

Success Stories of Mathematics Saving Lives

Prof.dr. Rob van der Mei

Centrum Wiskunde & Informatica (CWI)
Vrije Universiteit Amsterdam (VU)

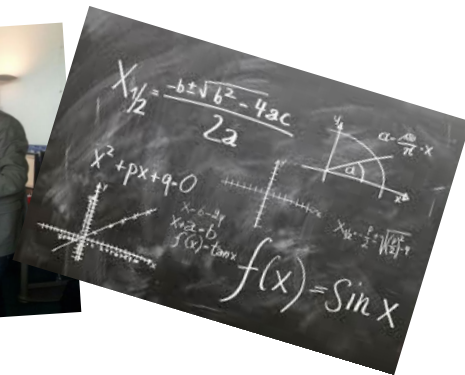
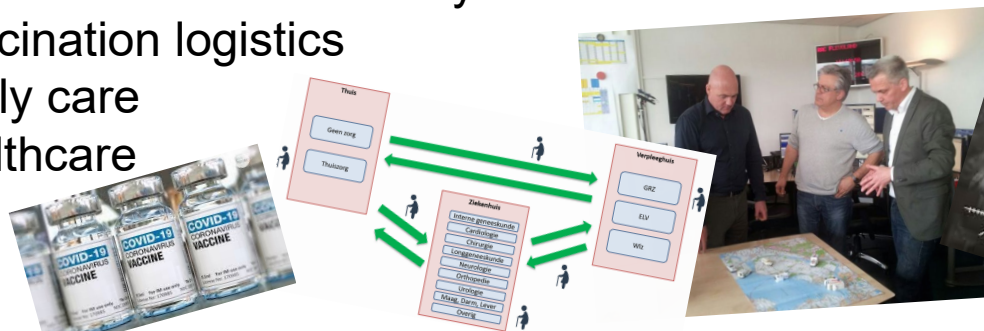
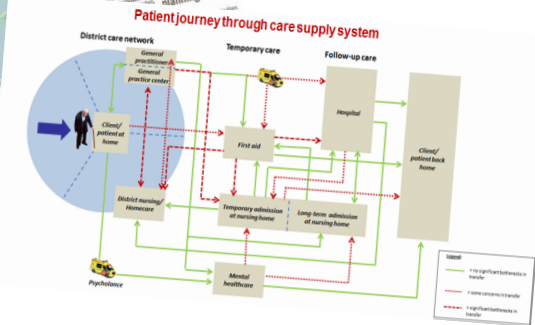
Overview:

1. Perspective

2. Examples of successful projects

- Emergency services: “when every second counts”
- COVID vaccination logistics
- Acute elderly care
- Mental healthcare

3. Discussion



Unboxing Logistics event, Arnhem, September 22, 2022

"Zorgen over de Zorg"

CWI

Centrum Wiskunde & Informatica

Kamer ontstemd: wachtlijsten verpleeghuizen flink langer dan verwacht

'Ambulance in steeds meer regio's zorgwekkend vaak te laat'

In een kwart van de ambulanceregio's in ons land zijn er ernstige zorgen omdat de ziekenwagen na een melding niet snel genoeg ter plekke is. Dit blijkt uit een brief van toezichthouder NZa die minister Bruins (Medische zorg) naar de Tweede Kamer heeft gestuurd.

Wachtlijst verpleeghuiszorg groeit opnieuw. 'Druk op mantelzorgers'

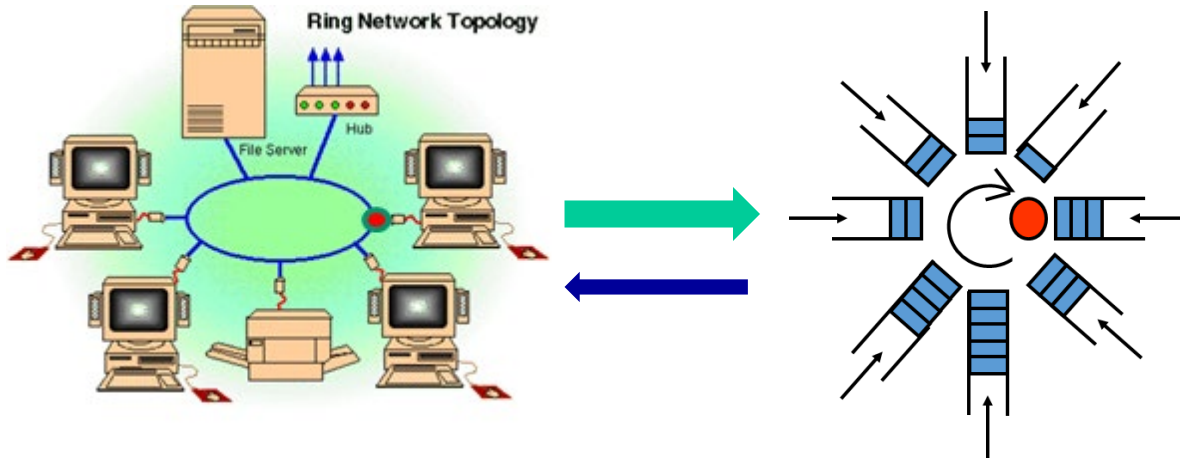
Nu.nl, 14-12-2023

'Kind in nood wacht gemiddeld tien maanden op hulp'

Maanden wachten op de juiste zorg: 'Mijn patiënt overleed op de wachtlijst'

In hoeverre kan het gebruik van **data analytics**, **AI**, **wiskundige modellering** en **optimalisatie** bijdragen aan betere zorglogistiek?

My Background



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

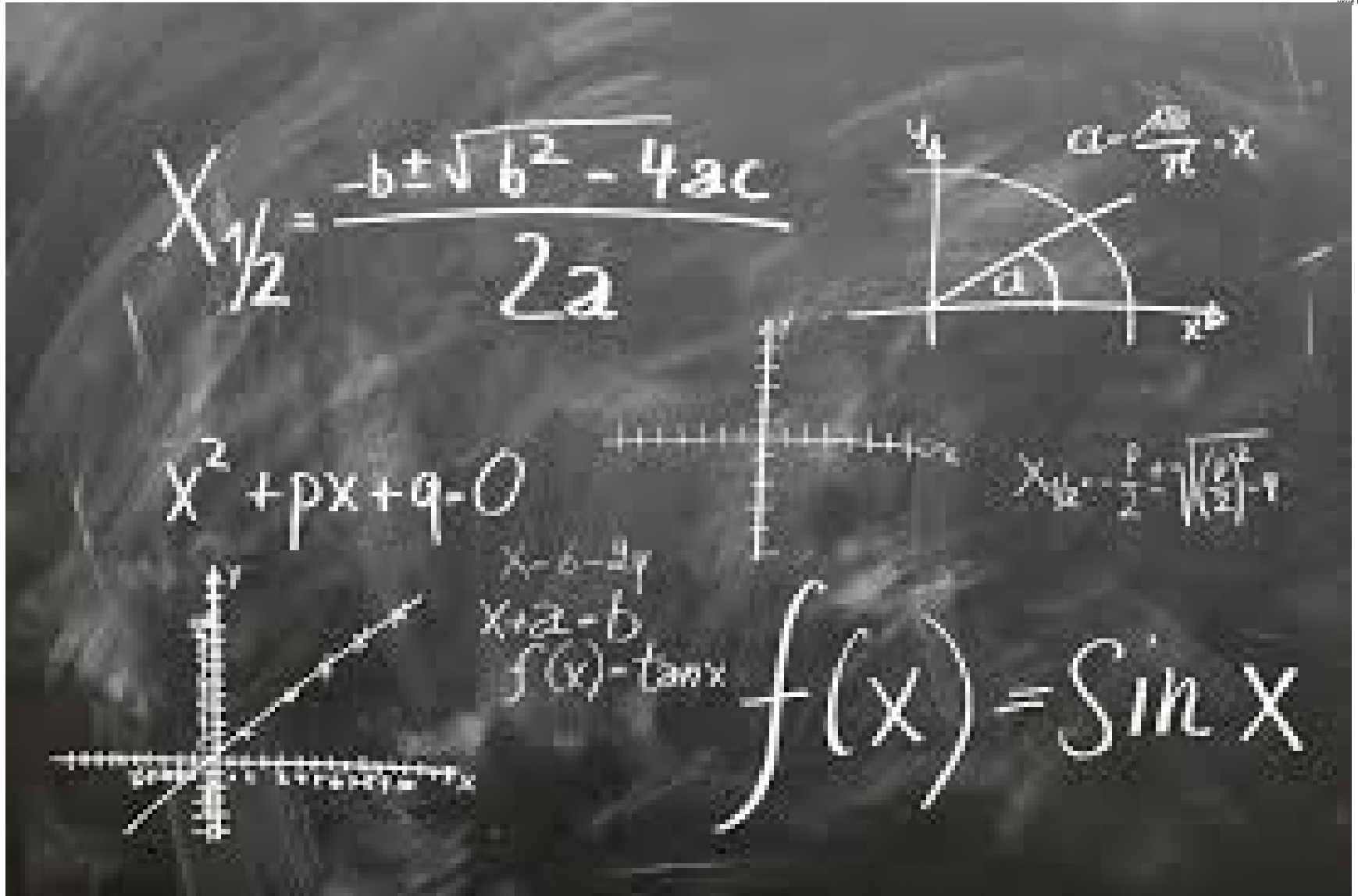
Since 2003

VU (Full Professor in Applied Mathematics)

Since 2004

Centrum Wiskunde & Informatica

Maths In the Good-Old Days...

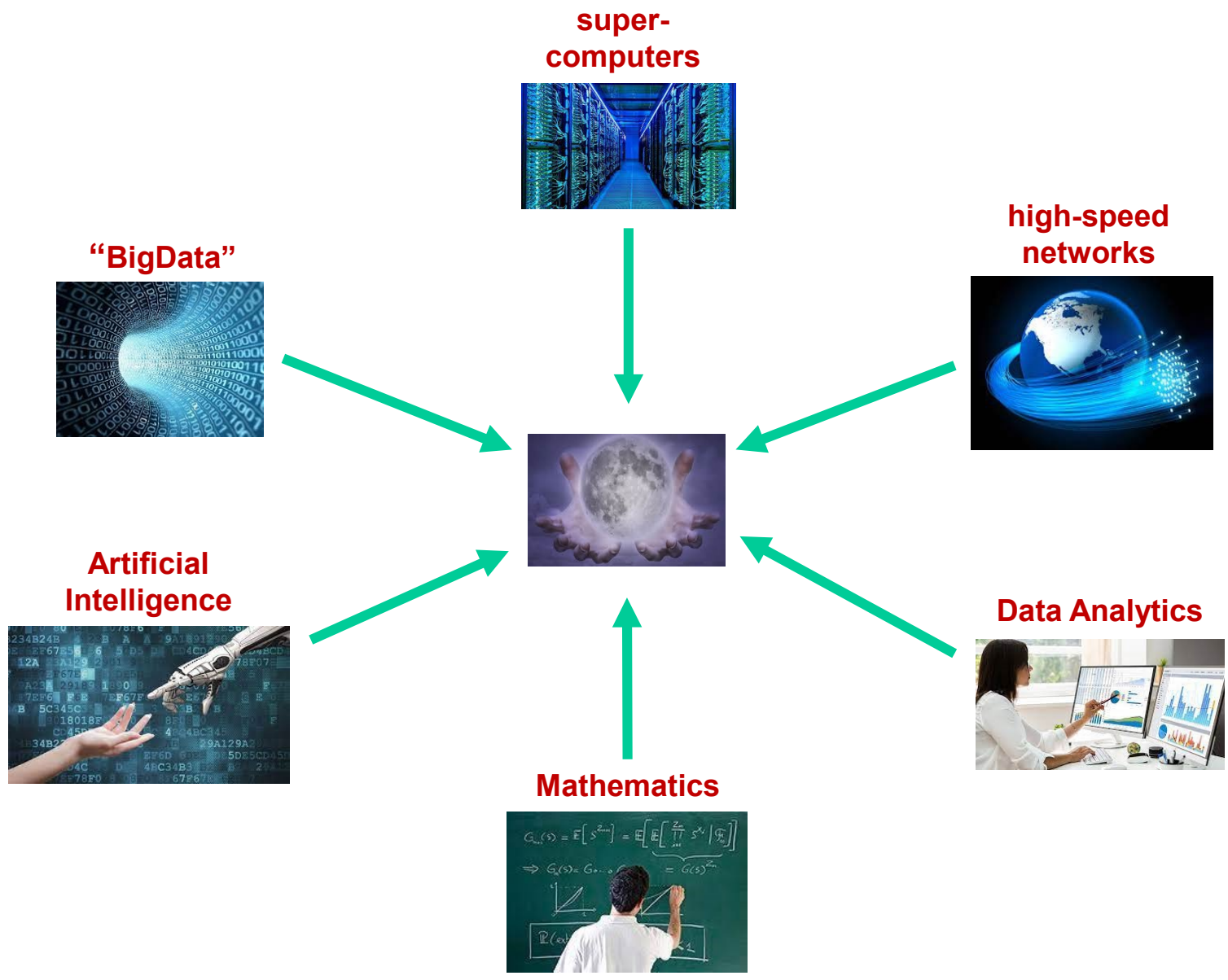


“Mathematics Inside”

