Usage of Game-Theory in Energy, Cyber Security and COVID-19

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Kingston University London

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Speaker background

Dr Luluwah Al-Fagih is an Assistant Professor in the Division of Engineering Management and Decision Sciences at Hamad Bin Khalifa University (HBKU), Qatar. Prior to joining HBKU, Dr Al-Fagih was a Senior Lecturer in the School of Computer Science and Mathematics at Kingston University London. Dr Al-Fagih holds a PhD in Financial Mathematics from The University of Manchester, UK and a BSc and MSc in Mathematics and Financial Mathematics from King's College London. She joined Kingston University as a Lecturer in 2013. Over the last few years, Dr Al-Fagih has developed research in Game Theory and its applications to smart energy management, cyber security and more recently, pandemics such as COVID-19.

Outline

- Game theory introduction
- Energy scheduling game
- COVID-19 Personal Protective Equipment (PPE) game

Game Theory Timeline

Cournot (1838)- first known application in economics to understand the behaviour of companies, markets, and consumers

J. von Neumann (1928 and 1944)- first formal representation (mainly 2 person, zero-sum games)

John Nash (1950)- a solution approach for *n*-player, non-zero-sum games, the *Nash equilibrium*

L. Hurwicz, E. S. Maskin, and R. B. Myerson (2007)- mechanism design (reverse GT)

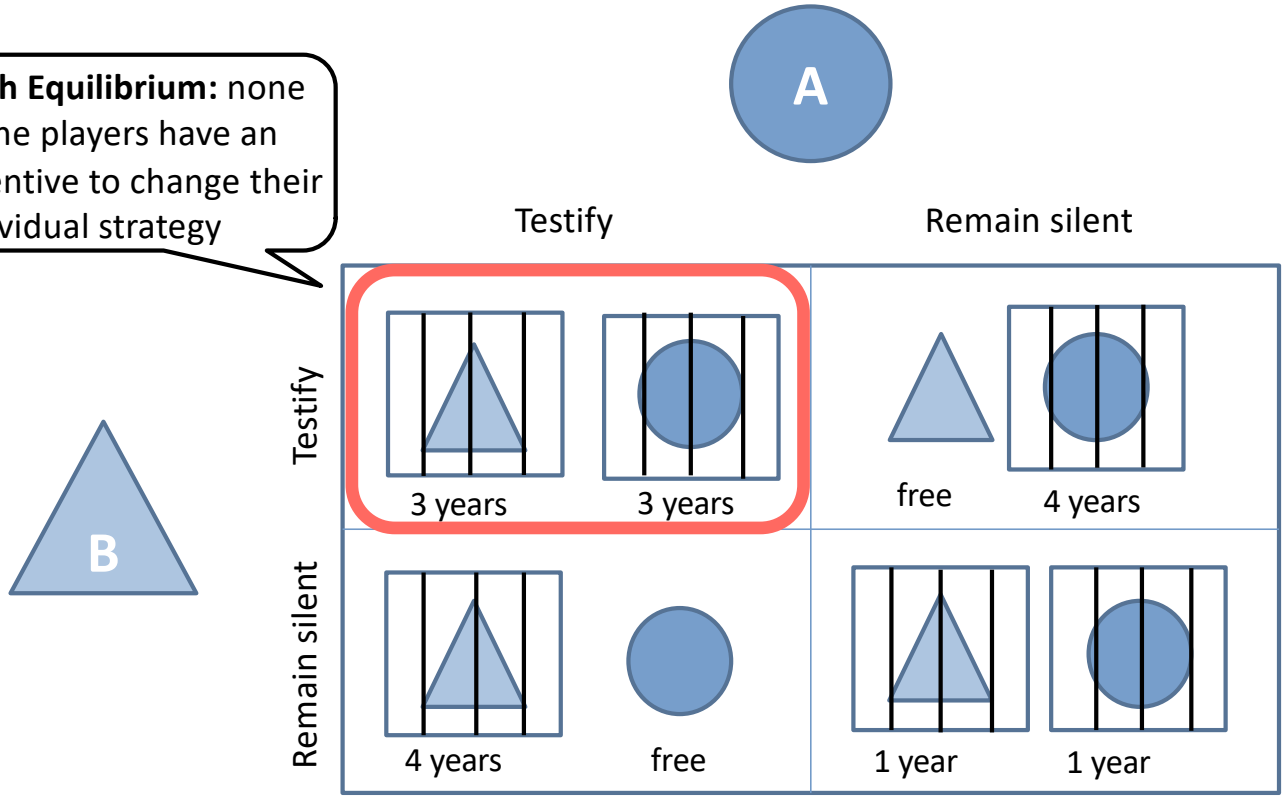
~ Seven Nobel prizes between 1972 and 2020

Game Theory Applications

- **Biology**: Evolutionary games, signalling games to study animal communication
- **Philosophy**: Answering questions about common knowledge between different individuals and consequences
- **Computer science:** Design of peer-to-peer systems
- **Auctions**: English auction, double auctions, or second-price auctions
- **Politics**: Design and analyse voting schemes

Example: The Prisoners' dilemma

Nash Equilibrium: none of the players have an incentive to change their individual strategy



