A systems improvement approach to traumatic brain injury in Myanmar: from lived experience to discrete event simulation

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Complete List of Authors:	Kohler, Katharina; University of Cambridge, Division of Anaesthesia, Department of Medicine Nwe Myint, Phyu Phyu ; University of Cambridge, Department of Clinical Neurosciences, Box 165 Wynn, Sein; University of Medicine I, Department of Neurosurgery Komashie, Alexander; University of Cambridge School of Technology, Engineering Design Centre, Department of Engineering; THIS Institute Winters, Robyn; Cambridge University Hospitals NHS Foundation Trust, Neurocritical Care Unit Thu, Myat; University of Medicine I, Department of Neurosurgery Naing, Mu Mu; University of Medicine I, Department of Intensive Care Hlaing, Thinn; THET, Myanmar Country Director Burnstein, Rowan; Cambridge University Hospitals NHS Foundation Trust, Department of Anaesthesia Wai Soe, Zaw; University of Medicine I, Rector Clarkson, John; University of Cambridge School of Technology, Department of Enginering Menon, David; University of Cambridge, Division of Anaesthesia, Department of Medicine Hutchinson, Peter; NIHR Global Health Research Group for Neurotrauma, University of Cambridge Bashford, Tom; University of Cambridge , NIHR Global Health Research Group for Neurotrauma
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A Systems Improvement Approach to Traumatic Brain Injury in Myanmar: from lived experience to discrete event simulation

Corresponding author:
Katharina Kohler * – kk371@cam.ac.uk
Division of Anaesthesia, Department of Medicine, University of Cambridge, Box 93, Hills Road, Cambridge CB2 0QQ, UK

Further authors:
Phyu Phyu Nwe Myint *
Department of Clinical Neurosciences, Box 165, Addenbrooke's Hospital, Hills Road, Cambridge CB2 0QQ, UK

Sein Wynn
Department of Neurosurgery, University of Medicine 1, 245 Myoma Kyaung Street, Lanmadaw Township, Yangon, Myanmar.

Alexander Komashie
Engineering Design Centre, Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, UK

The Healthcare Improvement Studies (THIS) Institute, University of Cambridge, Clifford Allbutt Building, Cambridge CB2 0AH, UK

Robyn Winters
Neurocritical Care Unit (NCCU), Addenbrooke's Hospital, Hills Road, Cambridge CB2 0QQ, UK

Myat Thu
Department of Neurosurgery, University of Medicine 1, 245 Myoma Kyaung Street, Lanmadaw Township, Yangon, Myanmar.

Mu Mu Naing
Department of Anaesthesia, University of Medicine 1, 245 Myoma Kyaung Street, Lanmadaw Township, Yangon, Myanmar.

Thinn Thinn Hlaing
THET Myanmar, c/o THET, 1 St. Andrews Place Regent's Park, London NW1 4LE, UK

Rowan M Burnstein
Department of Anaesthesia, Addenbrooke's Hospital, Hills Road, Cambridge CB2 0QQ, UK

Zaw Wai Soe
University of Medicine 1, 245 Myoma Kyaung Street, Lanmadaw Township, Yangon, Myanmar.

P John Clarkson
Engineering Design Centre, Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, UK

David K Menon
Division of Anaesthesia, Department of Medicine, University of Cambridge, Box 93, Hills Road, Cambridge CB2 0QQ, UK

Peter JA Hutchinson
Academic Division of Neurosurgery, Box 167, Addenbrooke's Hospital, Hills Road, Cambridge CB2 0QQ, UK

Tom Bashford
Division of Anaesthesia, Department of Medicine, University of Cambridge, Box 93, Hills Road, Cambridge CB2 0QQ, UK.
Engineering Design Centre, Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, UK

*Joint first author

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Abstract

Introduction

Traumatic brain injury (TBI) is a global health problem, whose management in low resource settings is hampered by fragile health systems and a lack of access to specialist surgical services. Improving the care of TBI at a local level is complex, given the interaction of multiple people, processes, and institutions. Understanding the pathway for TBI patients requires mixed-methods systems approaches, based upon the lived experience of a range of people, supported by quantitative methodologies.

Methods

We describe a systems approach to understanding TBI care in Yangon General Hospital, Myanmar, based on a programme of narrative exploration, participatory diagramming, data collection, and Discrete Event Simulation (DES), by an international research collaborative.

Results

A model architecture of the TBI pathway was outlined, with system boundaries defined around the management of TBI once admitted to the neurosurgical unit. Data collection showed 18% mortality, 71% discharge to home, and an 11% referral rate to another department or hospital. DES showed vulnerability to small surges in patient numbers, with critical points being access to CT scanning and observation ward beds. The model indicated the thresholds at which expansion of these services would no longer be flow-limiting, and indicated possible consequences of changes.

Conclusions

A systems approach to improving TBI care in resource-poor settings may be supported by modelling and simulation, informed by qualitative work to ensure models are grounded in the direct experience of those involved. Narrative interviews, participatory diagramming, and discrete event simulation represent one possible suite of methods which may be combined, and are deliverable in the context of an international partnership. Findings from this approach can support targeted investments to improve TBI care despite co-existing resource limitations, while also indicating concomitant risks from these proposed interventions.

Strengths and limitations of this study

- To our knowledge, this paper is the first to demonstrate the value of combing Discrete Event Simulation (DES) and narrative-driven participatory diagramming for understanding care pathways in a global health context.
- Narrative enquiry provided a participatory method for data creation which balances power between actors, providing robust qualitative data to inform the development of quantitative Discrete Event Simulation models.
- The Discrete Event Simulation model allowed the exploration of a range of scenarios to help understand the impact of key resources on clinical outcomes.
- The combined effects of the SARS CoV2 pandemic and the current pollical climate in Myanmar made it impossible to subsequently validate the model outside of the international research team.

Quantitative simulation models only account for a limited perspective, with the results requiring careful contextualisation before being used to change clinical practice.

Introduction

Traumatic brain injury (TBI) is a global public health issue, with the 2017 Lancet Commission on Traumatic Brain Injury (LNCTBI) estimating that over half of the world's population will suffer a TBI within their lifetime. (1) TBI is a particular problem in low- and middle-income countries (LMIC) where increasing automobile use, poor regulatory frameworks, and fragile health systems combine to provide not only an increasing risk of TBI, but an environment in which the pre- intra- and post- hospital care which TBI requires cannot be provided. (2) At the core of TBI management is the provision of surgical intervention, itself a challenge in many LMICs. The 2015 Lancet Commission on Global Surgery found that over 5 billion of the world's population lack access to safe, affordable, timely surgical care, and that surgery itself requires a functional healthcare system to support it. (3)

The management of TBI is complex and difficult to characterise. (4) While epidemiological studies have been conducted to explore the global picture, mapping practice at the level of the institution to drive service improvement remains a challenge. (5) This is exacerbated in settings which have low levels of routine data collection, or a lack of established clinical and organisational protocols and care pathways. One conceptual framework which has been advocated to help understand the complex environment of clinical care is systems thinking; either as a stand alone device or as part of an established corpus of knowledge such as systems engineering. This has been applied in many settings through a variety of methodological approaches, and is advocated by the World Health Organisation (WHO) as an approach for understanding healthcare. (6) One model for taking a systems approach to healthcare improvement is described in the 2017 report *Engineering Better Care*, which presents a recursive series of questions to be answered as part of such an approach, and which has been explicitly explored within the context of global health. (7,8)

Accurate and complete quantitative data collection is often considered a prerequisite for operational systems modelling. While data collection and analysis have been shown to be feasible in low- and middle-income countries, there are significant limitations in data collection associated with resource limited settings. (9) This is in contrast to high-income settings where electronic health records, implemented to facilitate clinical care, may provide data for operational research and systems analysis. (10) More participatory approaches, such as process mapping, have been described to improve surgical care but these do not have the power of quantitative models. (11)

Healthcare system modelling using Discrete Event Simulation (DES) is a common approach in operational research, supported by quantitative data in combination with local knowledge. It has been shown to be a useful tool to model a complex system and investigate the potential effects of resource reallocation or improvements. (12) However, extension of this type of modelling into LMIC healthcare systems has been sparse to date, with a few notable exceptions. (13,14) The success of DES depends on an appropriate representation of the system to be modelled and its applicability can be limited if the system is not well represented or described.

We describe a systems approach to understanding TBI care in a tertiary neurosurgical centre in Myanmar, to demonstrate the feasibility and utility of this approach to a resource-limited tertiary neurosurgical centre with a significant burden of TBI. This study is the product of an academic institutional health partnership combining the Cambridge Yangon Trauma Intervention Project (CYTIP) and the NIHR Global Health Research Group on Neurotrauma. (15)

Methods

Setting

The study was conducted across 2019-2020, prior to the SARS CoV2 global pandemic, in Yangon General Hospital (YGH), Myanmar. YGH is a tertiary neurotrauma referral centre in Myanmar receiving both local and regional patients and which functions as both the local and national trauma centre. It has a recently established Emergency Department and provides a comprehensive array of surgical services. The neurosurgical centre is physically distant from the main hospital campus, with patients requiring transfer between the two sites. We employed an integrated mixed-methods approach based upon narrative analysis, participatory diagramming, targeted prospective data collection, model refinement, and then model validation and verification. Nested within a wider academic partnership, this work is reported against the Good Reporting of a Mixed Methods Study (GRAMMS) criteria. (16)

Patient and public involvement

This works forms part of a portfolio of research funded by the NIHR Global Health Research Group on Neurotrauma (https://neurotrauma.world), who have partnered with patient representatives in both the UK and around the world to understand the consequences of TBI and set research priorities. This partnership informed the initial study design of this project. In Myanmar we were unable to identify specific patient groups or representatives pertinent to TBI care, and instead chose a participatory research design to include their perspectives within the formal data collection. While this meant patients and the public were not engaged at the outset of the study, the snowball participant sampling allowed them to identify further research participants and shape both the design and findings of the study. Similarly, the choice of narrative methodology allowed patient and public respondents to shape the research data in partnership with the research team. The intention of the research team was to use further patient and public work to understand how the research findings might best be shared with communities, but the cessation of research activity due to the SARS CoV2 pandemic and political events in Myanmar made this latter stage unworkable.

Ethical approval

This work has ethical approval from the Institutional Review Board of the Government of the Republic of the Union of Myanmar Federal Ministry of Health and Sports, Department of Medical Research (Ethics/DMR/2019/082). It also has approval from the University of Cambridge School of Humanities and Social Sciences Ethics Committee (18/181) and is sponsored by the University of Cambridge.

