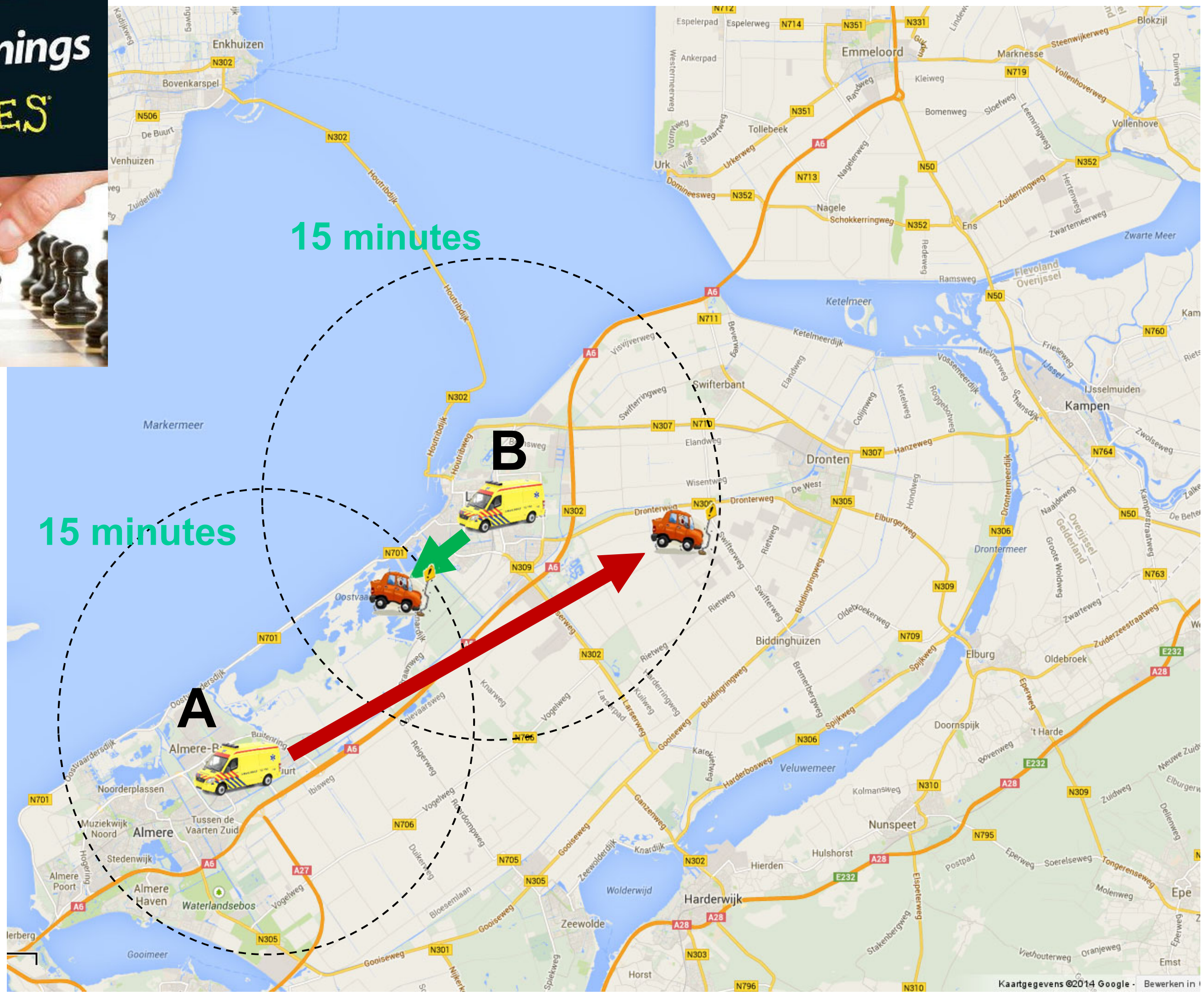


Mathematics in Action

Playing Chess

Chess for Dummies

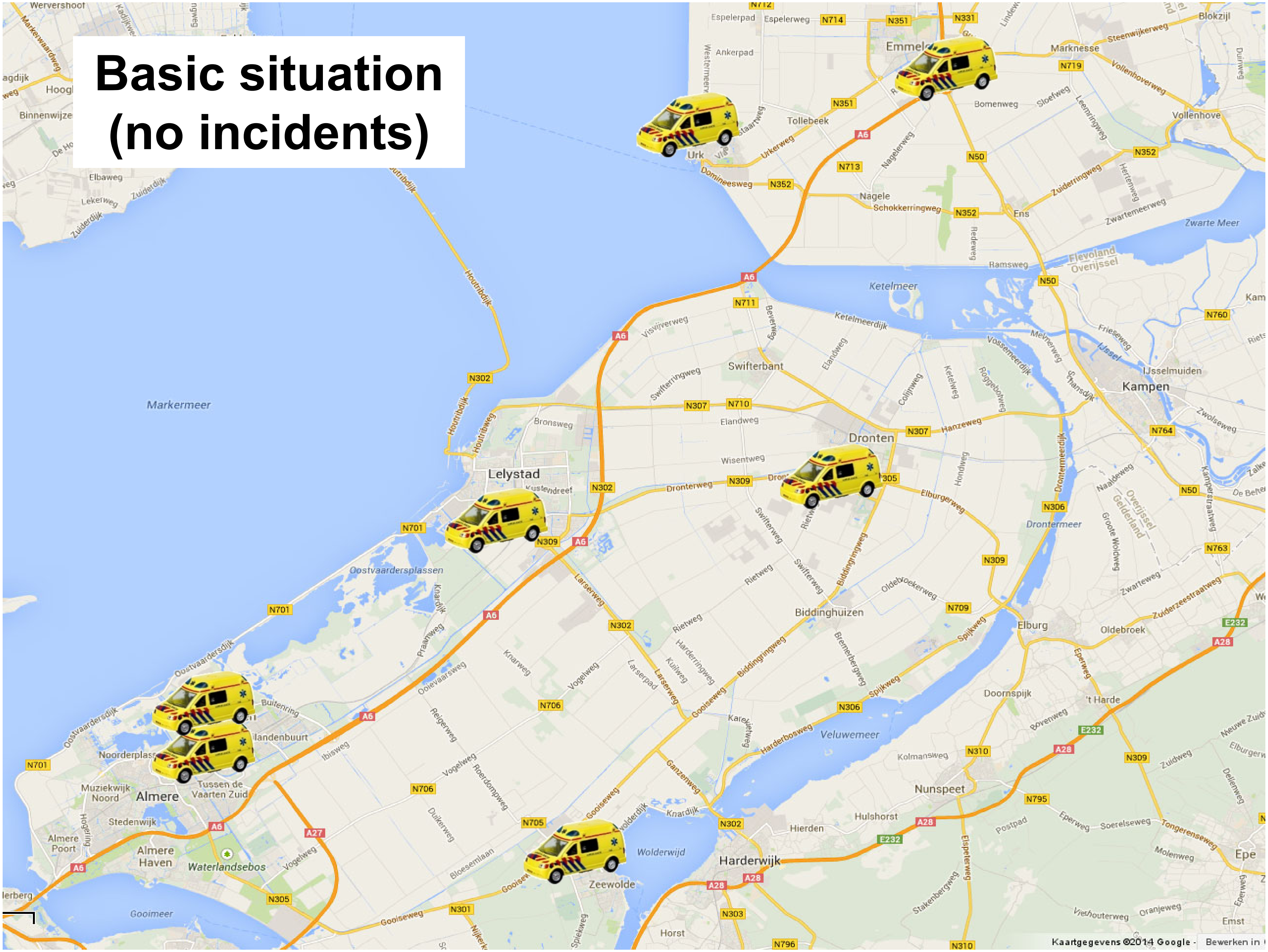




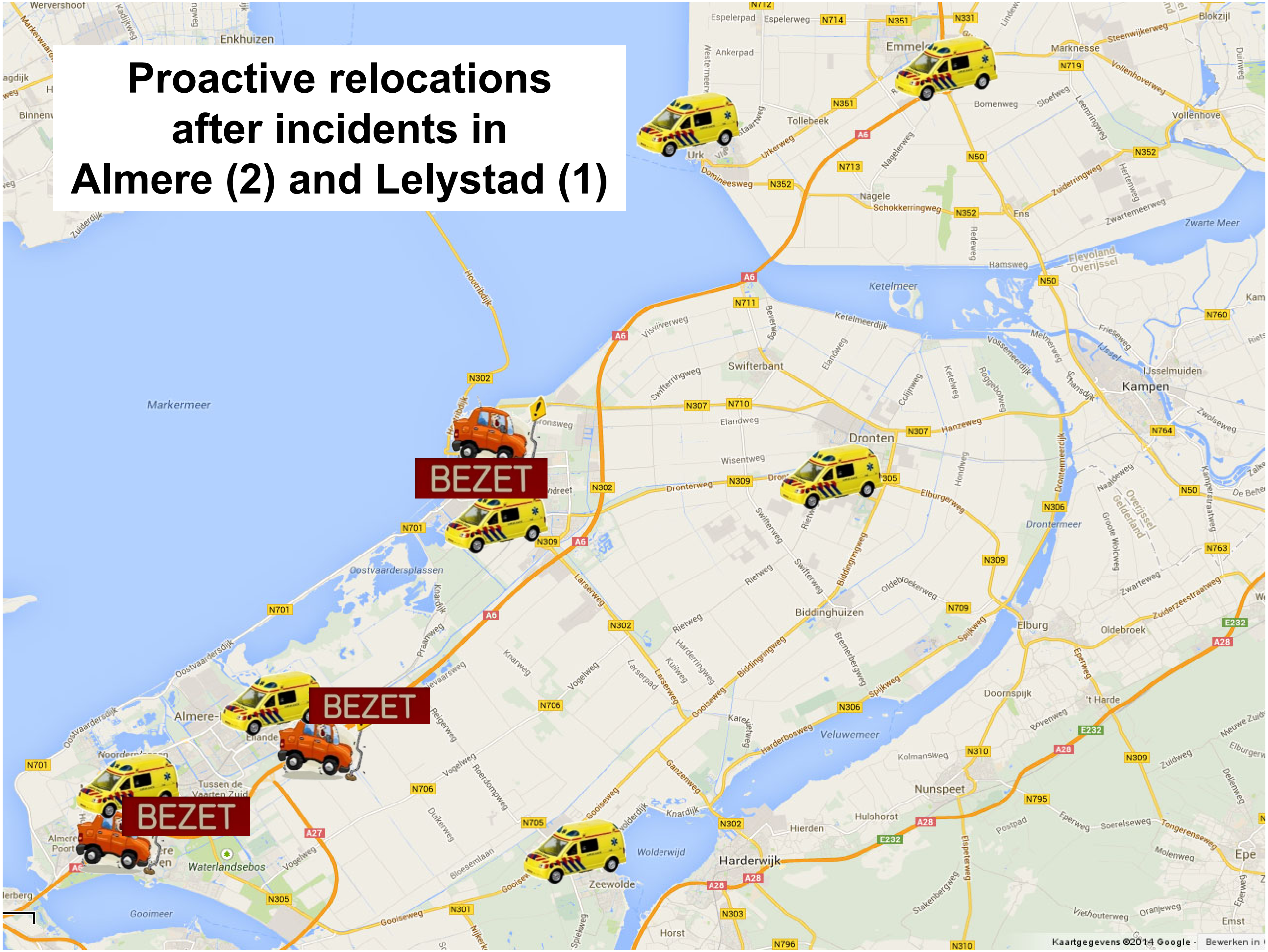
?

Chess for Professionals

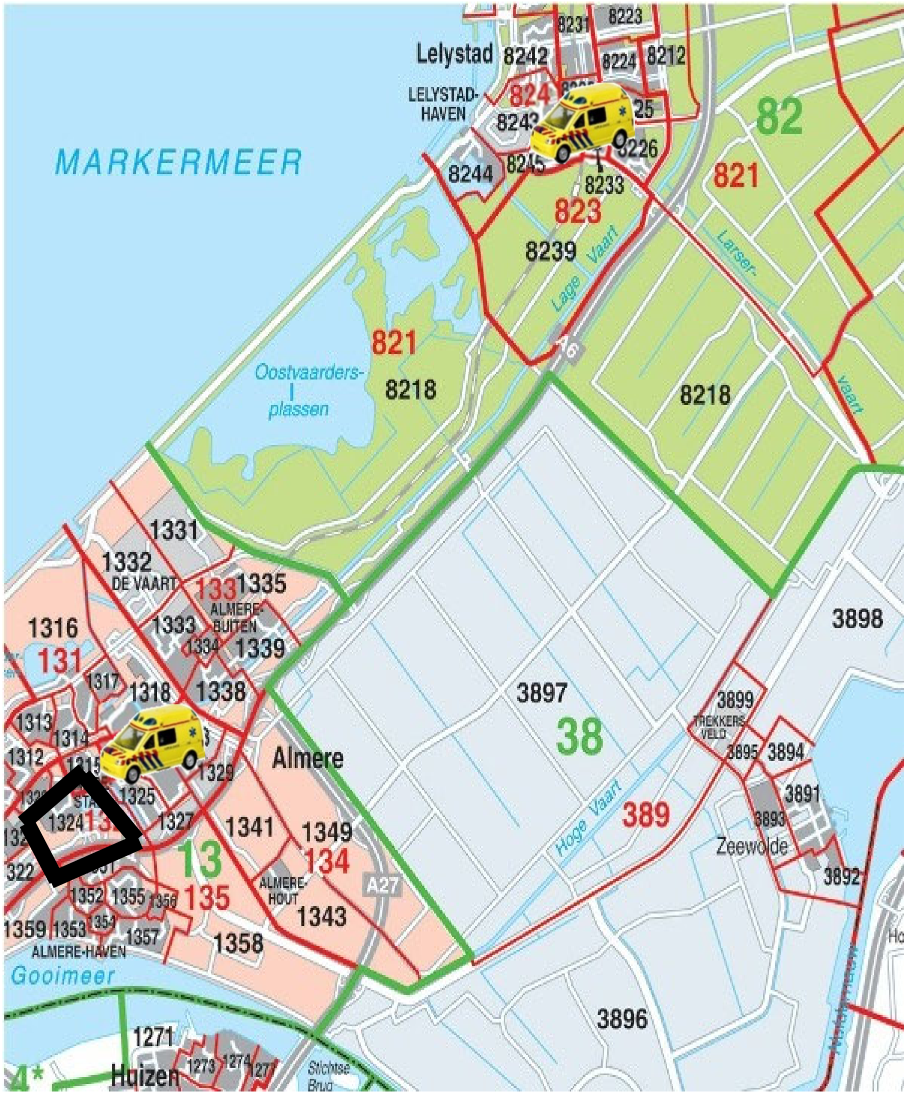
Basic situation (no incidents)



Proactive relocations after incidents in Almere (2) and Lelystad (1)