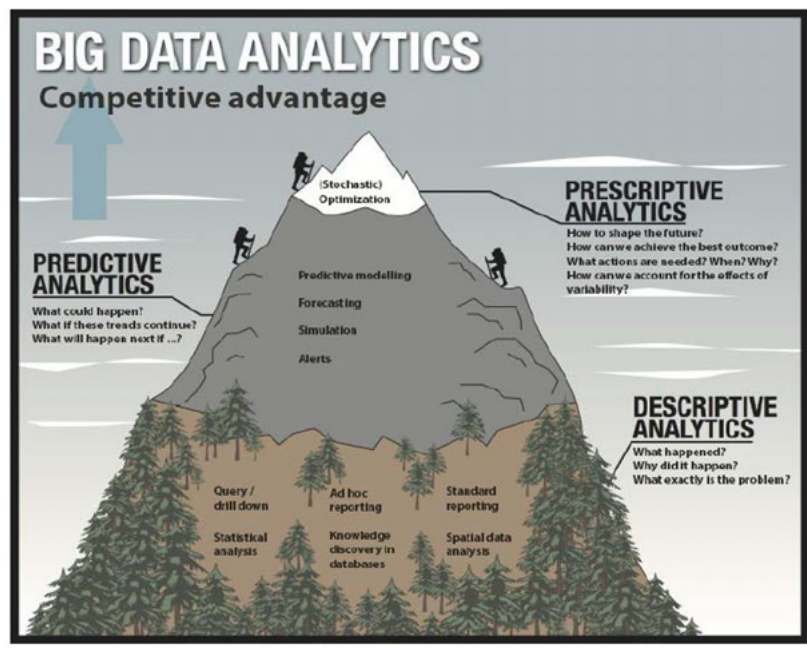
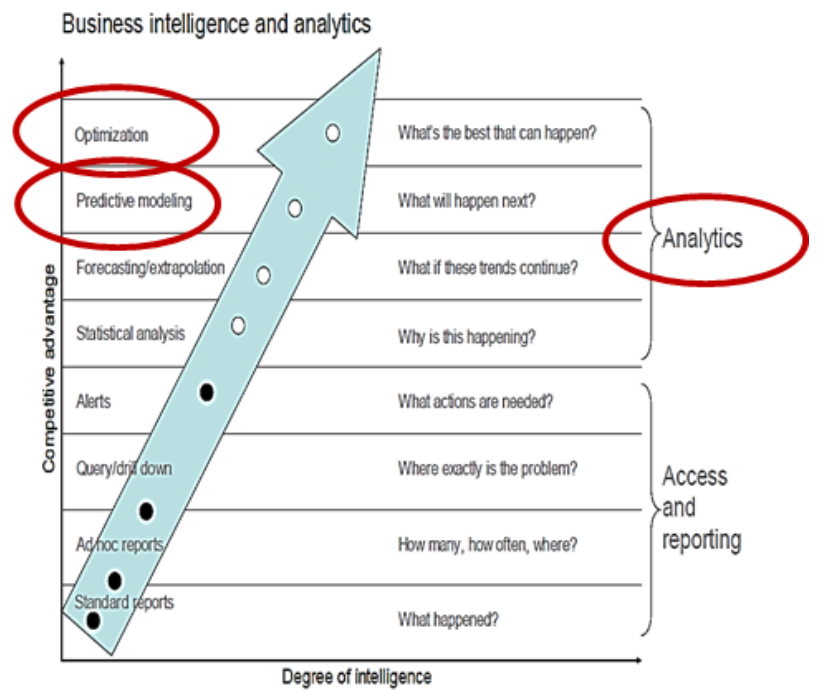


“Mathematics is like **oxygen**: you do not see it, but you would miss it if it were is no longer there...”

Now It All Comes Together...



Data Analytics en Optimalisatie



- Data Analytics staat hoog op de management agenda
- **Descriptive → Predictive → Prescriptive**
- Organisaties die gebruik maken van data analytics en optimalisatie presteren **aantoonbaar beter!**

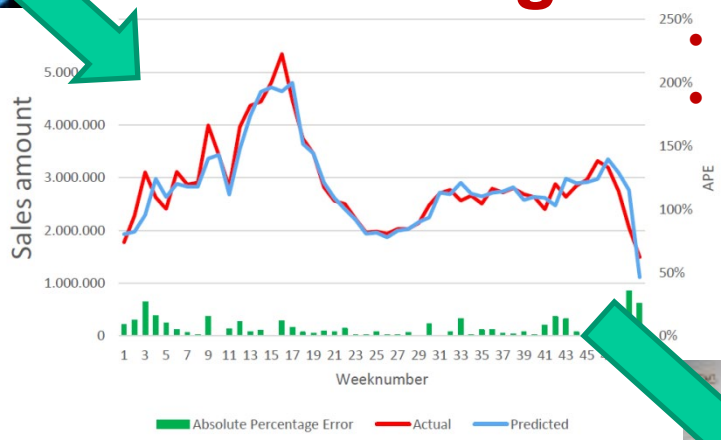
Data Analytics and Optimization

data



data analytics

insights and forecasting



Operations Research
Stochastic Optimization

optimization

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

optimization models



Over the Past 25 Years...



Over the years:

100+ consultancy projects, 100+ R&D projects, 60+ Ph.D. students, 100+ M.Sc. students, 200+ publications

Conclusion: Data analytics, mathematical modelling and optimization can make a difference in virtually all application domains

Pictures from veiligheidsregio Noord-Holland Noord



Unboxing Logistics event, Arnhem, September 22, 2022

Ambulance Care in NL



A1-calls: Urgent and life threatening

< 15 min

- severe incident

A2-calls: Urgent but not life-threatening

< 30 min

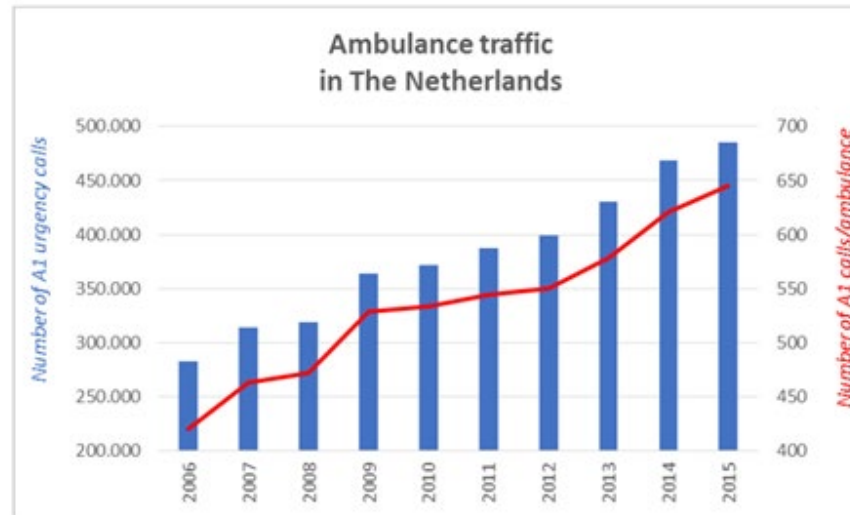
- broken leg

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



connexion



rivm

REPRO : from Reactive to Proactive

Wiskunde redt levens

Kansberekening en modellering moeten ambulanceplanning in Amsterdam verbeteren.

JORINE ZANDHUIS



WETENSCHAP 'Incidentplanning werkt als een schaakspel'

Ambulance is vaker op tijd dankzij de wiskunde.

De ambulance die een te lange aanrijtijd heeft om een leven te redden, het is een schrikbeeld. Rob van der Mei maakt met behulp van wiskundige modellen hulpdiensten met in balans te brengen en efficiënter.

ANN MEKKENBERG
JIM JANSSEN

Het is gekend dat de ambulance... incidentplanning werkt als een schaakspel... wiskunde... efficiënter... modellen... hulpdiensten... in balans te brengen... wiskundige modellen... efficiënter.

Paspoort

Wetenschappelijk... incidentplanning... wiskunde... efficiënter... modellen... hulpdiensten... in balans te brengen... wiskundige modellen... efficiënter.

93

3,2



Door scherpere voorspellingen met behulp van statistiek kunnen meer ambulances uitrukken voor minder geld.

Raim duizend wiskundigen... incidentplanning... wiskunde... efficiënter... modellen... hulpdiensten... in balans te brengen... wiskundige modellen... efficiënter.

meewerkers aanwezig. Deze plan... incidentplanning... wiskunde... efficiënter... modellen... hulpdiensten... in balans te brengen... wiskundige modellen... efficiënter.

'Ambulances kunnen veel tijdswinst boeken'

AMSTERDAM • De inzet van ambulances kan veel beter worden gepland. Er kan veel tijdswinst boeken. Dat stelt het Centrum voor Wiskunde en Informatica, samen met de komende vier jaar... incidentplanning... wiskunde... efficiënter... modellen... hulpdiensten... in balans te brengen... wiskundige modellen... efficiënter.

efficiënt inzetten van hun wagens. De inefficiency leidt volgens hem tot onnodige kosten. Het centrum wil op basis van voorbeeld verkeersdrukte in brengen hoe lang het duurt van de dag van A naar B. Ook kan worden groot de kans is dat... incidentplanning... wiskunde... efficiënter... modellen... hulpdiensten... in balans te brengen... wiskundige modellen... efficiënter.



SPOTS Nieuws & Entertainment Amsterdam

'Big Data' helpt politie

Via Wiskunde is aantal incidenten te voorspellen

PvdD: vragen over rioolwet

'Ambulances kunnen veel sneller'

AMSTERDAM - De inzet van ambulancediensten kan veel beter worden georganiseerd. Er kan veel tijdswinst worden geboekt.

De organisatie gaat, samen met de TU Delft, de komende 4 jaar iedere zondag mensen in nood sneller worden geholpen.

Het centrum wil op basis van bijvoorbeeld verkeersdrukte in kaart brengen hoe lang het duurt om ambulances op een bepaald moment van de dag van A naar B te krijgen. Ook kan worden berekend hoe groot de kans is dat er sowieso een ambulance nodig is.

amstlvn IEDERE ZONDAG SHOPPEN

www.stadshoortamstelveen.nl

Team Effort and Acknowledgments



The screenshot shows a news article on the ED.nl website. The main headline is "Hoe de ambulance vaker op tijd komt met behulp van de wiskunde van Rob". The article text states that an ambulance driver, Rob van der Mei, uses mathematical models to improve efficiency. The article is dated 25-05. The website header includes navigation links for REGIO, ALGEMEEN, SPORT, VIDEO, PODCAST, OPINIE, PUZZEL, and a search icon. There are also buttons for "ABONNEREN" and "INLOGGEN". A sidebar on the right lists various news topics like "Kan ik mijn autoverzekering beter wijzigen?", "Jordi moest al meerdere keren springen voor zijn leven", and "Nieuwe regels op komst voor rijtscholen". A Subway advertisement is visible at the bottom of the article content.

ED REGIO ALGEMEEN SPORT VIDEO PODCAST OPINIE PUZZEL ABONNEREN INLOGGEN

Binnenland Buitenland Politiek Economie Show Geld Gezin Gezond Bizar Wetenschap Auto Tech Wonen Reizen

25-05 'Kan ik mijn autoverzekering beter wijzigen?'

25-05 **PREMIUM** Jordi moest al meerdere keren springen voor zijn leven: 'We zijn...'

