Brunel University London

Data-driven simulation and strategic change

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Modelling & Simulation Group

HCDI Human Centred Design Institute
Institute of Environment, Health and Societies

Department of Computer Science

Background

- Senior Lecturer at Brunel University London in the Department of Computer Science
- Member of Institute of Environment, Health & Societies
- Founder and CTO of HecoAnalytics Limited
- Research areas include Modelling and Simulation (more specifically health, user experience and cyber security)
- Teach Digital Service Design (UX), Social Media Analytics (Graph Theory) and Cyber Security (Blockchain)
- Previously a Director at Deutche Bank (Emerging Markets Technology)

Brunel University London

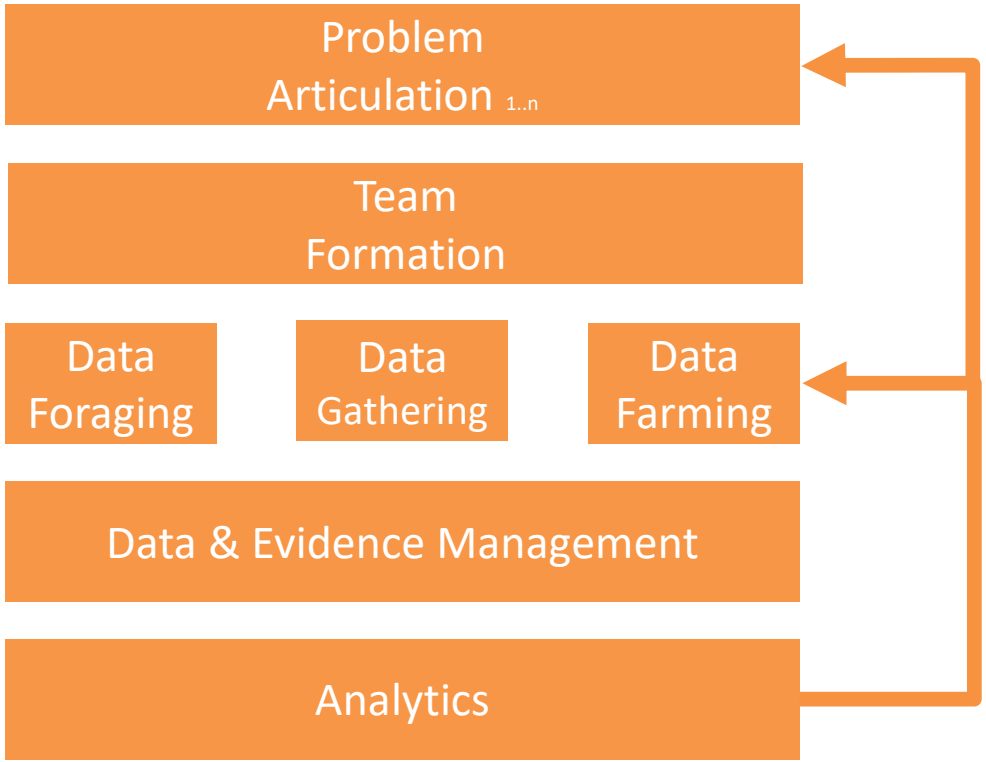
Modelling & Simulation Group Activities

- High Performance Simulation
  - Ford, Saker Solutions, Sellafield, SISO (Standard SISO-STD-006-2010)
- Cloud-based Simulation
  - CloudSME, CraftBrew, AIMS (MSaaS)
- e-Infrastructures & e-Science in Africa
  - eI4Africa, Sci-Gaia, TANDEM
- Healthcare simulation
  - Agent-based simulation of physical activity interventions to advise UK Department of Health (EMPHASIS)
  - NHS Hillingdon CCG
- Education
  - Courses (NATCOR, PG, UG, Royal Society) and student projects (Hillingdon NHS, AStudio, NASA, Mount Vernon CC)

Agenda

1. Big Data Perspectives
2. A non-elective care ‘whole system’ case study
3. Reflections on multidisciplinary projects
4. Strategy Synthesis

Strategy synthesis



Introduction

Perspectives, projects and motivations

Computing life so far…

1.28 billion users	facebook
255 million users	twitter
300 million users	LinkedIn
343 million users	Google+
31 million users	myspace
25% of South Koreans in 2005	cyworld
230 million users	tumblr.
220 million users	

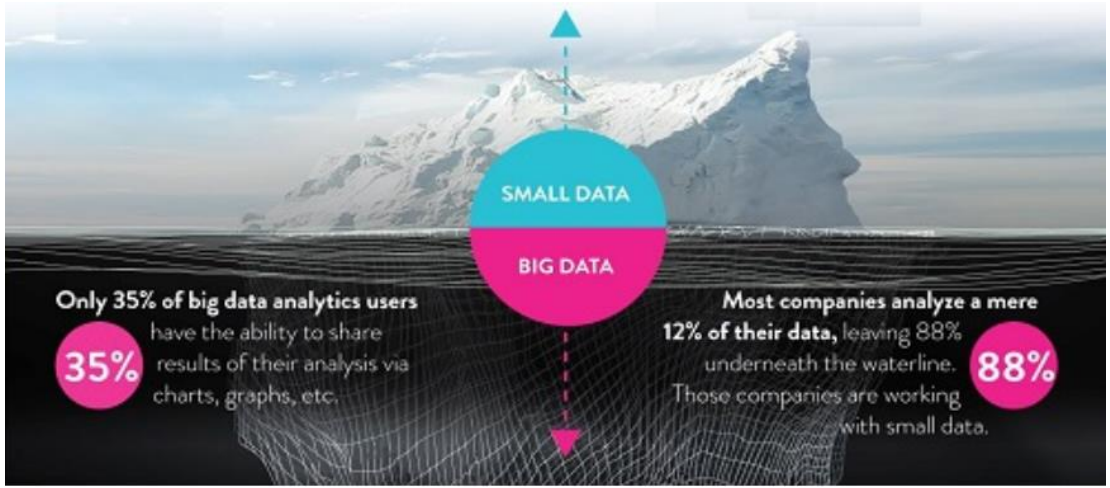
In my working lifetime so far…

What next…?


1.28 billion users
facebook
255 million users
twitter
300 million users
LinkedIn
343 million users
Google+
31 million users
myspace
25% of South Koreans in 2005
cyworld
230 million users
tumblr.
220 million users

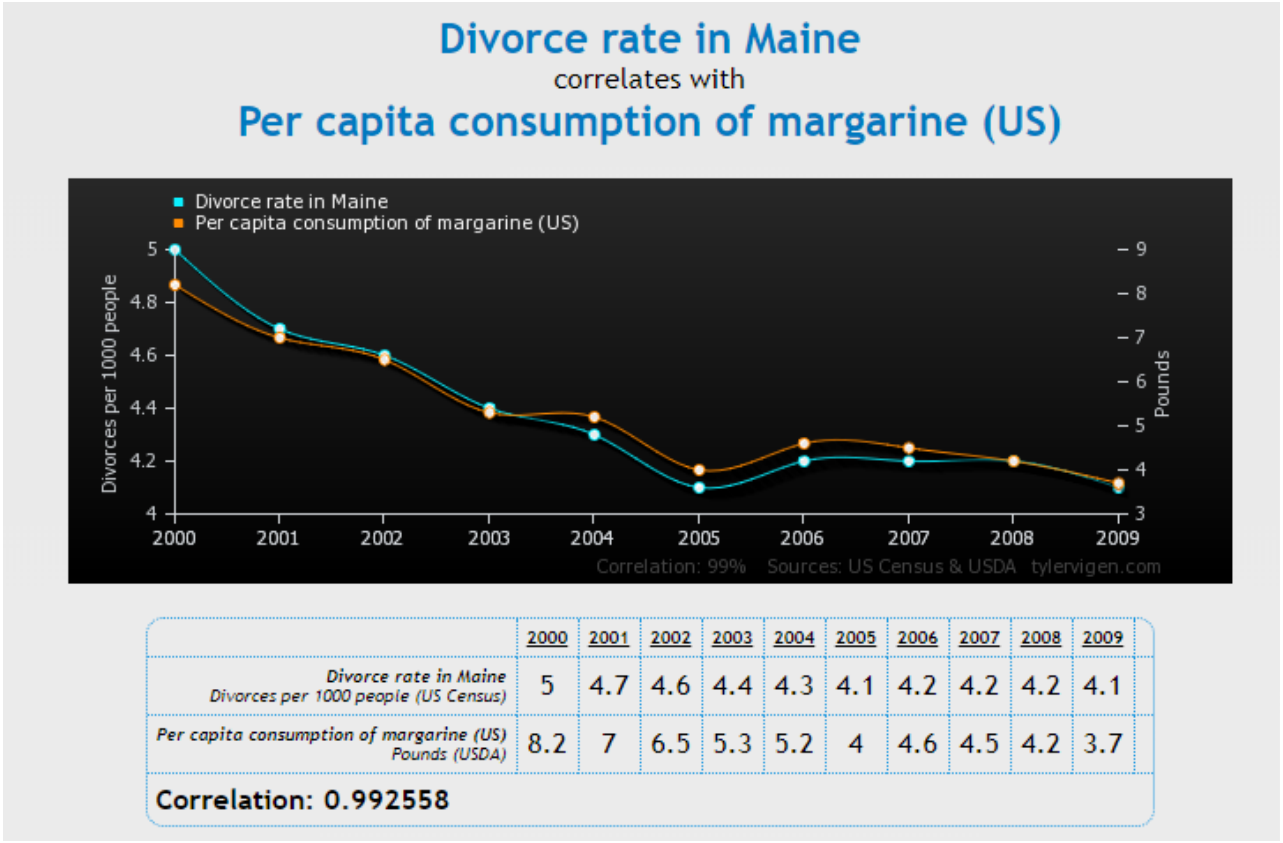
???

