

# Stroke Audit Machine Learning (SAMueL) Advisory Group November 2022

Investigating variation in thrombolysis use with clinical pathway  
simulation and explainable AI

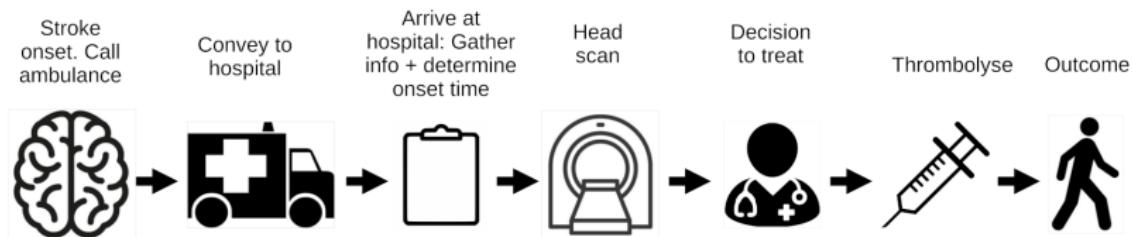
November 2022

# Outline

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- 4 Stroke outcome modelling based on times to treatment with thrombolysis and thrombectomy
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Modelled stroke pathway

# Breaking down the emergency stroke pathway into key steps



We can model key changes to pathway:

- What if the pathway were faster?
- What if hospital determined the stroke onset time in more patients?
- What if clinical decision-making was like that of *benchmark* hospitals?  
(Predict what treatment a patient would receive at other hospitals).

We model these changes with a hospital's own patient population, to allow for inter-hospital variation in patient population characteristics.

SAMueL-1 summary

# SAMueL-1 Summary: What is the problem?

There is a gap between target thrombolysis use (20%) and actual thrombolysis use (11–12%) in emergency stroke care

Clinical expert opinion on what *should be* happening



What is happening?



Unknown onset time or  
arrived too late to treat



Not suitable for treatment  
with thrombolysis



Treated with thrombolysis



Potentially treatable, but not  
treated with thrombolysis

## SAMueL-1 Summary: What did we test?

We used clinical pathway simulation and machine learning to analyse a series of *what if?* questions:

- What if arrival-to-treatment time was 30 minutes?
- what if all hospitals determined stroke onset time as frequently as an *upper quartile* hospital (a hospital ranked 25 out of 100, for determining stroke onset time).
- What if decisions to thrombolyse were made according to a majority vote of 30 benchmark hospitals?

For each hospital we use their own patients to ask these questions, to allow for differences in local patient populations.

# SAMueL-1 Summary: What did we find?

We found that making all these changes would increase thrombolysis use in England and Wales to 18–19%. Out of every 10 patients who were potentially treatable but did not receive treatment, we found the cause to be:



Hospital processes  
were **too slow**



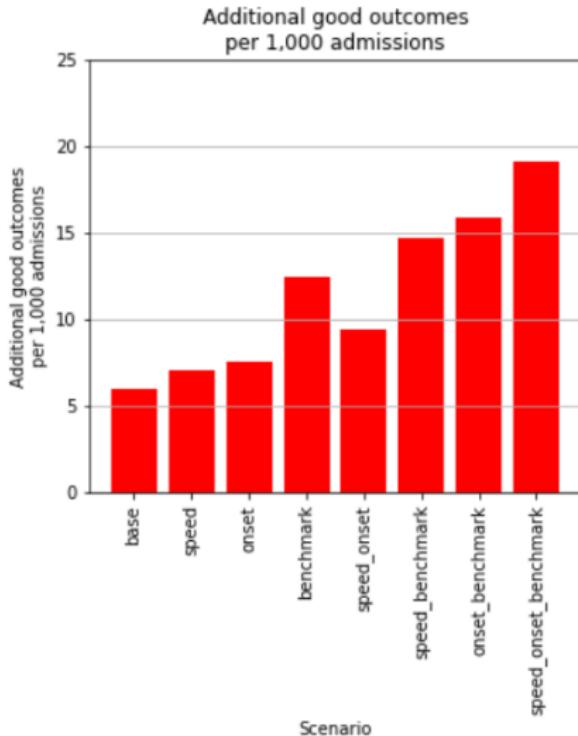
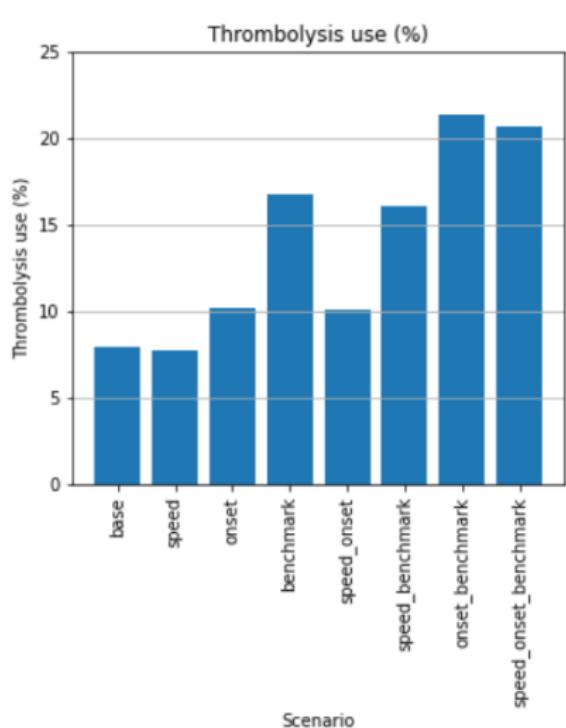
Stroke onset time was not  
**determined** when it  
potentially could have been



Doctors chose not to use thrombolysis  
when other higher-thrombolytic  
hospitals would have done

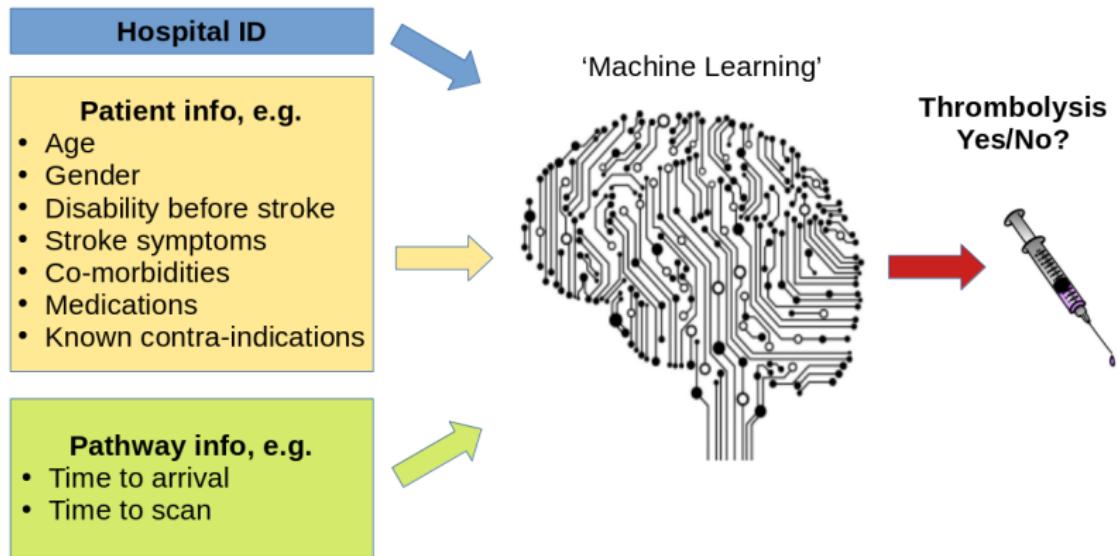


# Applying our models at hospital level



Machine learning - learning and comparing decisions  
to thrombolyse between hospitals

# Machine learning overview



Machine learning (and nearly all *artificial intelligence*) is based on the simple principle of recognising similarity to what has been seen before.

We accessed 240,000 emergency stroke admissions in England and Wales over three years.

# Model accuracy, and simplification

Our machine learning models use XGBoost classification, and are based on all patients who arrive within 4 hours of known stroke onset.