25-05 Nieuwe regels op komst voor rijtscholen om wanpraktijken tegen te gaan

25-05 **PREMIUM** 'Benzineprijs komt dit jaar niet meer onder de 2 euro'

BEKIJK ALLE ARTIKELEN

FIND YOUR SUBWAY, TRY IT NOW
CHICKEN TANDOORI

ENTER ZIPCODE

FIND RESTAURANT **SUBWAY**

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FIND YOUR

▲ Een ambulance verlaat met hoge snelheid de garage na een melding. © ANP / ANP XTRA

Hoe de ambulance vaker op tijd komt met behulp van de wiskunde van Rob

De ambulance die een te lange aanrijtijd heeft om een leven te redden, het is een schrikbeeld. Rob van der Mei maakt met behulp van wiskundige modellen hulpdiensten met ambulancevoertuigen efficiënter.

<https://www.ed.nl/auto/hoede-ambulance-vaker-op-tijd-komt-met-behulp-van-de-wiskunde-van-rob~a73c1c44/216123823/>

Thanks to: Karen Aardal, Caroline Jagtenberg, Pieter van den Berg, Thije van Barneveld, Theresia van Essen, Martin van Buuren, Sandjai Bhulai, Coen Huibers, Petra Vis, Lisette Sloof, Guido Legemaate, Rutger Kerckamp, Peter Dwars, Maria Mahfoud, Melania Calinescu, and others

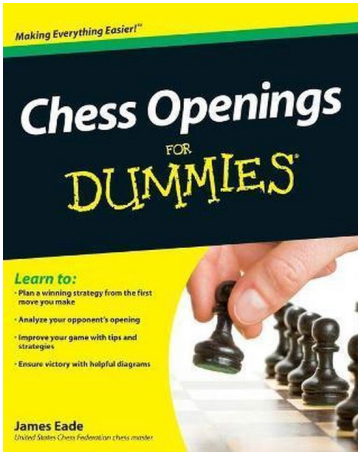
Mathematics in Action



Playing Chess



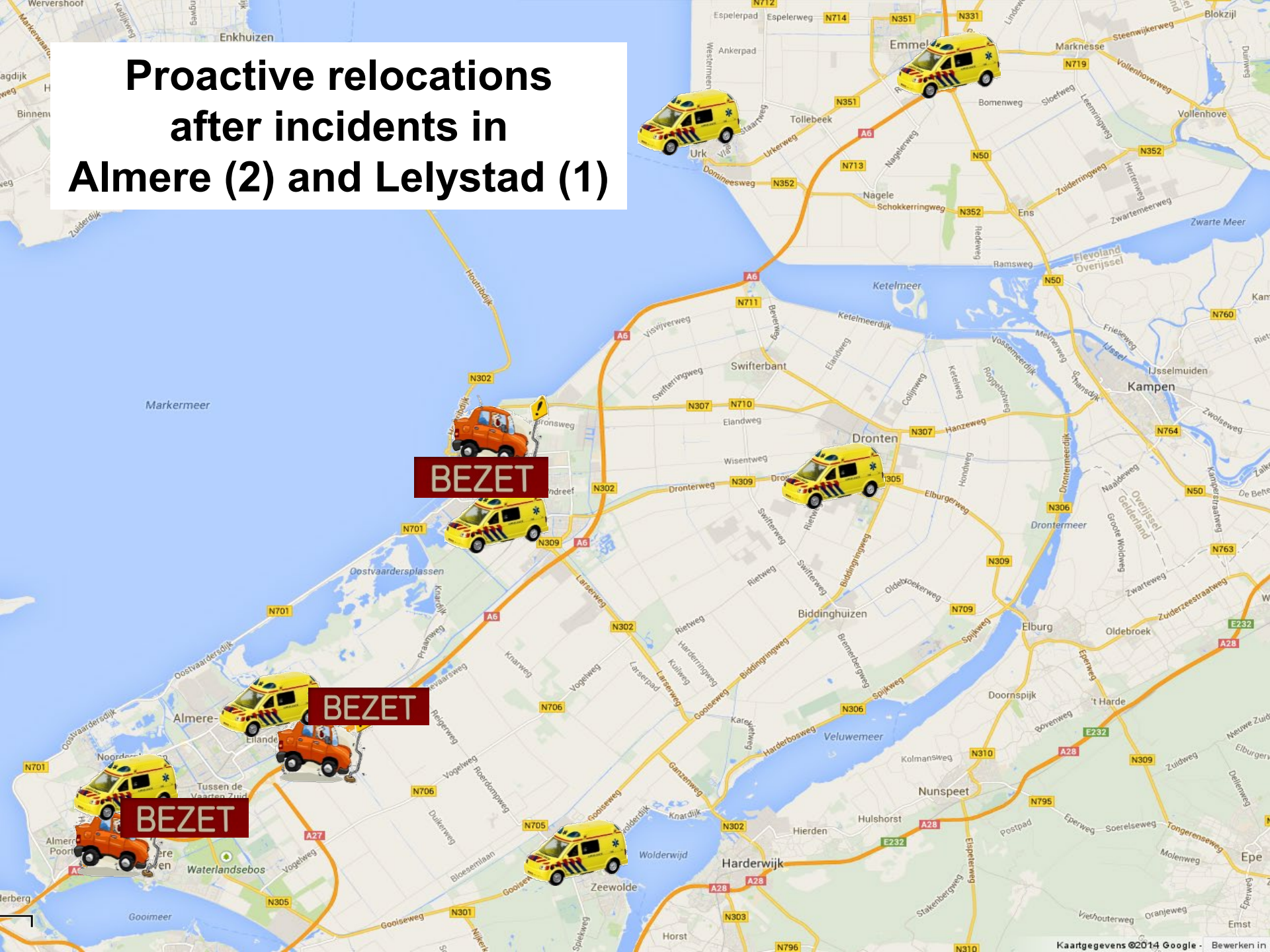
Chess for Dummies



Chess for Professionals

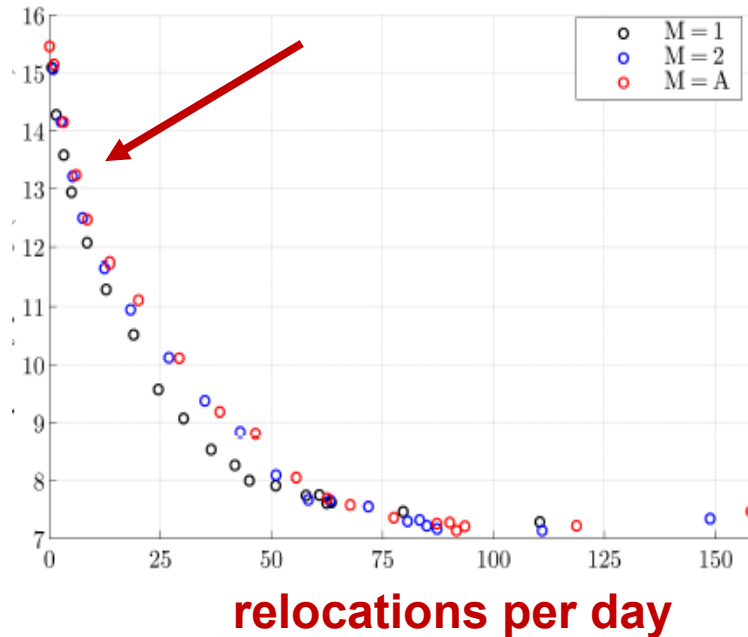


Proactive relocations after incidents in Almere (2) and Lelystad (1)



Effectiveness of Relocations

late arrivals



Good news:

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

Under the Hood...



Basic idea: maximize preparedness for next incident

Real-Time Decision Making



weather circumstances



real-time traffic information



mass events

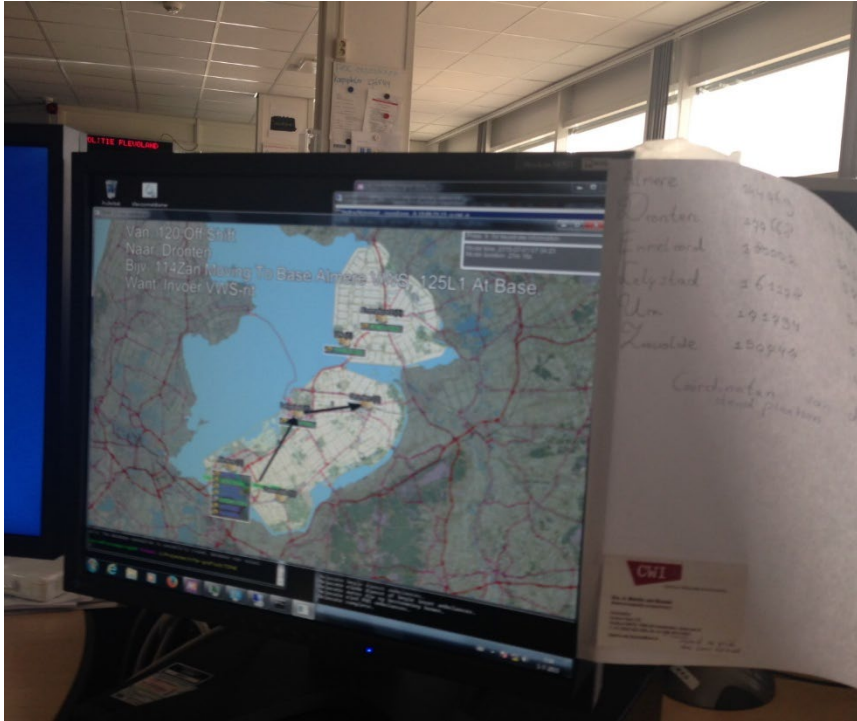
Acceptance in Practice?



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





Unboxing Logistics event, Arnhem, September 22, 2022



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 of Fire Stations

coverage

4 modifications

# wijzigingen	Dekking				Totaal
	TS	RV	HV	WO	
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	94,76
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!

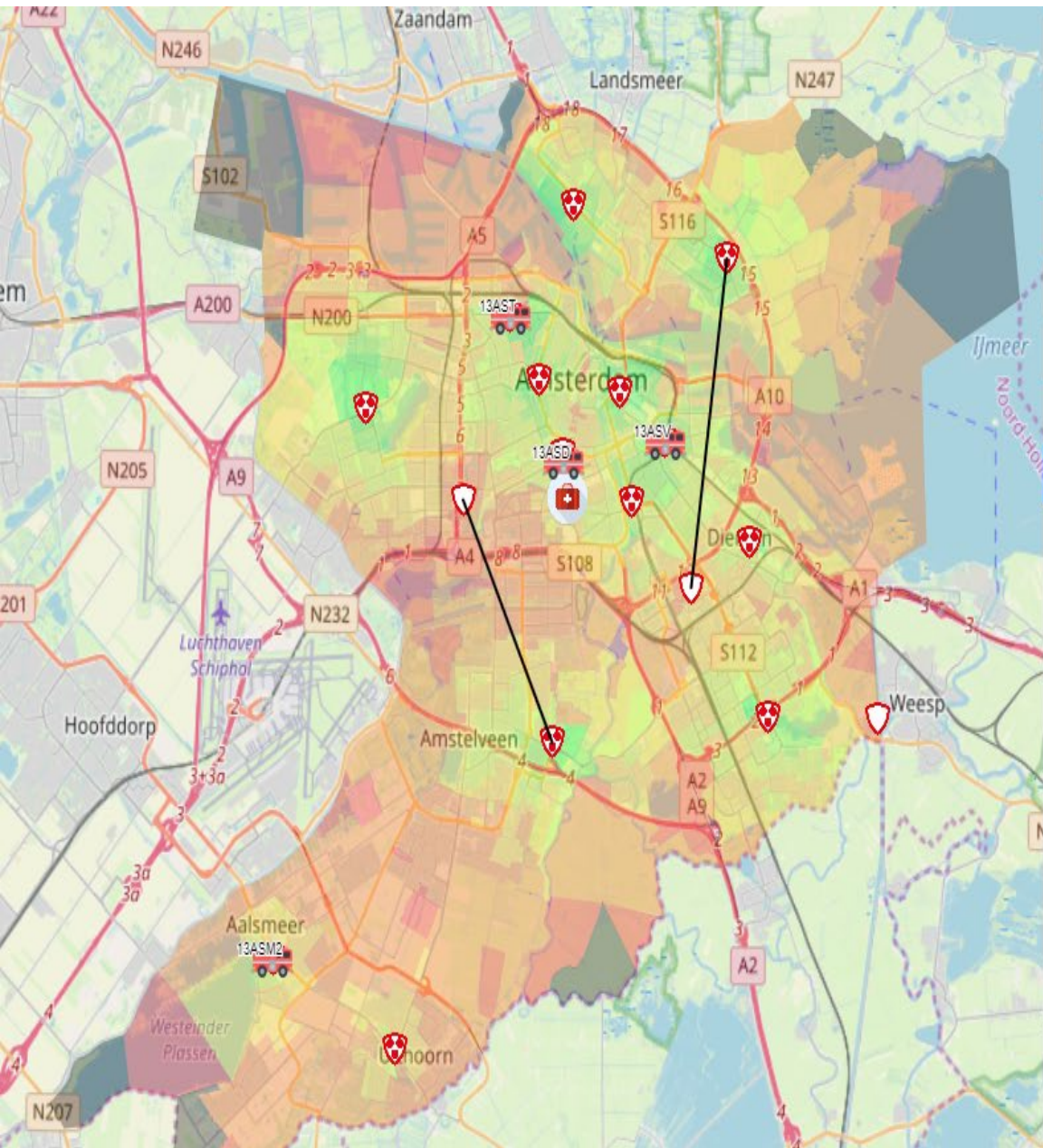
Letter by Commander in Chief:

“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.”