Data everywhere



Computer Weekly

Correlations – be careful



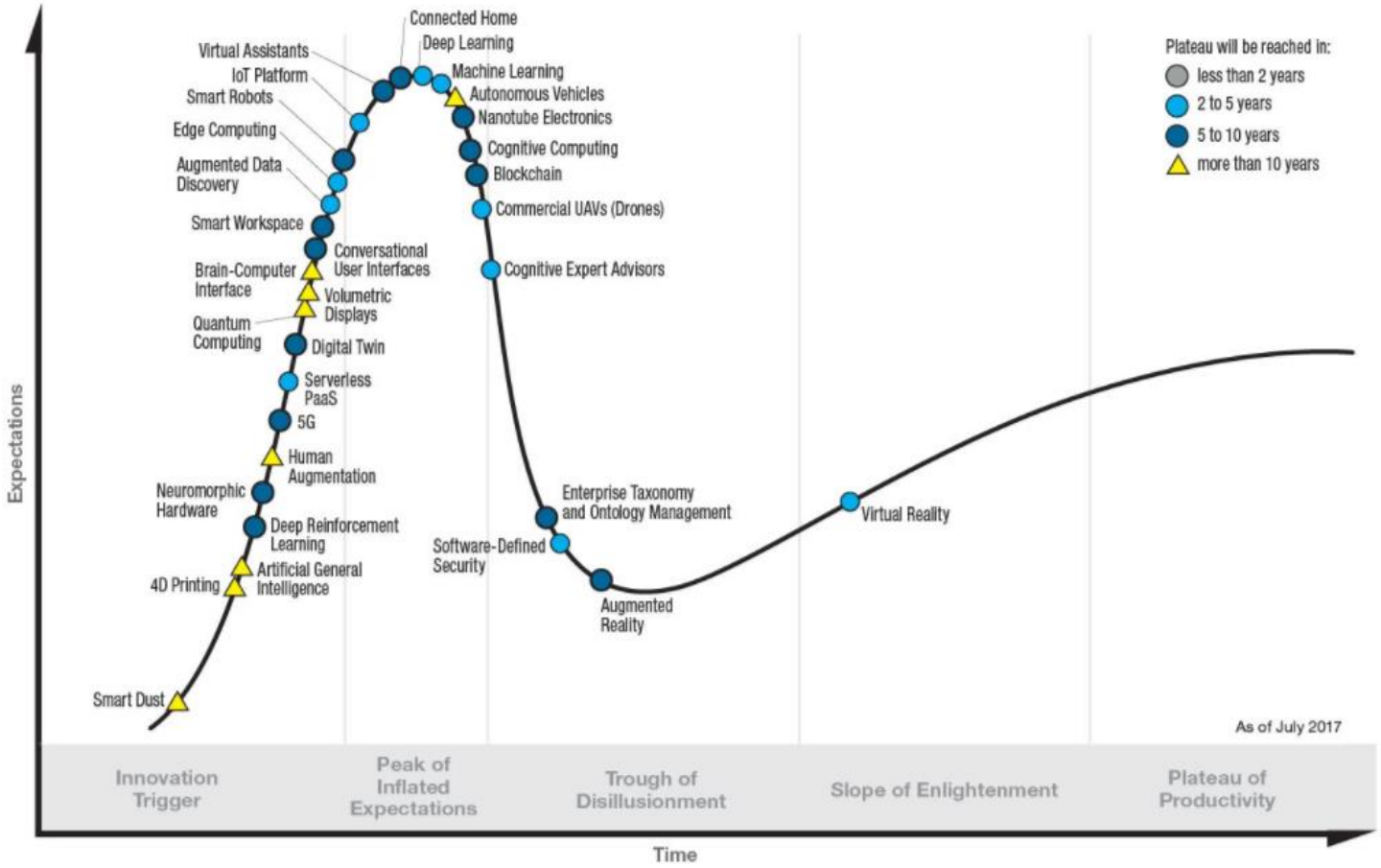
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Divorce rate in Maine *Divorces per 1000 people (US Census)*	5	4.7	4.6	4.4	4.3	4.1	4.2	4.2	4.2	4.1
Per capita consumption of margarine (US) *Pounds (USDA)*	8.2	7	6.5	5.3	5.2	4	4.6	4.5	4.2	3.7

Correlation: 0.992558

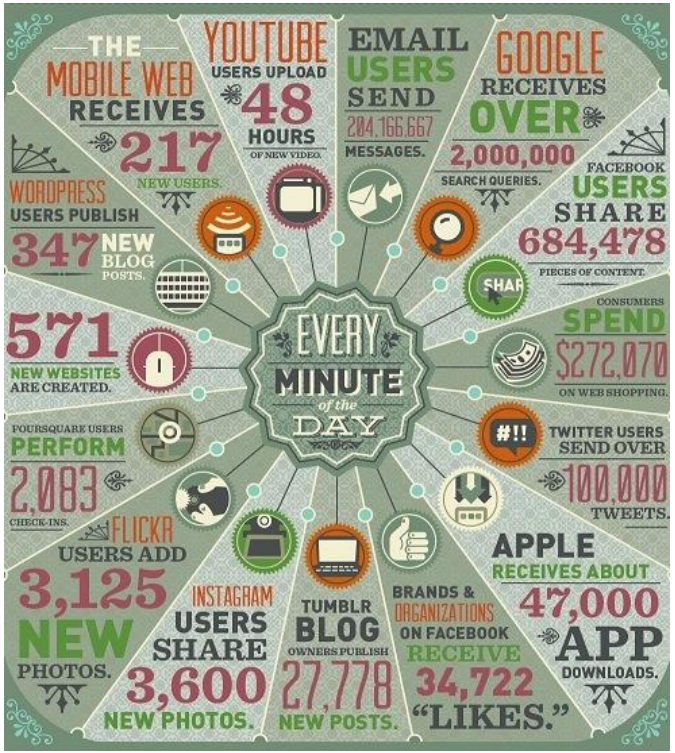
Causality

….Analytics

- The systematic computational analysis of data or statistics (OED)
- Describe statistical and mathematical data analysis that clusters, segments, scores and predicts what scenarios are most likely to happen. (Gartner)
- **The scientific process of transforming data into insight for making better decisions** (INFORMS – Liberatore & Luo, *Interfaces*, 41: 578-589, 2011)



Gartner (2017)



http://www.incrowdnow.com

....Data

Semantic Web

NHS
National Institute for Health and Clinical Excellence

Health Episode Statistics (HES)

Clinical Trials

Office for National Statistics

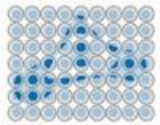
How do we use these rich data sets?

Machine Leaning  Simulation

Looking backward or forwards?

