A human factors approach to quality improvement in oxygen prescribing

Authors: Alastair Watson,[A] Rahul Mukherjee,[B] Dominic Furniss,[C] Jane Higgs,[D] Alastair Williamson[E] and Alice Turner[F]

ABSTRACT

The safe hospital administration of oxygen has been shown to improve outcomes for specific patient groups, including those with chronic obstructive pulmonary disease (COPD). Oxygen prescribing is therefore recognised as a quality standard within the COPD Clinical Audit of the National Asthma and Chronic Obstructive Pulmonary Disease Programme. Oxygen prescription within our hospital electronic prescribing system showed poor compliance, despite previous quality improvement (QI) interventions. Using the functional resonance analysis method (FRAM), a human factors methodology, alongside existing QI approaches allowed capture of everyday work ('work-as-done') using qualitative data. This confirmed the complexity of the socio-technical healthcare system in which care is delivered and the variability of steps in the process, and provided new potential interventions to improve the safe administration of oxygen. The use of human factors tools within QI projects may help bridge normative models of work-as-prescribed and inductive models of work-as-done to support improvement and sustainability of care delivery interventions.

KEYWORDS: oxygen prescribing, FRAM, quality improvement, oxygen therapy, COPD

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Introduction

Emergency oxygen remains one of the most commonly used drugs in acute settings, and oxygen prescription helps ensure staff deliver and monitor oxygen use safely and effectively.[1] However, over 40% of patients in the UK (about 6,000 per day) given oxygen receive it without prescription, while only 69% of patients with a prescribed target range are within their saturation limit.[1] This can result in harm to patients, particularly those at risk from high oxygen levels, including patients with chronic obstructive pulmonary disease (COPD), myocardial infarction (MI) and patients in intensive care units (ICUs).[2] Studies have supported decades of evidence that giving high oxygen concentrations to COPD patients can increase risk of death, usually associated with high blood carbon dioxide levels and increased requirement for interventions such as non-invasive ventilation (NIV).[3] Patients with MI and normal blood oxygen levels given high-concentration oxygen show an increase in the size of infarcted myocardium due to cardiac blood vessel constriction in response to oxygen.[4] There is also mounting evidence that very high blood oxygen levels in ICU patients are associated with increased death rates.[5] These recent studies support a guideline-recommended 'target range' for improving patient outcomes, as well as improving oxygen prescription to ensure patient safety.

The COPD Audit of the National Asthma and Chronic Obstructive Pulmonary Disease Programme (NACAP) produces run charts of oxygen prescription rates in COPD patients, one of the groups at highest risk of safety issues if oxygen is incorrectly administered. Local data indicated that only a small proportion of COPD patients receiving oxygen were prescribed it on the electronic prescribing system (EPS), and this had not changed over the 2 years prior to the start of our project; the national average is approximately 60%. This highlighted the need for quality improvement (QI) in this area, and also provided a convenient means of data collection for a long-term project.

We aimed to take a new combinatory approach to improvement by mapping out key factors influencing oxygen prescribing, with subsequent identification and implementation of potential interventions to improve oxygen prescribing and ultimately patient safety.

To do this we used an approach utilising the functional resonance analysis method (FRAM). FRAM is a flexible tool for modelling the performance variability in a complex sociotechnical system to understand the variability, issues, trade-offs and adaptations that occur in everyday work.[6] FRAM is different to an audit: rather than assessing a process against an agreed standard (a normative model of work-as-prescribed, for example protocols) and a narrow performance metric, it develops a broader

Authors: [A]medical student, Birmingham Medical School, University of Birmingham, Birmingham, UK; [B]consultant respiratory physician, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK; [C]human factors specialist, Human Reliability Associates, Wigan, UK; [D]ergonomics (human factors) advisor, West Midlands Academic Health Sciences Network, Institute for Translational Medicine, Birmingham, UK; [E]consultant anaesthetist, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK; [F]professor of respiratory medicine, Institute for Applied Health Research, University of Birmingham, Birmingham, UK

understanding of variability in the sociotechnical system (and the more complex inductive models of work-as-done, for example performance variability).