Qualitative data

A combination of narrative data supplemented by participatory diagramming was used to understand the lived experience of research participants. This was based upon the Soft Systems Methodology (SSM), adapted for use by a multiprofessional, cross-cultural research team. (17) Narrative inquiry and SSM are positioned within a constructivist paradigm in which the data are co-created by the research team and research participants. The data is a function of the context in which it is created, both on the micro (individual conversation) and macro (society, culture, and language) levels. The research team consisted of both UK and Burmese researchers, trained in the *Engineering Better Care* systems approach, SSM, narrative, and diagramming techniques, and with an expert knowledge of the clinical context under study.

A half-day workshop was held in February 2019 at YGH which was attended by 40 participants including neurosurgeons, neurosurgical nursing staff (ward and theatres), anaesthetists, emergency physicians, and physiatrists. Participants were grouped by both clinical speciality and seniority to encourage active participation and story-sharing, and facilitated in a mixture of Burmese and English by members of the research team. During the workshop, participants were encouraged to create visual maps of their accounts, identifying a mixture of physical structures, clinical processes, patient flow, and lines of communication. These visual maps were often supplemented by numerical figures to reinforce particular points.

Subsequently, two members of the research team (SW and PPNM) conducted 64 one-on-one interviews with a range of stakeholders including patients and their relatives, physicians, surgeons, nursing, and auxiliary staff. These interviews were again structured to encourage story-telling and the elicitation of individual narratives, using a combination of audio recording, note-taking, and participatory diagramming to capture these accounts. These interviews were conducted in Burmese, anonymized at source, and then professionally translated and transcribed.

Both the workshop and subsequent interviews were loosely structured to encourage the elicitation of rich narratives, rather than to address preconceived questions. Facilitators and interviewers referred to the questions posed in *Engineering Better Care* (**Figure 1**) to help guide the discussions, and sought to explore habitual, exceptional, and hypothetical narratives to gain an understanding of the lived experience of respondents. (18) At the same time, techniques of participatory diagramming and graphical elicitation were used to help interviewers and respondents structure this data during the course of the workshop and interviews, with the aim of prompting new insights, clarifying terms, and creating a mutual understanding of the narratives being related. (19)

The resulting qualitative dataset was imported into proprietary software (ATLAS.ti v8 Mac, Scientific Software Development GmbH). Narratives were analysed to identify key areas of concern, along with the development of a consensus understanding of the system features which were central to these: the boundary of the system under study, its physical components and their orientation to each other, the key clinical processes occurring within the system, and the flow of patients through it. A formal thematic analysis of the dataset was not conducted as part of this study.

Quantitative

This qualitative systems model informed the subsequent collection of prospective, targeted, quantitative clinical data. One of the research team (SW) collected a dataset of demographic, inpatient location, discharge destination, and outcome data over a one month period in February 2020. All neurotrauma admissions to the YGH neurosurgical unit who went on to receive a neurosurgical intervention were included, with collection of initial and subsequent Glasgow Coma Scores (GCS) as a measure of outcome.

Model building

Using a combination of the data from the two initial phases, a discrete event simulation was developed to represent a simplified model of the neurotrauma system at YGH. The focus of the model was on the pre- and post-operative care pathways of the neurotrauma patients including a model of the resource requirements. This focus was grounded in the narrative accounts, which indicated these stages as being the key determinants of overall patient outcome.

The qualitative data was used to structure the care pathway, with the quantitative information used to describe the distributions of resource usage, length of stay and discharge destination of patients moving along specific pathways. The model was developed iteratively using the software package Anylogic (university edition, The Anylogic Company, 2016 v7.3.7). The model was verified through an iterative development process involving the research team members, and critiqued against the existing literature.

Results

Qualitative data

Responses from the 104 respondents (40 workshop participants and 64 interviewees) were supplemented with interview data from workshop facilitators and members of the research team, and combined with field notes and written reflections into a single dataset. The workshops resulted in the creation of meta-narratives constructed as complex images which conveyed a range of information including physical infrastructure, patient flow, clinical decision making, investigations, and clinical interventions. These were closely allied to the 'rich pictures' created when using SSM **(Figure 2)**. The interview data consisted predominantly of either verbal narratives or co-created process flow diagrams.

From these, a formal system structure was synthesized, bounded within the neurosurgical unit and focusing on nodes consisting of neurosurgery admissions, the observation wards, the neurosurgery theatres, the CT scanner, the neurointensive care unit, and the neurosurgical wards. This boundary was chosen to facilitate targeted quantitative data collection, but also due to the expertise of the Burmese research team being biased toward this area of the hospital. A patient flow logic model was then superimposed upon these, with outputs chosen as discharge, referral to another centre, or death (**Figure 3**).

Quantitative data

The quantitative data showed 83 admissions with a median age of 33.4 years (range 11 to 66 years). The median length of stay was 3.8 days (range 1-18 days). There was a 18% mortality, 71% discharge to home with an 11% referral rate to another department or hospital upon discharge. This population information was used to inform the static distributions of patient flow in the simulation, as shown in figure 3.

The mean admitting GCS was 10.8 (range 3 to 15) and the mean discharge GCS was 12.6 (range 3 to 15). Six patients were transferred intubated from ED to the neurosurgery department. Location data collected was consistent with the qualitative system mapping, with the most reported locations being the admission unit, observation ward, neurosurgical ward (male and female), neurosurgery theatres and referral destinations. The initial admitting location for the surgical patients was the observation ward with almost all patients (98%) staying for at least 2 days before being transferred to the general neurosurgical ward.

Discrete Event Simulation

The DES model was structured using the model in figure 3 to explore key activities in a patient's journey from arrival at neurosurgery admissions to discharge home, referral to another hospital, or death. All processing times were modelled as triangular distributions to take account of variations and uncertainty in both the process and data. The distributions were developed based on quantitative information and expert experience. Two separate patient groups were identified - surgical and non-surgical treatment streams - that share the same resources but were assigned different distributions and care pathways.

The narrative data identified two key areas as bottlenecks in patient flow: the availability of CT scanning (a time-critical investigation for neurosurgical patients), and the occupancy of observation ward beds. These were subsequently used as the main targets to investigate through DES. These were explored across a range of patient flows to explore the resilience of the system to sudden changes in surgical burden.

The simulation was run with a warm-up period of 200 hours and over a period of 90 days. In addition to the three kinds of discharge from the system - home, referral and death - the model reported outputs on queue lengths, waiting times and resource utilisation in selected areas (Scenarios summarised in **Table 1**).

Scenario number	Patient arrival rate	Percentage of surgical patients	Observation ward capacity	Additional changes
0 (baseline)	13	50	20	-
1	8	20	20	-
2	8	80	20	-
3	15	20	20	-
4	15	80	20	-
5	15	80	30	-
6	13	50	30	-
7	15	50	20	-

8	15	80	20	Increased CT capacity to 2/slot
9a	15	80	20	Priority: CT
9b	15	80	20	Priority: CT & observation ward
9c	15	80	20	Priority: CT & observation & neuro ward

Table 1: Description of the scenarios used to explore the system. Three main variables were modified and the effects investigated. Additional improvement possibilities were explored in Scenario 8 and 9a-c.

Insights from the narrative data led to a decision to explore the effects of changing the admission rate, the percentage of surgical patients, the capacity of the observation ward, and the availability of CT scanning. CT availability was explored by both increasing the capacity of available scanners (increasing from one patient per two hour time window to two patients per two hour time window) and by increasing the priority of access to nursing staff for accompanying CT transfers, observation ward and neuro ward. In all, nine scenarios were developed including the baseline. Scenario 9 involved three variations testing different levels of priority access to nursing staff. For model validation, the results of length of stay from the model were within the range of 1 to 21 days estimated by Rock *et al* (20) based on empirical data from across Myanmar and consistent with clinical experience and the quantitative dataset.

The queue to access CT was modelled assuming a 2-hour round-trip based on local experience, with each patient requiring a single nurse escort. In scenario 4 – a high patient volume scenario – we found the wait to access a time-critical CT increased to clinically unacceptable levels of several hours in keeping with the narrative accounts. We explored two potential improvement strategies for reducing wait for CT: increasing the number of patients that can go at the same time to 2 (Scenario 8) and increasing the priority of CT scanning within the tasks for the available nursing staff (Scenario 9a-c).

We found that scenario 8 did not resolve the CT capacity problems with the queue persisting at similar levels to scenario 4. The adjusted prioritisation scenarios where the availability of nurse escorts is increased (9a: CT main priority, 9b: CT and observation ward as priority, 9c: CT, observation ward and neuro wards as priority) resolved the CT queuing and allowed for timely CT processing. However, this impacted on other areas of care as illustrated in **Figure 4**, which shows system performance measures (such as length of stay and queuing) normalised to scenario 4. As an example, the effect of prioritising CT escorts and observation ward staffing in scenario 9b resulted in a long queue for theatres with reduced theatre occupancy and prolonged neuro ward length of stay, all due to the lack of available nursing staff to perform the necessary tasks. Similar complex system effects can be seen for scenario 9a and 9c where the delays have been diverted to admissions and theatres.

In addition to the CT bottleneck, the effect of changing patient numbers on the observation ward bed occupancy was investigated. **Figure 5a** illustrates the effects of a change in population characteristics by changing the percentage of patients classified as "surgical". Scenario 4 (50% surgical patients) in black, scenario 3 (20% surgical patients) in blue, and scenario 7 (80% surgical patients) in red. The increased number of surgical patients with a longer stay on the observation ward care post-operatively results in an increase in the delay to access an observation ward bed. **Figure 5b** illustrates the effect of varying patient arrival rate. With increased arrivals the waiting time for the observation ward bed increases. In black is the baseline scenario 0 (13 patients/day), in blue is scenario 7 (15 patients/day). It is notable that with an increase in the arrival rate of just 2/day there is a significant increase in the waiting time for a bed, given that the observation ward occupancy is already >90% for the baseline scenario. These results were again consistent with local experience.

Consequently, a possible service change with a moderate expansion of the observation ward capacity from the baseline 20 beds to a potential 30 beds was explored. This was an illustrative change aiming to determine a potential alleviation of a bottleneck. The results are shown in **Figure 6**, with the baseline model (20 beds) shown in purple and scenario 6 (30 beds) in yellow. The delay to access an observation ward bed is shown in the top panel and the percentage occupancy in the bottom panel. The additional bed spaces resolved the near full capacity state of the observation ward and reduced the waiting time for a bed to negligible numbers.

Discussion

We describe a systems approach to understanding the care of neurosurgical patients in a resource-limited setting, based on a combination of qualitative exploration, prospective data collection, and discrete event simulation. The insights gained from this study are both practical and methodological. Practically, we show that changes in staffing allocation and observation ward capacity may improve patient flow despite co-existing resource limitations. Methodologically we show how a mixed-methods approach by a cross-cultural multiprofessional research team can deliver high quality systems modelling which is grounded in both the lived reality of local stakeholders, and in reliable prospectively acquired data.