Game-Theoretic Approaches to Storage Scheduling in Prosumer Communities

Joint work with Matthias Pilz

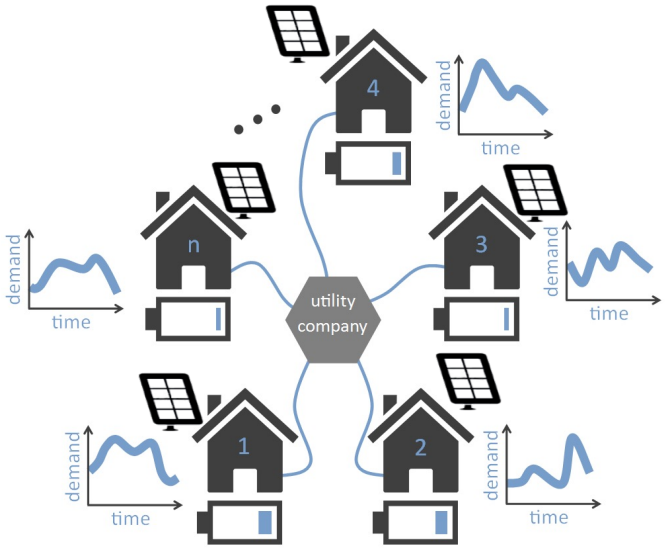
Other collaborators: Jean-Christophe Nebel, Eckhard Pfluegel, Mastaneh Davis, Fariborz Baghaei

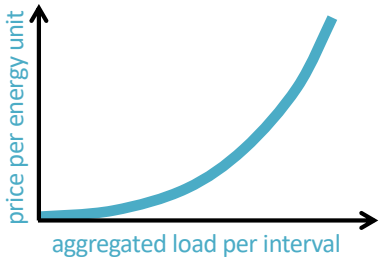
Demand-Side Management Schemes

- Control of consumption by the utility company at the consumer side
- Consumers can be incentivised to decrease consumption from grid during peak times, i.e. lower the peak-to-average ratio (PAR)
- Can include load shifting, i.e. operating household appliances at off-peak times, but this interferes with consumers' habits and comfort levels
- Battery scheduling can achieve same net effect without interfering with consumer habits
- Relies on the two-way communication of the future smart grid

The System Model

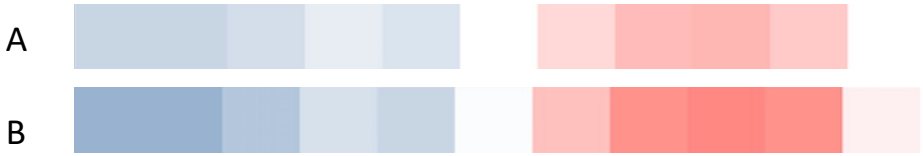
- **Prosumers = Pro**ducers + con**sumers**
- Two-way power flow and two-way communication (via smart meter)
- Load on grid = household demand + battery activity
- Divide following day into intervals
- Time-of-use tariff
  - different price for each interval
  - based on aggregated load
- Proportional billing