Methods

Ethical approval

This work was an internal QI project and as such did not require formal ethical approval. It comprised a human factors analysis and multiple plan–do–study–act (PDSA) cycles, aimed at improving oxygen prescribing, structured around the Model for Improvement. NHS approval was given by the research and development department, who agreed that the project did not constitute research, and the head of clinical service, who approved the project as a service evaluation. University ethics was not sought, as no University of Birmingham staff were involved at the data collection stage.

FRAM study design

The study took place at Birmingham Heartlands Hospital, now part of University Hospitals Birmingham NHS Foundation Trust. We conducted an inductive qualitative study to build a picture of oxygen assessment, prescribing and administration. Interviews and focus groups included registered nurses, student nurses, advanced nurse practitioners, patient flow coordinators, junior doctors and consultants.

FRAM data collection

The first step in FRAM analysis identifies the functions that describe how work is done in practice – in this case admission, prescribing, administration and monitoring. This process generated questions used for interviews with clinicians about their everyday work. Data were collected through one-to-one interviews and focus groups, held from February 2019 to March 2019 on the acute medical unit. Due to the practical challenges of data collection on a busy ward, participants were recruited using a pragmatic approach with convenience sampling. One-to-one interviews were initially performed on the ward and focus groups were undertaken subsequently after recruitment from a staff meeting. The Human Factors practitioner (JH) provided participants with printed information containing a high-level hexagon FRAM model outline with questions (supplementary material S1). The practitioner subsequently introduced themselves and the topic, emphasising the objective to understand how the oxygen assessment, prescribing and administration process works in reality – 'work-as-done' (supplementary material S2). They then generated an open discussion using a semi-structured script (supplementary material S2). The desire to hear from a diverse group of staff was communicated to gain insight into different perspectives and roles involved in the process. Discussions took up to 30 minutes and continued until participants felt they had nothing more to share or had no further time. Different avenues of discussion were explored based on participant feedback and on the six aspects of each function within FRAM (Fig 1). Data were collected through taking notes throughout the discussions. However, full interviews were not recorded or transcribed, due to concerns that this might make participants less likely to be open about everyday practice.

FRAM data analysis

A FRAM analysis using the qualitative data was undertaken to identify and describe each function involved in the process and then explore variability both within and between functions. For each function, the six aspects of FRAM (input, outcome, control, time, resource, and precondition) were described (Fig 2). With this data, a FRAM network diagram of oxygen prescribing and administration was developed using the FRAM Model Visualizer (FMV) software (March 2019).[7] Based upon this FRAM analysis, potential new interventions were considered for this project, as well as future lines of enquiry to manage the performance variability.

Interventions

A number of interventions were implemented in the study period via classical PDSA cycles through to final data collection in February 2020, with FRAM analysis identifying additional interventions that were either introduced or are currently being explored for future implementation (Table 1, Fig 3).

Oxygen prescribing data collection and analysis

Data on oxygen prescription rates in COPD patients were collected continuously as part of NACAP COPD Audit from the time of audit

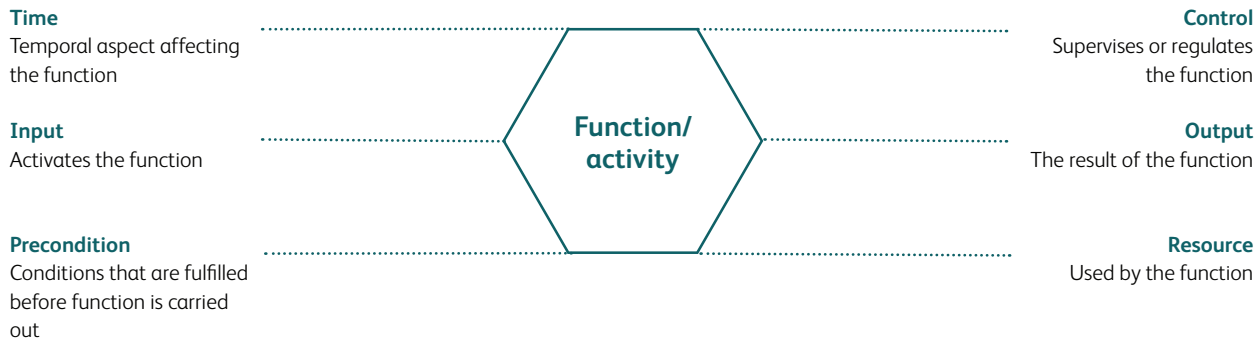

Fig 1. FRAM framework.