Understanding healthcare from a systems perspective presents both conceptual and pragmatic challenges. These are best met by marrying robust qualitative and quantitative approaches, however achieving this in resource limited settings where clinical services are stretched and routine data collection may be impossible is challenging. In addition, much of the systems thinking literature comes from a canon of thought developed in high-income countries, and this may not translate readily to other cultures or languages. Indeed, the Burmese members of the research team found translation of the *Engineering Better Care* questions very challenging, both linguistically and conceptually. Furthermore, while the project was conceived within the Soft Systems Methodology, a constructivist approach grounded in systems thinking which has been applied to healthcare in a range of contexts, this was found to be a barrier to participatory research as the terminology and theory was found to be difficult to translate into Burmese.

As a result, the research approach we describe uses narrative as a tool for understanding lived experience in order to overcome some of these barriers. Storytelling is common to all human society and is a mechanism for people to both conceive and communicate complex ideas.(21) Combining this with participatory diagramming provides a natural form of data creation, without requiring local research partners to engage with complex theoretical models. Narrative research also encourages a degree of transformation on the part of the research team, as they elicit and assimilate a variety of stories from widely different viewpoints. In the words of one of the research team:

"When we started this research I thought that all of our problems came from a lack of resources. Now I can see so many things we can improve without waiting for more money."

The participatory diagramming also provides a starting point for the DES model which is grounded in the primary experience of the research participants, providing reassurance that the model is close to reality, and that the prospective data collected is parsimonious and of maximum utility. Structuring both of these with the systems approach articulated in *Engineering Better Care* provides a degree of methodological rigour, and ensures that a focus on the function of the system as a whole, rather than discrete processes, remains at the heart of the data collection.

The discrete event simulation modelling facilitates the conversion of this rich narrative data into a more abstracted form, which can then be readily manipulated and used to predict changes to system behaviour within specific constraints. Consistent with the experience of the research team, our model explores the resource limitations around access to CT imaging and observation beds. However, the model challenges the narrative data, with access to CT scanning limited less by the access to CT machines, and more by the availability of nurse escorts. The model however agrees with the narrative report that nursing provision is stretched when patient volume increases and changing prioritisation of tasks only shifts the resulting delays to another care area. Similarly, the model indicates that while a modest expansion of observation beds improves patient flow, this does not scale indefinitely. Both insights have consequences for real-life improvement opportunities. Ideally, these insights would have been taken back through a process of qualitative exploration to better understand the findings, but both the SARS CoV2 pandemic and political events in Myanmar prevented this last phase of the research.

However, it is important to note that our DES model was created to look specifically at patient flow, again grounded in the reported experience that most patient complications arise from a delay to care. Traumatic brain injury, like other specific pathologies, is a time critical condition and it seems reasonable that delay is one of the key drivers of patient outcome. (22) However, any number of alternative models could be built to explore communication flow, institutional power, or clinical decision making. More complex concepts such as the quality of care are not addressed in our model. The provision of surgery may be considered at the interface of clinical need, access, and quality and our model currently explores only one of these dimensions. (23)

It is important to note that a variety of other models could have been built based upon our qualitative dataset. A different system boundary, such as that of the whole hospital as opposed to the neurosurgical unit, would have required different quantitative metrics and would have been much more complex to build. It would also have required a research team made of different clinical specialities in order to ground the qualitative and quantitative data within lived expert experience. However, the benefit of good early qualitative work is that it provides the opportunity to explore a variety of different future models, to address a wide range of clinical and operational improvement questions.

Conclusion

Traumatic brain injury is a growing burden in the global south, and efforts to improve care in this area are hampered by its complexity. A systems approach which combines rigorous qualitative approaches with discrete event simulation allows for modelling which is firmly grounded in local context, but informed by established mathematical theory. We demonstrate that such research can be carried out by a mixed research team based on the lived experience of a wide range of stakeholders. The resulting model retains validity when critiqued against this primary qualitative data, and provides new insights into specific areas for improvement and resource limitations. We suggest that a similar model would be of value across a huge range of clinical and geographical contexts.

In addition, our data supports the view that TBI care in resource poor environments is significantly affected by a lack of access to the necessary services, and the delay this engenders. This is consistent with the known pathophysiology of secondary brain injury, and experience from other studies which suggest that delay remains a key determinant of outcome in TBI. Our data suggest specific, targeted, improvements which may be made at the facility level to improve delays, and improve care.

Contributorship statement:
TB, KK, AK, PPNM, SW, RMB, PJC contributed to the design of the research. TB, SW, PP, KK, AK, RW, RMB conducted the data collection, model design and analysis. MT, PJC, PJAH, ZWS aided with project management and data analysis. TB, KK, AK, PPNM took the lead in writing the manuscript. All authors discussed the results and contributed to the writing of the manuscript.

Competing interests:
None declared.

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Data sharing statement:
Access to an anonymised, redacted dataset will be entertained upon reasonable request, but due to the sensitive nature data cannot be made publicly available.

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Figures:

Figure 1 A systems approach to health and care improvement framed as a series of recursive questions (reproduced with permission from *Engineering Better Care*, Royal Academy of Engineering, 2017).

Figure 2. ‘Rich pictures’ generated by workshop data (reproduced from Bashford 2021 with permission of the author, with participant names redacted)

Figure 3: DES model structure showing the variables, patient flow and proportions. The surgical patient pathway is denoted in red, the conservative/medical treatment pathway in black. Patients enter the DES on the left at “arrivals” and exit on the right into “Home”, “Referral” or “Death”.

Figure 4 illustrates the effects of changing staff priorities on the patient load in different locations. To improve CT flow in a high patient volume scenario (Scenario 4) we adjusted the CT capacity (Scenario 8) or the nursing staff task priorities (Scenario 9a – priority to CT, Scenario 9b – priority to CT and observation ward, Scenario 9c priority to CT, observation and neuro ward). The figure shows the queues waiting for theatre, CT and the observation ward, the LOS for neuro ward and to discharge with the values normalised to Scenario 4. Additionally, we show percent theatre utilisation. The locations are arranged in the order of patient flow.

Figure 5a illustrates the effect of a change in population by changing the percentage of patients classified as “surgical”. The increased length of stay on the observation ward is seen as an increase in delay for observation ward bed access. In yellow scenario 4 (50% surgical patients), in pink scenario 3 (20% surgical patients) and in purple is scenario 7 (80% surgical patients).
Figure 5b: Illustrates the effect of varying patient arrival rate. With increased arrivals the waiting time for the observation ward bed increases. Again, in yellow is the baseline scenario 4 (15 patients/day), in blue we show scenario 7 (13 patients/day).

Figure 6: Illustrates the change in patient load on the observation ward when the capacity is increased. In purple is the baseline scenario 0 (20 beds) and in yellow scenario 6 (30 beds). Figure 5a shows the delay to an observation ward bed, 5b shows the observation ward occupancy through the simulation period. The moderate increase in bed capacity clearly reduces the pressure on observation ward beds.

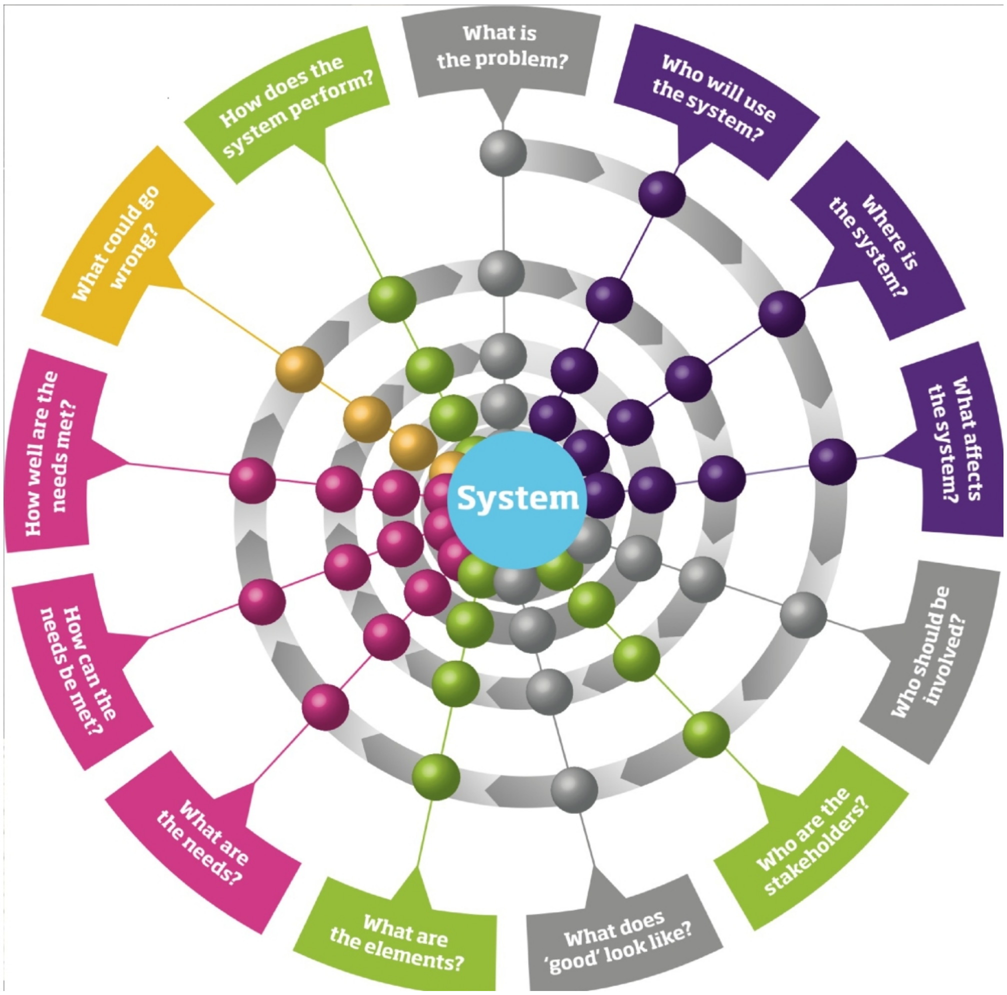

Figure 1 A systems approach to health and care improvement framed as a series of recursive questions (reproduced with permission from Engineering Better Care, Royal Academy of Engineering, 2017).