Data Driven Health Projects

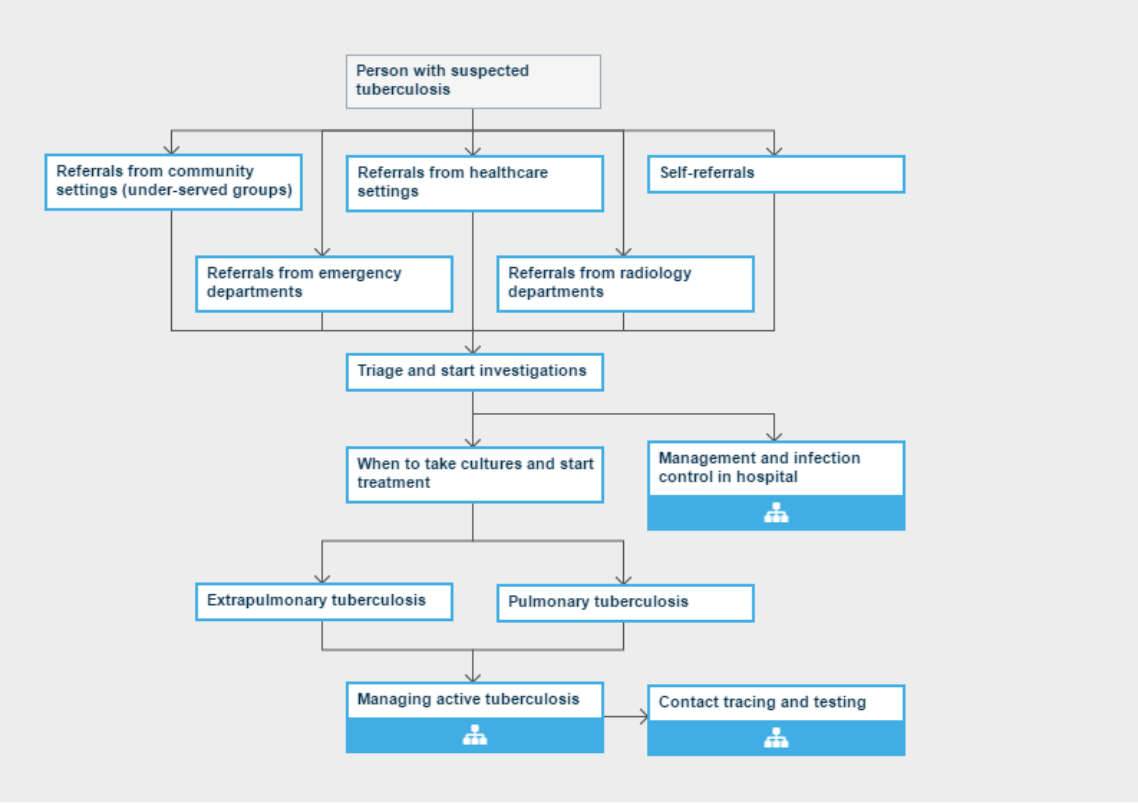
- UK EPSRC funded MATCH project
- Innovate UK funded **Tea-PoCT** project
- NHS funded A&E analysis
- UK EPSRC personal data project



TEA PoCT

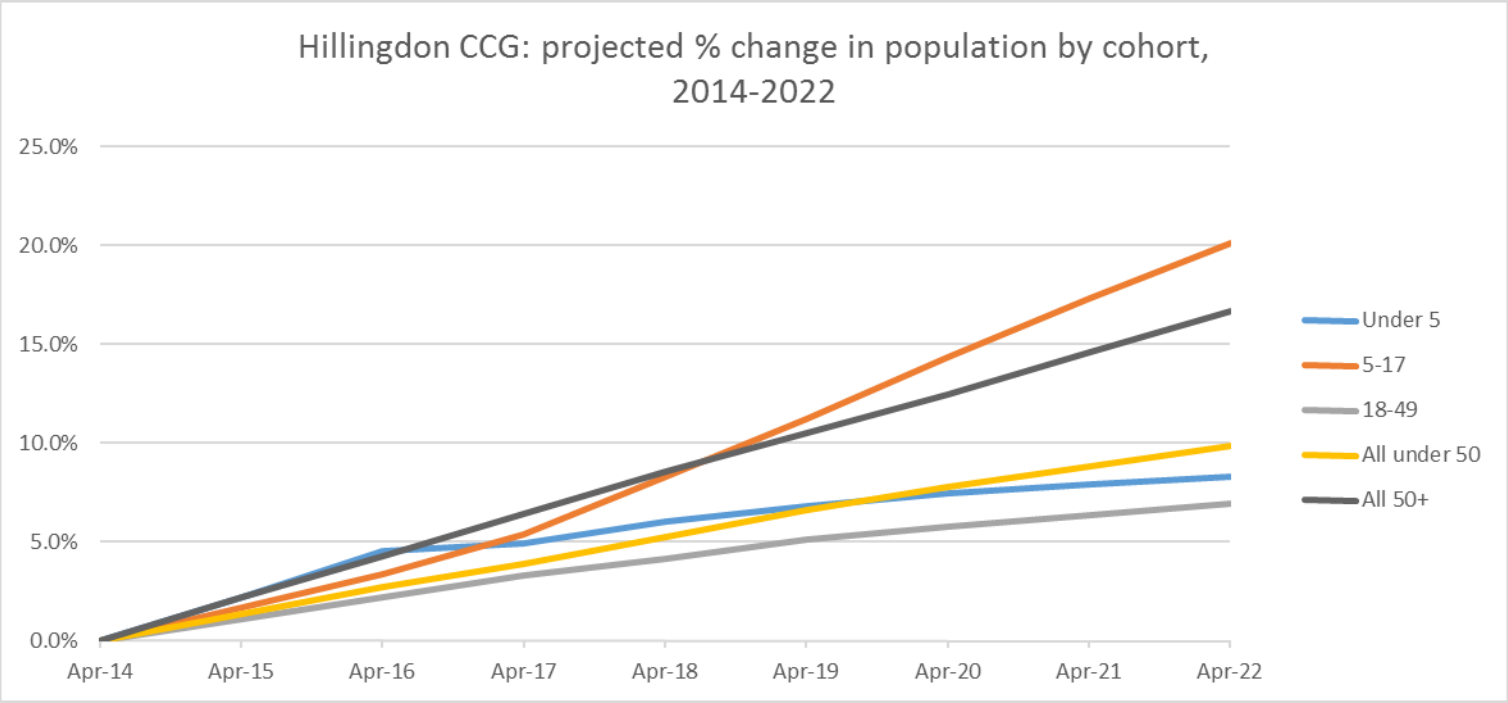
TheCumberlandInitiative

Existing Models: Nice Pathway for TB



National Institute for Health and Care Excellence
Nice.org.uk

ONS Data

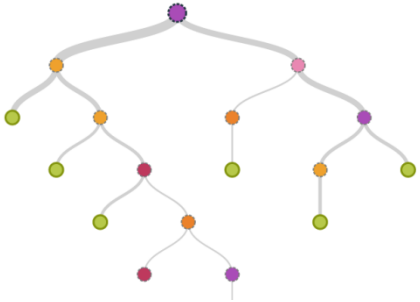


Office for National Statistics
https://www.ons.gov.uk/

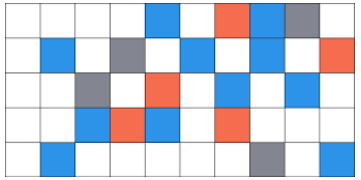
Personas – Clustering, DT, FCA, Agents

Digital Personhood

Clustering



Decision Tree (DT), Concept Analysis



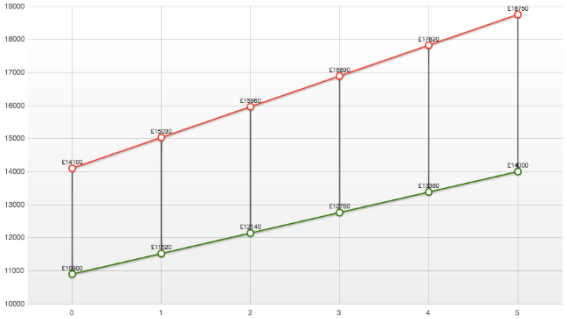
Agent Model

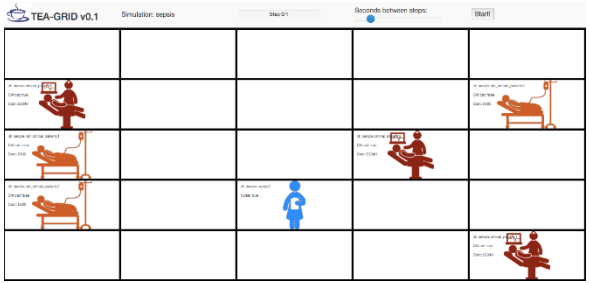
Bell, D., Kashefi, A., Saleh, N., Turchi, T. and Young, T., 2016, April. A data-driven agent based simulation platform for early health economics device evaluation. In *Proceedings of the Agent-Directed Simulation Symposium* (p. 5). Society for Computer Simulation International.