Tool ("fireScore")



- Map layers
- Incidents
- Fire stations
- Fire truck status
- Fire truck location
- Response times (pumpers)
- Relocations
- ▾ Forecast**

Forecast for wednesday September 25

Temperature: 17 °C

Wind: 5.8 m/s
Gusts: 7.5 m/s

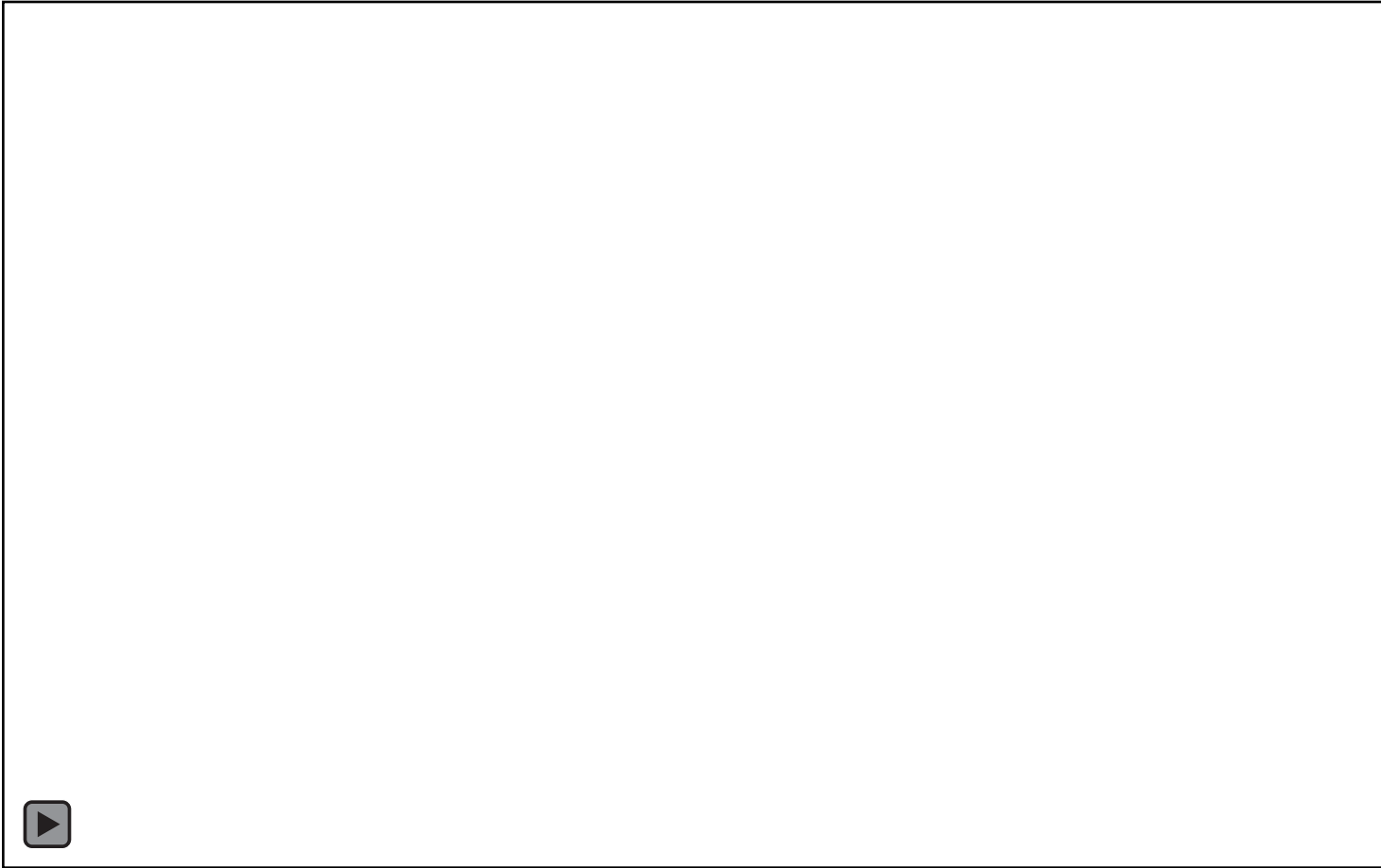
Precipitation: 65%
Precipitation: 9 mm

Incident (storm) forecast for today: **normal**

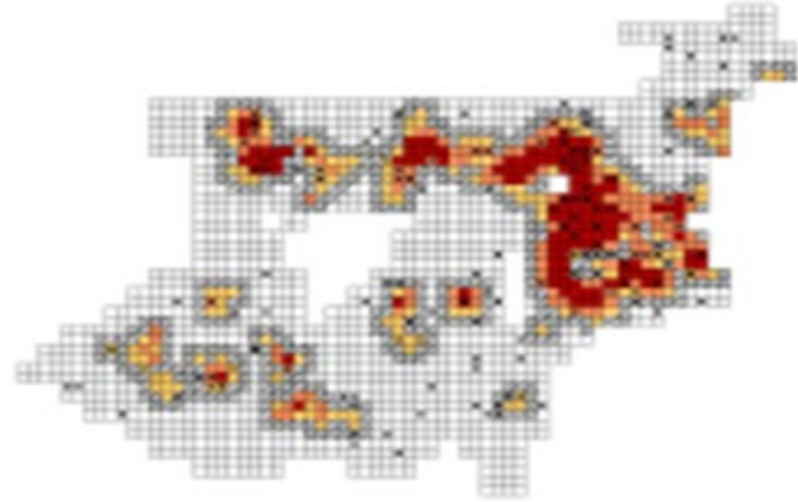
Incident (storm) forecast for tomorrow: **normal**

- Simulation
- Information
- Debug

Fighting Crime with Maths!



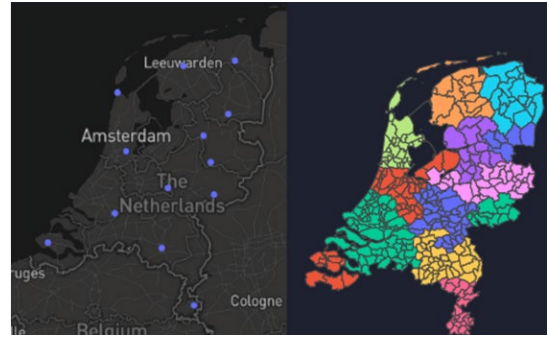
Predictive Policing



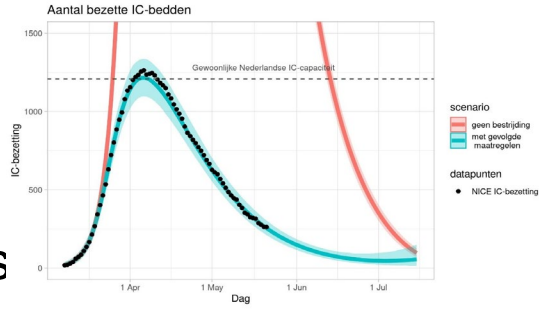
- **Goal:** reduction of **high-impact crimes**
- **Idea:** Allocation of man-power at 'hot' places
- Cross-correlation with demo- and geographic factors
- 'Near-repeat' phenomenon



Mathematics during COVID



- Forecasting number of patients
 - **Proper locations** of the vaccination hubs?
 - Optimal **distribution of patients** over hospitals
 - Waiting times of the different age and priority groups?
 - What are the implications of uncertainty in **vaccine availability**?
-
- Collaboration with GGD GHOR, RIVM and LCPS
 - Decision support system



113 zelfmoord
• • • •
preventie

- What combination of “factors” leads to high-risk profile?
- NLP to support the quality of service during chats or calls

Waiting Lists in Elderly Care

CWI

Centrum Wiskunde & Informatica



Kamer ontstemd: wachtlijsten verpleeghuizen flink langer dan verwacht

NOS, 15-01-2020

Wachtlijst verpleeghuiszorg groeit opnieuw: '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



2.100.000 ouderen van 75+

2030



+60%

Op elke oudere 4 werkenden



Op elke oudere 2 werkenden



-50%

800.000 ouderen bezoeken jaarlijks de SEH

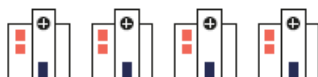


1.100.000 ouderen bezoeken jaarlijks de SEH



+40%

280.000 ouderen jaarlijks acuut opgenomen



390.000 ouderen jaarlijks acuut opgenomen



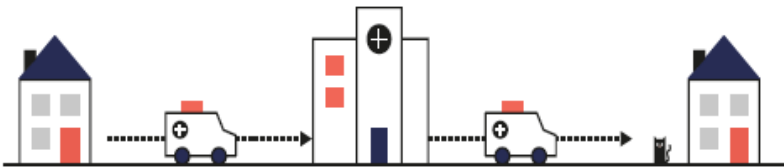
+40%

Current System Creates Demand

ONS HUIDIGE SYSTEEM CREËERT ZORGVRAAG



1 op de 5 ouderen (57.000) is binnen een maand terug op SEH.



1 op de 3 ouderen (85.000) is blijvend achteruit gegaan in functioneren.

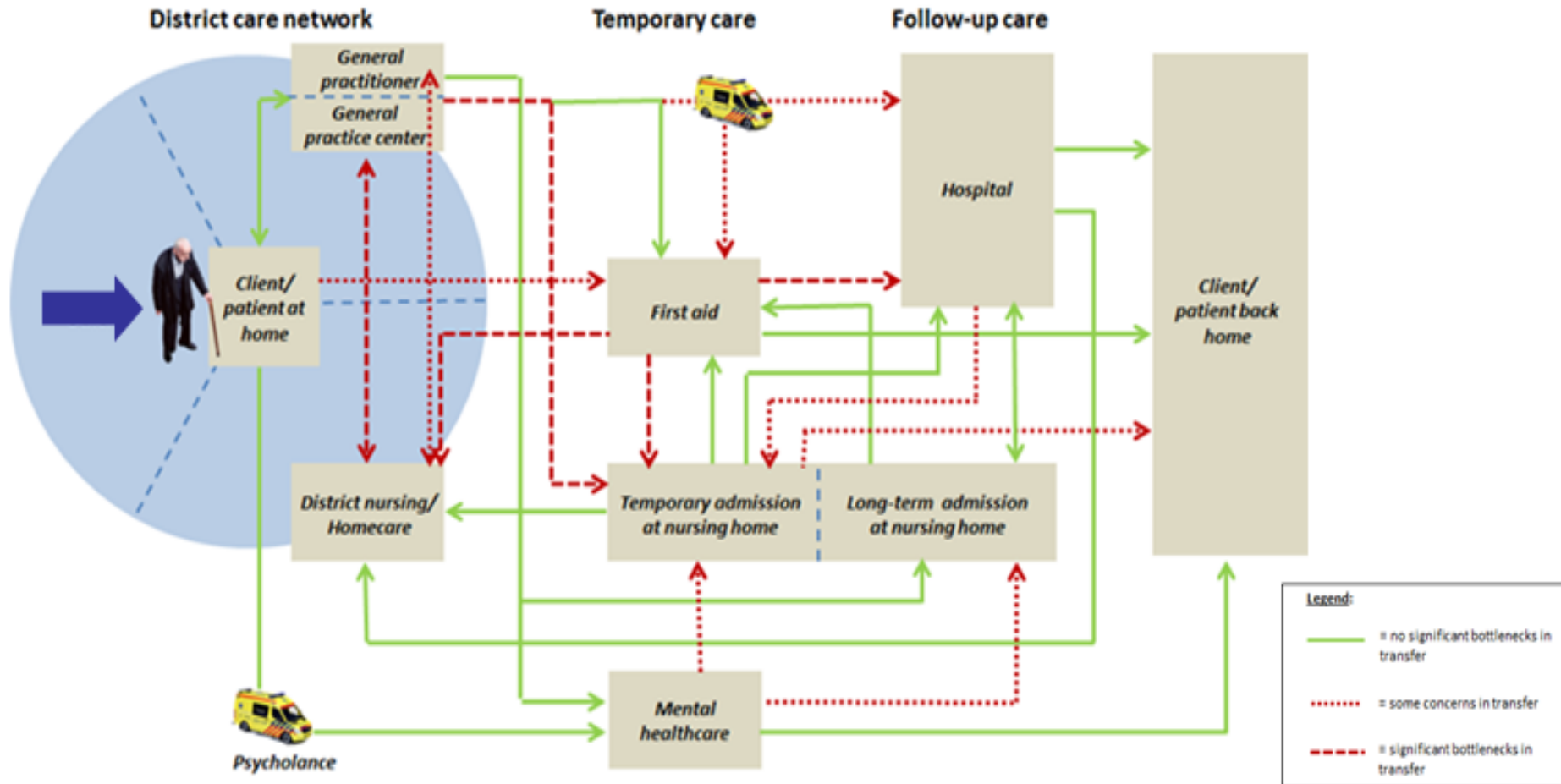


1 op de 3 ouderen (85.000) is binnen een jaar na opname overleden.