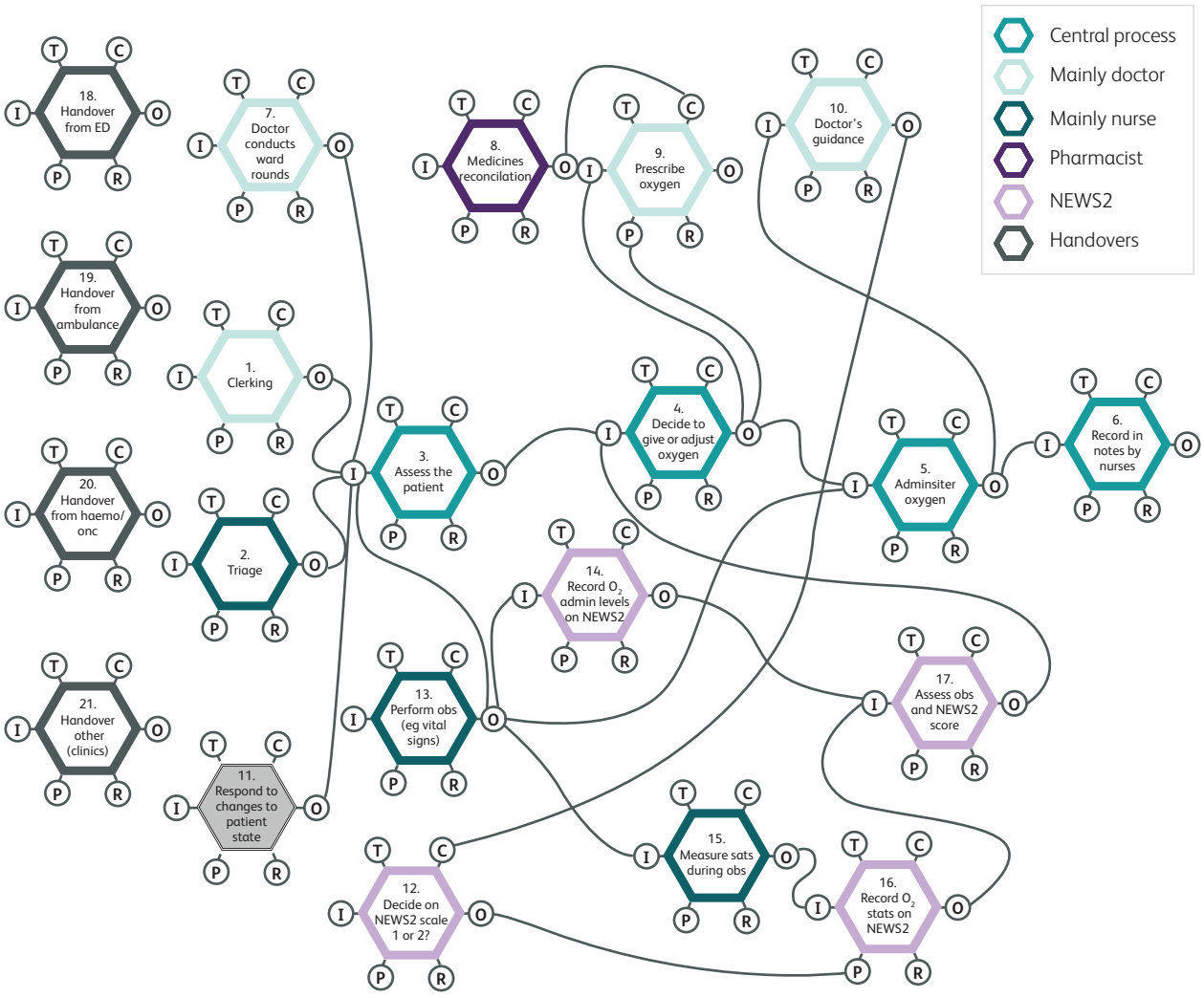

Fig 2. FRAM network diagram of oxygen prescribing and administration. Haemo = haematology; obs = observations; onc = oncology.

inception and plotted using statistical process control charts to give an indication of both variability of prescribing and change over time.