Bell, D. and Mgbemena, C., 2017. Data-driven agent-based exploration of customer behavior. SIMULATION [onlinefirst]

Hybrid techniques

- Economic Modelling
- Agent Modelling
- Systems and Discrete Event Modelling





About HecoAnalytics (Tea-PoCT Innovate Project)

- HecoAnalytics aims at providing diagnostics developers and manufacturers with a simple tool for early economic evaluation with the supporting data. The package will involve three elements:

✓ An on-line version of a Headroom Method, initially customised for Point of Care.
✓ An library of data, with a Wiki portal for evidence capture and description.
✓ A set of open interface standards for apps and data extraction (the Wiki is free-format input).
✓ Embedded economic modelling and scenario analysis

About HecoAnalytics

- **Early economic evaluation:**

  The Headroom Method

  It is used to assess the *cost-effectiveness* of a new technology in comparison to an existing ***gold standard*** technology, by defining a maximum cost (the headroom) that the adopter of the technology would be willing to incur.

- **At the design stage**, it allows analysis from the *supply side*, unlike the typical cost-effectiveness analysis, which is usually conducted from the *demand side*, i.e. after the product has been developed (McAteer & Lilford, 2012).

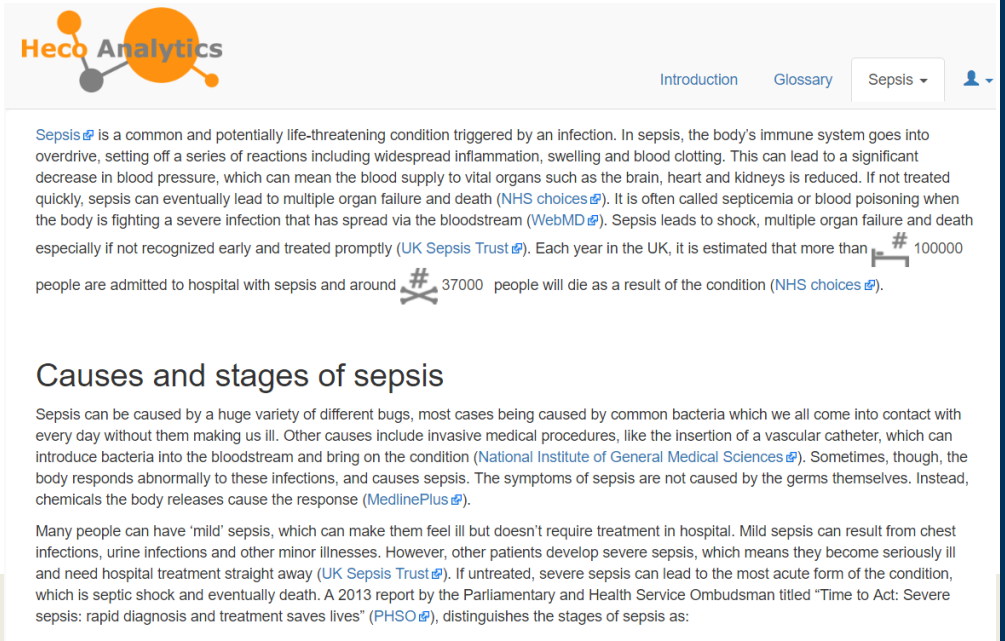
- Suitable for the healthcare sector, given the increasing scarcity of resources and the need to *show value-for-money* (McAteer & Lilford, 2012).

HecoAnalytics - Sepsis Data Sets

http://www.hecoanalytics.com & *semantic* wiki

- *View example data for Sepsis*
- *Edit evidence*
- *View embedded economic models*

https://www.linkedin.com/company/hecoanalytics-limited



HecoAnalytics

Data & Evidence Management

Heco Analytics

Tag	Trusted Source	Grey Literature	User Input
Cost	$£€	$£€	$£€
Detection			
Measure			
Mortality			
Patients			
QALY	#Q	#Q	#Q
Time			
Rate			

Quality-of-life and mortality after sepsis

Patients with sepsis have ongoing mortality beyond short-term end points and survivors consistently demonstrate impaired quality-of-life (QoL). Most studies have used a 28-day mortality as an end point for clinical studies (e.g. see Martin et al, 1979; Frevert and Martin 2004; De Jonghe et al, 2008; Stevens and Nyquist, 2008), but the use of 28-day outcomes (such as critical illness weakness, acute lung injury, delirium) may lead to inaccurate inferences (Winters et al 2010). Sepsis may have different long-term effects on mortality and QoL and the systematic review of studies by (Winters et al, 2010), shows incremental health effects that persist after hospital discharge. In particular, the study shows that patients with sepsis at various stages, including severe sepsis and septic shock, continue to die in the months and years after discharge from the hospital, results which are consistent with observational trials and randomised, controlled trials.

Another study by (Cuthbertson et al, 2013) used data from 26 adult intensive care units (ICUs) in Scotland and a total of 439 patients, to measure mortality at 3.5 and at 5 years after severe sepsis. Mortality was measured as 58 at 3.5 years and as 61 at 5 years follow-up, with the majority of patients being satisfied with their current QoL (80%), however, with QoL significantly lower than the QoL of population norms. They also showed slightly lower mental QoL compared to population norms up to five years after sepsis. All patients were willing to be treated in an ICU again if they become critically ill. Nevertheless, 19% reported having unpleasant memories and 29% recall of ICU events.

A more recent follow-up observational study by (Nesseler et al, 2013) evaluated mortality and health-related QoL in sepsis survivors 6 months after septic shock, by using data from 96 patients in France. Mortality was measured to 45 and despite improvements being reported, health related QoL remained significantly lower than the general population. The risk of dying persists for up to 5 years after hospitalisation.

Other studies, such as (Laupland et al, 2005) reported 90-day mortality rate of 57 and one-year mortality rate of 61 in 159 patients with bloodstream infection-associated septic shock. Further studies between 100 and 2834 septic patients reported 6-month mortality rates between 32 and 61 (Angus et al, 2004; Baudouin et al, 2005; Braun et al, 2004; Granja et al, 2004; Hofhuis et al, 2008; Perl et al, 1995; Sanks et al, 1997).

References

- Angus D. C., Laterre P. F., Helterbrand J., Ely E.W., Ball D.E., Garg R., Weissfeld L.A., Bernard G.R. (2004). The Effect of Drotrecogin Alfa (Activated) on Long-Term Survival After Severe Sepsis. *Critical Care Medicine*. Vol. 32, pp. 2199 - 2206.
- Baudouin S.V., Saunders D., Tiangyou W., Elson J.L., Poynter J., Pyle A., Keers S., Turnbull D. M., Howell N. and Chinnery P.F. (2005). Mitochondrial DNA and Survival After Sepsis: A Prospective Study. *Lancet*, Vol. 366, pp. 2118 - 2121.
- Braun L., Riedel A.A. and Cooper L.M. (2004). Severe Sepsis in Managed Care: Analysis of Incidence, One-Year Mortality and Associated Costs of Care. *Journal of Managed Care Pharmacy*, Vol. 10, pp. 521 - 530.
- Cuthbertson B. H., Elders A., Hall S., Taylor J., MacLennan G., Mackirdy F. and Mackenzie S. J. (2013). Mortality and Quality of Life in the Five Years After Severe Sepsis. *Critical Care*, Vol 17, Issue 2, open access: http://ccforum.com/content/17/2/R70

HecoAnalytics

Economic Modelling

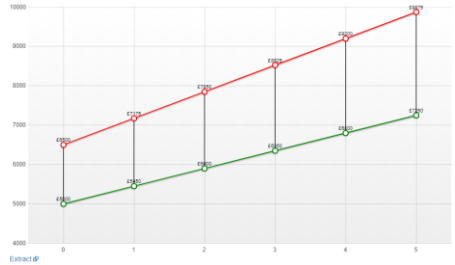
Heco Analytics

Introduction Glossary Sepsis

PoCT with Ability to Detect Haematology, Biochemistry and Clinical Factors	
QALY (Standard)	#Q 0.3
Total Service Cost (Standard)	$£€ 25000
Sensitivity of PoCT	90
Organ Injury Detection Feature	
Clinical Factors Measurement Feature	
PoCT Response Time	2.5