Patient Journey

Patient journey through care supply system



- “Waterbed model”

Excessive Waiting Times



incident



overload



surgery (after
14 days)

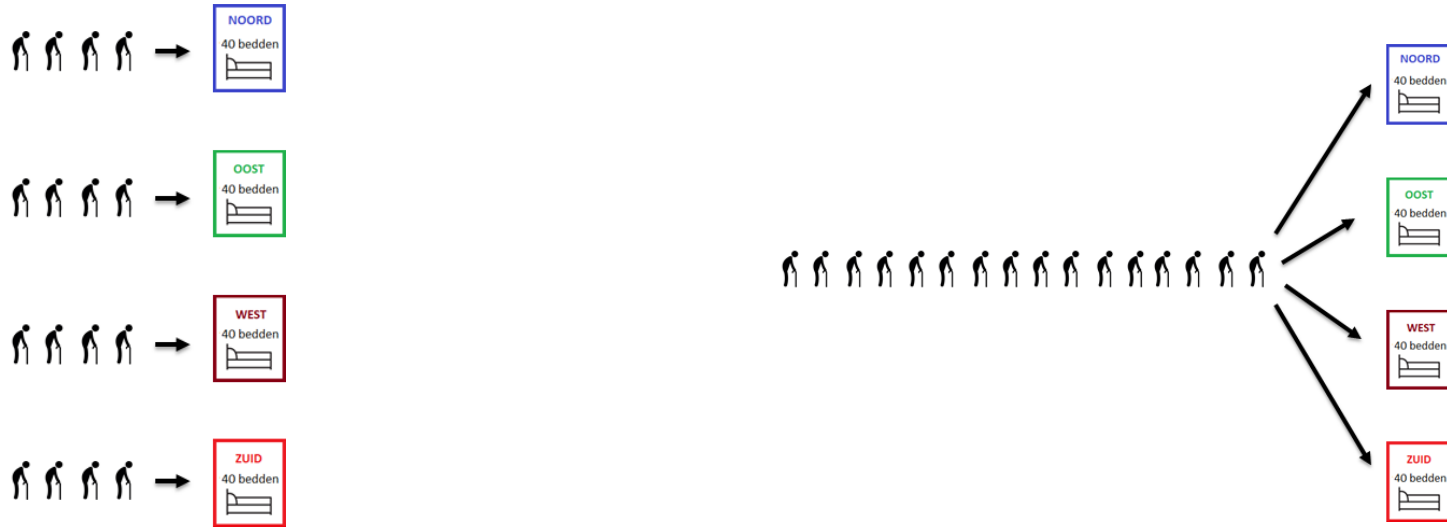


nursing home

- 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
- 16% of older adults in Spain die on the waiting list
- Regional shortages: Copenhagen, waiting time > 3.5 years

Cause for long waiting times: preferences for nursing homes

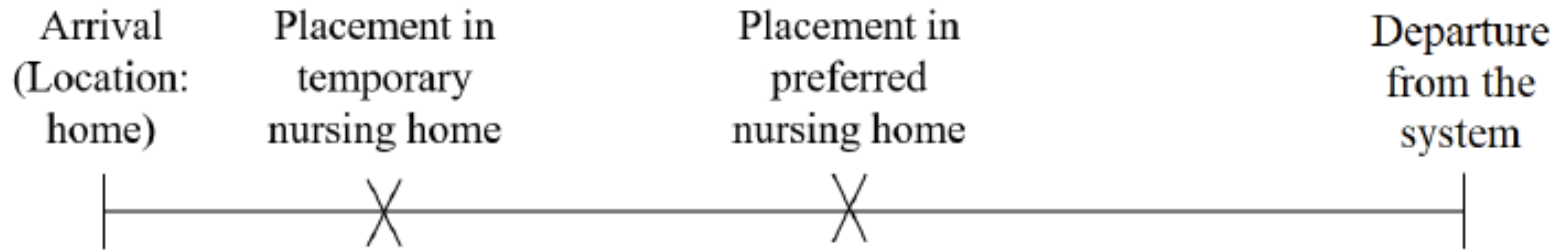
Balancing Trade-off



- + include personal preferences
- inefficient use of beds

- + efficient of use beds
- no individual preferences

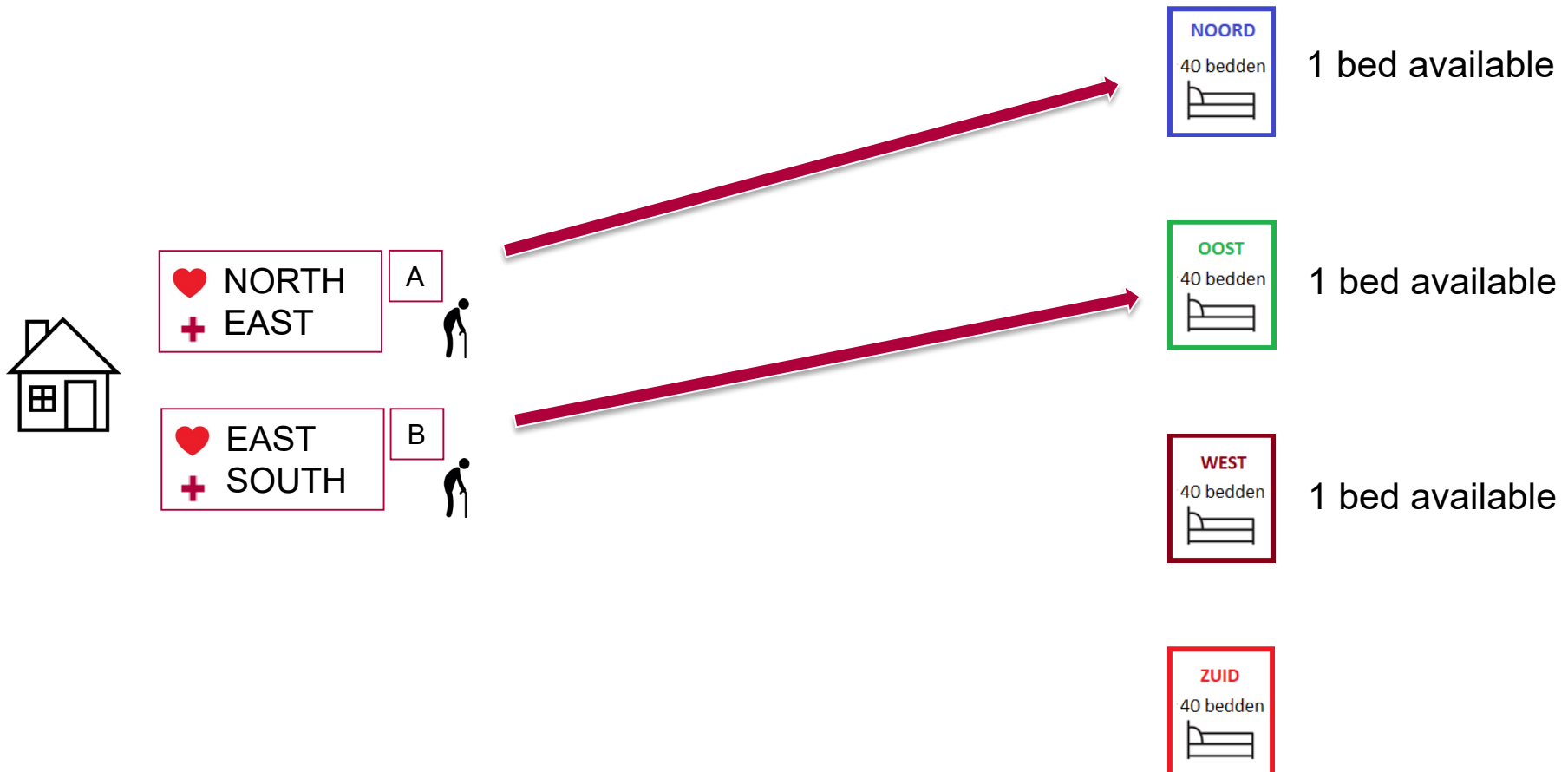
Common Way of Working



- Older adults typically apply for **preferred nursing home**
- They **wait at home** until a “bed” becomes available
→ probably placed in a temporary nursing home
- **Limited coordination!**
- **Our approach:** centralized approach using allocation model