Results

Three focus groups of five or six participants (a total of 16 participants) were undertaken. Participants included three registered nurses, one student nurse, nine junior doctors and three consultants (two respiratory specialists). One-to-one interviews were undertaken with four junior doctors, one registrar, two staff nurses and one flow coordinator. Staff were generally interested, open and enthusiastic about sharing their opinions and practices. There was no overt reticence to discuss practices even if these ran contrary to policy.

Understanding oxygen prescribing variability using FRAM

Discussions with healthcare professionals made it clear that oxygen prescribing was perceived as an administrative step, while oxygen administration was seen as more important clinically, with oxygen often being given before it had been prescribed (Table 1). When doctors prescribed oxygen, they sometimes prescribed all oxygen concentration variants so that they would be available if needed. One doctor went further and stated they prescribed all levels of oxygen to all patients regardless of whether it was needed so that it was available to nurses if required (Table 1).

Oxygen prescribing was often not doctor-led, with one doctor admitting that they did not know that oxygen needed prescribing. The nurses reported wanting and appreciating guidance from doctors on oxygen administration. However, the process of oxygen administration seemed to be predominantly nurse-led, as they would assess the patient, decide if they needed oxygen, administer it, and then seek the doctor's advice (Table 1). Prescribing was often done later when doctors were prescribing other medications on the EPS. However, this process could vary depending on the patient's oxygen need, complexity, the requirement for doctor's input, and doctor availability.

Through using this qualitative data to develop a FRAM network diagram, we gained a deeper understanding of oxygen

Table 1. Key themes identified through FRAM analysis, aspect of functions which these relate to, and traditional and new interventions which were identified through FRAM analysis and considering these aspects

Findings/quotation	Related FRAM aspect(s)	Traditional interventions	New interventions identified through FRAM analysis
Prescribing was done for convenience rather than need 'We prescribe all the oxygen categories available on the EPS [electronic prescribing system] so that whatever the patient needs, it's covered. Patient need is so variable that it doesn't make sense to be too precise.' (Junior doctor)	Control	Electronic observation charts with reminders based on observed data[a]	Automatic prompt within EPS on prescription type based on history and observations, to encourage healthcare professionals to think about what oxygen to prescribe and why, rather than prescribing all the different types[b] Involvement of pharmacy team as part of drug reviews to add an extra layer of control and review[b]
Knowledge of harms of oxygen was variable	Outcome	Education of medical and nursing staff, via formal e-learning and face-to-face methods, as well as informal reminders on ward[a]	Screensavers about safe oxygen use to remind healthcare professionals what outcomes we are trying to achieve and what we are trying to avoid[a]
Oxygen was readily available, so prescribing did not influence receipt 'Nurses give oxygen before the patient's been seen by a doctor – it's not practical to wait for a doctor. And doctors would think they [nurses] were mad for bleeping them to come and prescribe oxygen!' (Nurse)	Resources; time		Reminders next to oxygen ports on wall[b] Highlighting to staff within the Trust cost savings programme[b]
Cost of oxygen was not something staff thought much about			
Responsibility for oxygen seemed to fall between nurses and doctors, with each perceiving some level of responsibility for the other staff group 'The most important thing is that the nurses and doctors discuss the patient's oxygen needs – putting the prescription on the EPS doesn't really help or mean anything.' (Nurse)	Precondition	Education, as above[a]	Implementation of ward round checklist to have a regular review of what oxygen is/is not prescribed and the target saturations[b] Implementing Trust QI leadership standards to promote an MDT approach, encourage conversations between groups and promote all members to effect positive change of organisational cultures and microcultures, to facilitate improvement in safe oxygen administration[b]
Giving oxygen is more important than prescribing it See quote given under 'Precondition'	Input	Education, as above[a] Posters pertaining to oxygen prescription to remind staff[a]	
Prescribing practices focused on saving staff time 'I just prescribe oxygen for every patient I clerk, even if they don't seem like they're going to need it. Then it's on there if they do need it.' (Junior doctor)	Time	Education as above[a]	Guidance within EPS on prescription type[b] Staffing level review[b]