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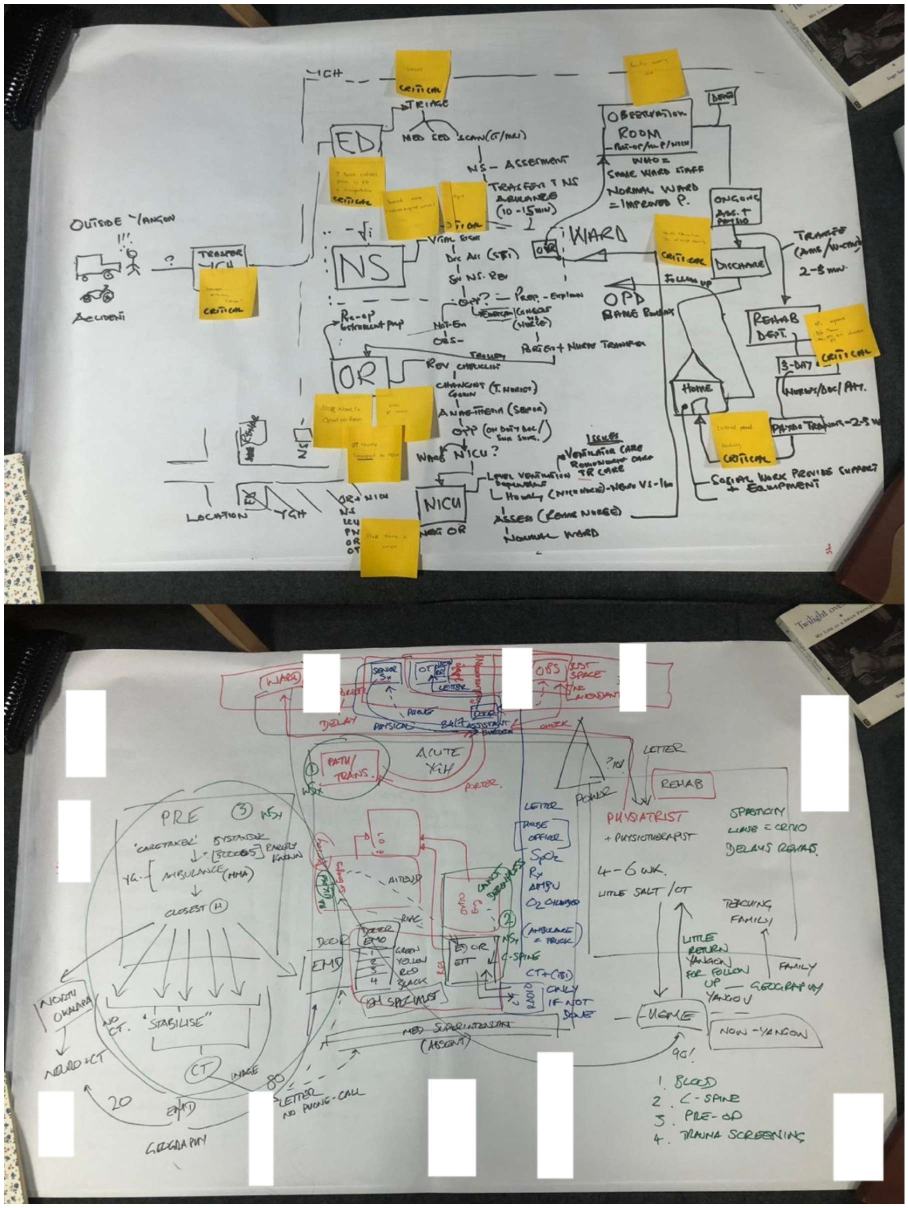
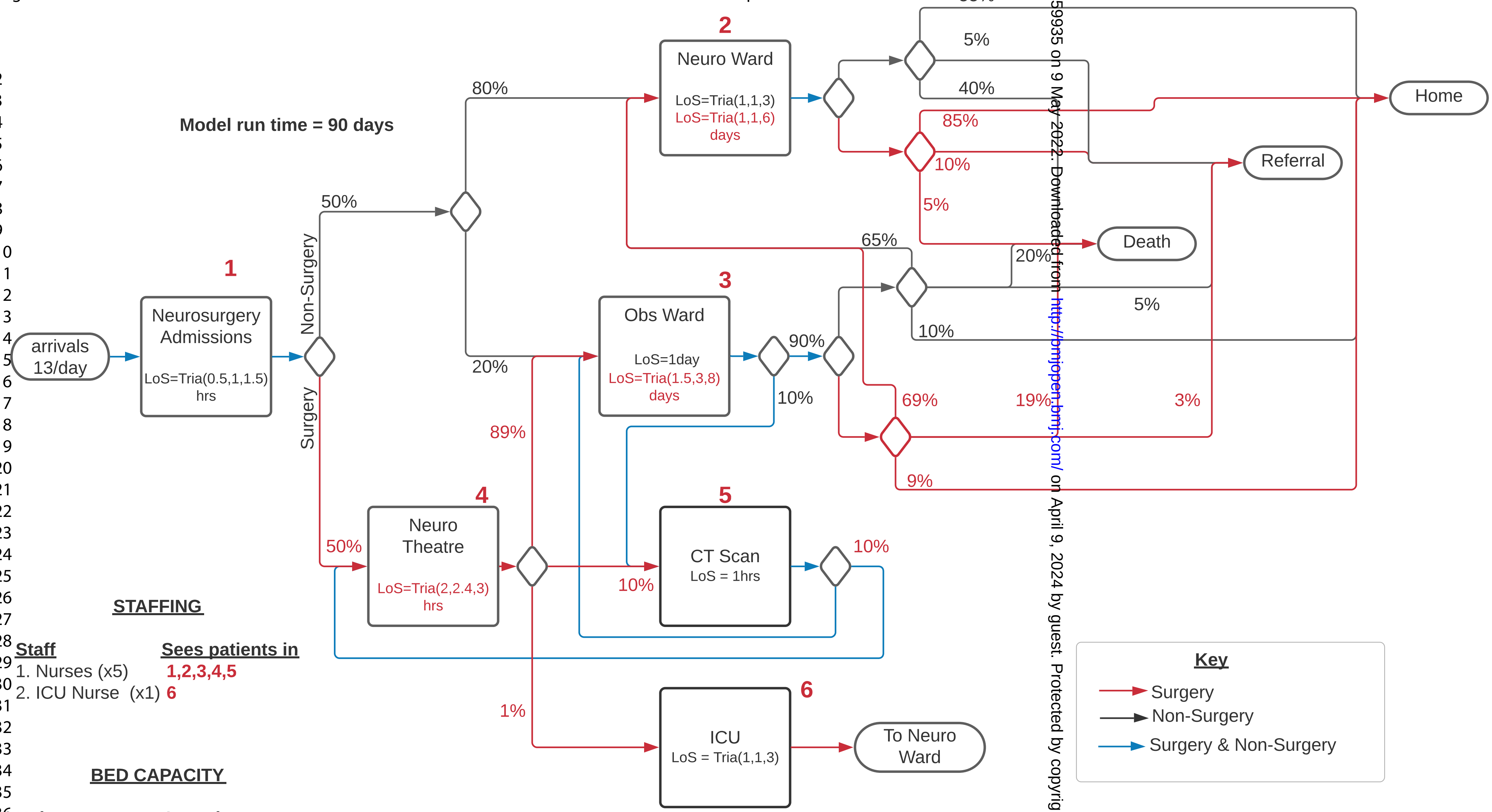


Figure 2. 'Rich pictures' generated by workshop data (reproduced from Bashford 2021 with permission of the author, with participant names redacted)

338x451mm (300 x 300 DPI)

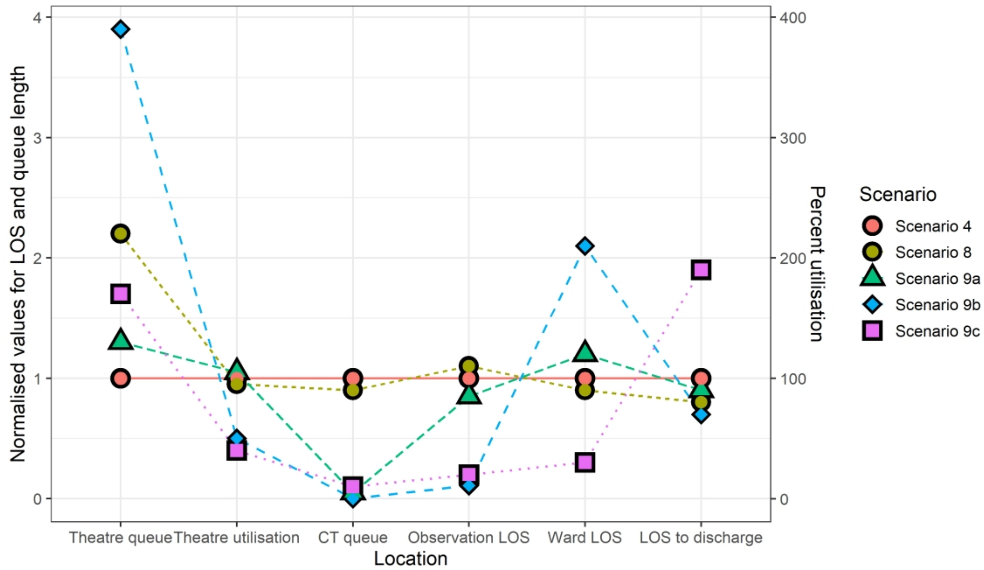


STAFFING

Staff	Sees patients in
1. Nurses (x5)	1,2,3,4,5
2. ICU Nurse (x1)	6

BED CAPACITY

Unit	Capacity
Neuro Ward	40
Obs Ward	20
ICU	2



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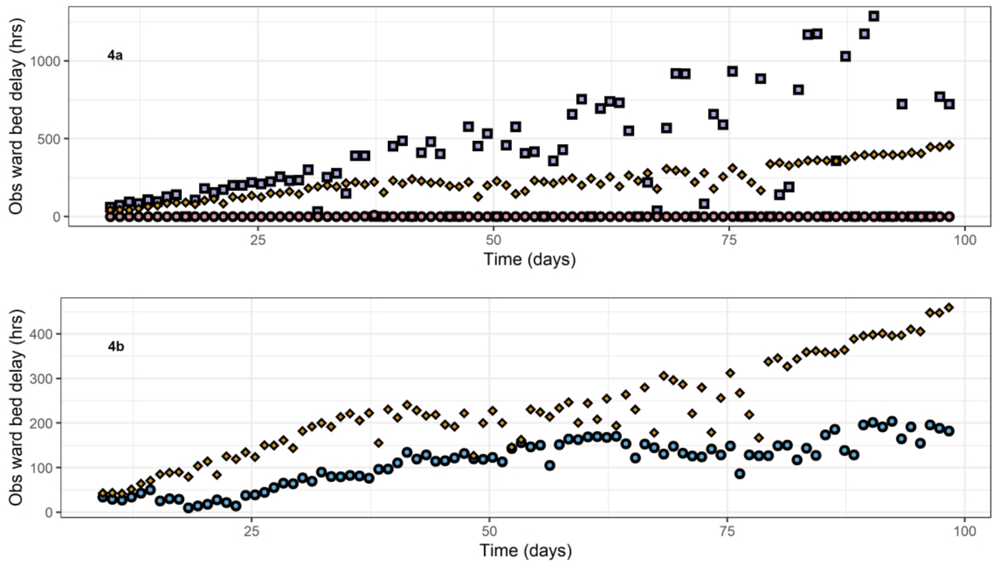
304x177mm (300 x 300 DPI)