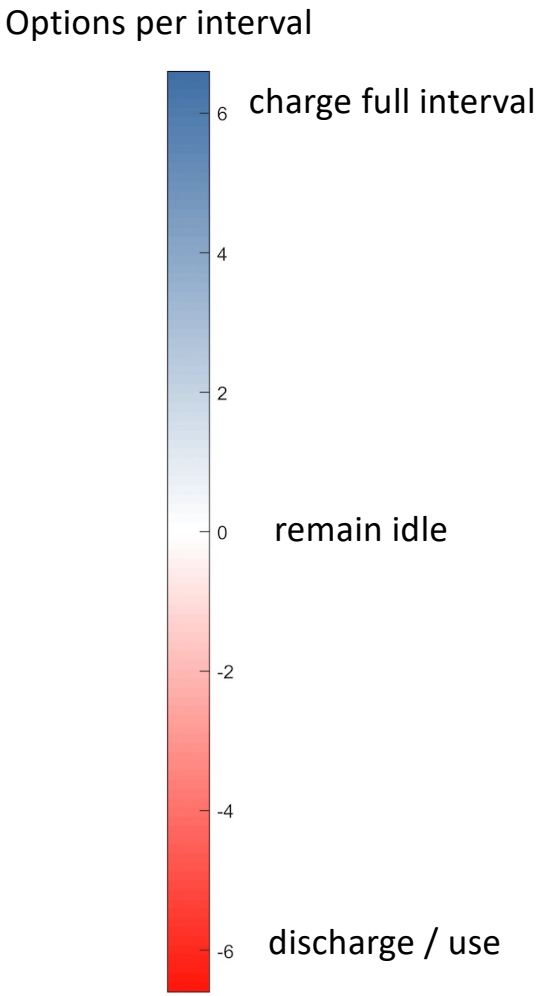


The Scheduling Game

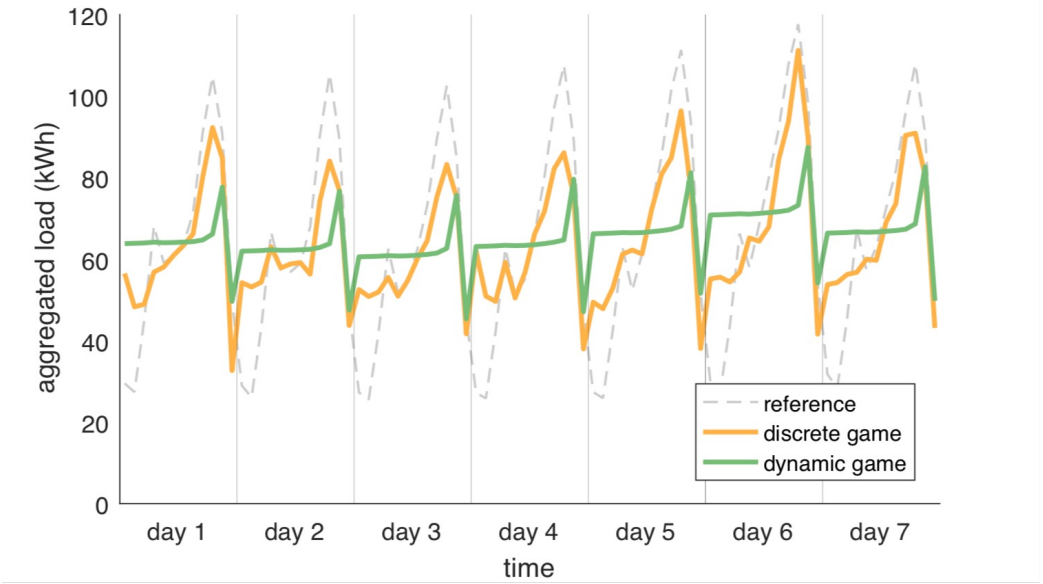
- Players
  - households with varying demand
- Actions
  - day-ahead schedules of battery usage