Aspects are related to individual FRAM functions, as seen within the network diagram where the full breakdown and network can be seen (Fig 1). However, to simplify reporting, we have extrapolated findings up to consider the singular system function within this table. [a]Intervention implemented during project. [b]Future and potential interventions.

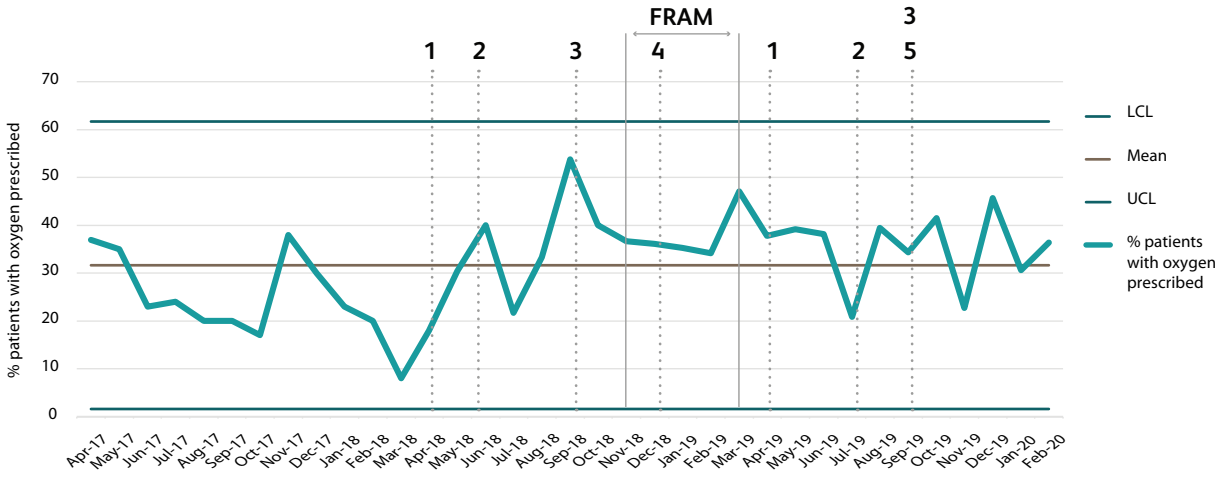

Fig 3. Oxygen prescription in COPD patients at Heartlands Hospital. The SPC chart shows upper and lower control limits (UCL and LCL, respectively). The following interventions are indicated. 1 = addition of oxygen session to junior doctor training (April 2018 and April 2019). 2 = regular face-to-face training of ward nurses by clinical nurse specialist (May to June 2018 and July 2019). 3 = posters pertaining to oxygen prescription on wards (September 2018 and September 2019. 4 = introduction of National Early Warning Score 2 (NEWS2) chart, and electronic training set up (e-learning) (December 2018). 5 = informative screensavers (September 2019). FRAM = FRAM data collection and analysis.

administration and we were able to focus on work-as-done (Fig 2). The system was much broader and more complex than originally thought and for effective interventions it was clear that, to appreciate the different elements of the sociotechnical system that interact to create safe administration of oxygen, there was a need to consider healthcare professionals' roles and not just focus on doctors (Fig 2 and Table 1).