The full model has 61 patient features:

- Overall accuracy = 85.2%
- Best combined sensitivity and specificity = 84.3%
- ROC AUC = 0.921

A simplified model with 8 features

- Overall accuracy = 84.8%
- Best combined sensitivity and specificity = 83.8%
- ROC AUC = 0.916

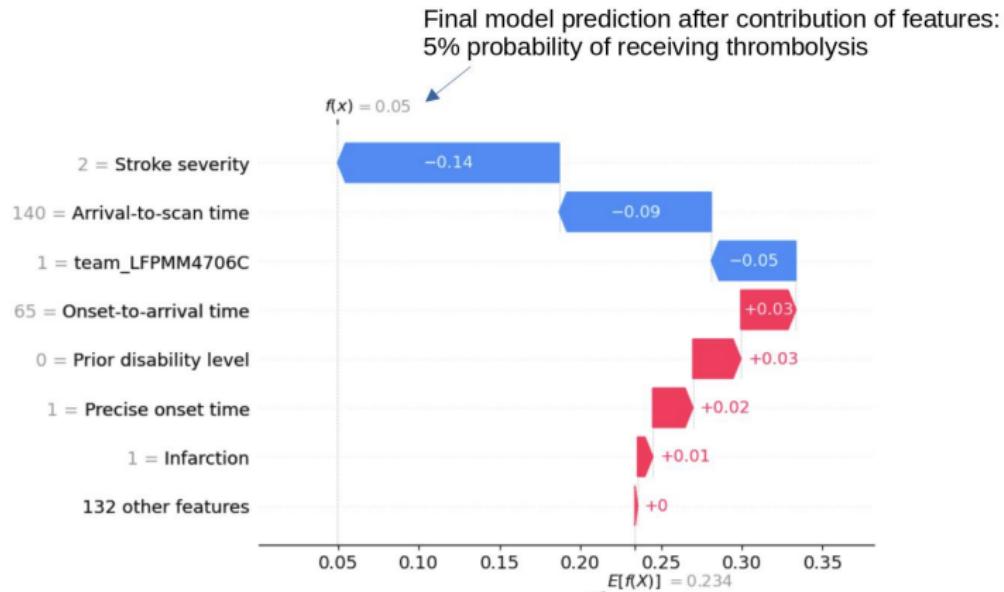
The 8 features of the simplified model are:

- ① Arrival-to-scan time
- ② Stroke type (infarction/haemorrhage)
- ③ Stroke severity (NIHSS)
- ④ Precise or estimated stroke onset time
- ⑤ Prior disability level (mRS)
- ⑥ Stroke team
- ⑦ Use of AF anticoagulants
- ⑧ Onset-to-arrival time

There are only very weak correlations between the selected features with no R-squared being greater than 0.05.

# Explaining model predictions with SHAP values

SHAP values show the influence of features (even for '*black box*' models).