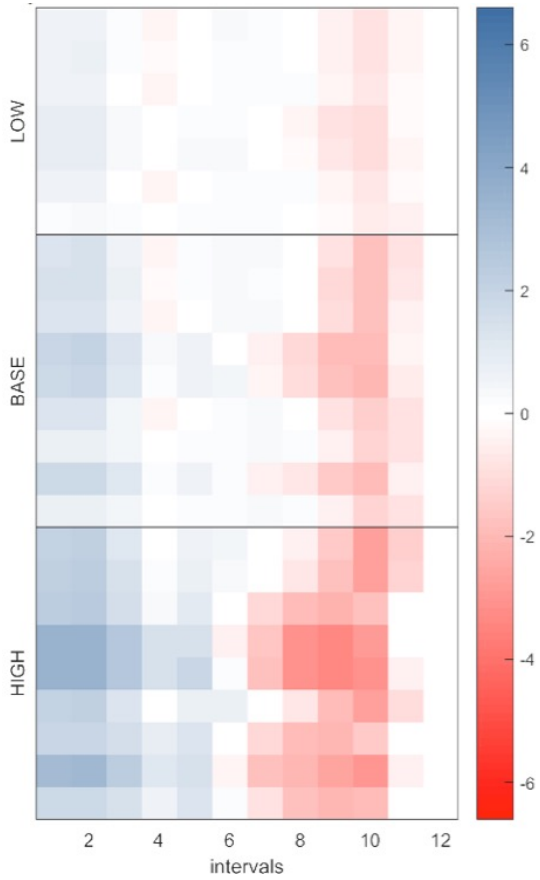


- Payoff
  - individual energy bill



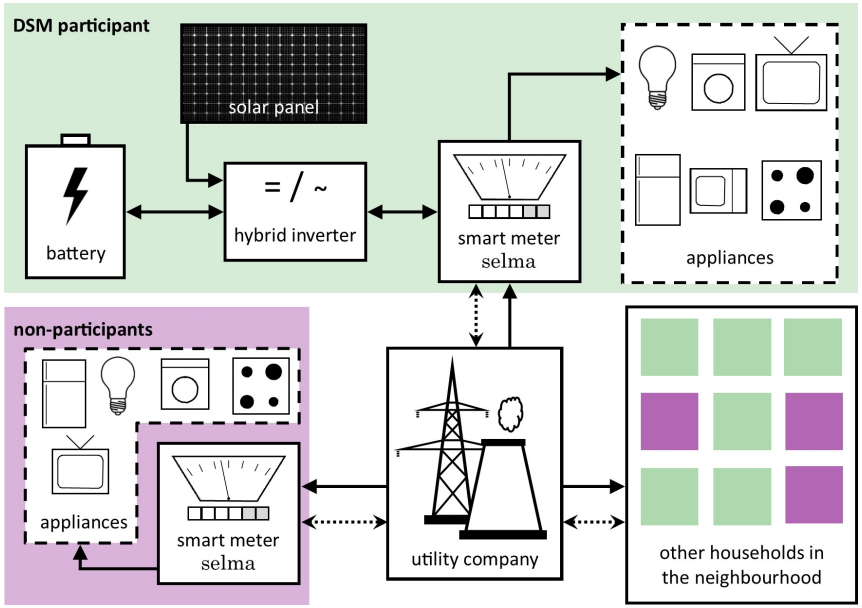
Nash Equilibrium schedules

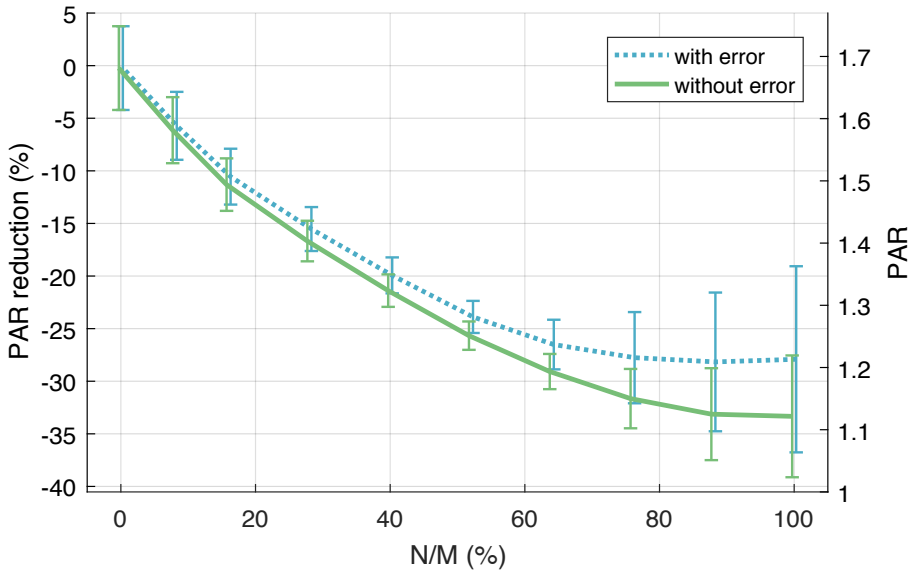




- Reduction of peak-to-average (PAR) ratio > 14 %
- Energy cost reduction > 6.5 %
- High demand users use their battery the most

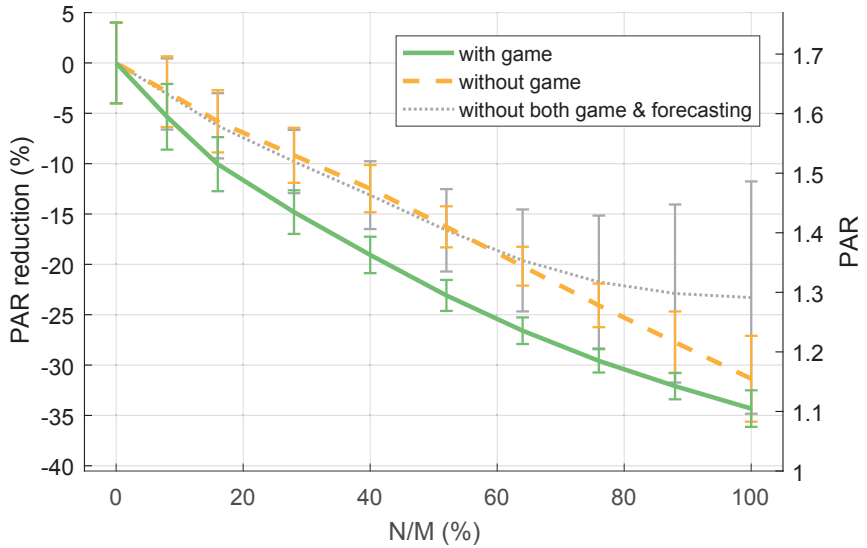
Community with non-participants & forecasting errors





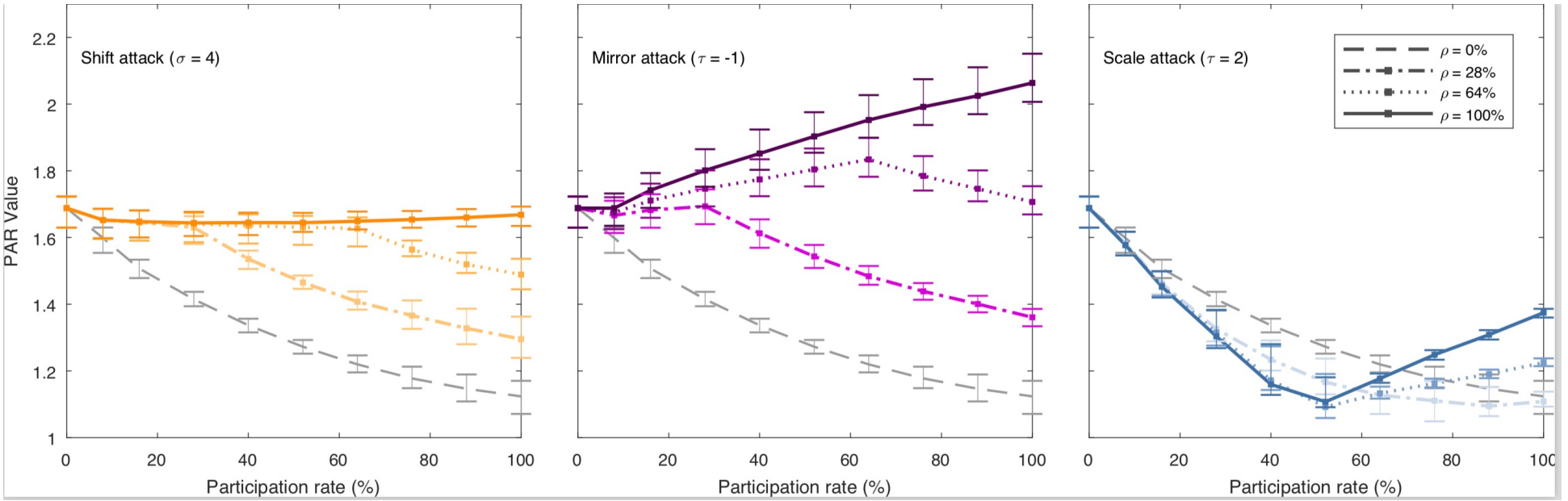
Pilz, M. and Al-Fagih, L. A Dynamic Game approach for Demand-Side Management: Scheduling Energy Storage with Forecasting Errors. *Dynamic Games and Applications (Springer) 2019.*

Is it worth playing the game?