Identification of new interventions through focusing on work-as-done

Prior to implementation of the FRAM approach to qualitative data collection and analysis, the original scope for QI interventions included traditional means of educating and training doctors and nurses to comply with best practice (Fig 3 and Table 1). However, FRAM analysis expanded the scope of the systems model and understanding of oxygen prescribing by identifying functions in a network and delineating connections between the different aspects and performance variability to focus on work-as-done (Fig 2). This provided new insights and allowed the identification of additional interventions to help manage performance variability for ongoing QI, of which some have been implemented and some are currently being explored (Table 1). For example, by considering the 'control' aspect of FRAM functions and supervision of oxygen prescribing, the potential intervention of having prompts on the EPS was identified. Furthermore, the role of the wider team, including pharmacists, in oxygen prescribing became apparent and the potential intervention of using a multidisciplinary team (MDT) approach and involving the pharmacy team as part of drug reviews to add an extra layer of control and review was identified, as well as the potential utility of a ward round checklist to regularly review target oxygen saturations and what oxygen is or is not prescribed. Considering the 'resource' aspect of FRAM functions also provided new insights around the cost of oxygen administration not being considered by staff. This led to potential interventions being identified around raising awareness of cost savings through having prompts for staff next to oxygen ports and incorporating this into the Trust's cost savings programme. Finally, understanding 'outcomes' led to the identification of new ways to educate and train staff, including informative screensavers to remind healthcare professionals of the outcomes we are attempting to achieve and avoid.

Oxygen prescribing baseline and follow-up data

Between April 2018 and September 2019, various interventions were implemented with the aim of improving oxygen prescribing, including both traditional interventions based around staff education and training and interventions that had been newly identified through FRAM analysis (Table 1 and Fig 3). Fig 3 shows oxygen prescribing in COPD patients between April 2017 and February 2020. There was an overall trend of improvement over time, with a sustained period of shift in increased oxygen prescribing above the mean for 11 months between August 2018 and June 2019, which subsequently dropped below the mean in July 2019. The former period coincided with an introduction of posters (September 2018), NEWS2 charts (December 2018), electronic set up (December 2018) and observation of ward and emergency department prescribing (November 2018 to February 2019) and a repeated educational intervention for doctors (April 2019). Initial education of doctors (April 2018) and nurses (May to June 2018) coincided with small effects on performance; repeating them (April to July 2019) with some adaptations, for example making posters simpler and more visually engaging as well as introducing informative screensavers (September 2019), appeared to stabilise performance.

Discussion

This mixed methods QI project achieved a sustained improvement in oxygen prescribing practices around the time of our FRAM

analysis. However, when considering the whole 3-year period this was within normal variation. While the FRAM analysis identified new perspectives for improvement interventions, some of which have been implemented, our ability to implement these has been hampered by the huge changes wrought by healthcare reorganisation and their impact on our continual QI is yet to be seen.

Incorporating human factors in QI efforts

Prior to April 2018, we spent several years trying to improve oxygen prescribing using standard approaches to improvements that were focused around training and education, without achieving significant change. A successful bid for funding from our local Academic Health Science Network (AHSN) for projects focusing on patient safety enabled us to expand the project to add a human factors element. The exploratory qualitative approach of FRAM complemented the existing audit data by adding answers about *why* change was (or was not) occurring, whereas the numerical data could only describe *what* was going on. Conceptualising our change ideas using the six aspects of FRAM made us re-evaluate the project and take an expanded view of the sociotechnical system involved in creating safety on the ward. While some of the barriers and enablers to oxygen prescription – such as knowledge, availability of equipment and treatment of oxygen as different from other drugs – have been observed before, adding a human factors perspective using FRAM brought new understanding and ideas to the change initiative.[8] For example, in all other elements of prescribing, pharmacists exert significant control, but they were not actively involved in aiding oxygen prescribing control. There were also obvious tensions between the ease of oxygen delivery and the requirement to make oxygen available for medical emergencies, and the regulatory requirement that oxygen should be prescribed before administration or the costing of oxygen delivery. From the resource aspect, it would not be safe to remove oxygen access, nor would it be feasible to have a cut-off time related to prescription (for instance) introduced to the oxygen delivery system; hence interventions targeting resource would need to be more nuanced.