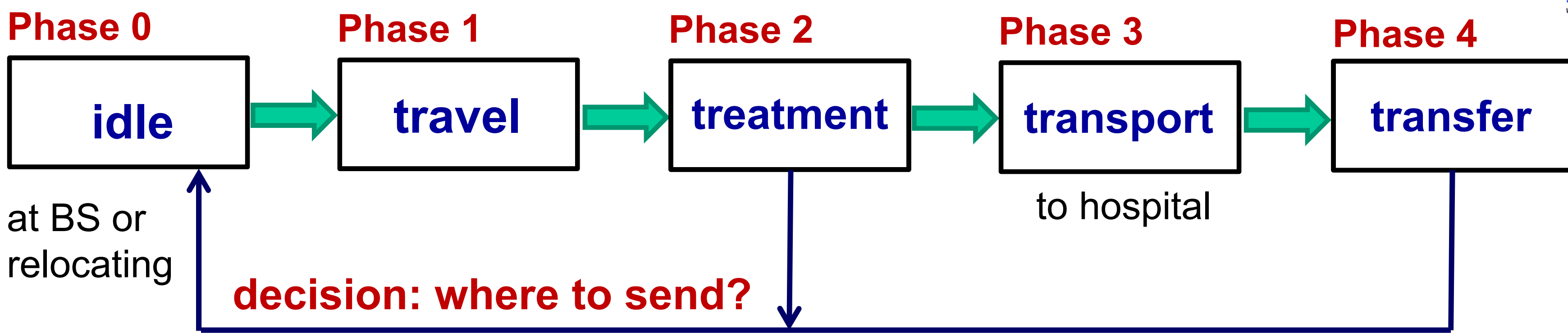


Simple Model



- 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



Relocation decision moments:

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

Single-Coverage Heuristic

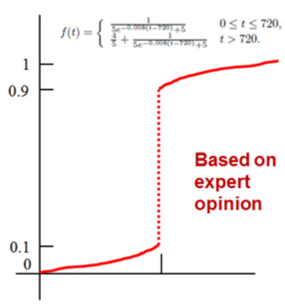
Basic idea: minimize ‘unpreparedness’

- **System state:**

  for each ambu: (location/destination, phase)