Pilz, M., Nebel, J.C. and Al-Fagih, L. A Practical Approach to Energy Scheduling: A Game Worth Playing? *2018 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe). Sarajevo, Bosnia-Herzegovina.*

False Data Injection Attacks



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Game Theory to Enhance Stock Management of Personal Protective Equipment (PPE) Supply during the COVID-19 Outbreak

with Khaled Abedrabboh, Matthias Pilz, Zaid Al-Fagih, Othman S. Al-Fagih and Jean-Christophe Nebel

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The problem

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Hospital leaders attack government as anger over PPE shortage grows

Denis Campbell
Health policy editor

Hospital leaders have directly attacked the government for the first time during the coronavirus crisis over the PPE shortage after a desperately needed consignment of surgical gowns, which had been announced by ministers, failed to arrive.

In an unprecedented intervention that hospital leaders say privately is the result of "intense frustration and exasperation", the organisations representing NHS trusts in England urged ministers to "just focus on what we can be certain of" after weeks of "bitter experience" with failed deliveries.

The NHS Confederation and NHS Providers spoke out amid continuing alarm that equipment shortages will would soon have disastrous effects, with representatives of intensive-care staff warning yesterday that the critical shortage of PPE (personal protective equipment) could lead to some of them refusing to work there.

After the Guardian revealed on Friday that doctors and nurses had been asked to work without protective full-length coverings and instead use aprons, the cabinet minister Robert Jenrick promised that 84 tonnes of PPE, including 400,000 much-needed surgical gowns, would be arriving from Turkey yesterday.

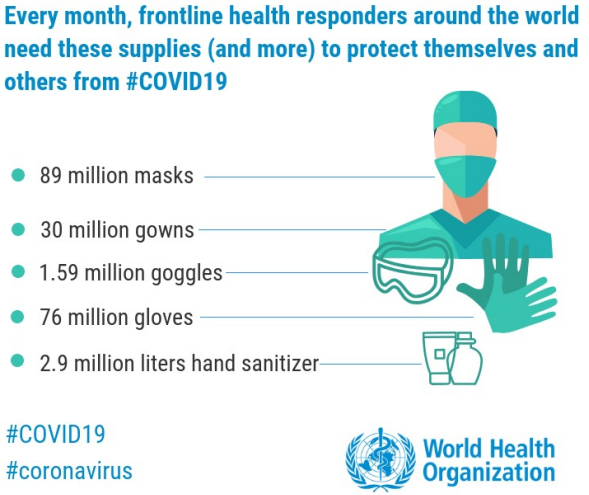
But after the shipment was delayed without explanation, hospital chiefs' frustrations boiled over. Dozens of trusts were now at risk of running out of gowns over the next few days unless fresh supplies can be found, a well-placed NHS source told the Guardian.

After previous promised shipments either did not arrive or contained the wrong items, NHS Providers – representing hospital trusts – wants ministers including the health secretary, Matt Hancock, to stop talking about expected deliveries in public and only announce them once they have arrived. Shipments trailed in advance that do not arrive increase anxiety among frontline staff and make it harder for

'We will expect announcements when supplies have arrived, not promises about what may or may not be delivered'

Niall Dickson
NHS Confederation

- Initial data early in the pandemic showed that 10-20% of Covid-19 cases found in healthcare workers (HCWs)
- 20% of inpatient & 89% of HCW cases caught in hospitals