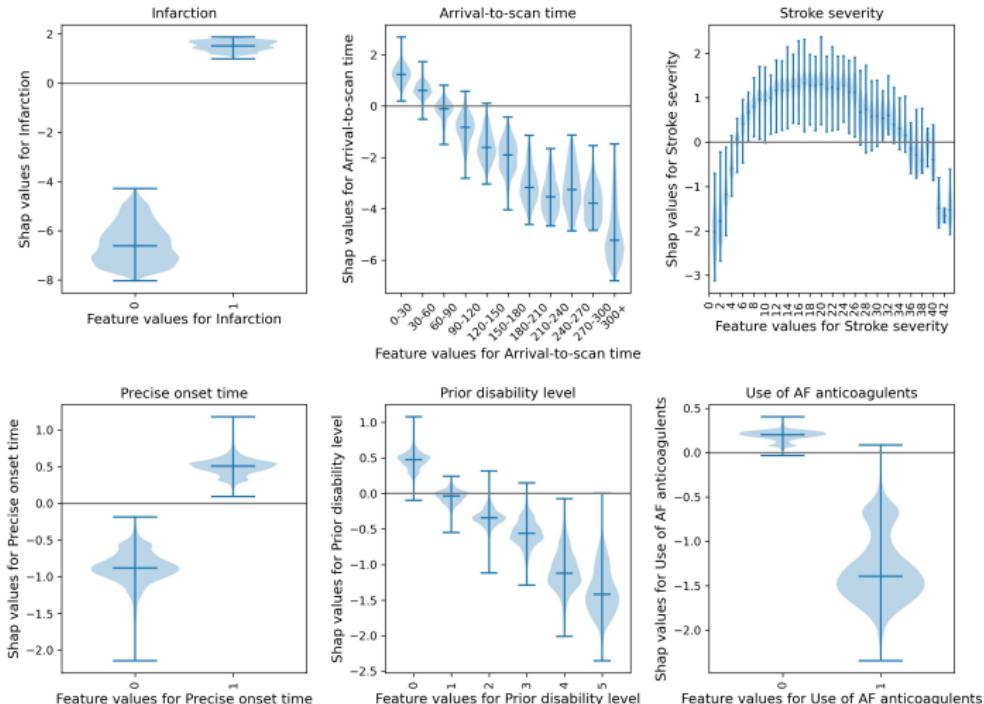


Base model prediction before contribution of features:  
23% probability of receiving thrombolysis

Note: The effect of team ID can depend on other patient characteristics.

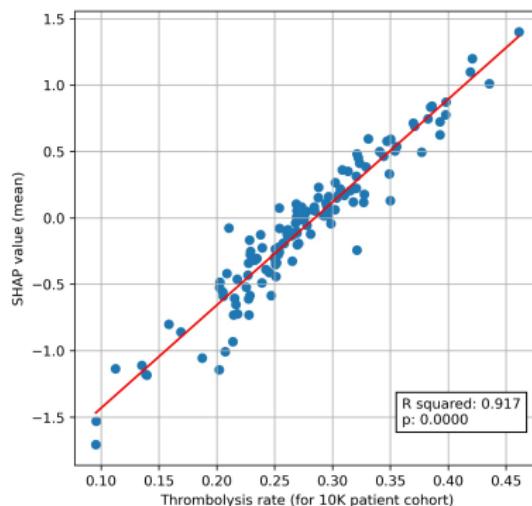
# What drives use of thrombolysis across all hospitals?

Note: SHAP values here are *log odds*. Each step-change in value of  $\pm 1$  changes the chances of receiving thrombolysis about 3-fold. (Plots are in order of feature importance.)



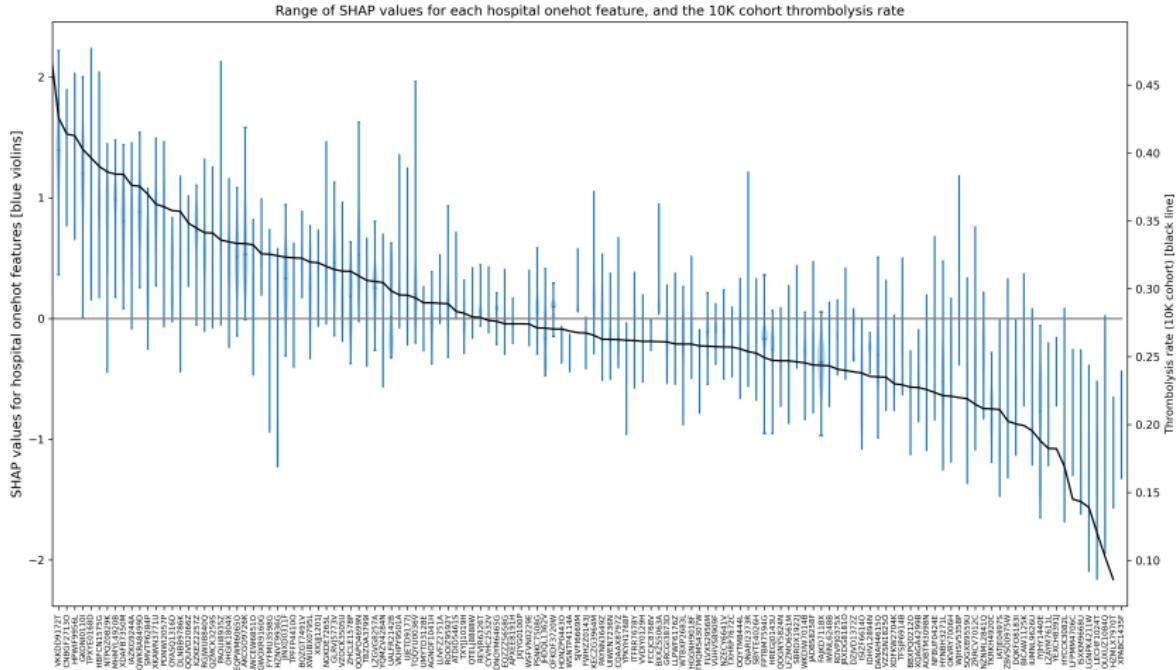
# Comparing hospital SHAP value with the predicted thrombolysis rate if all hospitals say the same 10k patients