- **Unpreparedess:**

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



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

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

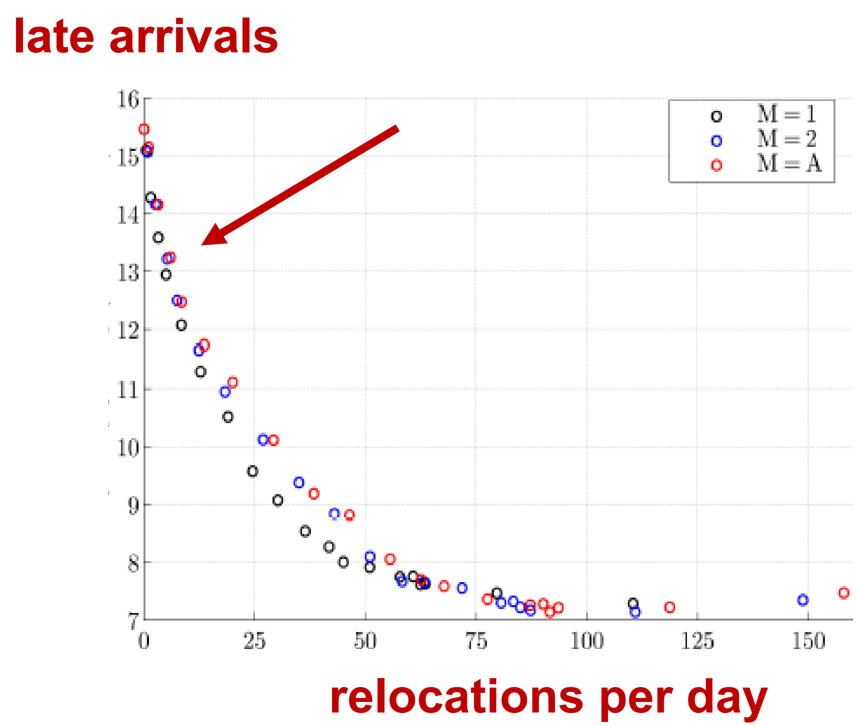
Single-Coverage Heuristic (ct'd)

	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

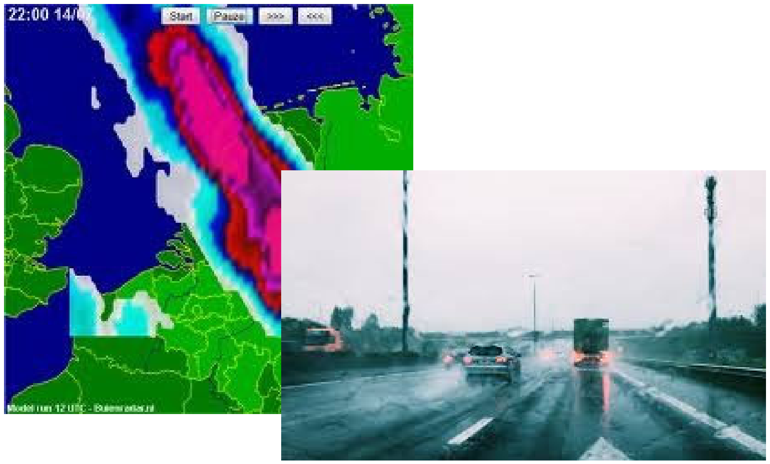
Effectiveness of Relocations



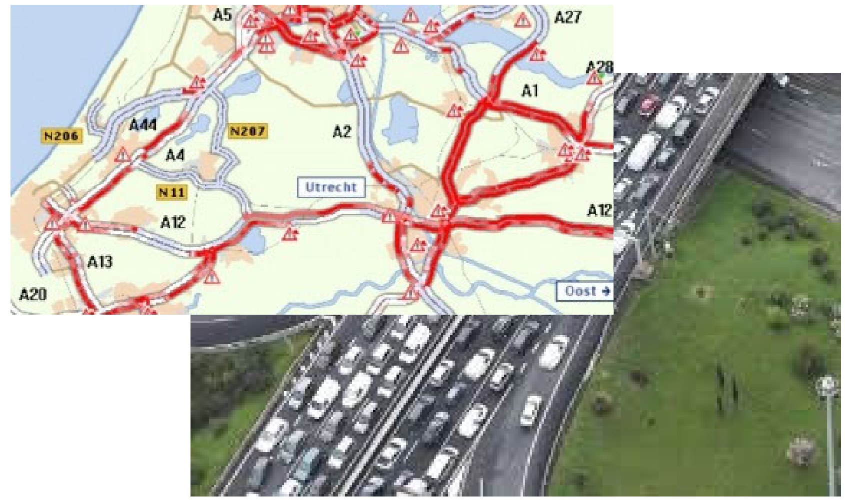
Good news:

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

Real-Time Decision Making



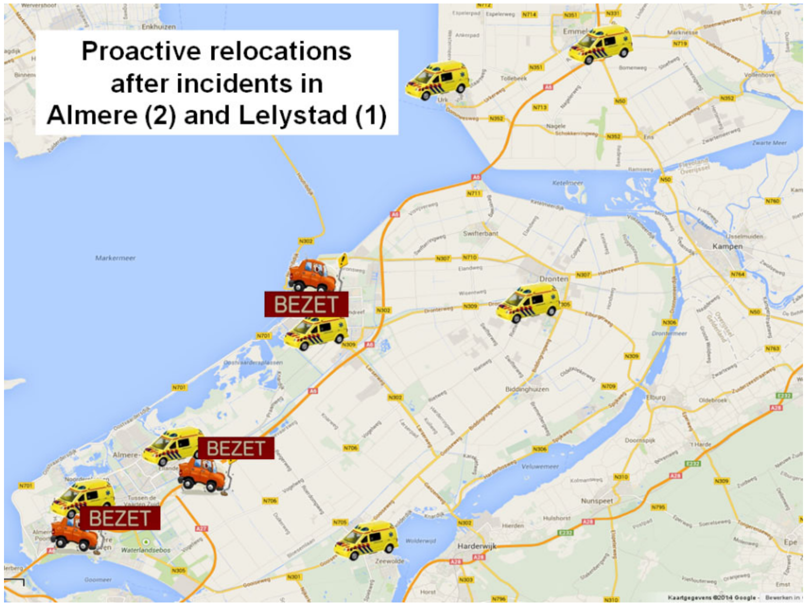
weather circumstances



real-time traffic information

mass events

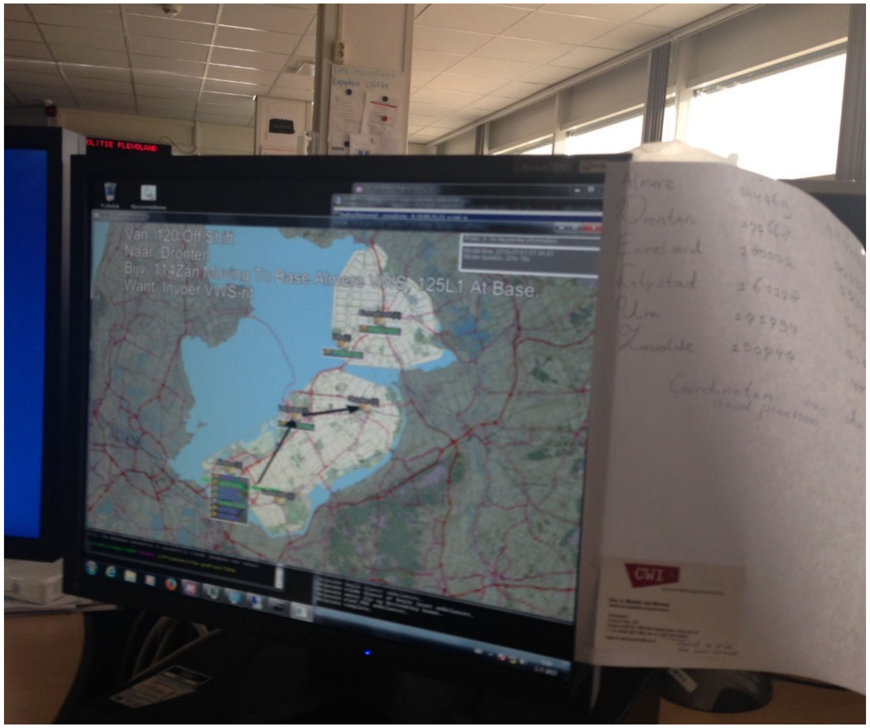
Acceptance in Practice?



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...