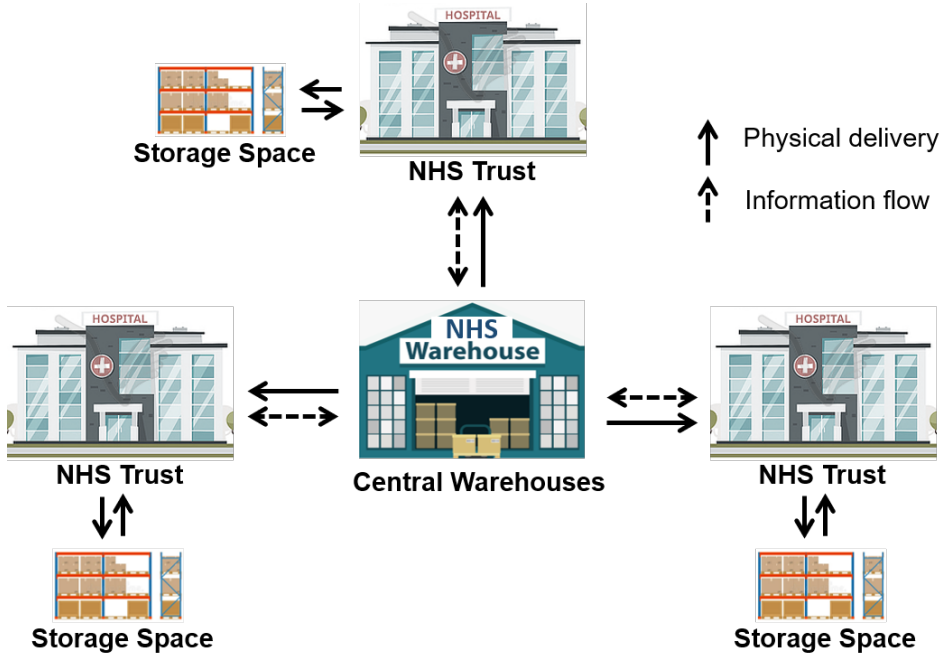


The PPE Challenge

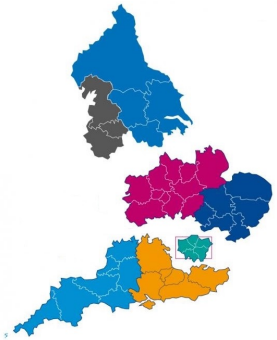
- The higher the aggregated demand, the more challenging it is to fulfil due to:
  - sourcing new suppliers, higher shipping costs
  - increased production (overtime, extra staff and/or equipment)
  - higher demand -> higher costs.
- The daily aggregated demand should be minimal and ‘constant’, otherwise there would be a supply issue!

Proposed system architecture

- PPE supply chain
- Centralised – decentralised



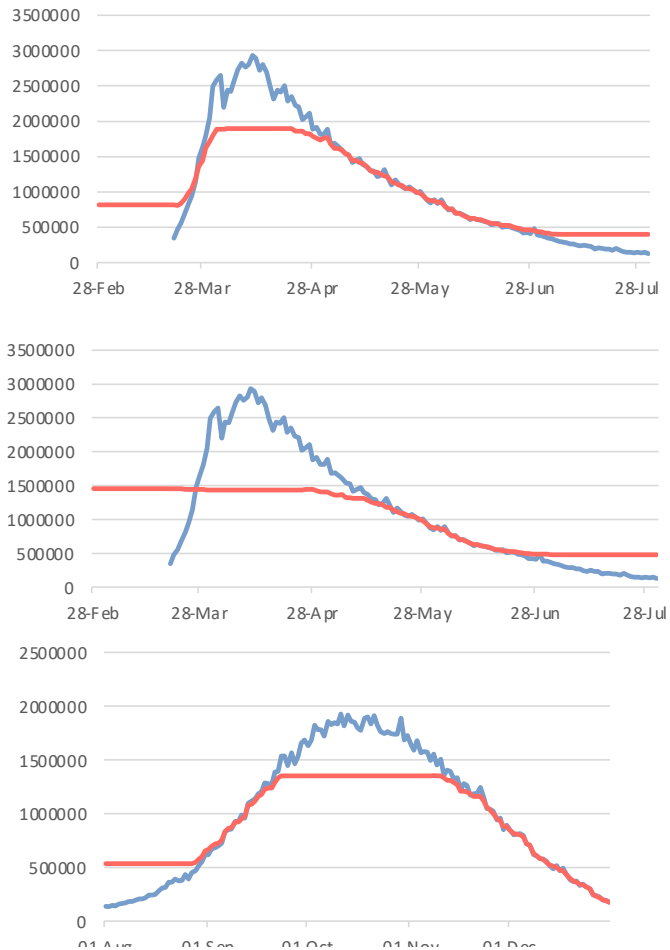
The PPE Game



- Players:
  - Seven regions of NHS (National Health Service) England
- Actions:
  - Each region to schedule their daily PPE orders for the whole period
- Goal:
  - Each player attempts to get PPE at the lowest cost while still meeting their full demand

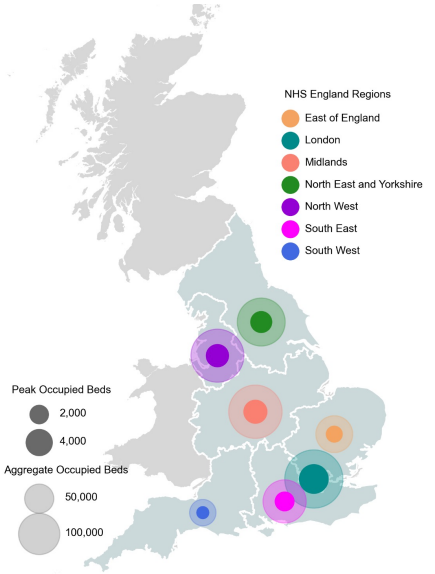
Questions

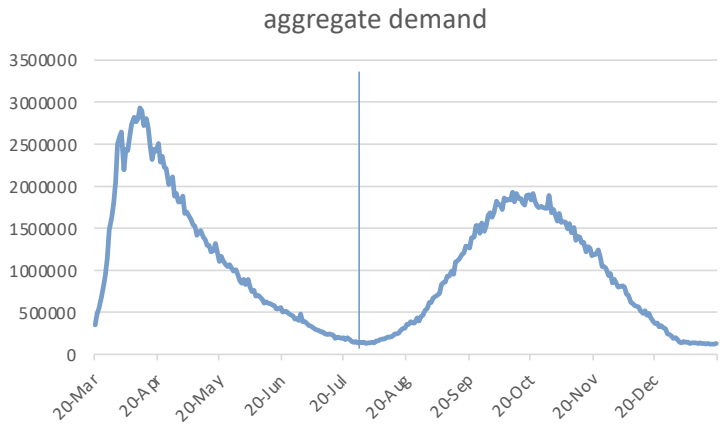
- Early stockpiling
  - Would it have eased the challenge of securing PPE ? If yes, how early ?
- Storage space
  - Are the current storage capacities enough ? How much more space is required ?
- Second wave
  - How early a second wave of PPE demand can be handled with this game ?