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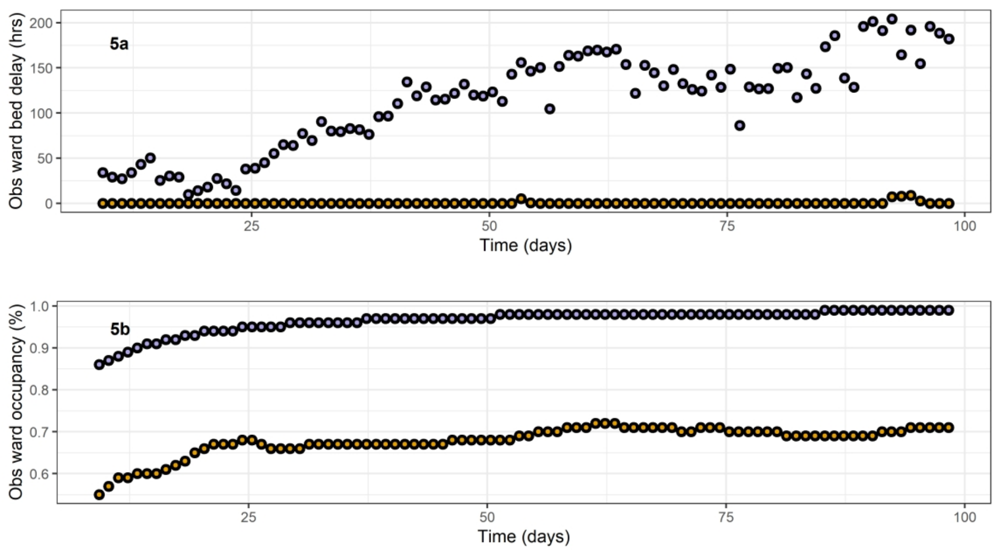

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Good Reporting of A Mixed Methods Study (GRAMMS)

1. Describe the justification for using a mixed methods approach to the research question

This study seeks to understand traumatic brain injury (TBI) care in Yangon, Myanmar, and explore specific potential improvements to that care. TBI care is a complex process involving an array of people, processes, and institutions. Furthermore, this research was conducted by an international research team with complicating issues around culture, language, and clinical experience in the setting under study.

Improving complex systems first requires an understanding of the system of interest. Qualitative techniques facilitate a rich understanding of the system, from the perspectives of a range of stakeholders. However the exploration of tangible interventions requires predictive quantitative models. In order for these models to be representative of the lived experience of stakeholders, the qualitative and quantitative aspects need to be tightly integrated. This study selected a mixed methods approach in order to focus the rich, contextual insights provided by qualitative study toward specific, discrete, interventions which can be modelled using quantitative techniques.

2. Describe the design in terms of the purpose, priority and sequence of methods

Mixed methods were employed to maximise the understanding of the system and allow the development of a discrete-event simulation based on lived experience. Different aspects of the system were captured via different methods – the process and system structure, broad system understanding and staff/patient experiences were best explored with a participatory storytelling approach, but to explore specific areas for improvement a discrete event simulation model was selected. Participatory diagramming was used to bridge the gap between these two, allowing a system architecture to be co-created by participants as opposed to being imposed by the research team. This architecture was then populated with a prospectively collected dataset, a model built and then refined with the research team in light of the initial narrative analysis. In this way qualitative exploration was used to frame, bound, and understand the quantitative model derived.

The design of this study follow the systems approach outlined by the Royal Academy of Engineering, the Royal College of Physicians and the Academy of Medical Sciences in their 2017 report *Engineering Better Care* (www.raeng.org.uk/publications/reports/engineering-

better-care). This approach can be defined as a series of questions, which were addressed by the different aspects of this integrated mixed methods design. Broadly, the quantitative and qualitative components addressed the following questions:

Narrative analysis and participatory diagramming: *Who will use the system? Where is the system? What affects the system? Who are the stakeholders? What are the elements? What are the needs?*

Discrete Event Simulation: *How does the system perform? What is going on? What could go wrong? How can we make it better? How can the needs be met? How well are the needs met?*

3. Describe each method in terms of sampling, data collection and analysis

Qualitative data

A combination of narrative data supplemented by participatory diagramming was used to understand the lived experience of research participants. This was based upon the Soft Systems Methodology (SSM), adapted for use by a multiprofessional, cross-cultural research team. (17) Narrative inquiry and SSM are positioned within a constructivist paradigm in which the data are co-created by the research team and research participants. The data is a function of the context in which it is created, both on the micro (individual conversation) and macro (society, culture, and language) levels. The research team consisted of both UK and Burmese researchers, trained in the *Engineering Better Care* systems approach, SSM, narrative, and diagramming techniques, and with an expert knowledge of the clinical context under study.

A half-day workshop was held in February 2019 at YGH which was attended by 40 participants including neurosurgeons, neurosurgical nursing staff (ward and theatres), anaesthetists, emergency physicians, and physiatrists. Participants were grouped by both clinical speciality and seniority to encourage active participation and story-sharing, and facilitated in a mixture of Burmese and English by members of the research team. During the workshop, participants were encouraged to create visual maps of their accounts, identifying a mixture of physical structures, clinical processes, patient flow, and lines of communication. These visual maps were often supplemented by numerical figures to reinforce particular points.

Subsequently, two members of the research team (SW and PPNM) conducted 64 one-on-one interviews with a range of stakeholders including patients and their relatives, physicians, surgeons, nursing, and auxiliary staff. These interviews were again structured to encourage story-telling and the elicitation of individual narratives, using a combination of audio recording, note-taking, and participatory diagramming to capture these accounts. These interviews were conducted in Burmese, anonymized at source, and then professionally translated and transcribed.

Both the workshop and subsequent interviews were loosely structured to encourage the elicitation of rich narratives, rather than to address preconceived questions. Facilitators and interviewers referred to the questions posed in *Engineering Better Care* to help guide the discussions, and sought to explore habitual, exceptional, and hypothetical narratives to gain an understanding of the lived experience of respondents. At the same time, techniques of participatory diagramming and graphical elicitation were used to help interviewers and respondents structure this data during the course of the workshop and interviews, with the aim of prompting new insights, clarifying terms, and creating a mutual understanding of the narratives being related.

The resulting qualitative dataset was imported into proprietary software (ATLAS.ti v8 Mac, Scientific Software Development GmbH). Narratives were analysed to identify key areas of concern, along with the development of a consensus understanding of the system features which were central to these: the boundary of the system under study, its physical components and their orientation to each other, the key clinical processes occurring within the system, and the flow of patients through it. A formal thematic analysis of the dataset was not conducted as part of this study.

Quantitative

This qualitative systems model informed the subsequent collection of prospective, targeted, quantitative clinical data. One of the research team (SW) collected a dataset of demographic, inpatient location, discharge destination, and outcome data over a one month period in February 2020. All neurotrauma admissions to the YGH neurosurgical unit who went on to receive a neurosurgical intervention were included, with collection of initial and subsequent Glasgow Coma Scores (GCS) as a measure of outcome.

Model building

Using a combination of the data from the two initial phases, a discrete event simulation was developed to represent a simplified model of the neurotrauma system at YGH. The focus of

the model was on the pre- and post-operative care pathways of the neurotrauma patients including a model of the resource requirements. This focus was grounded in the narrative accounts, which indicated these stages as being the key determinants of overall patient outcome.

The qualitative data was used to structure the care pathway, with the quantitative information used to describe the distributions of resource usage, length of stay and discharge destination of patients moving along specific pathways. The model was developed iteratively using the software package Anylogic (university edition, The Anylogic Company, 2016 v7.3.7). The model was verified through an iterative development process involving the research team members, and critiqued against the existing literature.

4. Describe where integration has occurred, how it has occurred and who has participated in it

Integration of methods in this study occurs throughout the philosophy, design and delivery of the research programme. Narrative elicitation, participatory diagramming, and discrete event simulation were all selected due to their epistemological pedigree in understanding complex systems. As such, they represent an integrated suite of approaches by which the *Engineering Better Care* systems approach may be enacted. Narrative elicitation and participatory diagramming were themselves distilled out of the Soft Systems Methodology to better suit a cross-cultural research team. The use of systems thinking as an overarching framework allowed the qualitative work, situated withing a constructivist paradigm, to be then integrated into a more positivist quantitative paradigm. Discrete event simulation provides an accessible graphical interface by which results of the model can be reintegrated into the qualitative data for validation and verification. It might be concluded that the images used in both cases provide the methodological interface between the different methods and their philosophical bases.

5. Describe any limitation of one method associated with the presence of the other method

In general, narrative elicitation sits within a constructivist philosophy in which data is co-created between research participants and the researchers. Knowledge is made and remade within the discussion, and no boundaries are placed upon the data created other than those which arise from the interaction of the two. However, the desire to frame this project with a

systems thinking framework, and to employ a quantitative technique to explore system improvements, necessarily biased the narratives toward describing a system. This is a conceptual framework which comes from the research team as opposed to the participants. A series of conceptual devices was then used to abstract this narrative data to render it suitable for modelling: participatory diagramming provided a constructivist approach to describing system architecture which was then further abstracted to build the discrete event simulation. This simulation was then populated with a limited dataset and built to explore those concepts deemed by the research team to represent tangible improvement opportunities within the neurosurgical service.

This approach then bounds both the qualitative and quantitative methodologies on order for them to integrate with each other – the qualitative sacrifices richness and nuance, while the quantitative sacrifices data.

6. Describe any insights gained from mixing or integrating methods

The integration of methods show how it is possible to bridge both methodological and philosophical positions using the overarching concept of systems thinking, and the device of imagery to describe the system under study. Pragmatically, the qualitative data suggested specific areas for improvement in TBI care in Yangon – access to CT scanning and observation ward beds – which could then be modelled using the discrete event simulation. Modelling suggested that while CT access becomes a bottleneck at increasing patient loads, this may be improved by changing the prioritisation of nursing staff but not by increasing the number of patients which the CT scanner can accommodate. However this comes at a cost to other areas of the system, which then show increased queuing times. These insights suggest that increasing overall nursing numbers sits on the critical path to improving CT access, and the simply investing in a further scanner may not deliver the looked-for benefits. Similarly, the simulation suggests that while an increase in the number of observation ward beds does alleviate the queuing seen with high patient numbers, the need for expansion is bounded with ten beds completely reliving queuing and no further benefit seen beyond this. These are powerful insights into system function with real-world impacts on potential resource allocation in an impoverished healthcare system.