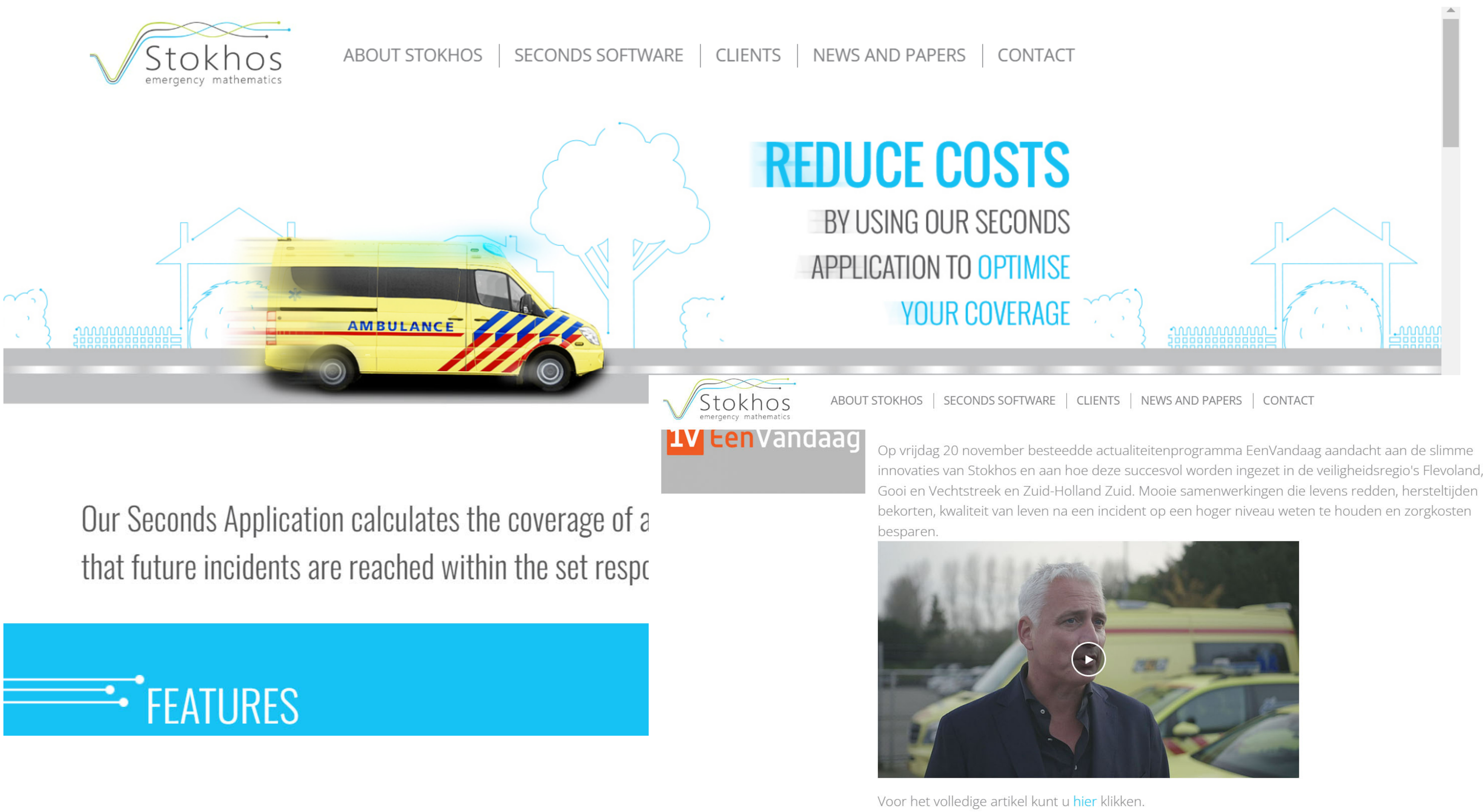
Pilot with tool implementation

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



What Made the Difference?