Data and experimental setup

- Occupied hospital beds with COVID-19 illness is representative of how much a hospital is responding to the pandemic.
- Bed occupation data publicly available for the 7 NHS (National Health Service) England regions
- Changes in NHS guidelines, e.g. 2nd April, 'Sessional' use of PPE: the same clothing could be used throughout **one shift instead** of solely for **one patient**



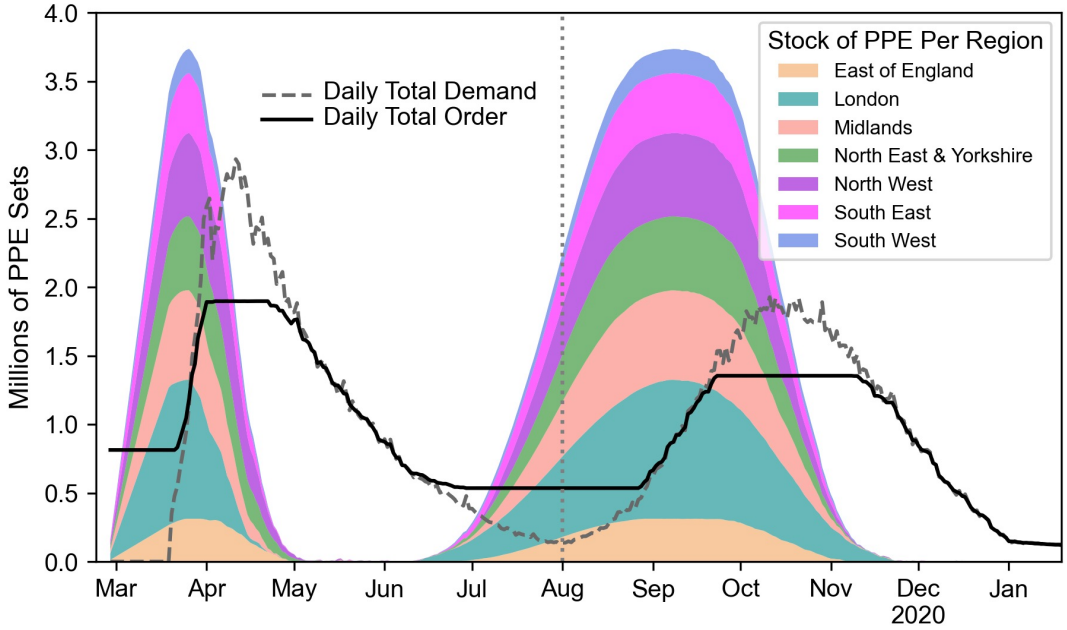


Experimental implementation

- Early stockpiling dates:
  1. **20 March 2020**: data on COVID-19 cases and occupied hospital beds in England made public
  2. **11 March 2020**: WHO declared COVID-19 a pandemic
  3. **28 February 2020**: European Union proposed bulk-buy PPE scheme to UK
  4. **07 February 2020**: WHO warned of PPE shortages
  5. **31 January 2020**: First COVID-19 case confirmed in the UK
- Storage capacities: 5 values (no additional capacity, 5x, 10x, 15x and 20x original capacity)
- Estimates for peak of second wave: 5 values from October 2020 to February 2021

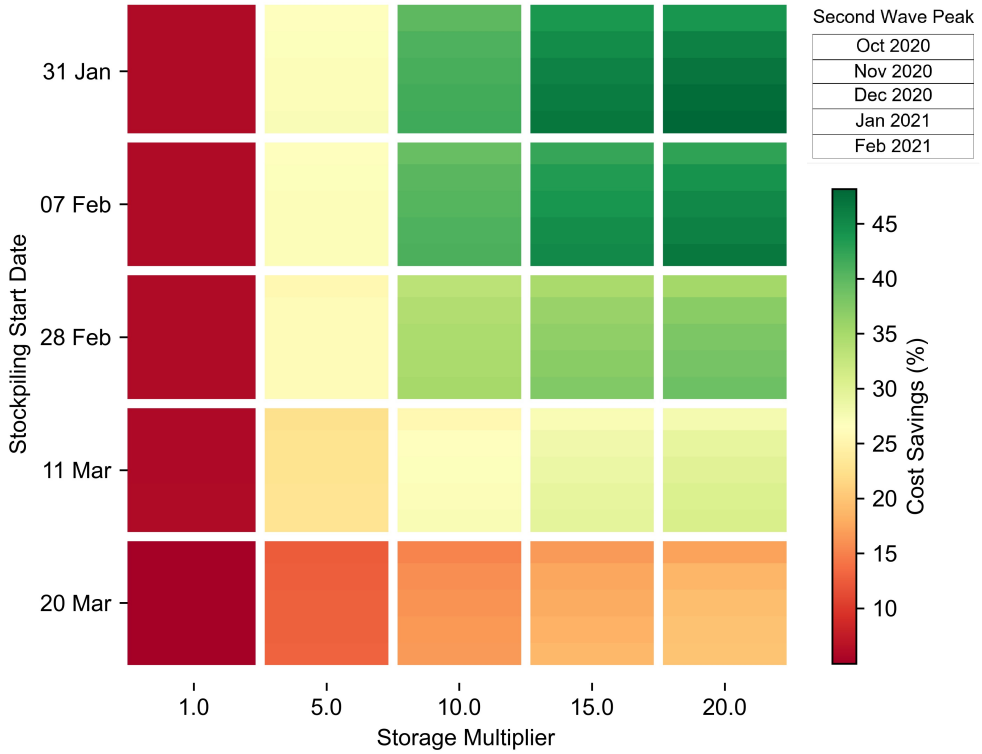
An example simulation of stockpiling game