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A Systems Approach to Improving Traumatic Brain Injury Care in Myanmar: a mixed-methods study from lived experience to discrete event simulation

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A Systems Approach to Improving Traumatic Brain Injury Care in Myanmar: a mixed-methods study from lived experience to discrete event simulation

Corresponding author:
Katharina Kohler * – kk371@cam.ac.uk
Division of Anaesthesia, Department of Medicine, University of Cambridge, Box 93, Hills Road, Cambridge CB2 0QQ, UK

Further authors:
Phyu Phyu Nwe Myint *
Department of Clinical Neurosciences, Box 165, Addenbrooke's Hospital, Hills Road, Cambridge CB2 0QQ, UK

Sein Wynn
Department of Neurosurgery, University of Medicine 1, 245 Myoma Kyaung Street, Lanmadaw Township, Yangon, Myanmar.

Alexander Komashie
Engineering Design Centre, Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, UK

The Healthcare Improvement Studies (THIS) Institute, University of Cambridge, Clifford Allbutt Building, Cambridge CB2 0AH, UK

Robyn Winters
Neurocritical Care Unit (NCCU), Addenbrooke's Hospital, Hills Road, Cambridge CB2 0QQ, UK

Myat Thu
Department of Neurosurgery, University of Medicine 1, 245 Myoma Kyaung Street, Lanmadaw Township, Yangon, Myanmar.

Mu Mu Naing
Department of Anaesthesia, University of Medicine 1, 245 Myoma Kyaung Street, Lanmadaw Township, Yangon, Myanmar.

Thinn Thinn Hlaing
THET Myanmar, c/o THET, 1 St. Andrews Place Regent's Park, London NW1 4LE, UK

Rowan M Burnstein
Department of Anaesthesia, Addenbrooke's Hospital, Hills Road, Cambridge CB2 0QQ, UK

Zaw Wai Soe

University of Medicine 1, 245 Myoma Kyaung Street, Lanmadaw Township, Yangon, Myanmar.

P John Clarkson
Engineering Design Centre, Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, UK

David K Menon
Division of Anaesthesia, Department of Medicine, University of Cambridge, Box 93, Hills Road, Cambridge CB2 0QQ, UK

Peter JA Hutchinson
Academic Division of Neurosurgery, Box 167, Addenbrooke's Hospital, Hills Road, Cambridge CB2 0QQ, UK

Tom Bashford
Division of Anaesthesia, Department of Medicine, University of Cambridge, Box 93, Hills Road, Cambridge CB2 0QQ, UK.
Engineering Design Centre, Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, UK

*Joint first author

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Abstract:

Objectives:

Traumatic brain injury (TBI) is a global health problem, whose management in low resource settings is hampered by fragile health systems and lack of access to specialist services. Improvement is complex, given the interaction of multiple people, processes, and institutions. We aimed to develop a mixed-method approach to understand the TBI pathway based upon the lived experience of local people, supported by quantitative methodologies, and to determine potential improvement targets.

Design:

We describe a systems approach based on narrative exploration, participatory diagramming, data collection, and Discrete Event Simulation (DES), conducted by an international research collaborative.

Setting:

The study is set in the tertiary neurotrauma centre in Yangon General Hospital, Myanmar prior to the SARS-CoV2 pandemic.

Participants:

The qualitative work involved 40 workshop participants and 64 interviewees to explore the views of a wide range of stakeholders including staff, patients and relatives. The one-month retrospective admission snapshot covered 85 surgical neurotrauma admissions.

Results:

The TBI pathway was outlined, with system boundaries defined around the management of TBI once admitted to the neurosurgical unit. Retrospective data showed 18% mortality, 71% discharge to home, and an 11% referral rate. DES was used to investigate the system , showing its vulnerability to small surges in patient numbers, with critical points being CT scanning and observation ward beds. This explorative model indicated that a modest expansion of observation ward beds to 30 would remove the flow-limitations and indicated possible consequences of changes.

Conclusions:

A systems approach to improving TBI care in resource-poor settings may be supported by simulation and informed by qualitative work to ground it in the direct experience of those involved. Narrative interviews, participatory diagramming, and DES represent one possible suite of methods deliverable within an international partnership. Findings can support targeted

improvement investments despite co-existing resource limitations while indicating concomitant risks.

Strengths and limitations of this study

- To our knowledge, this paper is the first to demonstrate the value of combing Discrete Event Simulation (DES) and narrative-driven participatory diagramming for understanding care pathways in a global health context.
- Narrative enquiry provided a participatory method for data creation which balances power between actors, providing robust qualitative data to inform the development of quantitative Discrete Event Simulation models.
- The Discrete Event Simulation model allowed the exploration of a range of scenarios to help understand the impact of key resources on clinical outcomes.
- The combined effects of the SARS CoV2 pandemic and the current pollical climate in Myanmar made it impossible to subsequently validate the model outside of the international research team. Quantitative simulation models only account for a limited perspective, with the results requiring careful contextualisation before being used to change clinical practice.

Introduction

Traumatic brain injury (TBI) is a global public health issue, with the 2017 Lancet Commission on Traumatic Brain Injury (LNCTBI) estimating that over half of the world's population will suffer a TBI within their lifetime. (1) TBI is a particular problem in low- and middle-income countries (LMIC) where increasing automobile use, poor regulatory frameworks, and fragile health systems combine to provide not only an increasing risk of TBI, but an environment in which the pre- intra- and post- hospital care which TBI requires cannot be provided. (2)

At the core of TBI management is the provision of surgical intervention, itself a challenge in many LMICs. The 2015 Lancet Commission on Global Surgery found that over 5 billion of the world's population lack access to safe, affordable, timely surgical care, and that surgery itself requires a functional healthcare system to support it. (3) In addition, TBI care depends on time-critical investigations, such as CT scans, which can also be a challenge to access without delay in resource poor environments. The effects of delay are consistent with the known pathophysiology of secondary brain injury and experience from other studies which suggest that delay remains a key determinant of outcome in TBI (1).

The management of TBI is complex and difficult to characterise. (4) While epidemiological studies have been conducted to explore the global picture, mapping practice at the level of the institution to drive service improvement remains a challenge. (5) This is exacerbated in settings which have low levels of routine data collection, or a lack of established clinical and organisational protocols and care pathways. One conceptual framework which has been advocated to help understand the complex environment of clinical care is systems thinking; either as a standalone device or as part of an established corpus of knowledge such as systems engineering. This has been applied in many settings through a variety of methodological approaches and is advocated by the World Health Organisation (WHO) as an approach for understanding healthcare. (6) One model for taking a systems approach to healthcare improvement is described in the 2017 report *Engineering Better Care*, which presents a recursive series of questions to be answered as part of such an approach, and which has been explicitly explored within the context of global health. (7,8)

Accurate and complete quantitative data collection is often considered a prerequisite for operational systems modelling. While data collection and analysis have been shown to be feasible in low- and middle-income countries, there are significant limitations in data collection associated with resource limited settings. (9) This contrasts with high-income settings where electronic health records, implemented to facilitate clinical care, may provide data for operational research and systems analysis. (10) More participatory approaches, such as process mapping, have been described to improve surgical care but these do not have the power of quantitative models. (11)

Healthcare system modelling using Discrete Event Simulation (DES) is a common approach in operational research, supported by quantitative data in combination with local knowledge. It has been shown to be a useful tool to model a complex system and investigate the potential effects of resource reallocation or improvements. (12) However, extension of this type of modelling into LMIC healthcare systems has been sparse to date, with a few notable exceptions. (13,14) The success of DES depends on an appropriate representation of the system to be modelled and its applicability can be limited if the system is not well represented or described.

We describe a mixed-methods systems approach to understanding TBI care in a tertiary neurosurgical centre in Myanmar, to demonstrate the feasibility and utility of this approach to a resource-limited tertiary neurosurgical centre with a significant burden of TBI. This study is the product of an academic institutional health partnership combining the Cambridge Yangon Trauma Intervention Project (CYTIP) and the NIHR Global Health Research Group on Neurotrauma. (15)

Methods

Setting

The study was conducted across 2019-2020, prior to the SARS CoV2 global pandemic, in Yangon General Hospital (YGH), Myanmar. YGH is a tertiary neurotrauma referral centre in Myanmar receiving both local and regional patients and which functions as both the local and national trauma centre. It has a recently established Emergency Department and provides a comprehensive array of surgical services. The neurosurgical centre is physically distant from the main hospital campus, with patients requiring transfer between the two sites. We employed an integrated mixed-methods approach based upon narrative analysis, participatory diagramming, targeted prospective data collection, model refinement, and then model validation and verification. Nested within a wider academic partnership, this work is reported against the Good Reporting of a Mixed Methods Study (GRAMMS) criteria. (16)

Patient and public involvement

This works forms part of a portfolio of research funded by the NIHR Global Health Research Group on Neurotrauma (https://neurotrauma.world), who have partnered with patient representatives in both the UK and around the world to understand the consequences of TBI and set research priorities. This partnership informed the initial study design of this project. In Myanmar we were unable to identify specific patient groups or representatives pertinent to TBI care, and instead chose a participatory research design to include their perspectives within the formal data collection. While this meant patients and the public were not engaged at the outset of the study, the snowball participant sampling allowed them to identify further research participants and shape both the design and findings of the study. Similarly, the choice of narrative methodology allowed patient and public respondents to shape the research data in partnership with the research team. The intention of the research team was to use further patient and public work to understand how the research findings might best be shared with communities, but the cessation of research activity due to the SARS CoV2 pandemic and political events in Myanmar made this latter stage unworkable.

Ethical approval

This work has ethical approval from the Institutional Review Board of the Government of the Republic of the Union of Myanmar Federal Ministry of Health and Sports, Department of Medical Research (Ethics/DMR/2019/082). It also has approval from the University of Cambridge School of Humanities and Social Sciences Ethics Committee (18/181) and is sponsored by the University of Cambridge.

Qualitative data

A combination of narrative data supplemented by participatory diagramming was used to understand the lived experience of research participants. This was based upon the Soft Systems Methodology (SSM), adapted for use by a multiprofessional, cross-cultural research team. (17) Narrative inquiry and SSM are positioned within a constructivist paradigm in which the data are co-created by the research team and research participants. The data is a function of the context in which it is created, both on the micro (individual conversation) and macro (society, culture, and language) levels. The research team consisted of both UK and Burmese researchers, trained in the *Engineering Better Care* systems approach, SSM, narrative, and diagramming techniques, and with an expert knowledge of the clinical context under study.