- We can assess each hospital's 'propensity to use thrombolysis' by passing the same 10k cohort of patients through all hospital prediction models.
- We can compare this 10k thrombolysis rate to the average hospital SHAP.
- These two different methods of isolating the effect of the hospital on thrombolysis use give very similar results.



## SHAP for all patients at each hospital

Though each hospital has an average SHAP effect, the effect of the hospital varies with patients, depending on the hospital's own patterns of who they are more/less likely to give thrombolysis to.



## Investigating how hospitals differ in thrombolysis decision-making (Patient 1: Base patient)

Assuming there are no reasons not stated here to exclude a patient from use of thrombolysis, would you give this patient thrombolysis?

- Onset to arrival = 80 mins
- Arrival to scan = 20 mins
- Infarction = Yes
- NIHSS = 15
- Prior disability level = 0
- Precise onset time = Yes
- Use of AF anticoagulents = No

Our model predicts 131 out of 132 (99%) hospitals would give this patient thrombolysis.

## Investigating how hospitals differ in thrombolysis decision-making (Patient 2: Milder stroke)

Assuming there are no reasons not stated here to exclude a patient from use of thrombolysis, would you give this patient thrombolysis?

- Onset to arrival = 80 mins
- Arrival to scan = 20 mins
- Infarction = Yes
- NIHSS = 4
- Prior disability level = 0
- Precise onset time = Yes
- Use of AF anticoagulents = No

Our model predicts 97 out of 132 (73%) hospitals would give this patient thrombolysis.

## Investigating how hospitals differ in thrombolysis decision-making (Patient 3: Pre-stroke disability)

Assuming there are no reasons not stated here to exclude a patient from use of thrombolysis, would you give this patient thrombolysis?

- Onset to arrival = 80 mins
- Arrival to scan = 20 mins
- Infarction = Yes
- NIHSS = 15
- *Prior disability level = 3\**
- Precise onset time = Yes
- Use of AF anticoagulents = No

Our model predicts 114 out of 132 (86%) hospitals would give this patient thrombolysis.

\*Moderate disability; requires some help, but able to walk without assistance.

## Investigating how hospitals differ in thrombolysis decision-making (Patient 4: Estimated stroke onset time)

Assuming there are no reasons not stated here to exclude a patient from use of thrombolysis, would you give this patient thrombolysis?

- Onset to arrival = 80 mins
- Arrival to scan = 20 mins
- Infarction = Yes
- NIHSS = 15
- Prior disability level = 0
- *Precise onset time* = No
- Use of AF anticoagulents = No

Our model predicts 84 out of 132 (64%) hospitals would give this patient thrombolysis.

# Machine Learning key findings

General observations about thrombolysis use: The chance of receiving thrombolysis is increased by:

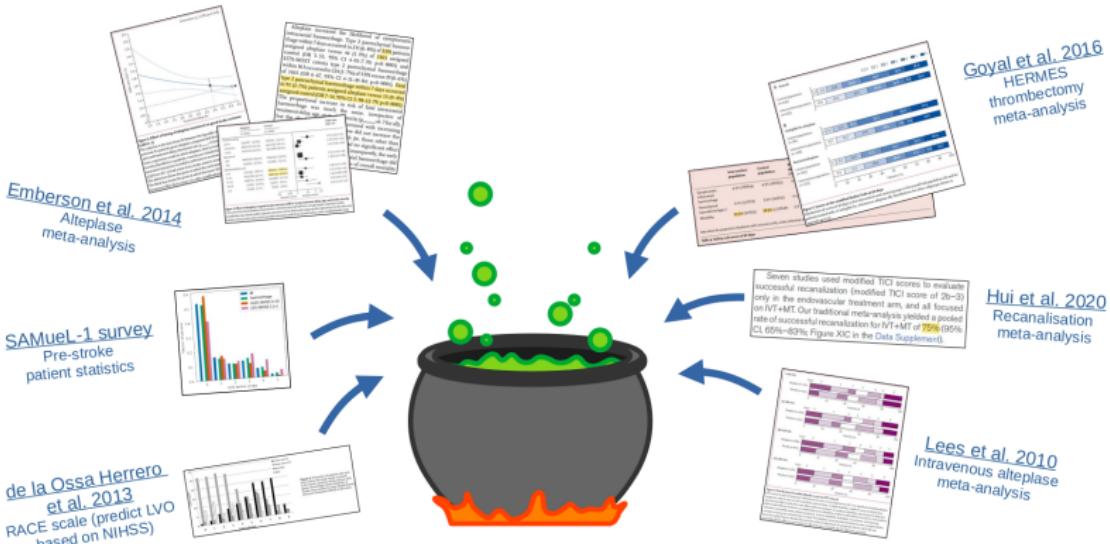
- *Shorter arrival-to-scan times*
- *Mid-level stroke severity*
- *Precise onset time*
- *Lower pre-stroke disability*

Lower thrombolysing units are particularly less likely to give thrombolysis to patients with:

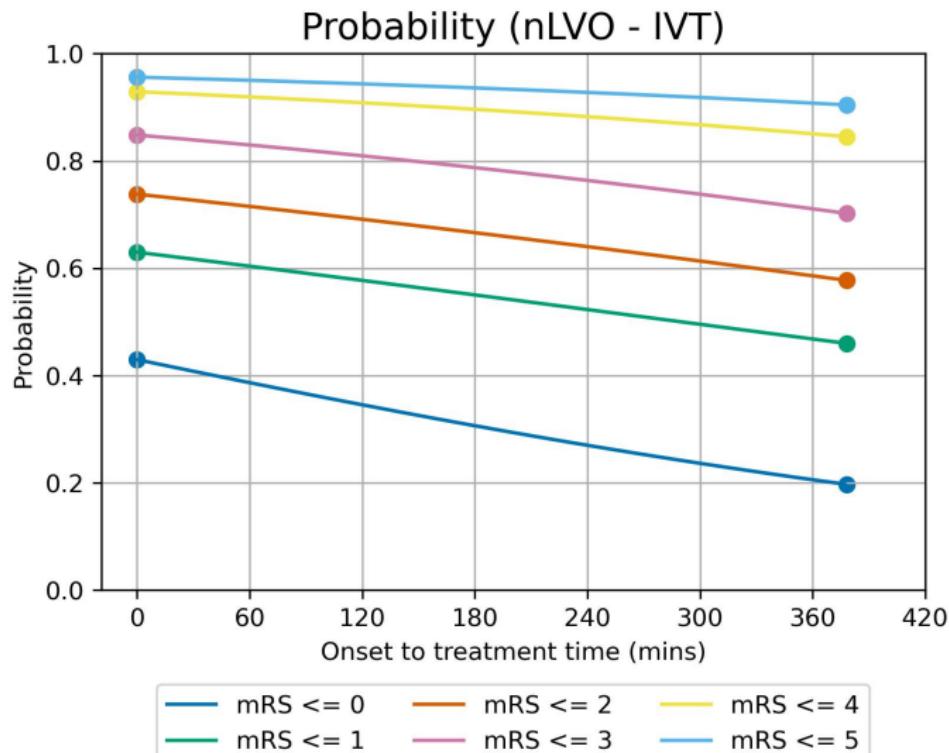
- *Low or high stroke severity*
- *Higher pre-stroke disability*
- *Estimated onset time*

Stroke outcome modelling based on times to treatment with thrombolysis and thrombectomy