- Stockpiling started on 28 Feb 2020
- Standard storage capacity multiplied by 5
- Peak of second wave expected to happen in mid October 2020



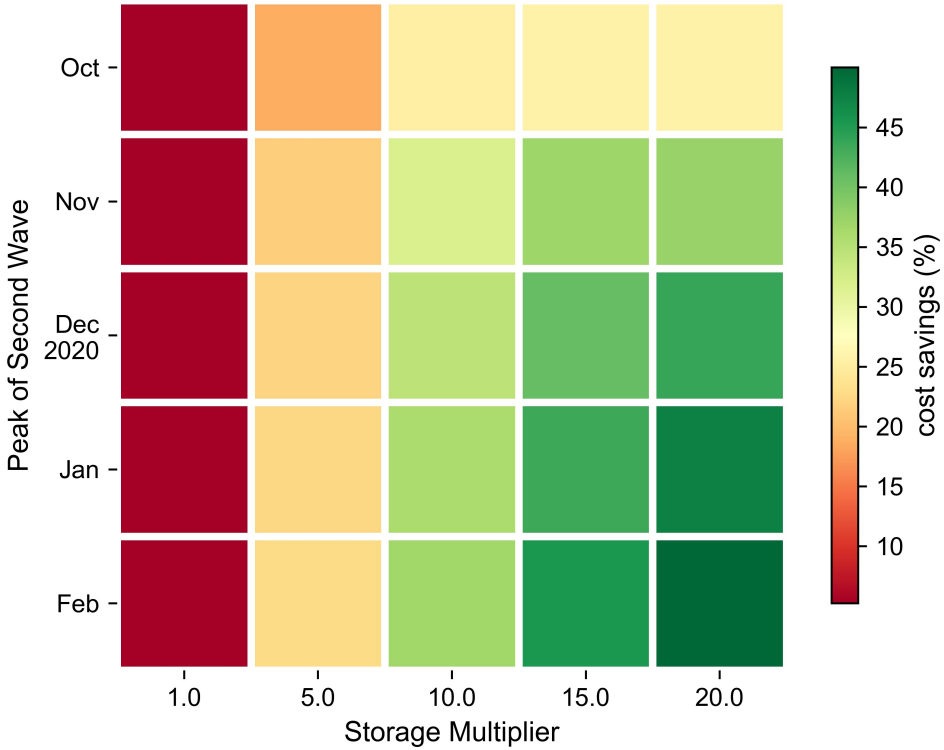
Millions of PPE sets required daily nationally (dotted line), ordered daily nationally (bold line) according to the game, and stored in each of the 7 regions

Results



Challenge in terms of fulfilling PPE demand delivery according to the amount of available storage capacity (x-axis), the stockpiling starting date in 2020 (y-axis), and the peak date of a putative second wave of COVID-19 (each cell in the grid is divided in five stripes corresponding, from top to bottom, to peak dates in October, November, December 2020, January and February 2021).

Results



Challenge in terms of fulfilling PPE demand delivery according to the amount of available storage capacity (x-axis) and the peak date of a putative second wave of COVID-19 (y-axis).

Conclusion

- PPE shortages can be avoided by installing temporary storage space such as marquees. Increasing PPE storage capacity by a factor of 15 would have been required to minimise the pressure on the NHS
- Early stockpiling could ease the challenge significantly
- Looking ahead, steady stockpiling is still a more viable option than panic buying
- Could have delivered cost savings of 38% had stockpiling begun on February 7 (the date WHO warned of PPE shortages)
- Read about this work on Forbes!

Related publications

- Pilz, M., Al-Fagih, L. A Dynamic Game Approach for Demand-Side Management: Scheduling Energy Storage with Forecasting Errors. *Dyn Games Appl* **10,** 897–929 (2020). https://doi.org/10.1007/s13235-019-00309-z
- M. Pilz, J. Nebel and L. Al-Fagih, A Practical Approach to Energy Scheduling: A Game Worth Playing?, *2018 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe)*, https://doi.org/10.1109/ISGTEurope.2018.8571522
- Pilz, M., Naeini, F.B., Grammont, K. *et al.* Security attacks on smart grid scheduling and their defences: a game-theoretic approach. *Int. J. Inf. Secur.* **19,** 427–443 (2020). https://doi.org/10.1007/s10207-019-00460-z
- Abedrabboh K, Pilz M, Al-Fagih Z, Al-Fagih OS, Nebel J-C, Al-Fagih L (2021) Game theory to enhance stock management of Personal Protective Equipment (PPE) during the COVID-19 outbreak. PLoS ONE 16(2) https://doi.org/10.1371/journal.pone.0246110