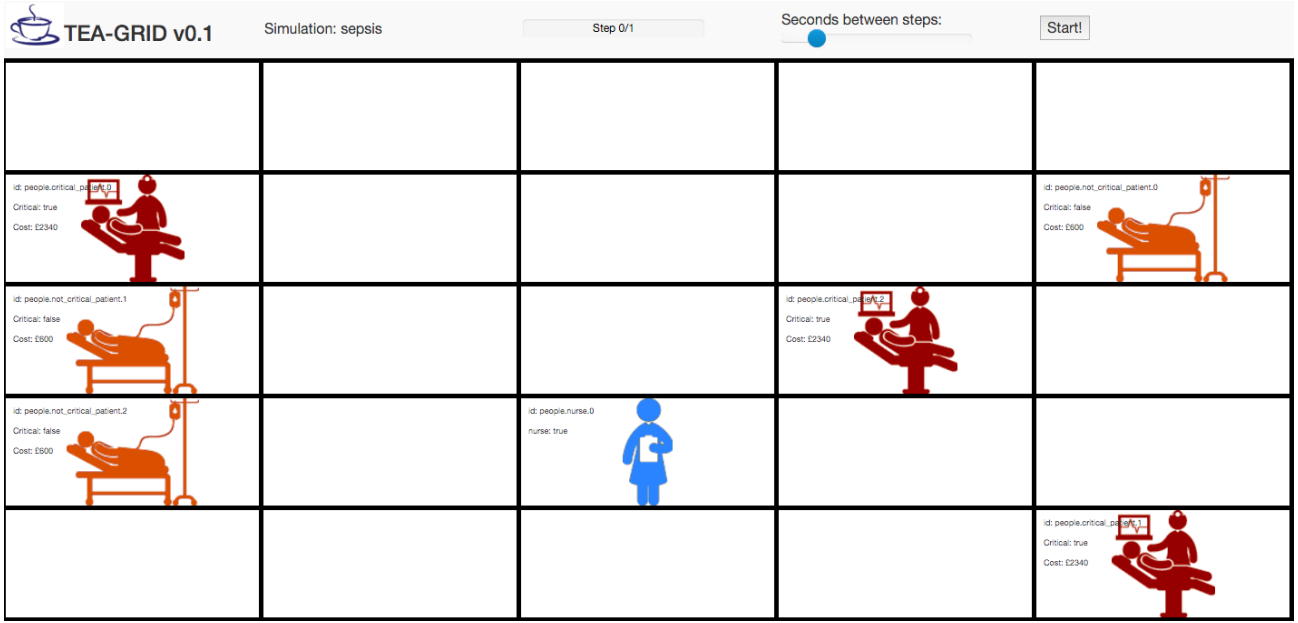
PoCT QALY and cost	
QALY (PoC)	0.45
Total Service Cost (PoC)	23000

Percentage QALY increase per year (0.05 = 5%)						
	-	0.05	0.10	0.15	0.20	0.25
Mean QALY	0.45	0.473	0.495	0.518	0.54	0.563
ΔQALY	0.15	0.173	0.195	0.218	0.24	0.263
Headroom (WTP £20000)	5000	5450	5900	6350	6800	7250
Headroom (WTP £30000)	6500	7175	7850	8525	9200	9875



Agent Simulation

- ***ABS Visual Example***



CCG Case Study

Non-elective care

(Brunel University London, SIMUL8, WSP)

Aims

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TRANSFORMING HEALTHCARE QUALITY AND COSTS

To test admission avoidance and discharge strategies with engagement of stakeholders to determine their likely impact during winter pressures.

Measures of achievement

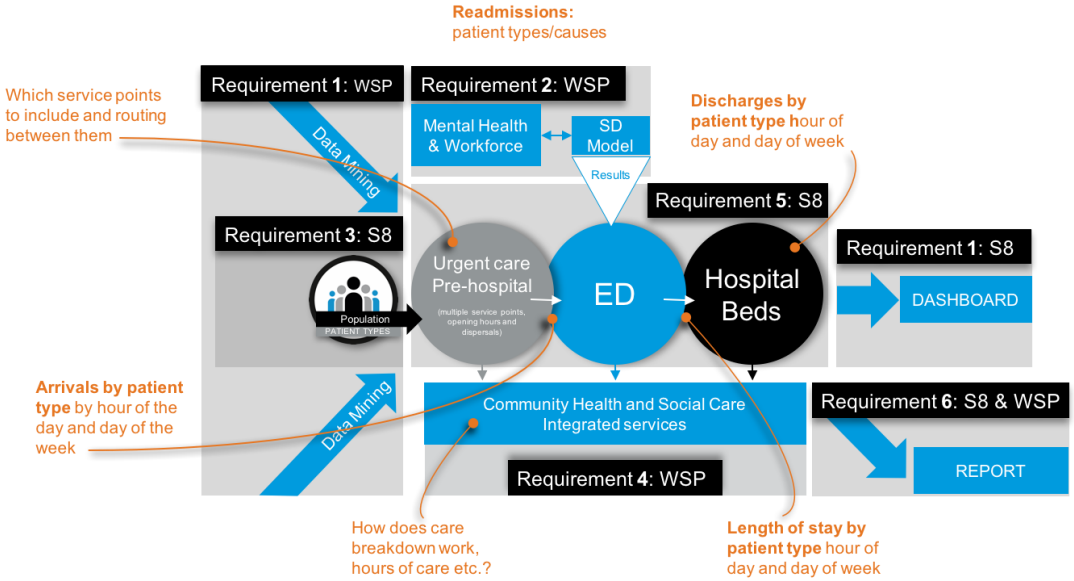
- A 10% reduction in unplanned attendances for Hillingdon Registered Patients.
- A 20% reduction in readmission rates for patients discharged following an unplanned admission and then readmitted within 30 days

Methodology

The Cumberland Initiative partners, Brunel University, **SIMUL8 Corporation** and **Whole Systems Partnership** collaborated to work with **Hillingdon CCG and the Transformation Board** to simulate the emergency care pathway across the whole health and social care system in order to test improvement interventions on the two requirements set out in the aims above.

The simulation combined two methodologies, systems dynamics and discrete event simulation to give both a strategic and operational view of the likely impacts taking into account changing demographics and expected flows of patients with emergency care needs on both hospital and primary and community providers.

Data was provided by the CCG and interviews were conducted with key stakeholders to provide context and insight into the health system. Regular workshops and reviews were held with the CCG and the SRG to validate the simulation.



Stakeholder engagement - objectives

- To understand what stakeholders in the wider health and care system see as the principal issues from their perspective that currently have an impact on the core unplanned care pathway, especially unplanned attendances and/or readmissions
- To identify known/ expected system changes that are likely to affect these in the future
- To explore ‘what if’ scenarios with potential to improve performance in the unplanned care pathway, to inform system dynamic modelling
- To identify key sources of local intelligence focused on the emerging issues

Simulation Approach

Demographics and Out of Hospital Care:

Modelling demand scenarios with System Dynamics

Basic data and core demographic model?

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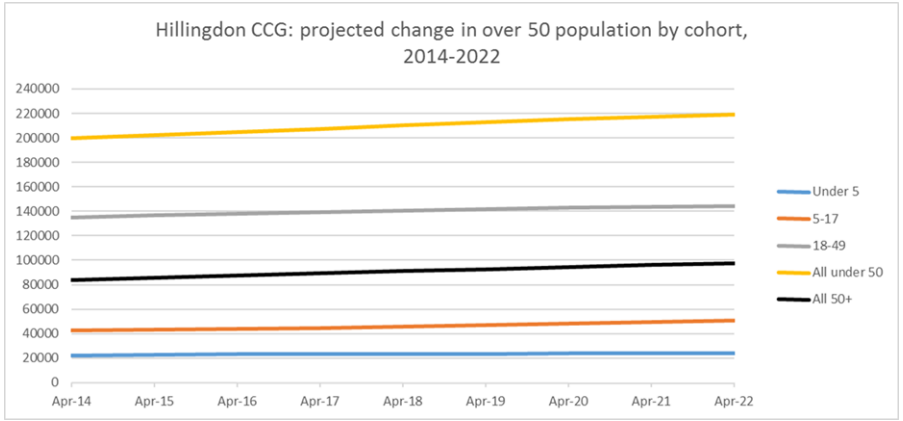
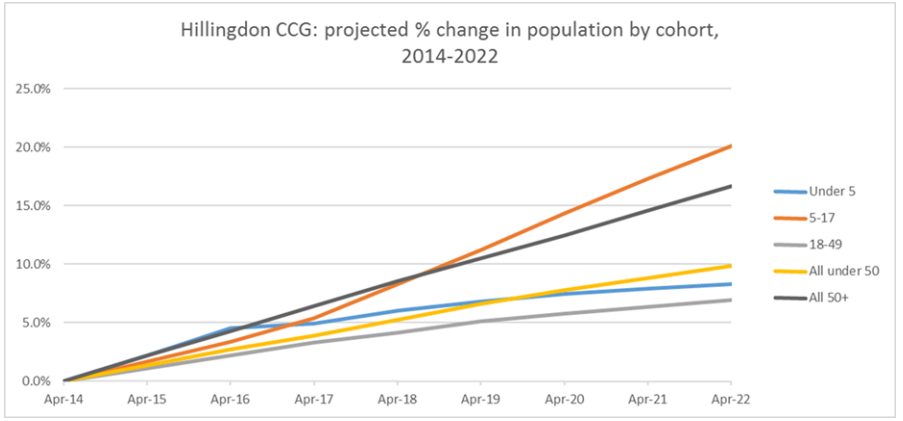
- Demographic projections for modelling unplanned demand
- Projected demographic changes in baseline unplanned demand
- Projected demographic changes in baseline unplanned demand for over 50 cohorts

Projected demographic changes in baseline unplanned demand

- Projected change in actual numbers in each age group April 2014 - March 2022.