A half-day workshop was held in February 2019 at YGH which was attended by 40 participants including neurosurgeons, neurosurgical nursing staff (ward and theatres), anaesthetists, emergency physicians, and physiatrists. All participants provided written informed consent. Participants were grouped by both clinical speciality and seniority to encourage active participation and story-sharing and facilitated in a mixture of Burmese and English by members of the research team. During the workshop, participants were encouraged to create visual maps of their accounts, identifying a mixture of physical structures, clinical processes, patient flow, and lines of communication. These visual maps were often supplemented by numerical figures to reinforce particular points.

Subsequently, two members of the research team (SW and PPNM) conducted 64 one-on-one interviews with a range of stakeholders including patients and their relatives, physicians, surgeons, nursing, and auxiliary staff. Again, participants provided written informed consent and were selected through purposive snowball sampling to explore as wide a range of stakeholders' views as possible. Children and those unable to provide written informed consent were excluded. These interviews were again structured to encourage story-telling and the elicitation of individual narratives, using a combination of audio recording, note-taking, and participatory diagramming to capture these accounts. These interviews were conducted in Burmese, anonymized at source, and then professionally translated and transcribed.

Both the workshop and subsequent interviews were loosely structured to encourage the elicitation of rich narratives, rather than to address preconceived questions. Facilitators and interviewers referred to the questions posed in *Engineering Better Care* (**Figure 1**) to help guide the discussions, and sought to explore habitual, exceptional, and hypothetical narratives to gain an understanding of the lived experience of respondents. (18) Prompting questions for these narratives included broad questions such as "what does a normal day look like?", "what is the best experience you have had?", "what was the worst case you have ever seen?". However, interviewers were encouraged to use a variety of approaches to encourage rich and reflective narratives, including sharing personal stories and observations. No fixed interview schema was used, with an emphasis placed on the quality of the data created, rather than its reproducibility. At the same time, techniques of participatory diagramming and graphical elicitation were used to help interviewers and respondents structure this data during the workshop and interviews, with the aim of prompting new insights, clarifying terms, and creating a mutual understanding of the narratives being related. (19)

The resulting qualitative dataset was imported into proprietary software (ATLAS.ti v8 Mac, Scientific Software Development GmbH). Narratives were analysed to identify key areas of concern, along with the development of a consensus understanding of the system features which were central to these: the boundary of the system under study, its physical components and their orientation to each other, the key clinical processes occurring within the system, and the flow of patients through it. A formal thematic analysis of the dataset was not conducted as part of this study.

Quantitative

This qualitative systems model informed the subsequent collection of prospective, targeted, quantitative clinical data. One of the research team (SW) collected a dataset of demographic, inpatient location, discharge destination, and outcome data over a one-month period in February 2020. All neurotrauma admissions to the YGH neurosurgical unit who went on to receive a neurosurgical intervention were included, with collection of initial and subsequent Glasgow Coma Scores (GCS) as a measure of outcome.

Model building

Using a combination of the data from the two initial phases, a discrete event simulation was developed to represent a simplified model of the neurotrauma system at YGH. The focus of the model was on the pre- and post-operative care pathways of the neurotrauma patients including a model of the resource requirements. This focus was grounded in the narrative accounts, which indicated these stages as being the key determinants of overall patient outcome.

The qualitative data was used to structure the care pathway, with the quantitative information used to describe the distributions of resource usage, length of stay and discharge destination of patients moving along specific pathways. The model was developed iteratively using the software package Anylogic (university edition, The Anylogic Company, 2016 v7.3.7). The model was verified through an iterative development process involving the research team members, and critiqued against the existing literature.

Results

Qualitative data

Responses from the 104 respondents (40 workshop participants and 64 interviewees) were supplemented with interview data from workshop facilitators and members of the research team, and combined with field notes and written reflections into a single dataset. The workshops resulted in the creation of meta-narratives constructed as complex images which conveyed a range of information including physical infrastructure, patient flow, clinical decision making, investigations, and clinical interventions. These were closely allied to the 'rich pictures' created when using SSM **(Figure 2)**. The interview data consisted predominantly of either verbal narratives or co-created process flow diagrams.

From these, a formal system structure was synthesized, bounded within the neurosurgical unit and focusing on nodes consisting of neurosurgery admissions, the observation wards, the neurosurgery theatres, the CT scanner, the neuro-intensive care unit, and the neurosurgical wards. This boundary was chosen to facilitate targeted quantitative data collection, but also due to the expertise of the Burmese research team being biased toward this area of the hospital. A patient flow logic model was then superimposed upon these, with outputs chosen as discharge, referral to another centre, or death (**Figure 3**).

Quantitative data

The quantitative data showed 83 admissions with a median age of 33.4 years (range 11 to 66 years). The median length of stay was 3.8 days (range 1-18 days). There was a 18% mortality, 71% discharge to home with an 11% referral rate to another department or hospital upon discharge. This population information was used to inform the static distributions of patient flow in the simulation, as shown in figure 3.

The mean admitting GCS was 10.8 (range 3 to 15) and the mean discharge GCS was 12.6 (range 3 to 15). Six patients were transferred intubated from ED to the neurosurgery department. Location data collected was consistent with the qualitative system mapping, with the most reported locations being the admission unit, observation ward, neurosurgical ward (male and female), neurosurgery theatres and referral destinations. The initial admitting location for the surgical patients was the observation ward with almost all patients (98%) staying for at least 2 days before being transferred to the general neurosurgical ward.

Discrete Event Simulation

The DES model was structured using the model in figure 3 to explore key activities in a patient's journey from arrival at neurosurgery admissions to discharge home, referral to another hospital, or death. All processing times were modelled as triangular distributions to take account of variations and uncertainty in both the process and data. The distributions were developed based on quantitative information and expert experience. Two separate patient groups were identified - surgical and non-surgical treatment streams - that share the same resources but were assigned different distributions and care pathways.

The narrative data identified two key areas as bottlenecks in patient flow: the availability of CT scanning (a time-critical investigation for neurosurgical patients), and the occupancy of observation ward beds. These were subsequently used as the main targets to investigate through DES. These were explored across a range of patient flows to explore the resilience of the system to sudden changes in surgical burden.

The simulation was run with a warm-up period of 200 hours and over a period of 90 days. In addition to the three kinds of discharge from the system - home, referral and death - the model reported outputs on queue lengths, waiting times and resource utilisation in selected areas (Scenarios summarised in **Table 1**).

Scenario	Patient arrival	Percentage of	Observation	Additional

number	rate	surgical patients	ward capacity	changes
0 (baseline)	13	50	20	-
1	8	20	20	-
2	8	80	20	-
3	15	20	20	-
4	15	80	20	-
5	15	80	30	-
6	13	50	30	-
7	15	50	20	-
8	15	80	20	Increased CT capacity to 2/slot
9a	15	80	20	Priority: CT
9b	15	80	20	Priority: CT & observation ward
9c	15	80	20	Priority: CT & observation & neuro ward

Table 1: Description of the scenarios used to explore the system. Three main variables were modified and the effects investigated. Additional improvement possibilities were explored in Scenario 8 and 9a-c.

Insights from the narrative data led to a decision to explore the effects of changing the admission rate, the percentage of surgical patients, the capacity of the observation ward, and the availability of CT scanning. CT availability was explored by both increasing the capacity of available scanners (increasing from one patient per two-hour time window to two patients per two-hour time window) and by increasing the priority of access to nursing staff for accompanying CT transfers, observation ward and neuro ward. In all, nine scenarios were developed including the baseline. Scenario 9 involved three variations testing different levels of priority access to nursing staff. For model validation, the results of length of stay from the model were within the range of 1 to 21 days estimated by Rock *et al* (20) based on empirical data from across Myanmar and consistent with clinical experience and the quantitative dataset.

The queue to access CT was modelled assuming a 2-hour round-trip based on local experience, with each patient requiring a single nurse escort. In scenario 4 – a high patient volume scenario – we found the wait to access a time-critical CT increased to clinically unacceptable levels of several hours in keeping with the narrative accounts. We explored two potential improvement strategies for reducing wait for CT: increasing the number of patients that can go at the same time to 2 (Scenario 8) and increasing the priority of CT scanning within the tasks for the available nursing staff (Scenario 9a-c).

We found that scenario 8 did not resolve the CT capacity problems with the queue persisting at similar levels to scenario 4. The adjusted prioritisation scenarios where the availability of nurse escorts is increased (9a: CT main priority, 9b: CT and observation ward as priority, 9c: CT, observation ward and neuro wards as priority) resolved the CT queuing and allowed for timely CT processing. However, this impacted on other areas of care as illustrated in **Figure 4**, which shows system performance measures (such as length of stay and queuing) normalised to scenario 4. As an example, the effect of prioritising CT escorts and observation ward staffing in scenario 9b resulted in a long queue for theatres with reduced theatre occupancy and prolonged neuro ward length of stay, all due to the lack of available nursing staff to perform the necessary tasks. Similar complex system effects can be seen for scenario 9a and 9c where the delays have been diverted to admissions and theatres.

In addition to the CT bottleneck, the effect of changing patient numbers on the observation ward bed occupancy was investigated. **Figure 5a** illustrates the effects of a change in population characteristics by changing the percentage of patients classified as “surgical”. Scenario 4 (50% surgical patients) in black, scenario 3 (20% surgical patients) in blue, and scenario 7 (80% surgical patients) in red. The increased number of surgical patients with a longer stay on the observation ward care post-operatively results in an increase in the delay to access an observation ward bed. **Figure 5b** illustrates the effect of varying patient arrival rate. With increased arrivals the waiting time for the observation ward bed increases. In black is the baseline scenario 0 (13 patients/day), in blue is scenario 7 (15 patients/day). It is notable that with an increase in the arrival rate of just 2/day there is a significant increase in the waiting time for a bed, given that the observation ward occupancy is already >90% for the baseline scenario. These results were again consistent with local experience.

Consequently, a possible service change with a moderate expansion of the observation ward capacity from the baseline 20 beds to a potential 30 beds was explored. This was an illustrative change aiming to determine a potential alleviation of a bottleneck. The results are shown in **Figure 6**, with the baseline model (20 beds) shown in purple and scenario 6 (30 beds) in yellow. The delay to access an observation ward bed is shown in the top panel and the percentage occupancy in the bottom panel. The additional bed spaces resolved the near full capacity state of the observation ward and reduced the waiting time for a bed to negligible numbers.

Discussion

We describe a systems approach to understanding the care of neurosurgical patients in a resource-limited setting, based on a combination of qualitative exploration, prospective data collection, and discrete event simulation. The insights gained from this study are both practical and methodological. Practically, we show that changes in staffing allocation and observation ward capacity may improve patient flow despite co-existing resource limitations. Methodologically we show how a mixed-methods approach by a cross-cultural multiprofessional research team can deliver high quality systems modelling which is grounded in both the lived reality of local stakeholders, and in reliable prospectively acquired data.