Computer zet ambulances slimmer in
Flevoland 2 juli 2017

Martin van Buuren

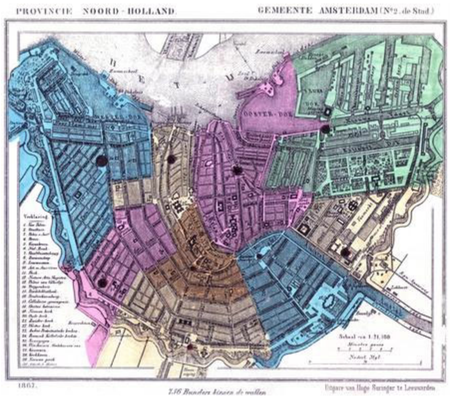
Lessons Learned

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

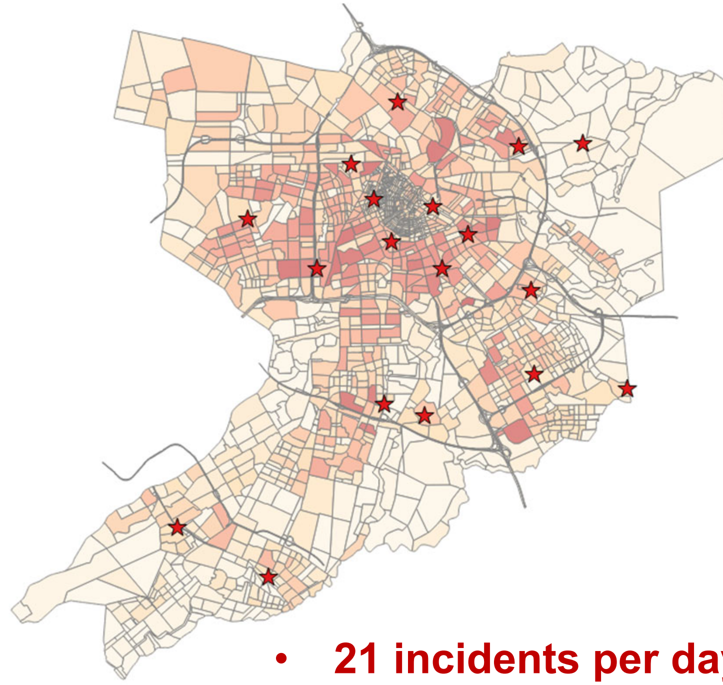
Demand Changing over Time

Amsterdam in 1600



Amsterdam in 2020

Service region Amsterdam/Amstelland

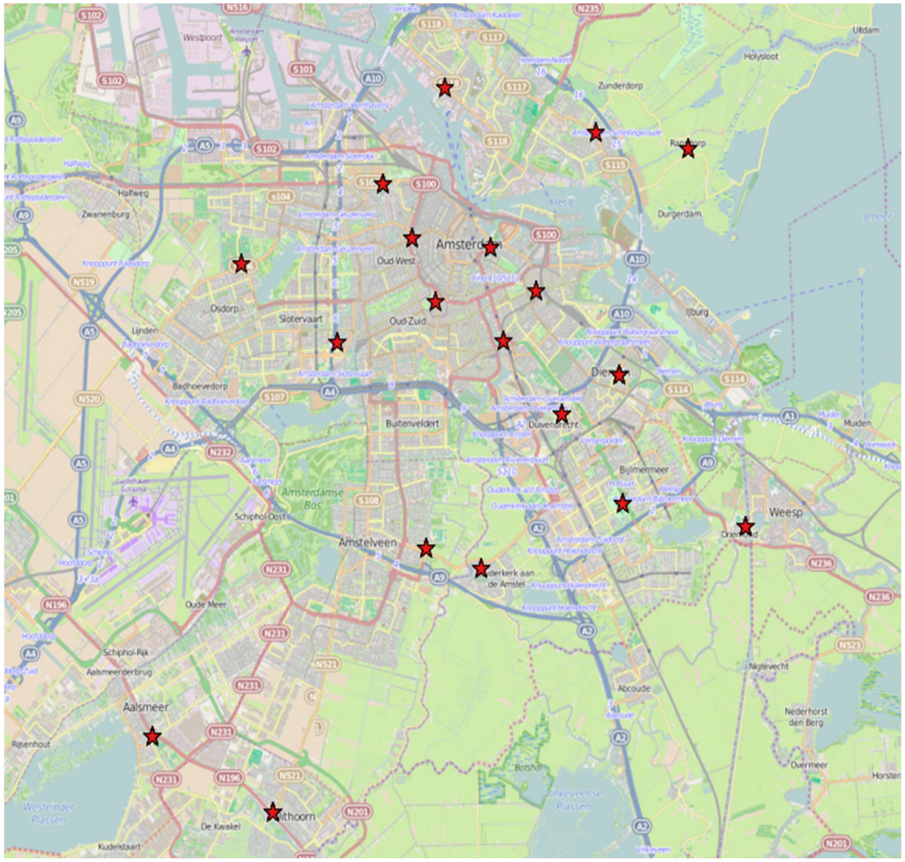


- **21 incidents per day**
- **duration 1 hour**

<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

Observation

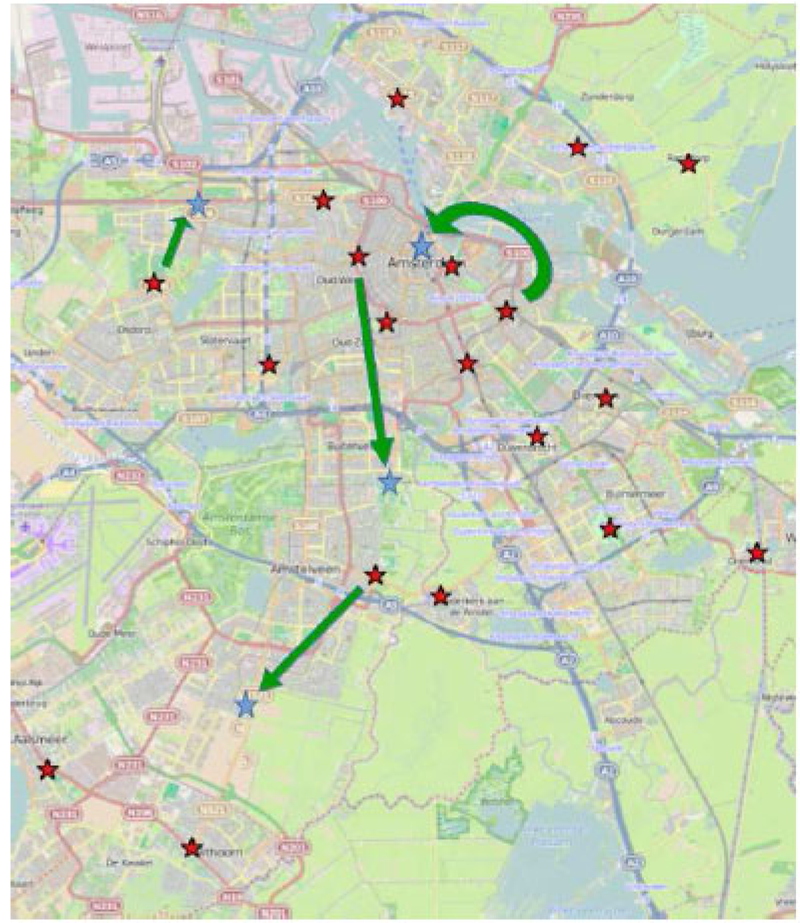
% late arrivals can be reduced by > 50% by relocating only 4 stations!

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.

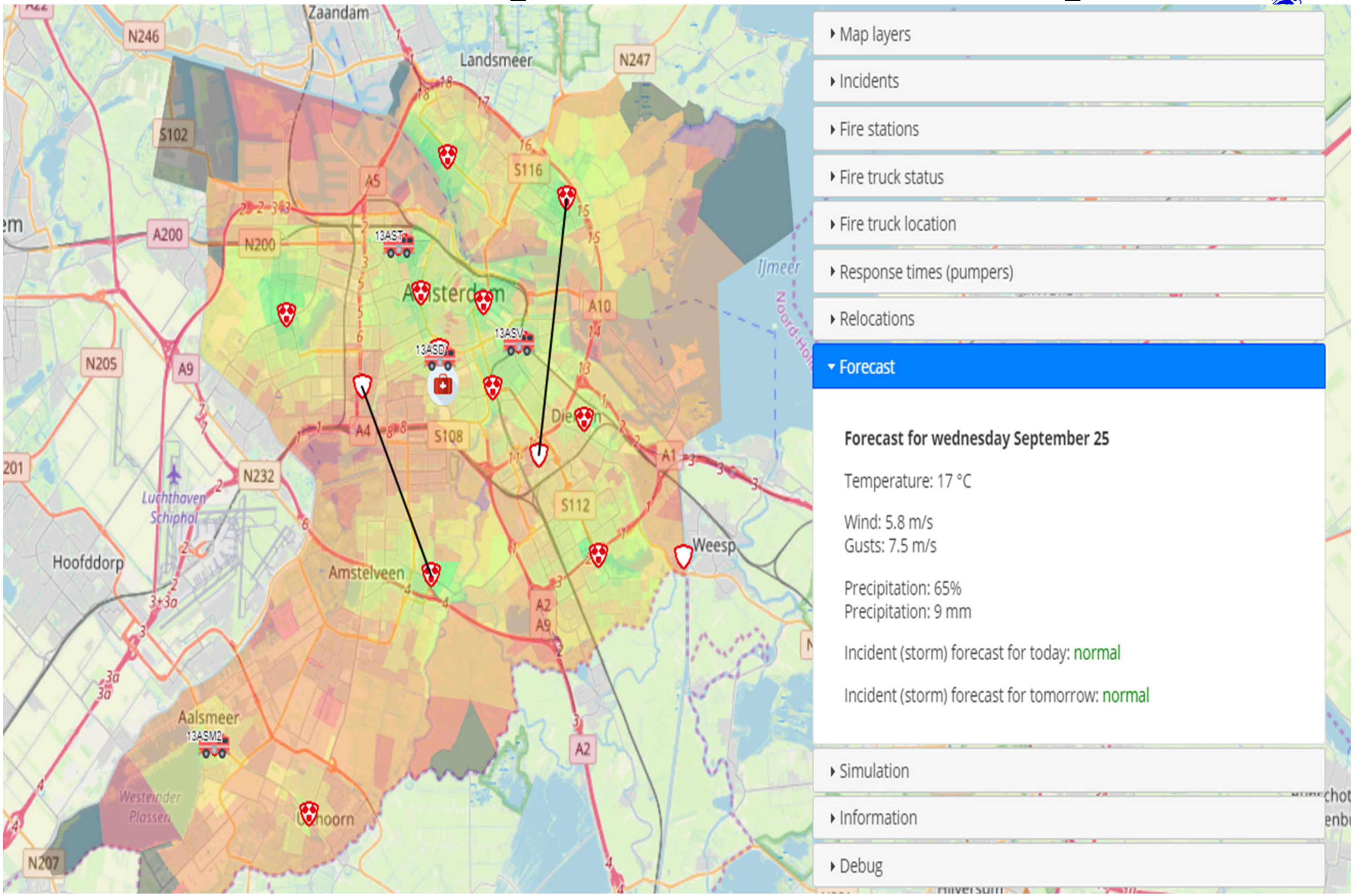
"Furthermore, we have identified another process which can greatly benefit from optimizations the model provides. When during a large scale incident multiple base stations are being called upon, we are now able to re-allocate remaining resources (vehicles) to better positions to regain optimal overall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

4 modifications



→ next step: relocations during major incidents

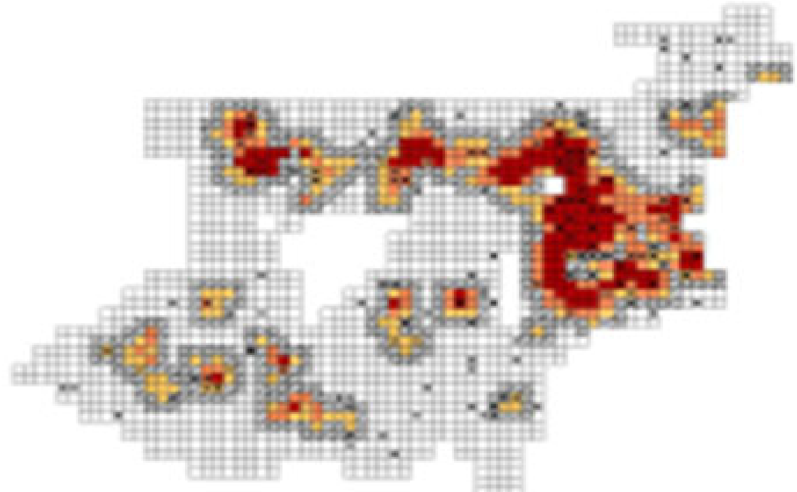
Tool ("fireSCore")



Fighting Crime with Maths!