- Percentage change for each age group 2014-2022, compared to April 2014.



- Children aged 5-17 show the largest rate of increase over this time (20.1%, or an average of 2.5% per year).
- The number of over 50s is projected to increase by 16.6% or an average of 2.1% per year.

Modelled impact of whole system change on key outputs

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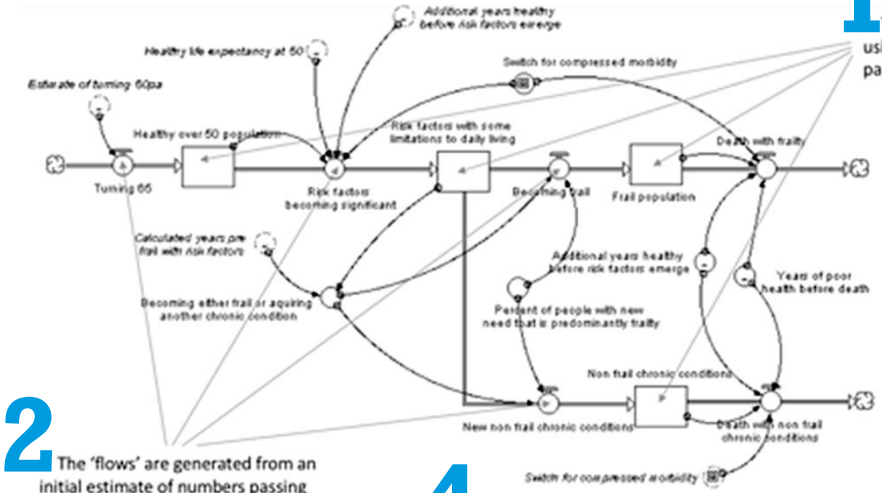
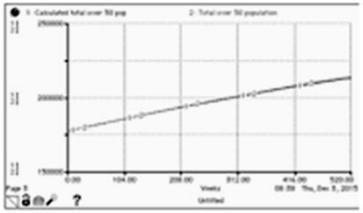
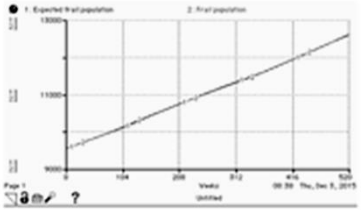
- Unplanned attendances
- Unplanned admissions
- Readmissions



1 The 'stocks' in the model are initialised using the methodology described in this paper.





2 The 'flows' are generated from an initial estimate of numbers passing 50 from ONS population projections & then from average LE@50 and HLE@50 at the cohort level.

3 Together these produce a good fit with ONS projections (the red lines above) and the simulated population estimates over the 10yrs (the blue lines above).

4 The frailty population is then used to inform further elements of a simulation model such as capacity requirements, the impact of service change or workforce needs, including the potential contribution that compressed morbidity might make were it to be evidenced.

How the models combine

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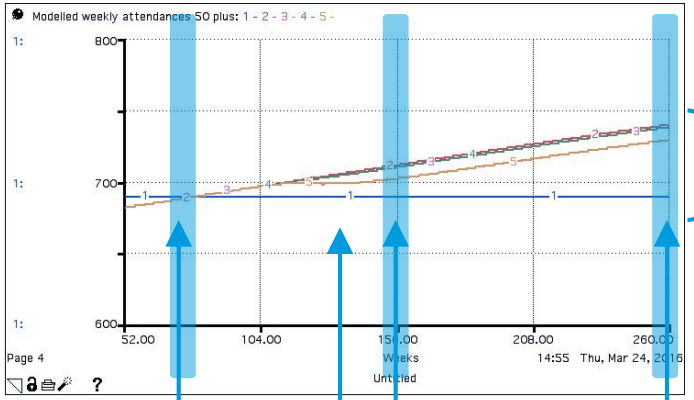
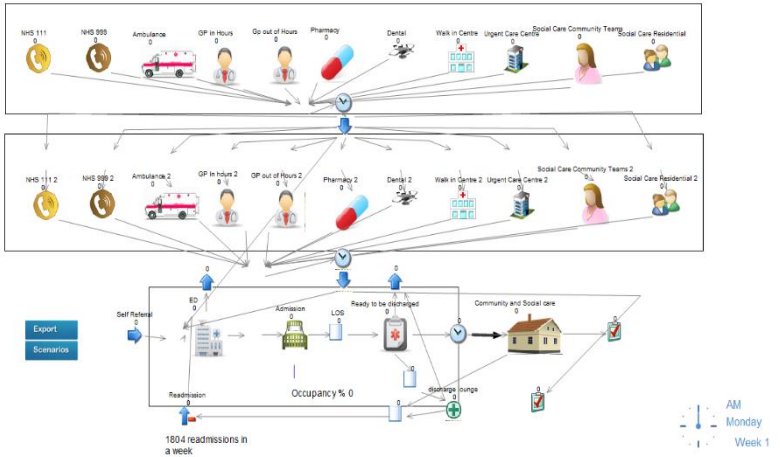
Wider system changes over time



The SD model runs over time under a small number of different assumptions.



Mid-year 15/16

NOW

March 2017

March 2019

Three snap-shots of data at points in time reflecting conditions arising from the different simulation runs

The DES model runs multiple times for a single set of initial conditions and scenario assumptions to arrive at statistically significant results.

Simulation Approach

Patient flow through urgent care

using discrete event simulation

Discrete event simulation

Simulation is described by Robinson (2014) as an "Experimentation with a simplified imitation (on a computer) of an operations system as it progresses through time, for the purpose of better understanding and/or improving the system." SIMUL8 software was used to build a Discrete Event Simulation. SIMUL8 can be used to build a "time based visual model which emulates every significant step that occurs in a process and every significant interaction between resources in a process so as to gain insight about the impact potential decisions on that process. The model shows you visually what will happen in the process if you make changes to it and it records performance measures of your system under different scenarios." (SIMUL8 Manual 2000). SIMUL8 is a flexible tool that can be used in many industries. It is especially utilized in healthcare as it minimizes the risk to patients and providers of making changes to a system, which is often complex and difficult to understand.

> "Experimentation with a simplified imitation (on a computer) of an operations system as it progresses through time, for the purpose of better understanding and/or improving the system"

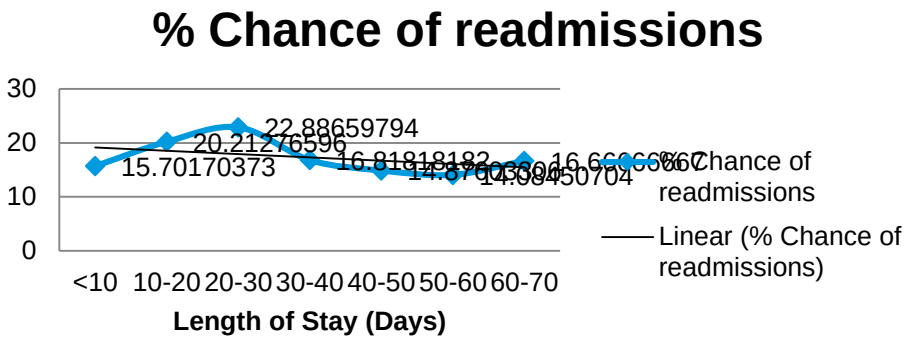
Robinson (2014)

Scenarios tested in the simulation

- Baseline- Runs the simulation with no changes to the current system based on Hillingdon data.
- Care Home Support- Prevents a user defined percentage of over 65 patients entering the system
- Impact of Beds Closing- Reduces the number of overall inpatients beds by a user defined number
- Ambulances see and treat- Increases the amount of patients who are seen and treated in an ambulance by a user defined percentage
- Increased Ambulatory Care- Prevents a user defined percentage of admissions and a user defined percentage of readmissions
- Ealing Hospital Demand- Increases the maternity and pediatric patient arrivals by a user defined number.
- Increased Primary Care Services- Increases primary care either between 18:00 and 20:00 on week days, between 09:00 and 17:00 on weekends or both by a user defined percentage