Responsibility for oxygen seemed to fall between doctors and nurses – these ambiguities were a product of the system, which had cultural antecedents. Schein describes three relevant aspects of culture: organisational culture, subculture and microculture.[9] Subcultures often arise from particular occupational groups – such as hospital doctors – and may be driven by external factors including professional bodies (like the Royal College of Physicians), while microcultures may encompass different professions working on a particular task.[9] Organisational cultures and microcultures, in particular, appeared to be areas we could begin to address internally; our Trust QI leadership and associated strategy are bringing strands of improvement by the entire MDT to the fore, emphasising that anyone can effect positive change, not just medical staff for whom QI is already embedded well in training curricula and consultant appraisals. Dialogue between doctors and nurses was perceived as important depending on need, something we plan to promote through a new electronic and paper-based ward round 'checklist', supporting an MDT approach to elements of care, such as nursing, medication prescribing and nutrition. Imposition of culture by leaders is unlikely to succeed; if culture actually resides in people and their interactions, as complexity theorists suggest, then encouraging conversation between groups may be more effective than a formal strategy.[10]

QI in context: barriers and opportunities for interventions

This project has been undertaken in a hospital where there have been significant organisational changes due to financial challenges in 2015 and the subsequent interim executive leadership before a merger in 2018 to form the present organisation, University Hospitals Birmingham Foundation Trust. The operational, financial and governance restructuring associated with the merger has presented challenges to the project, especially when proposed interventions involve IT system changes such as EPS prompts. This proposal from 2019 was not a strategic priority for IT within the new organisation, especially as a new EPS was being developed for the merged Trust. This restricted the possible IT interventions identified. Elements requiring policy change, such as oxygen port labelling, have also been trickier to change than might have been the case in a more established organisation, as policy channels morphed gradually into the forms adopted by the new merged organisation.

However, this change also brought opportunity, through partnering with the AHSN to access, first, human factors expertise to support the education efforts started by members of the Heartlands clinical team and, second, an active network of improvers in the region whose experiences we drew on when optimising interventions. The impact of this was visible prior to the FRAM analysis, in that several interventions were put in place and a continual downward track of performance was arrested and improved. While education of doctors and nurses appeared to have small effects individually on performance, this dropped off, consistent with most studies of passive educational methods where effects may not be sustained.[11] Repeating and redesigning these is a feature of our project that we intend to maintain.

COVID-19 has also brought much transformation and prompted discussion in the QI community about how to continue improving amidst the pandemic; there is recognition that sustainable change in this environment requires confidence from clinicians, and appropriate tools, resources and incentives.[12,13] Data entry to NACAP ceased in early March, thus removing our source of continuous data for our project and use of oxygen and attitudes to it may well have changed during the first COVID-19 wave, thus prompting us to end our analysis in February 2020. However, staff attitudes to improvement may be more open if they have had positive experiences of change during the pandemic; indeed we have found that central support for our ward round checklist and rapid desire to implement across many clinical areas has occurred now during the second wave.

Strengths and limitations

This exploratory project was successful in utilising a human factors approach and FRAM in partnership with a traditional QI project to gain a deeper understanding around safe oxygen prescribing in everyday work. While it is difficult to provide quantitative evidence to demonstrate the benefit of this approach, with the introduction of numerous interventions, many prior to FRAM analysis completion, this approach provided additional insights and allowed the identification of new QI interventions for safe oxygen prescribing. Future work will investigate the ongoing impact of these additional interventions, which were newly identified by

FRAM analysis, as part of our ongoing QI project. The use of FRAM analysis in wider healthcare settings has been relatively scant, with only a few studies, such as its use understanding sepsis management, reporting this approach.[14,15] Use of this methodology at other sites to understand safe oxygen prescribing, as well as other clinical systems, would help demonstrate the wider potential of this exploratory approach to guide QI. However, it is important to note that, due to the practical challenges of data collection on a busy ward, participants were recruited pragmatically, using staff who were available to take part, and precise levels of training were not documented. Furthermore, notes were taken throughout the conversations, without the full transcription of conversations to mitigate the impact this could have on openness of discussion. Therefore, sampling and reporting biases could have impacted this study and we are not able to fully rule this out. While we collected data from both doctors and nurses at different levels of training, future larger projects using well-defined recruitment, sampling and data collection methodologies and involving a wider variety of healthcare professionals with well-documented levels of training may provide additional understanding.