SPITS
Nieuws & Entertainment
Amsterdam
Bruisende buurt?
'Big Data' helpt politie
Via Wiskunde is aantal incidenten te voorspellen
PvdA: vragen over rioolvet
amstlvn
IEDERE ZONDAG SHOPPEN
www.stadshartamstelveen.nl

Predictive Policing

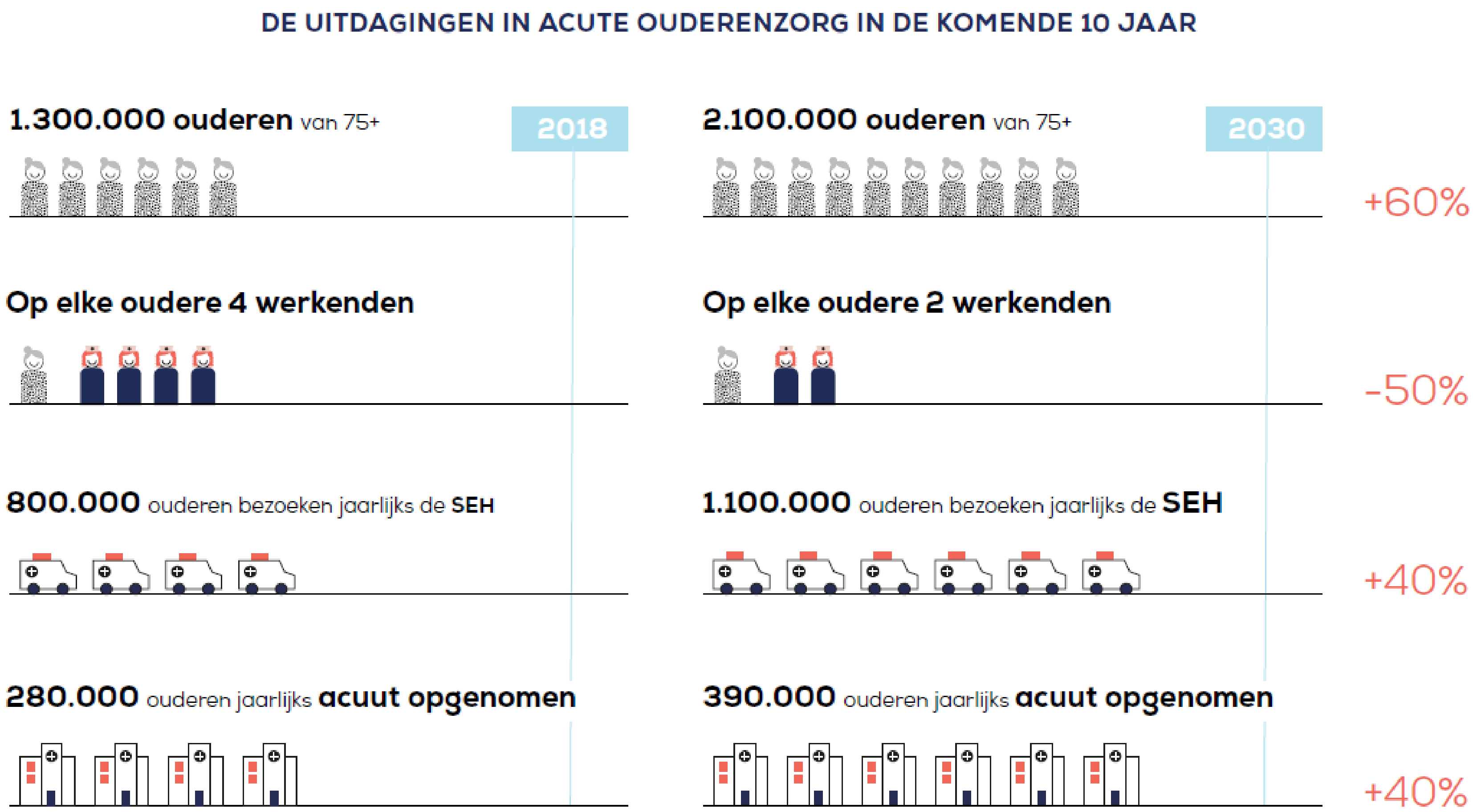


- **Goal:** reduction of **high-impact crimes**
- **Idea:** Allocation of man-power at ‘hot’ places
- Cross-correlation with demo- and geographic factors
- ‘Near-repeat’ phenomenon

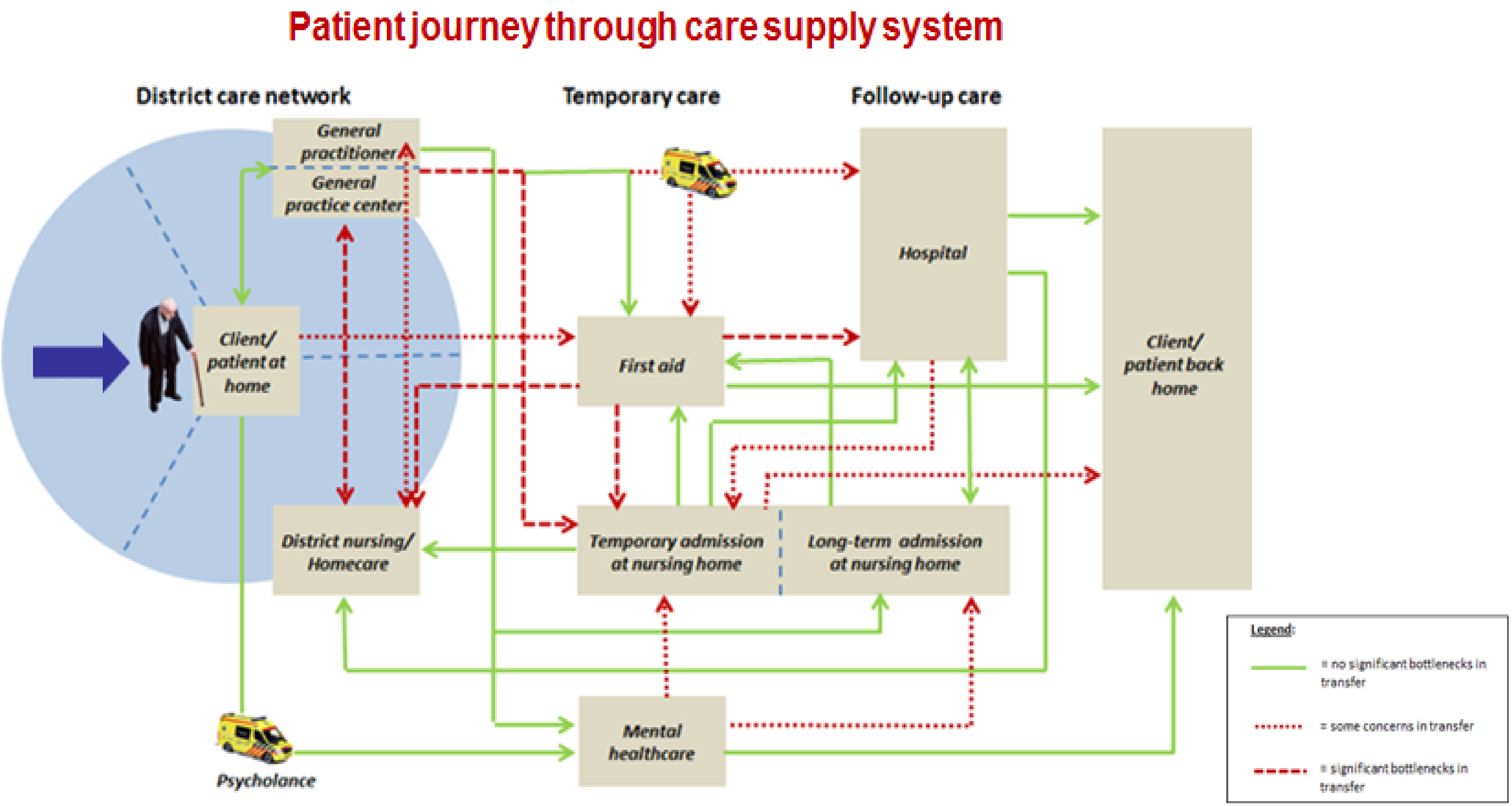
Waiting Lists Health Care

Centrum Wiskunde & Informatica

Challenges in Acute Elderly Care



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

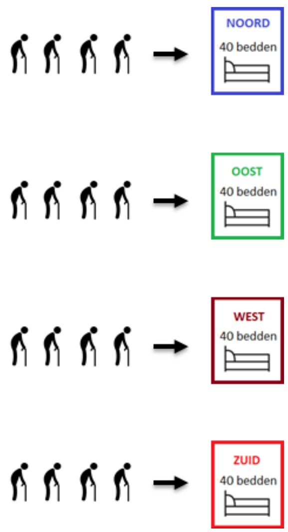
   47% in Lithuania

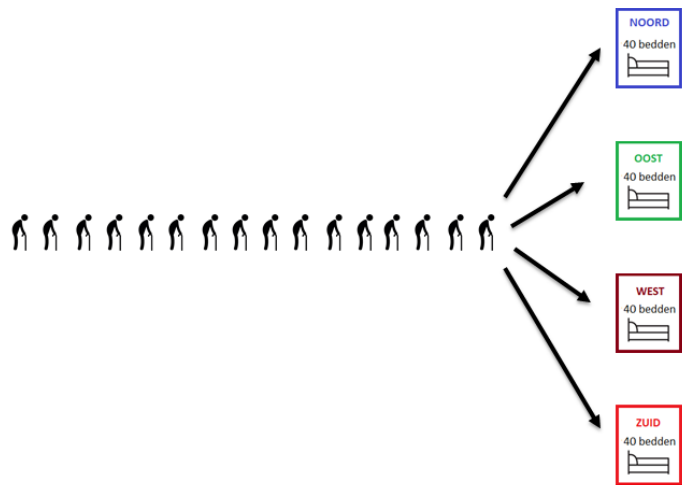
2. 16% of older adults in Spain die on the waiting list