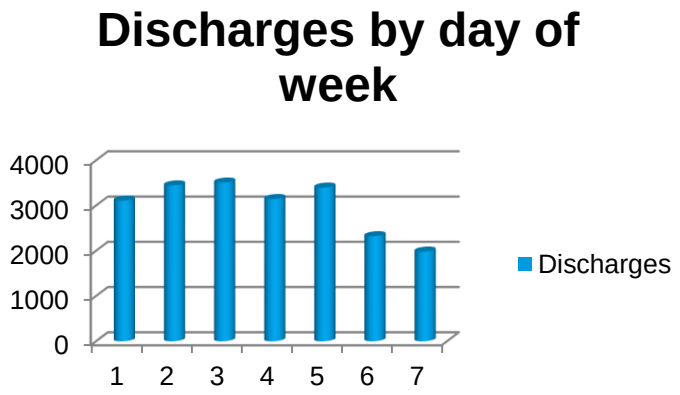
1. Length of Stay

- Pressures on beds could, in theory, put pressure on clinicians to discharge patients before they are truly ready to be discharged. This could make the chances of readmitting higher. The Chi Squared testing showed **that a patients Length of stay can be used to predict likelihood of readmission** supporting the theory that releasing patients 'too quickly' could increase the chances of readmission.
- Interestingly, when we look at the charted data, despite a linear trend, those with the shortest length of stay aren't the most likely to readmit. The patients who stay between 10 and 30 days are most likely. This could be because those with a very short length of stay often have the least serious conditions or are typically younger patients who we know are less likely to readmit. It is also worth noting that those staying over 30 days may be more likely to die in hospital and therefore this skews their chance of readmitting. To explore this further we would like to talk to clinicians who may be able to provide more insight.



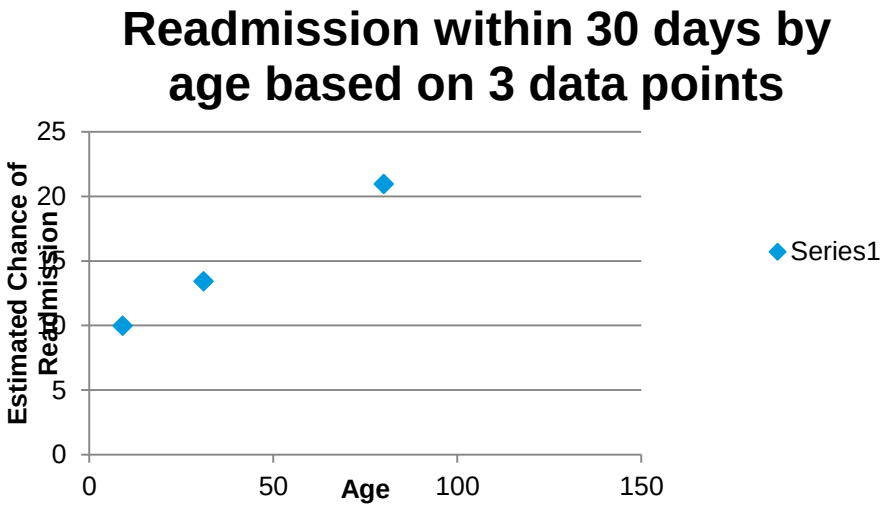
2. Discharge Day of the week

- In a ‘5 day system’ senior clinicians will have less of a presence over the weekend and junior doctors may have less confidence in discharging patients so fewer patients are likely to be discharged on Saturdays and Sundays. A further impact of this could be higher discharges on a Friday to free up capacity over the weekend or some of the patients who were technically well enough to be released over the weekend actually being discharged at the start of the week. When these compromises to ‘optimum’ discharge time need to be made because of the way a system works there is a chance this could lead to inappropriate discharges, especially on a Friday where there is a rush to release patients. Discharges by day of the week in the Hillingdon system show these lower discharges over the weekend and a spike on Fridays.

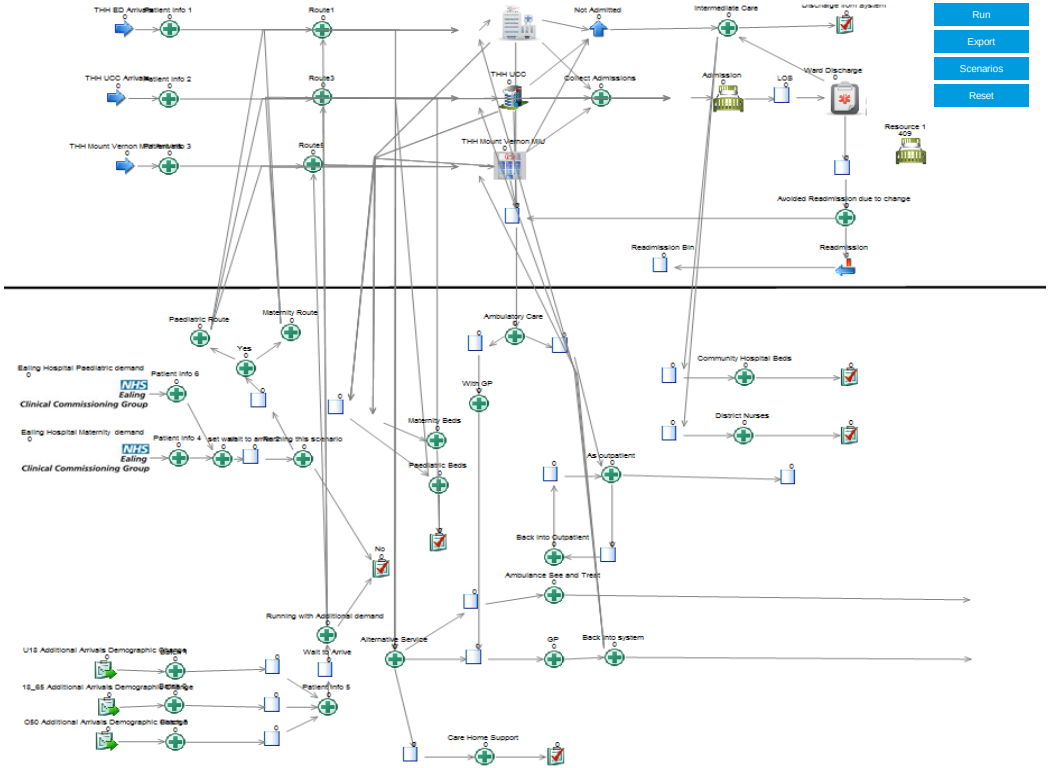


3. Patient Age

- Older patients may need more support when leaving the hospital and if they do not get this care it could mean they are more likely to readmit, with common problems being falls and heart conditions. If age does make a difference we need to capture this. Patients were split into 3 categories, under 18, 18-65 and over 65. There was an upwards exponential trend between age and likelihood to readmit. The results of the Chi squared test showed that this difference was statistically significant so **age can be used as a predictor of likelihood to readmit.**



Discrete Event Simulation



Results Analysis

Recommendations

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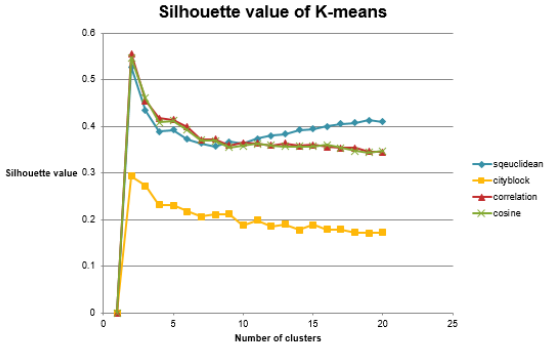
- Scenario 3 provides the best result largely due to an increase in ambulatory care. So we would recommend focusing on increasing ambulatory care as much as possible.
- Improving ambulance see and treat numbers by 21.4% also has a good improvement on all results so should be a secondary focus, although the savings in admissions are likely to be patients with short length of stays who are unlikely to admit and use beds for long periods of time so will not be the best cohort to target if beds are to be lost
- With these changes it would be realistic to expect to reduce beds by 20 in the baseline, 35 in scenario 2 and 50 in scenario 3. To make this most effective ambulatory care should look to target those patient types with the longest length of stays. For example the over 65s.
- Beds should be lost gradually as ambulatory care increases to minimize risks. There are ambitious increases in ambulatory care and until these take effect losing beds will result in failures against performance metrics.