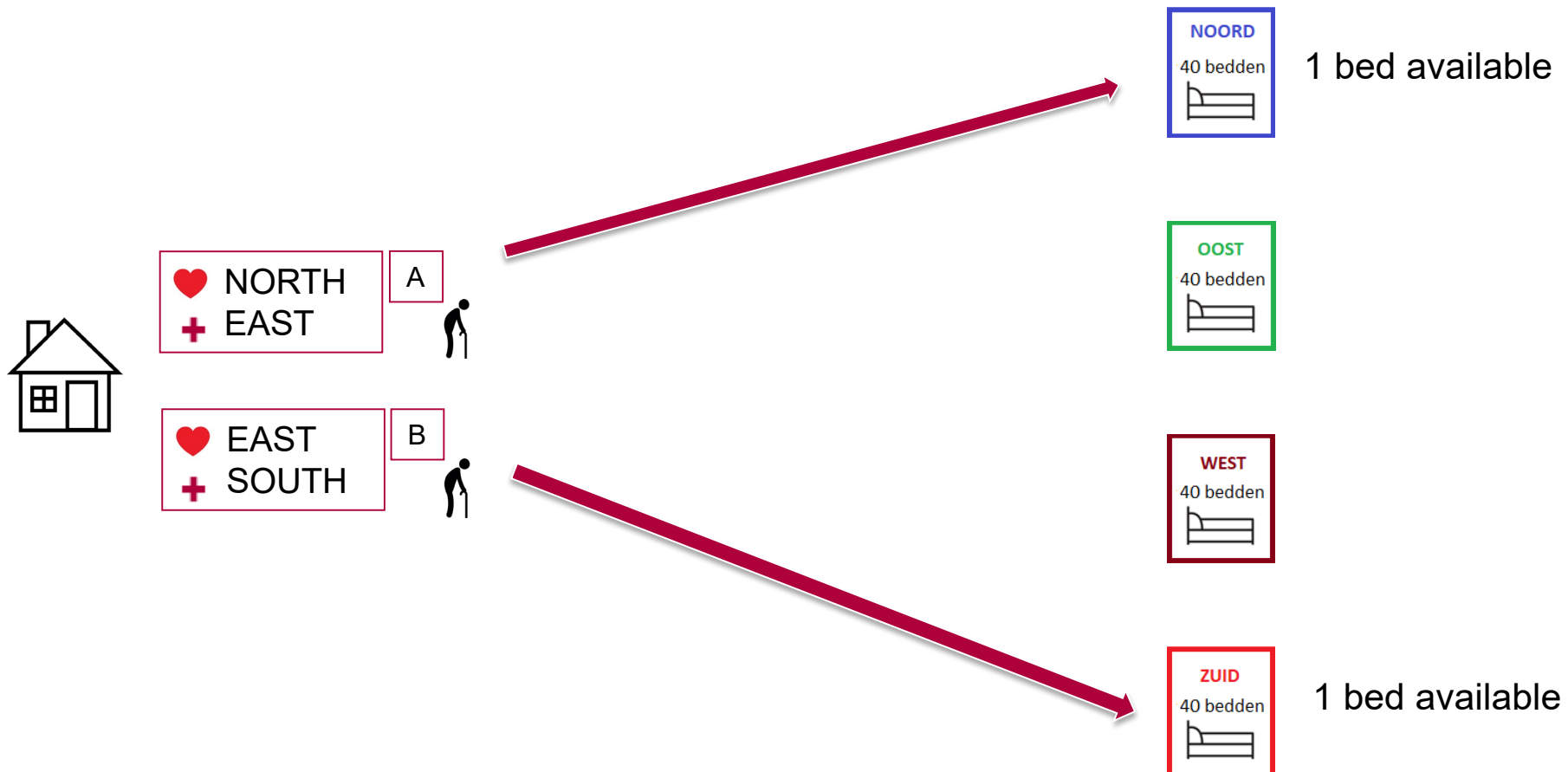
Toy Example

(1) Preferences of patients



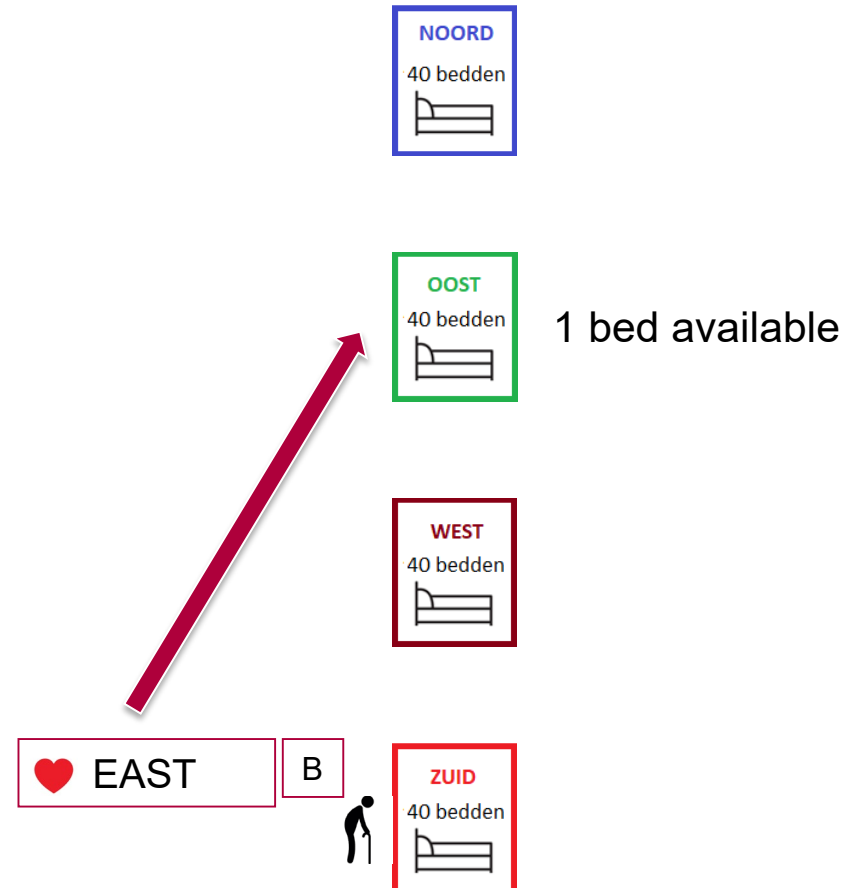
Toy Example

(2) Transitions between care centers



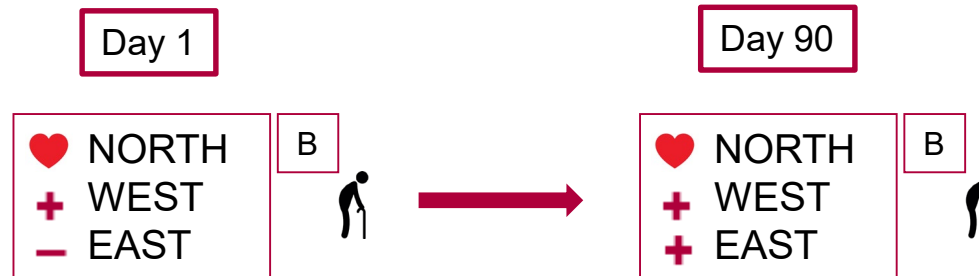
Toy Example

(2) Transitions between care centers



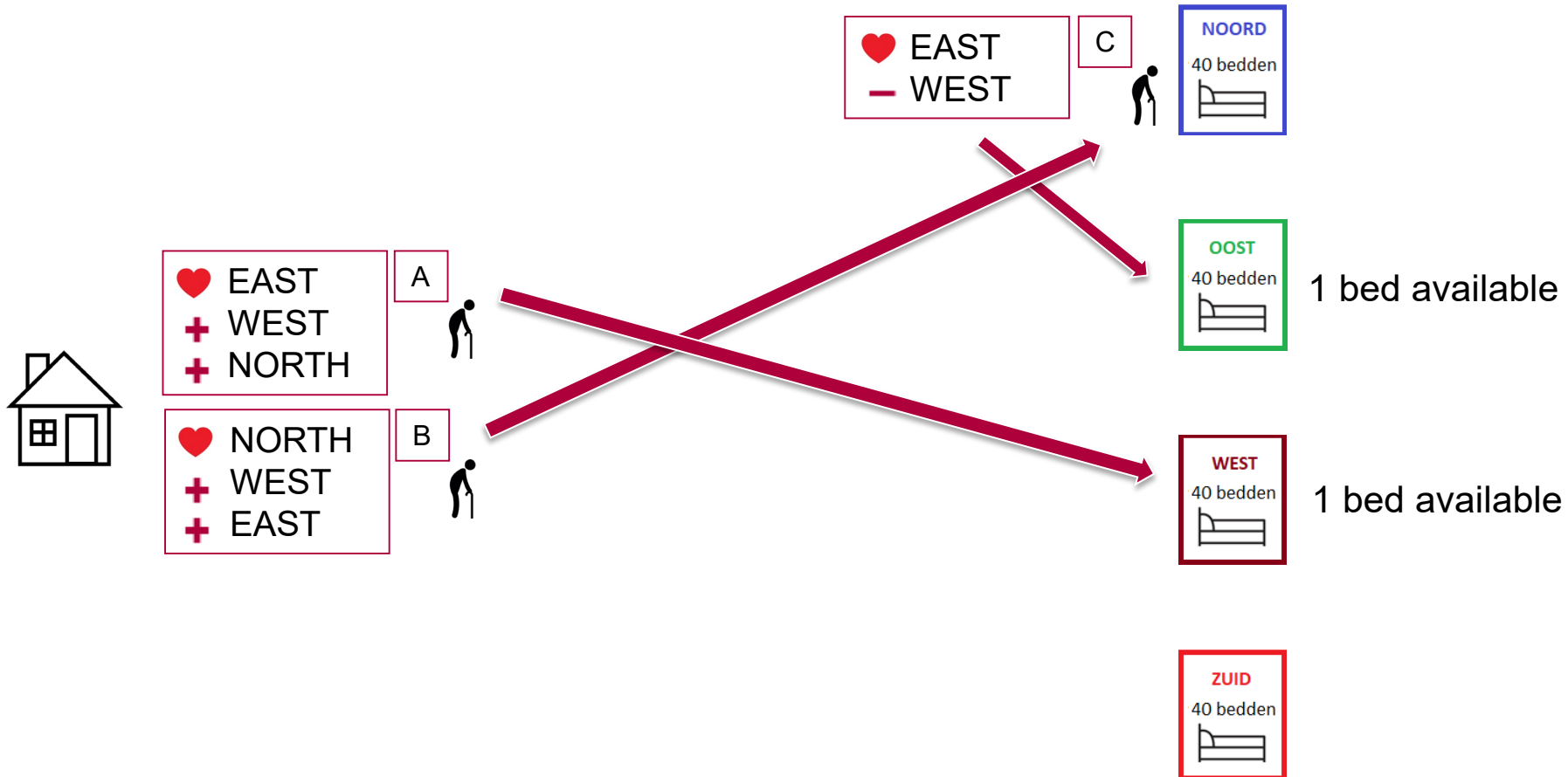
Toy Example

(3) Increase in urgency



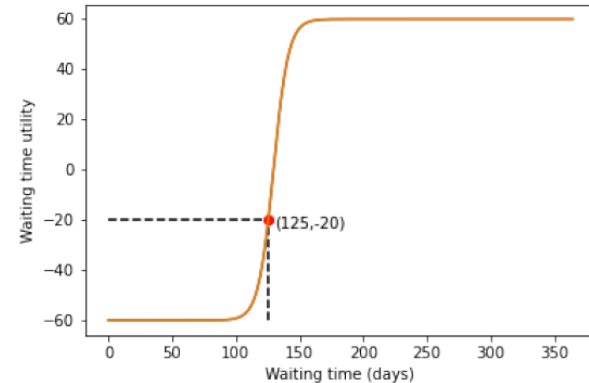
Toy Example

(4) Transition to preferred nursing home



“Bed” Allocation Model

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



Mathematical optimization model

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

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

$$\sum_{n \in N} x_{pn} = 1$$

$$x_{pn} \in \{0, 1\}$$

$$\forall n \in N$$

$$\forall p \in P$$

$$\forall p \in P, n \in N.$$

maximize “happiness”

Case Study 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)

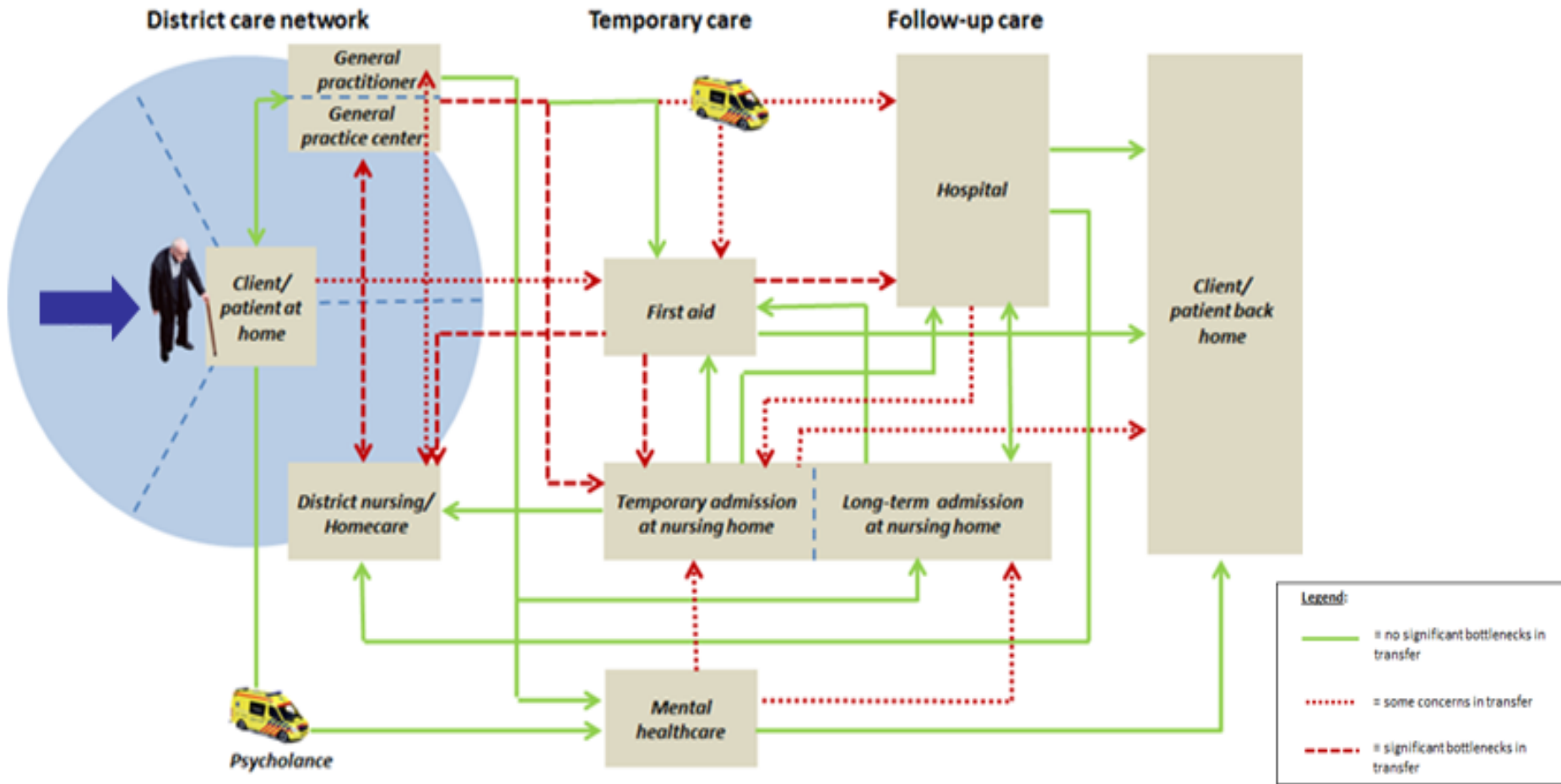
Centralized approach:

1. Includes individual preferences
2. Dramatic reduction in waiting time

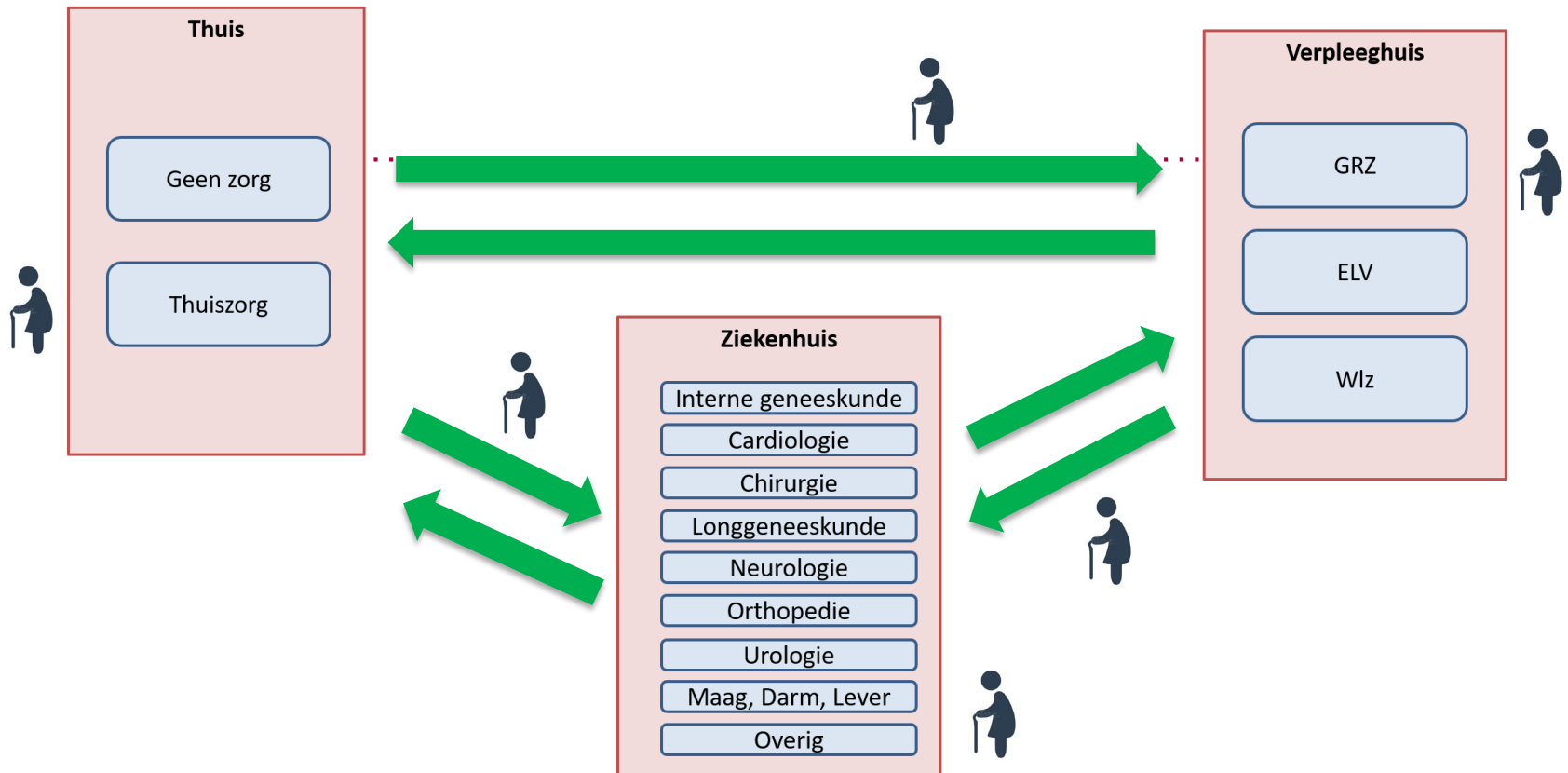
also psychiatry, youth care,...

Waterbed model

Patient journey through care supply system



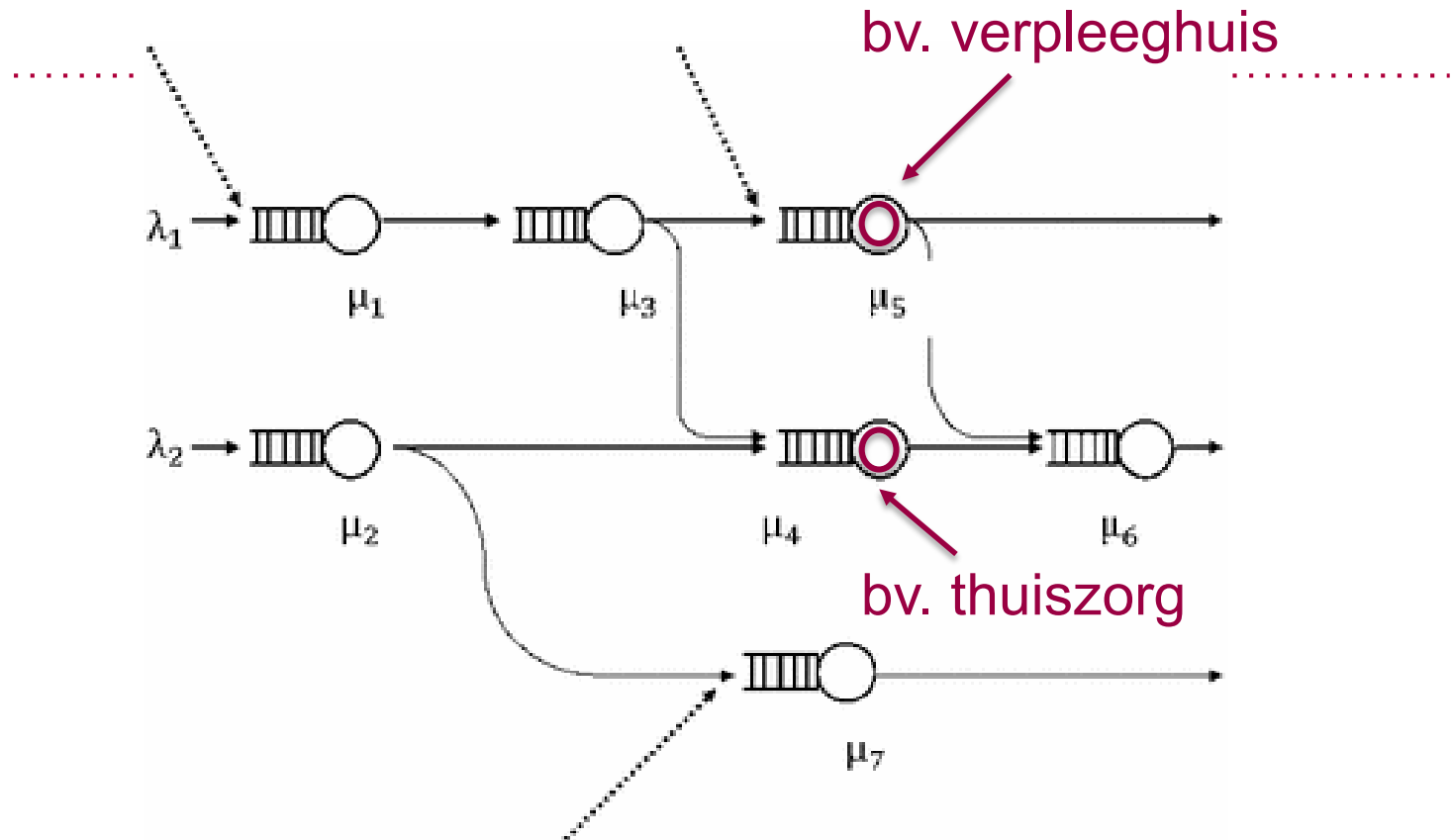
Acute Elderly Care Network



Typische vragen

- Waar zitten de bottlenecks?
- Hoe effectief zijn maatregelen voor reductie wachttijden?

Wiskundig Macro-Model



- Stochastische netwerk van zorgaanbieders (onzekerheid)
- Doorlooptijden, wachttijden

Waterbed "What-if"-tool

Amsterdam Elderly Care System Dashboard

Overview Looking Forward Calculator Help

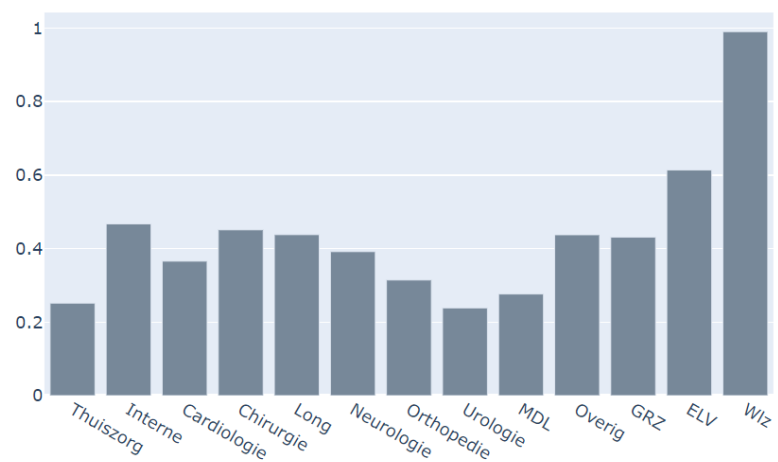
Input: Beds and new arrivals Plot: Traffic Intensity Plot: All Sublocations

Stabilize Reset Compare with current situation Total Cost (€): 1427332135 + 1078341035

Number of beds per facility

Thuiszorg	10000
Interne	33
Cardiologie	31
Chirurgie	27
Long	18
Neurologie	15
Orthopedie	13
Urologie	12
MDL	9
Overig	17
GRZ	290
ELV	160
Wlz	20262