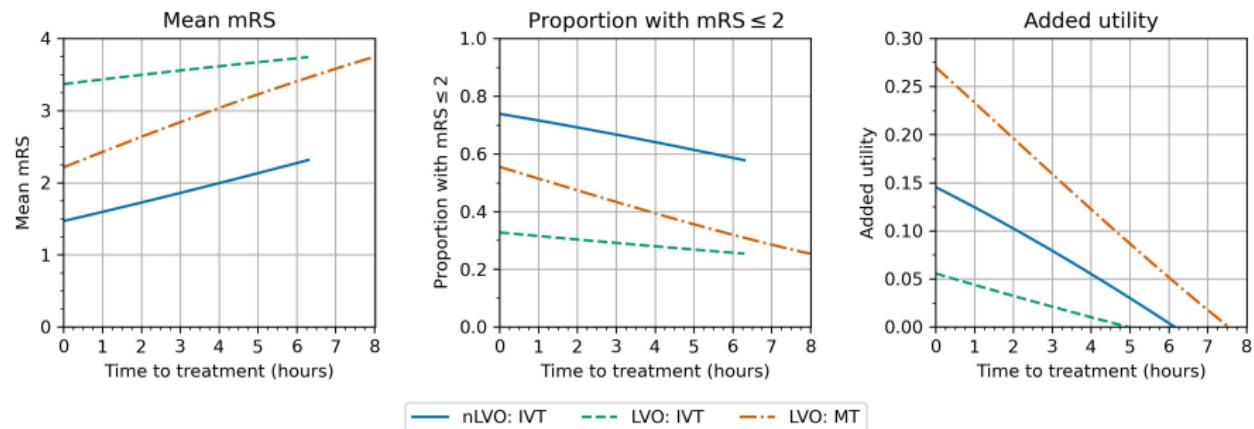
# Model combines multiple data sources



# Prediction of mRS-level outcomes based on time to treatment



# Summary of benefit and added utility by stroke type and treatment type



HQIP data request

## HQIP data request

- Request for new data has been submitted to HQIP
- New data will de-anonymize hospitals, and include ambulance times
- Knowledge of hospital will allow linkage to SSNAP organisational audit data
- We had informal input from HQIP, and agreement that our data request can be considered as anonymised data, but there remains a small risk that HQIP will not consider data sufficiently anonymised.

Qualitative research

## Qualitative research key themes

*"Finding out what does it take to get AI stuff USEFULLY incorporated [adopted] into a national audit"*

Qualitative research has been reviewed, and we are now proposing three components:

- Observation case studies
- Interviews (individual and group)
- Model and AI development stakeholder meetings

## Observation case studies

- 2 weeks each at three hospitals
- Observation of emergency stroke care
- Interviews about SAMueL analysis for that hospital
- If possible, a (virtual) stakeholder workshop at each hospital, with modellers

## Interviews (individual and group)

- Broaden input to wider than three main case study hospitals

## Model and AI development stakeholder meetings

Engage stakeholders with SAMueL analysis, seek feedback, and refine models and presentation.

This may occur outside of formal qualitative research.

Stakeholders include:

- Individual hospitals (stroke teams)
- Integrated Stroke Delivery Networks
- NHS-E Communities of Practice
- *Key Informers*, e.g. you!, Sally Evans (NHS-E National Stroke Programme Clinical Policy Unit)

## Timelines

- Qualitative work was delayed by time taken to recruit, and by re-assessment of qualitative plans.
- HRA submission now due January 9<sup>th</sup>.
- Active research to start April.
- Work depends on approval by HRA REC *and* NIHR (approval of amendment to protocol). We believe risk of rejection by NIHR is low as we are providing some more in-depth research at no requested extension to project timelines and cost.

Further project materials

## Further project materials

- Key project documents:  
<https://github.com/samuel-book/samuel-2-reference>
- SHAP work:  
[https://samuel-book.github.io/samuel\\_shap\\_paper\\_1/](https://samuel-book.github.io/samuel_shap_paper_1/)
- Stroke outcome modelling:  
[https://samuel-book.github.io/stroke\\_outcome/](https://samuel-book.github.io/stroke_outcome/)



# Reserve slides

# When will low thrombolysing units not use thrombolysis when higher thrombolysing would?

Here, a high SHAP shows when a low-thrombolysing unit will reject use of thrombolysis when a higher thrombolysing hospital would use thrombolysis. (Plots are in order of feature importance.)