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

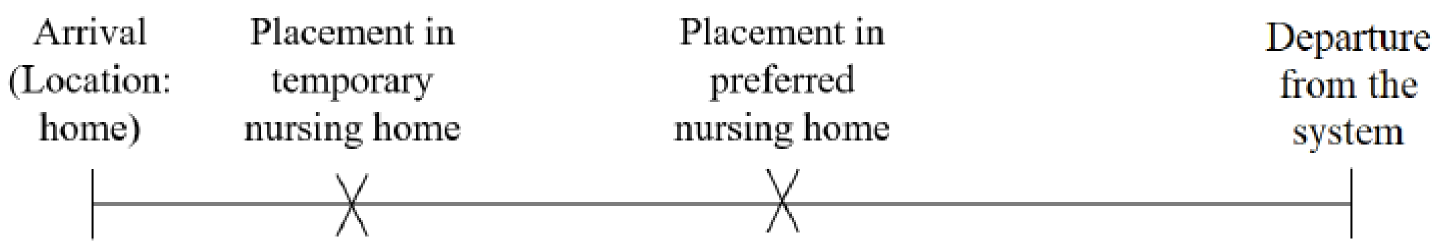
Current Way of Working

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

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

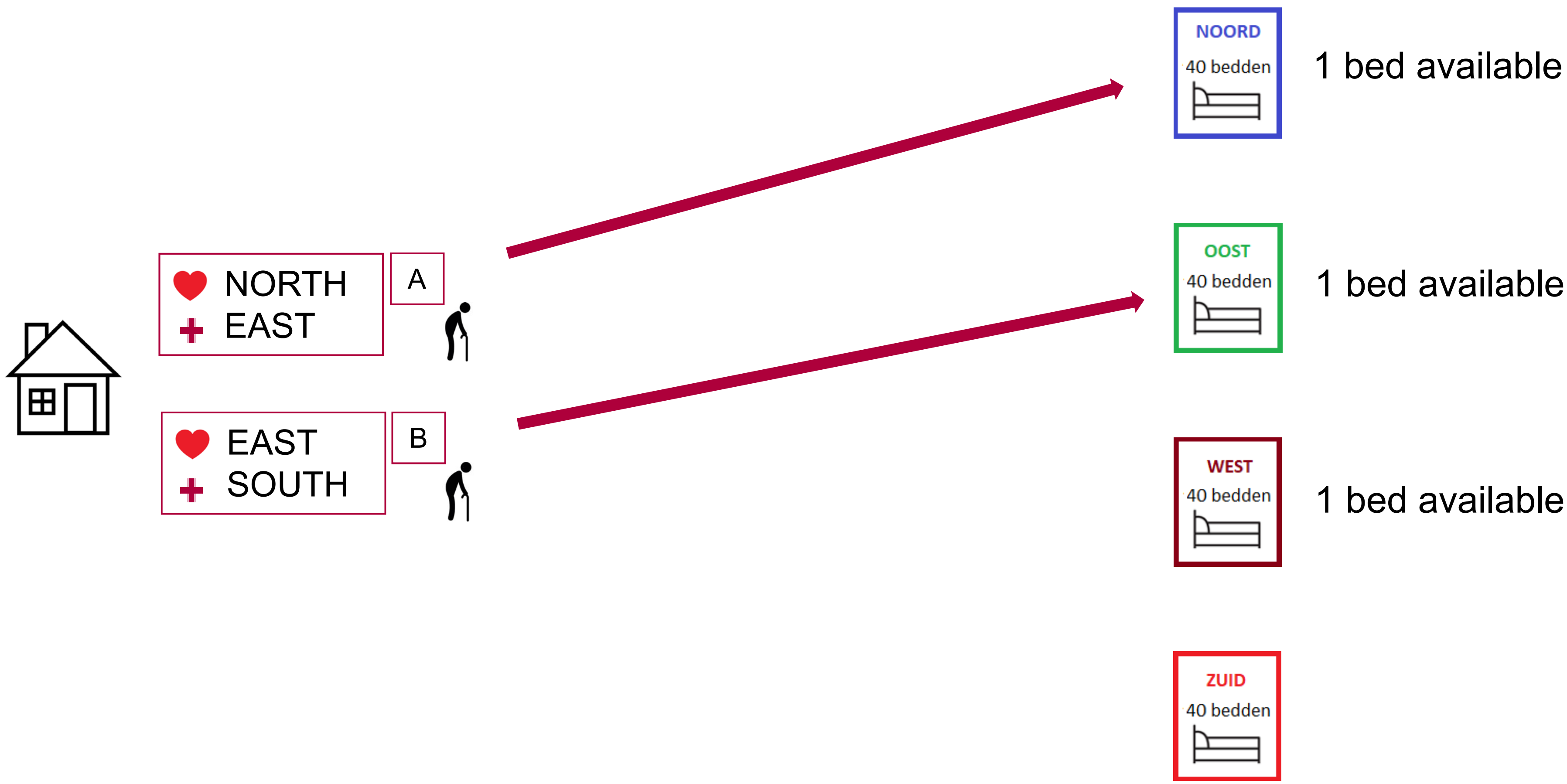
- **Hardly any coordination!**

- **Our approach:** centralized approach using allocation model



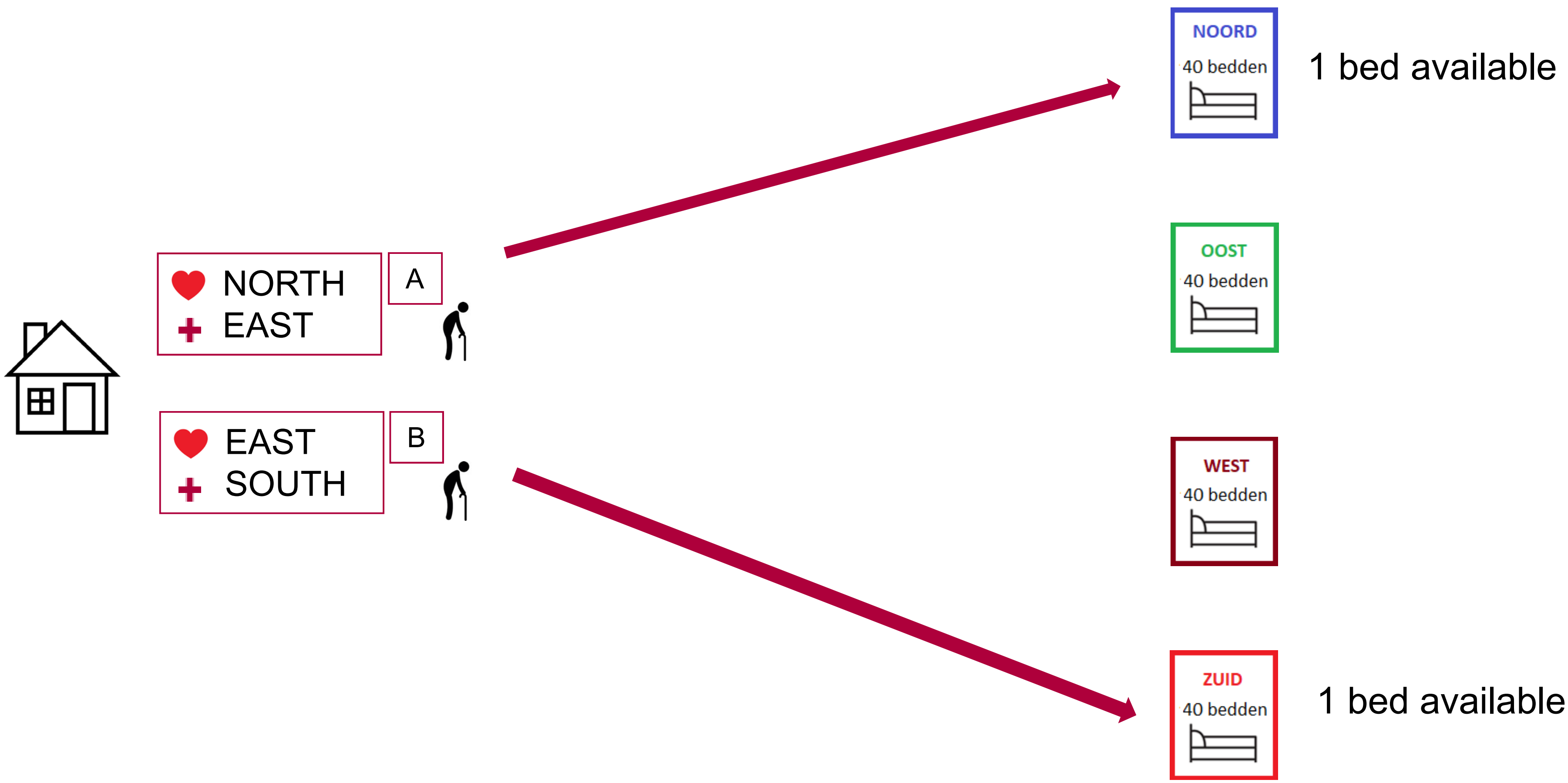
Toy Example

(1) Preferences of patients



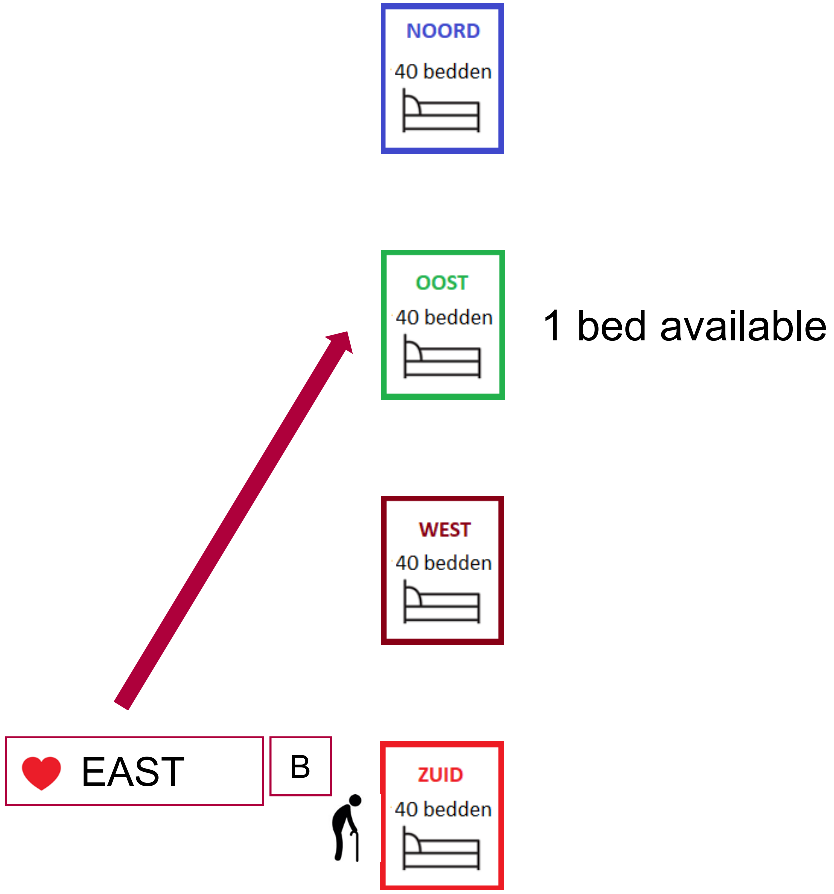
Toy Example

(2) Transitions between care centers



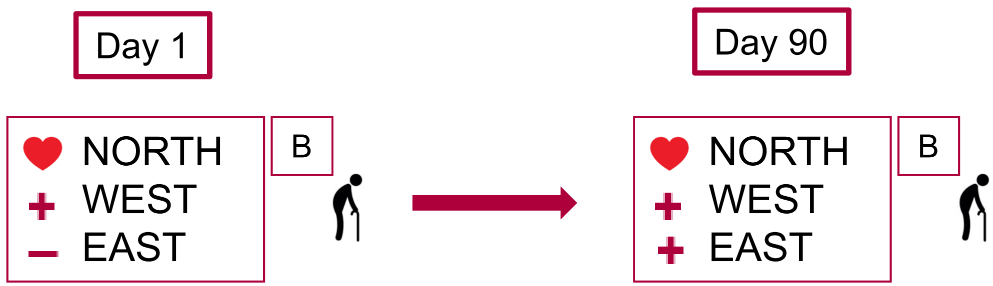
Toy Example