Traffic Intensity per Facility



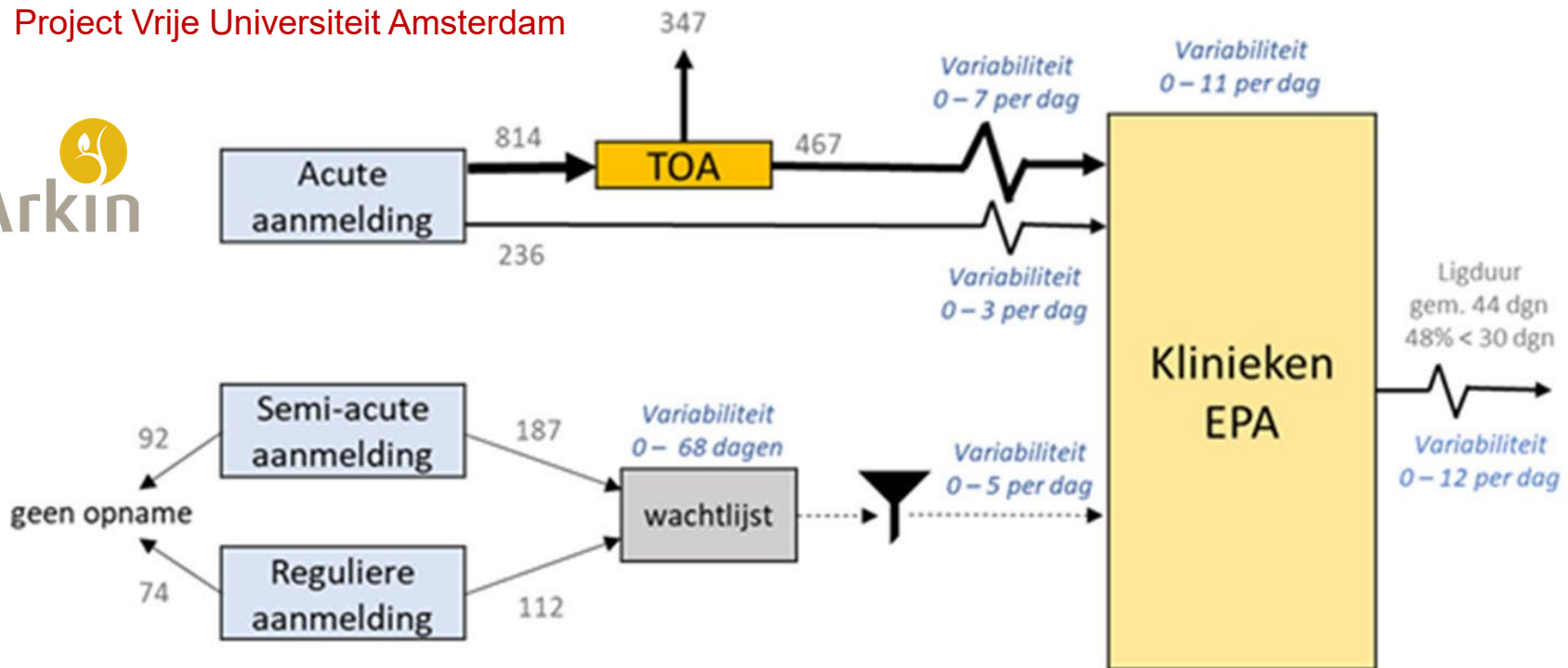
- Thuiszorg
- Interne
- Cardiologie
- Chirurgie
- Long
- Neurologie
- Orthopedie
- Urologie
- MDL
- Overig
- GRZ
- ELV
- Wlz

Select



Use case Mental Healthcare

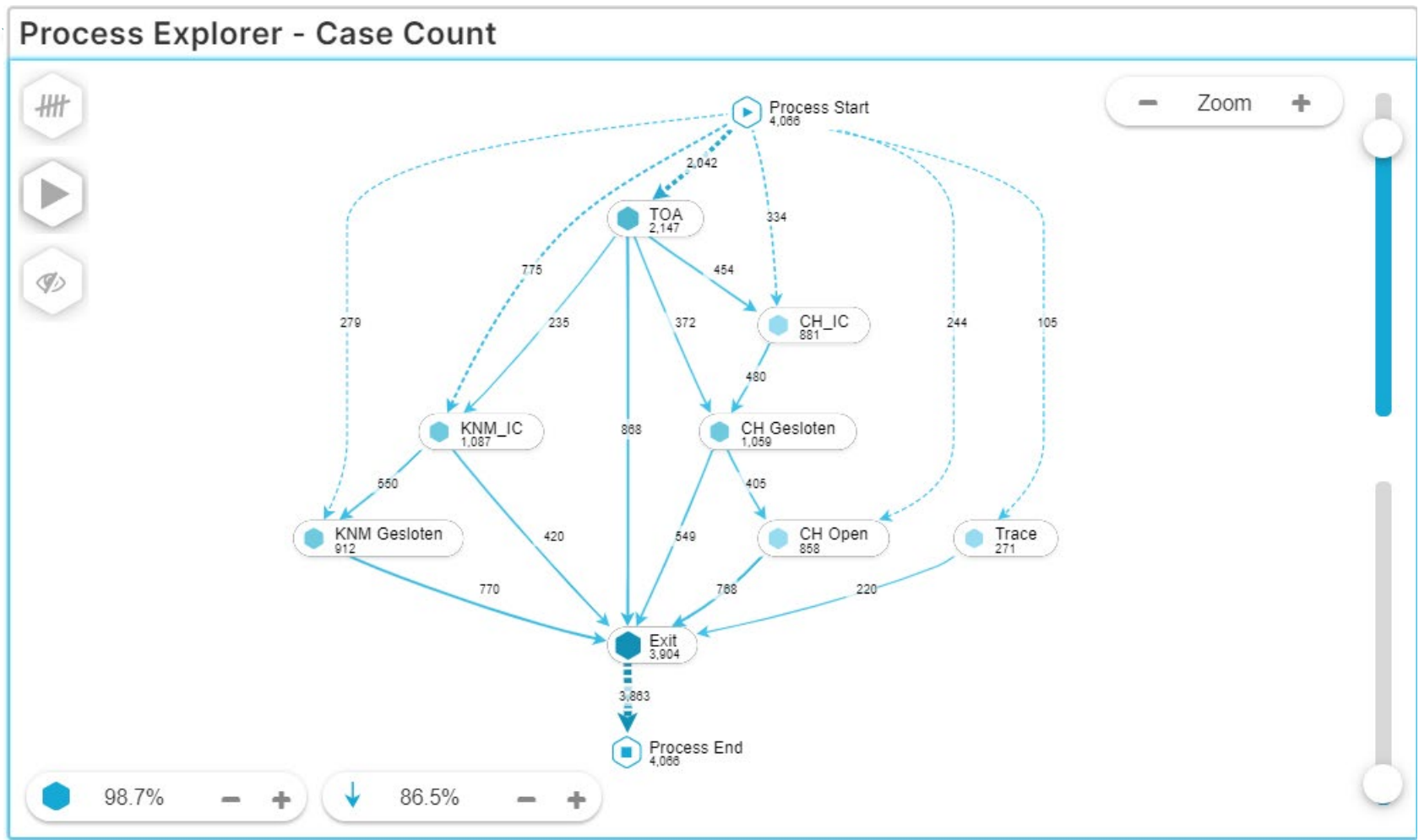
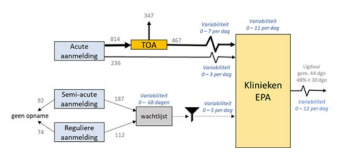
Project Vrije Universiteit Amsterdam



Typische “what-if”-vragen:

1. Hoe presteren we nu eigenlijk?
2. Wat zijn de capaciteitsbottlenecks?
3. Hoe effectief zijn maatregelen in capaciteitsmanagement?
 - wachttijden, doorstroom, ...
4. Wat als instroom van klanten met 10% toeneemt?

Process Mining



Vraag: Hoe ziet onze process-flow er eigenlijk uit?

“What-if” Planning Tool

Input

Department 1A
Department 1B
Department 2B
Department 3A
Department 3B
Department 4A
Department 4B
TOA
Transfers

Department 1A

General setup

Available resources

Number of beds in department: 8

Patient triage on intake

Proportion of rejected patients: 0.05

Note:

The information about the department has been completed according to analysis of the historic data. In some cases, values of 0 represent absence of records.

Please adjust the corresponding inputs to test a new scenario.

Distribution of the arrival process

Arrival rate, patients per day

Acute patients: 0.057

Semi-acute patients: 0.0702

Regular patients: 0.0104

Distribution of the length of stay

Mean length of stay, in days

Acute patients: 19.47

Semi-acute patients: 28.94

Regular patients: 26.6

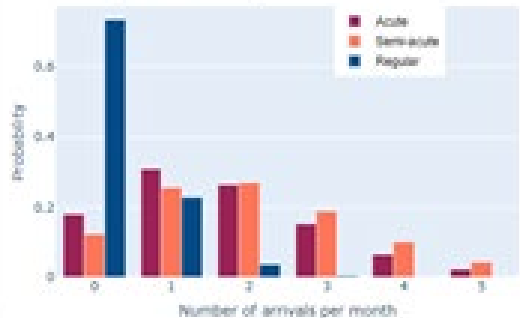
Standard deviation, in days

Acute patients: 19.34

Semi-acute patients: 32.64

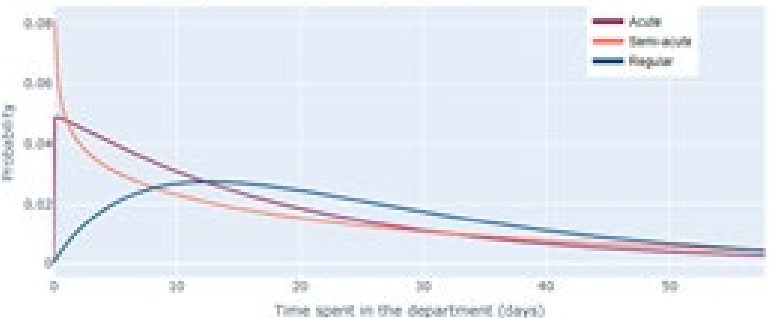
Regular patients: 19.24

Number of patient arrivals per month



Number of arrivals	Acute	Semi-acute	Regular
0	0.18	0.12	0.70
1	0.30	0.25	0.20
2	0.25	0.25	0.05
3	0.15	0.18	0.02
4	0.08	0.10	0.01
5	0.02	0.05	0.00

Distribution of the length of stay, by severity



Time spent (days)	Acute	Semi-acute	Regular
0	0.08	0.05	0.00
10	0.03	0.02	0.02
20	0.01	0.01	0.01
30	0.005	0.005	0.005
40	0.002	0.002	0.002
50	0.001	0.001	0.001

"What-if" Planning Tool

Output

Browser address bar: Not secure | dolcevita-dashboard.ddns.net:8054

Navigation: Google, Hora Finita, Google Scholar, CANVAS, Homepage VU, VUNET, CWI Webmail, TINA, CWI Intranet, ROOM kamerhuur, Other bookmarks

Total number of patients on the waiting list

Min	Max	Mean	Std Dev	Median	75% <	90% <	95% <
0	4	0.05	0.33	0	0	0	0

Average bed occupancy rate

Min	Max	Mean	Std Dev
0.18	0.62	0.38	0.07

TOA bed occupancy rate

Min	Max	Mean	Std Dev
0	1	0.32	0.18

Total | Transfers | From TOA

Total number of patients on the waiting list

Distribution of average bed occupancy rate

Distribution of the TOA bed occupancy

Jaarafrekening_30_...pdf

Show all

Windows taskbar: File Explorer, Chrome, Firefox, Edge, Word, Excel, PowerPoint, Outlook, Teams, Zoom, OneDrive, etc. Time: 13:43, 21-9-2022

Discussion

Question 1:

What limitations and obstacles do you see in using Mathematics and analytics in improving healthcare logistics?

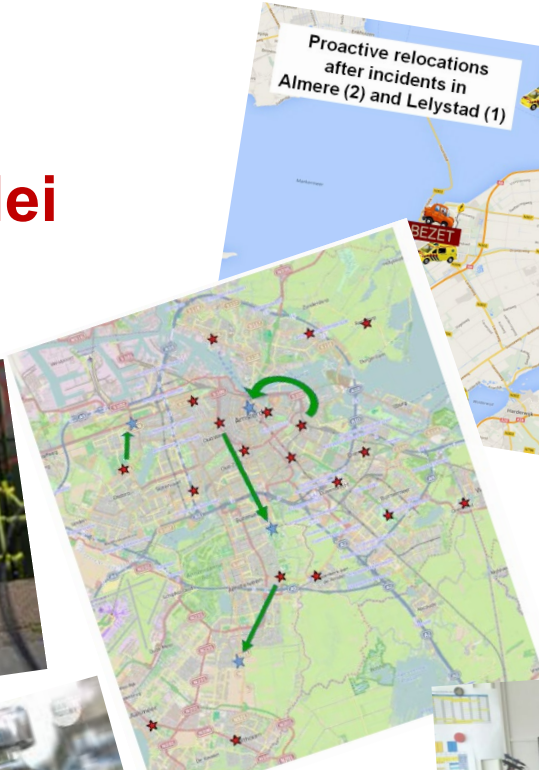
Question 2:

What are new possibilities for improving healthcare logistics have not yet been fully explored?

Success Stories of Mathematics Saving Lives

Rob van der Mei

Contact: mei@cwi.nl



Wiskunde redt levens

Kansberekening en modellering moeten ambulanceplanning in Amsterdam verbeteren.