Findings

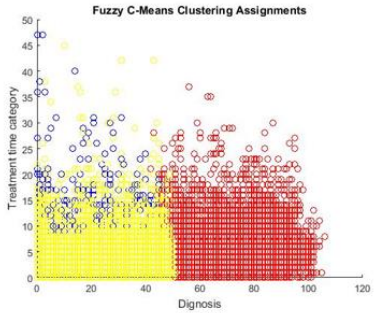
- Demand for urgent care is set to grow significantly over the next 5 years in the geographical area particularly in children aged 5-17 and people over 50. In the over 50s, people who are frail and living with multiple chronic conditions are the fastest growing group and will place increasing demand on health and care services
- Increased support out of hospital is essential to achieving the in-hospital reductions – we have explored the impact of increasing rapid response referrals and intermediate care capacity by up to 50%, demonstrating the contribution this can make
- Modelled scenarios of increased support outside hospital show that it is possible to reduce hospital admissions and readmissions by at least 10%
  - Based on 2017 population attendances reduce by 5-10% and admissions by up to 32%. Readmission rates could improve by up to 47%
  - In change scenario 2 with more modest changes to the Urgent Care Pathway, 1% of attendances, 14% of admissions and 22% of readmissions are prevented
  - Change scenario 3 has the best overall impact, although there no saving in attendances, there is a reduction of 29% of admissions and 48% of readmissions much of this again relies on a large increase in ambulatory care. This scenario also safeguards against the largest increase in Ealing hospital demand
- The largest impact is made by increasing Ambulatory Care with Ambulance See and Treat coming second. Ambulance See and Treat mainly affects short stay admissions, so the impact on beds is not as significant.
- With planned changes beds could be reduced by 20 in the baseline, 35 in scenario 2 and 50 in scenario 3. Patients with the longest length of stays should be targeted. For example the over 65s.
- Beds should be lost gradually as ambulatory care increases to minimize risks. There are ambitious increases in ambulatory care and until these take effect losing beds will result in failures against performance metrics.
- By 2019, despite these changes, there will be an increase in demand reducing benefits by 10%
- A caveat to this is that the working age population is decreasing and finding staff to work in the community may be a challenge

- Methodology for team working (communication)
- New analytical approaches

Our recent works (K-means)

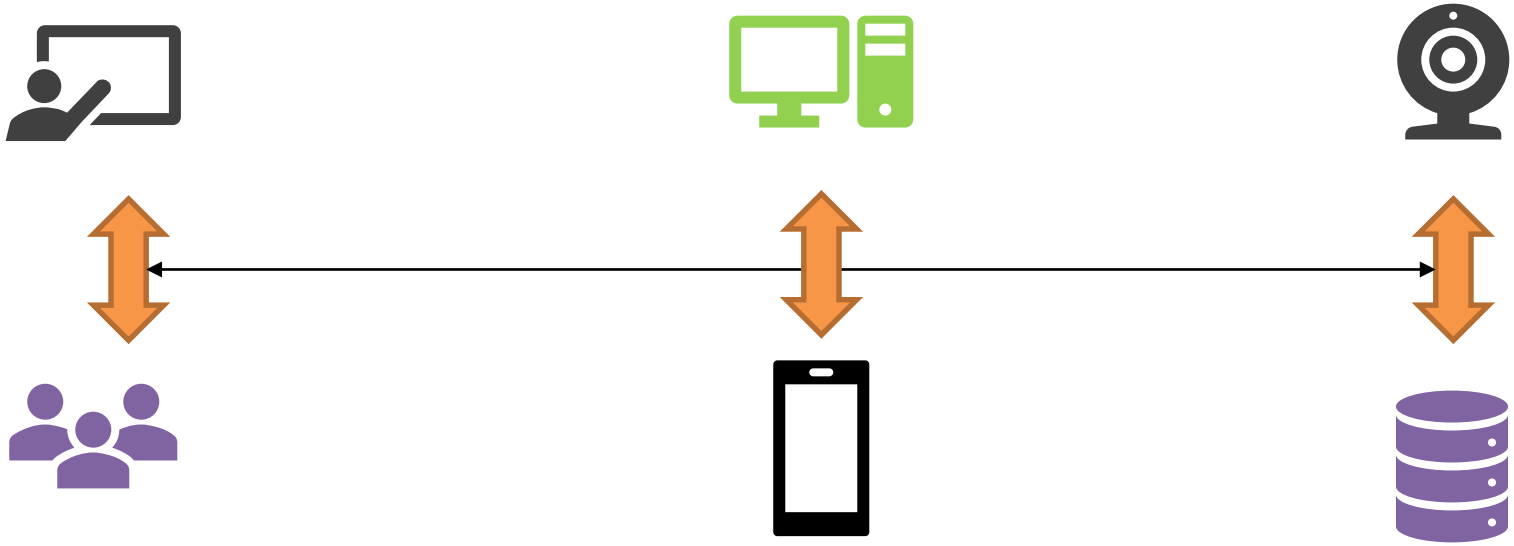


Our recent works (Fuzzy C-means)

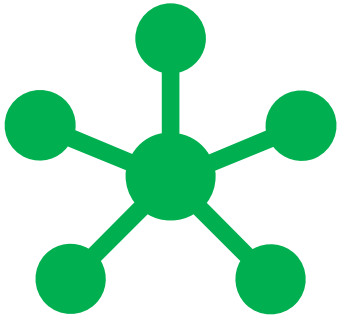


Collaboration – Code and Models

- Models (concept to simulation models)
- Methods (algorithms and modelling)
- Measures (data and instrumentation)



What methods, models or data are re-used…



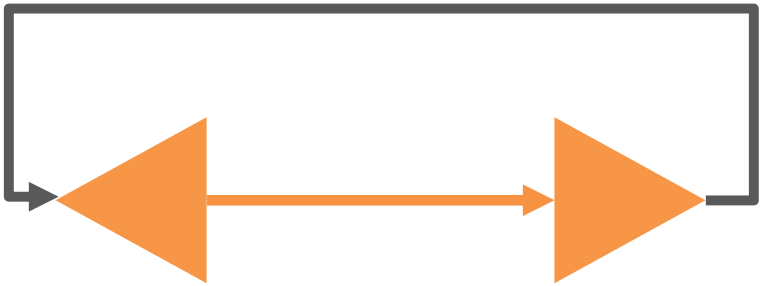
Data Farming with Simulation

Generating big data…

Summary

- Prediction is difficult
- Exploration is time consuming and costly, but likely cheaper than failure or bad investment
- Modelling is learning for all of the project
- Evidence is important and should not be lost (or generalised)
- Dynamic formation of problem oriented teams require active management and communication
- Data underpins all of the above

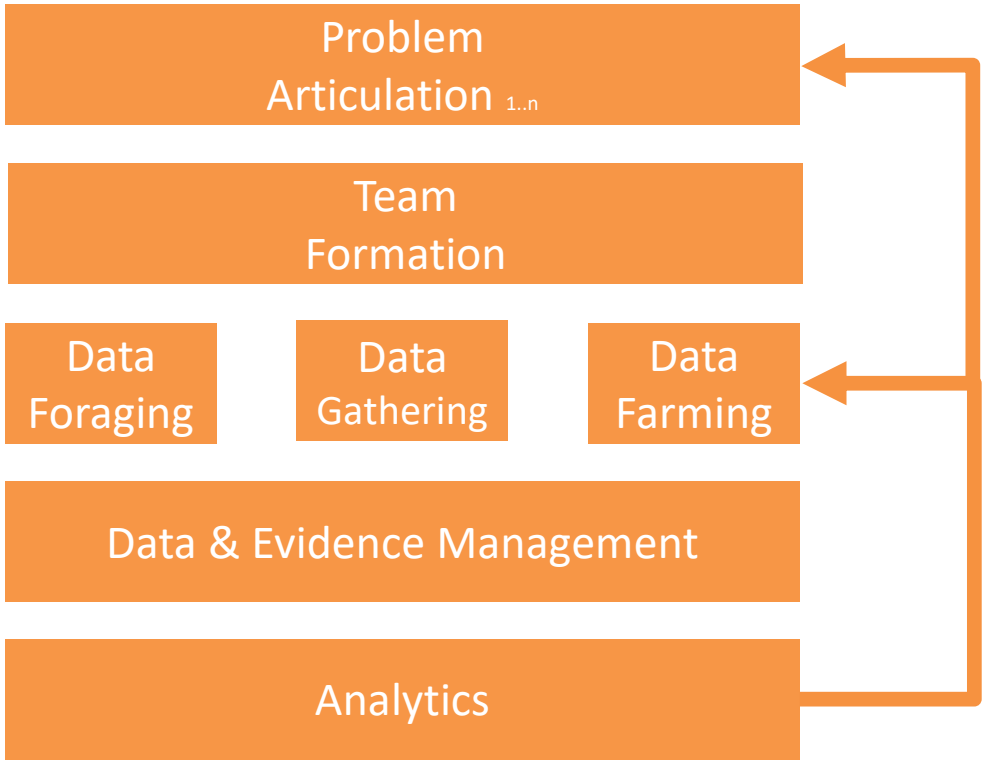
How do we use these rich data sets?



Look backward in order to look forwards

Analytics

Strategy synthesis



Some challenges

- How do we re-use models in other regions?
- How do we explore the unknown problem space?
- How can different users interact with analytical processes?

Thankyou and questions

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