(2) Transitions between care centers



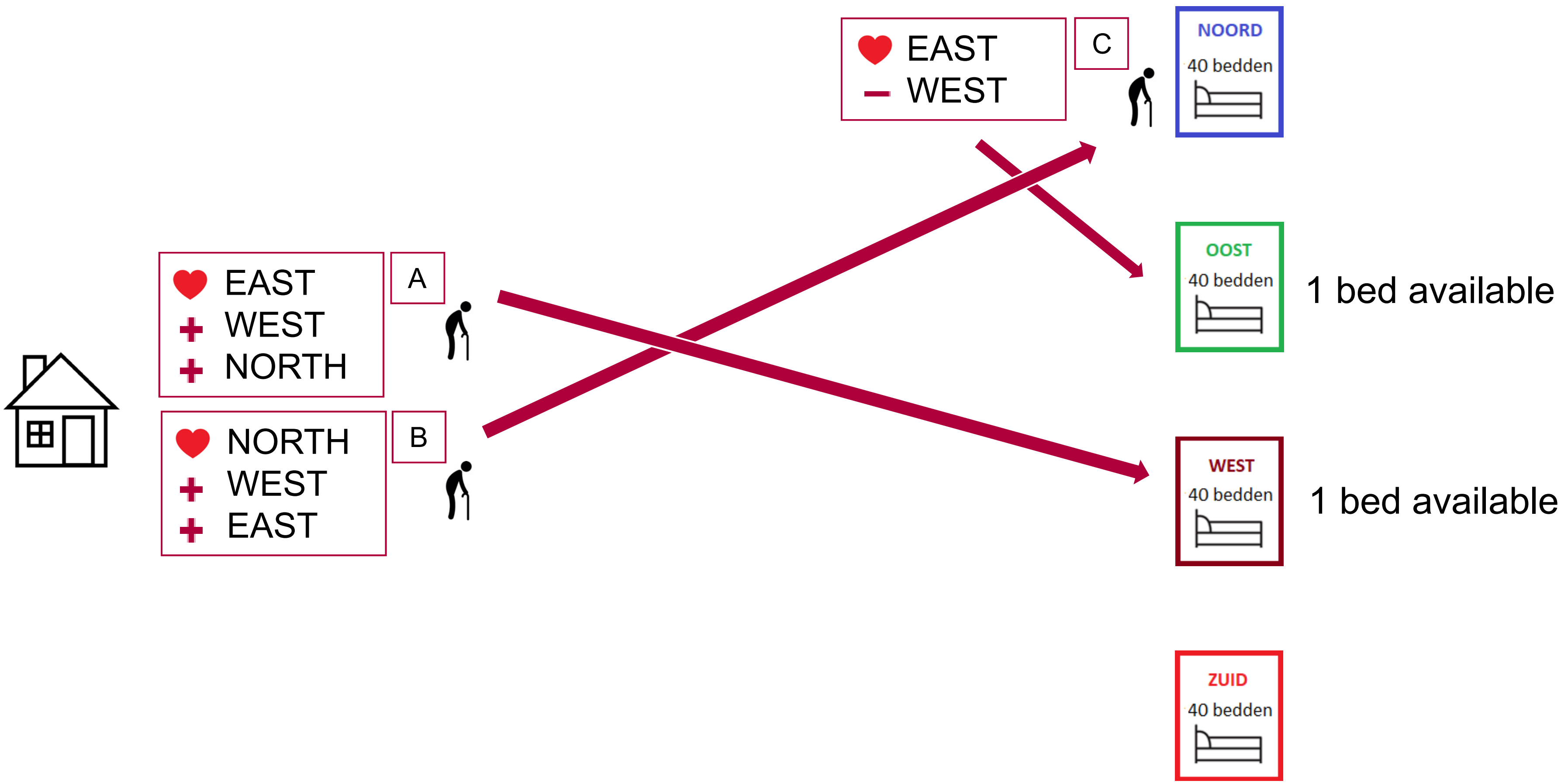
Toy Example

(3) Increase in urgency



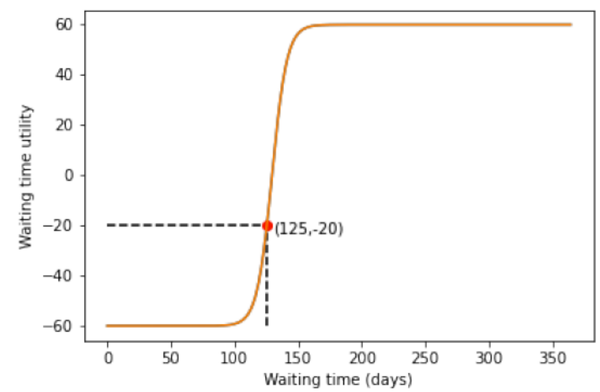
Toy Example

(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

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

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

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

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,…

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Rob van der Mei

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IARIA Congress, Nice, July 24-28, 2022