Conclusion

A human factors approach, such as FRAM, can add to QI efforts by helping to bridge between normative models of work-as-prescribed, for example protocols, and the more complex inductive models of work-as-done, for example performance variability. However, implementing change ideas related to human factors is likely to require high-level organisational support. Ensuring that Trust QI strategy and associated support teams have human factors expertise could aid adoption of this inductive learning style. ■

Supplementary material

Additional supplementary material may be found in the online version of this article at www.rcpjournals.org/clinmedicine:
S1 – Variability in oxygen prescribing and administration: what goes well and what could go wrong?
S2 – Semi-structured script used to generate discussion.

References

1 O'Driscoll B. *British Thoracic Society emergency oxygen audit report*. BTS, 2015. https://www.brit-thoracic.org.uk/media/219414/bts-emergency-oxygen-audit-report-2016-final-290416.pdf [Accessed 13 December 2021].
2 O'Driscoll BR, Howard LS, Earis J, Mak V. BTS guideline for oxygen use in adults in healthcare and emergency settings. *Thorax* 2017;72:ii1–ii90.
3 Roberts CM, Stone RA, Buckingham RJ, Pursey NA, Lowe D. Acidosis, non-invasive ventilation and mortality in hospitalised COPD exacerbations. *Thorax* 2011;66:43–8.
4 Cabello JB, Burls A, Emparanza JI, Bayliss SE, Quinn T. Oxygen therapy for acute myocardial infarction. *Cochrane Database Syst Rev* 2016;2016:CD007160.
5 Girardis M, Busani S, Damiani E *et al*. Effect of conservative vs conventional oxygen therapy on mortality among patients in an intensive care unit: The oxygen-ICU randomized clinical trial. *JAMA* 2016;316:1583–9.
6 Furniss D, Curzon P, Blandford A. Using FRAM beyond safety: a case study to explore how sociotechnical systems can flourish or stall. *Theor Issues Ergon Sci* 2016;17:507–32.
7 Hollnagel E, Hill R. *FRAM model visualiser instructions. Version 0.3.2*. www.functionalresonance.com/onewebmedia/FMV_instructions_0.3.2.pdf [Accessed 27 October 2020].
8 Cousins JL, Wark PAB, Hiles SA, McDonald VM. Understanding clinicians' perceived barriers and facilitators to optimal use of acute oxygen therapy in adults. *Int J Chron Obstruct Pulmon Dis* 2020;15:2275–87.
9 Schein EH. *Organizational culture and leadership*. San Francisco, CA: Jossey-Bass, 2010.
10 Shaw PJ. *Changing conversations in organizations: a complexity approach to change*. Oxon, UK: Routledge, 2002.
11 Mansouri M, Lockyer J. A meta-analysis of continuing medical education effectiveness. *J Contin Educ Health Prof* 2007;27:6–15.
12 Lewis R, Pereira P, Thorlby R, Warburton W. *Understanding and sustaining the health care service shifts accelerated by COVID-19*. Health Foundation, 2020. www.health.org.uk/publications/long-reads/understanding-and-sustaining-the-health-care-service-shifts-accelerated-by-COVID-19 [Accessed 30 November 2020].
13 Watson A, Barnard H, Antoine-Pitterson P *et al*. The impact of COVID-19 on acute non-invasive ventilation services: A case for change. *Respirology* 2021;26:1106–9.
14 McNab D, Freestone J, Black C, Carson-Stevens A, Bowie P. Participatory design of an improvement intervention for the primary care management of possible sepsis using the functional resonance analysis method. *BMC Medicine* 2018;16174.
15 Patriarca R, Di Gravio G, Woltjer R *et al*. Framing the FRAM: A literature review on the functional resonance analysis method. *Saf Sci* 2020;129:104827.

Address for correspondence: Prof Alice Turner, Institute for Applied Health Research, University of Birmingham and UHB, Birmingham, UK.
Email: A.M.Turner@bham.ac.uk
Twitter: @AlphaCopdDoc