Understanding healthcare from a systems perspective presents both conceptual and pragmatic challenges. These are best met by marrying robust qualitative and quantitative approaches, however achieving this in resource limited settings where clinical services are stretched and routine data collection may be impossible is challenging. In addition, much of the systems thinking literature comes from a canon of thought developed in high-income countries, and this may not translate readily to other cultures or languages. Indeed, the Burmese members of the research team found translation of the *Engineering Better Care* questions very challenging, both linguistically and conceptually. Furthermore, while the project was conceived within the Soft Systems Methodology, a constructivist approach grounded in systems thinking which has been applied to healthcare in a range of contexts, this was found to be a barrier to participatory research as the terminology and theory was found to be difficult to translate into Burmese.

As a result, the research approach we describe uses narrative as a tool for understanding lived experience to overcome some of these barriers. Storytelling is common to all human society and is a mechanism for people to both conceive and communicate complex ideas.(21) Combining this with participatory diagramming provides a natural form of data creation, without requiring local research partners to engage with complex theoretical models. Narrative research also encourages a degree of transformation on the part of the research team, as they elicit and assimilate a variety of stories from widely different viewpoints. In the words of one of the research team:

"When we started this research I thought that all of our problems came from a lack of resources. Now I can see so many things we can improve without waiting for more money."

The participatory diagramming also provides a starting point for the DES model which is grounded in the primary experience of the research participants, providing reassurance that the model is close to reality, and that the prospective data collected is parsimonious and of maximum utility. Structuring both of these with the systems approach articulated in *Engineering Better Care* provides a degree of methodological rigour and ensures that a focus on the function of the system as a whole, rather than discrete processes, remains at the heart of the data collection.

The discrete event simulation modelling facilitates the conversion of this rich narrative data into a more abstracted form, which can then be readily manipulated and used to predict changes to system behaviour within specific constraints. Consistent with the experience of the research team, our model explores the resource limitations around access to CT imaging and observation beds. However, the model challenges the narrative data, with access to CT scanning limited less by the access to CT machines, and more by the availability of nurse escorts. The model however agrees with the narrative report that nursing provision is stretched when patient volume increases and changing prioritisation of tasks only shifts the resulting delays to another care area. Similarly, the model indicates that while a modest expansion of observation beds improves patient flow, this does not scale indefinitely. Both insights have consequences for real-life improvement opportunities. Ideally, these insights would have been taken back through a process of qualitative exploration to better understand the findings, but both the SARS CoV2 pandemic and political events in Myanmar prevented this last phase of the research.

However, it is important to note that our DES model was created to look specifically at patient flow, again grounded in the reported experience that most patient complications arise from a delay to care. Traumatic brain injury, like other specific pathologies, is a time critical condition and it seems reasonable that delay is one of the key drivers of patient outcome. (22) However, any number of alternative models could be built to explore communication flow, institutional power, or clinical decision making. More complex concepts such as the quality of care are not addressed in our model. The provision of surgery may be considered at the interface of clinical need, access, and quality and our model currently explores only one of these dimensions. (23)

The DES model was developed to demonstrate the kinds of insight that are possible when the technique is combined with participatory systems mapping and the rich narrative data from qualitative methods. As a result, several assumptions were made that may be considered limitations of the model. For example, all Length of Stay (LoS) durations and processing times were modelled as triangular distributions in the absence of numerical data to allow theoretical curve-fitting. The triangular distribution is pragmatic, intuitive and effective in situations of insufficient numerical data (24). Another assumption made was the absence of priority in the allocation of nurses and beds. Patients were allocated these resources on a First Come First Served (FCFS) basis.

It is important to note that a variety of other models could have been built based upon our qualitative dataset. A different system boundary, such as that of the whole hospital as opposed to the neurosurgical unit, would have required different quantitative metrics and would have been much more complex to build. It would also have required a research team made of different clinical specialities to ground the qualitative and quantitative data within lived expert experience. However, the benefit of good early qualitative work is that it provides the opportunity to explore a variety of different future models, to address a wide range of clinical and operational improvement questions.

Conclusion

Traumatic brain injury is a growing burden in the global south, and efforts to improve care in this area are hampered by its complexity, a lack of access to the necessary services, and the delay this engenders.

Our mixed-methods systems approach which combines rigorous qualitative approaches with discrete event simulation allows for modelling firmly grounded in local context but informed by established mathematical theory. We demonstrate that such research can be carried out by a diverse research team based on the lived experience of a range of stakeholders. The resulting model retains validity when critiqued against this primary qualitative data, provides insights into resource limitations and specific targets for improvement and should be of value across a huge range of clinical and geographical contexts.

Contributorship statement:

TB, KK, AK, PPNM, SW, RMB, PJC contributed to the design of the research. TB, SW, PPNM, KK, AK, RW, RMB conducted the data collection, model design and analysis. MT, PJC, PJAH, ZWS aided with project management and data analysis. TB, KK, AK, PPNM took the lead in writing the manuscript. SW, MMN, MT, DKM, PJC and TTH discussed the results and contributed to the writing of the manuscript.

Competing interests:
None declared.

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Data sharing statement:
Access to an anonymised, redacted dataset will be entertained upon reasonable request, but due to the sensitive nature data cannot be made publicly available.

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Figures:

Figure 1 A systems approach to health and care improvement framed as a series of recursive questions (reproduced with permission from *Engineering Better Care*, Royal Academy of Engineering, 2017).

Figure 2. 'Rich pictures' generated by workshop data (reproduced from Bashford 2021 with permission of the author, with participant names redacted)

Figure 3: DES model structure showing the variables, patient flow and proportions. The surgical patient pathway is denoted in red, the conservative/medical treatment pathway in black. Patients enter the DES on the left at "arrivals" and exit on the right into "Home", "Referral" or "Death".

Figure 4 illustrates the effects of changing staff priorities on the patient load in different locations. To improve CT flow in a high patient volume scenario (Scenario 4) we adjusted the CT capacity (Scenario 8) or the nursing staff task priorities (Scenario 9a – priority to CT, Scenario 9b – priority to CT and observation ward, Scenario 9c priority to CT, observation and neuro ward). The figure shows the queues waiting for theatre, CT and the observation ward, the LOS for neuro ward and to discharge with the values normalised to Scenario 4. Additionally, we show percent theatre utilisation. The locations are arranged in the order of patient flow.

Figure 5a illustrates the effect of a change in population by changing the percentage of patients classified as "surgical". The increased length of stay on the observation ward is seen as an increase in delay for observation ward bed access. In yellow scenario 4 (50% surgical patients), in pink scenario 3 (20% surgical patients) and in purple is scenario 7 (80% surgical patients).
Figure 5b: Illustrates the effect of varying patient arrival rate. With increased arrivals the waiting time for the observation ward bed increases. Again, in yellow is the baseline scenario 4 (15 patients/day), in blue we show scenario 7 (13 patients/day).

Figure 6: Illustrates the change in patient load on the observation ward when the capacity is increased. In purple is the baseline scenario 0 (20 beds) and in yellow scenario 6 (30 beds). Figure 5a shows the delay to an observation ward bed, 5b shows the observation ward occupancy through the simulation period. The moderate increase in bed capacity clearly reduces the pressure on observation ward beds.

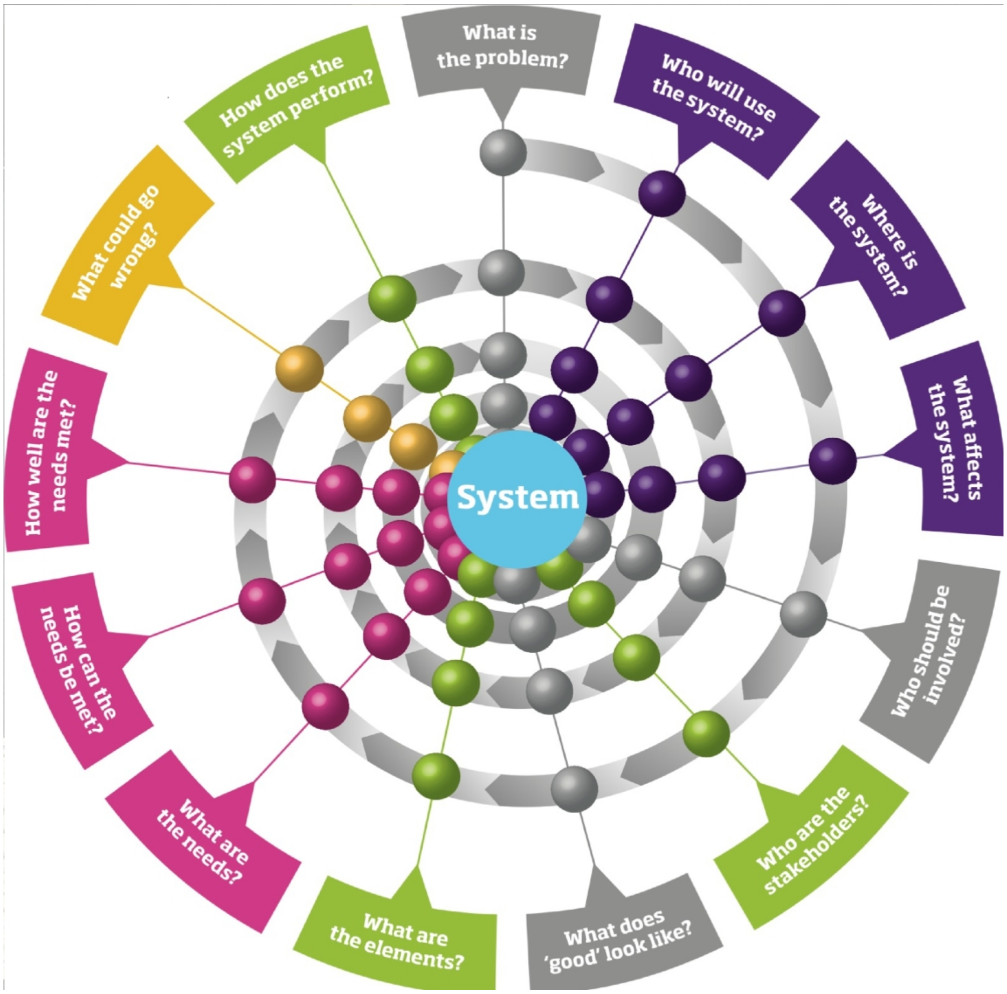


Figure 1 A systems approach to health and care improvement framed as a series of recursive questions (reproduced with permission from Engineering Better Care, Royal Academy of Engineering, 2017).

231x228mm (300 x 300 DPI)

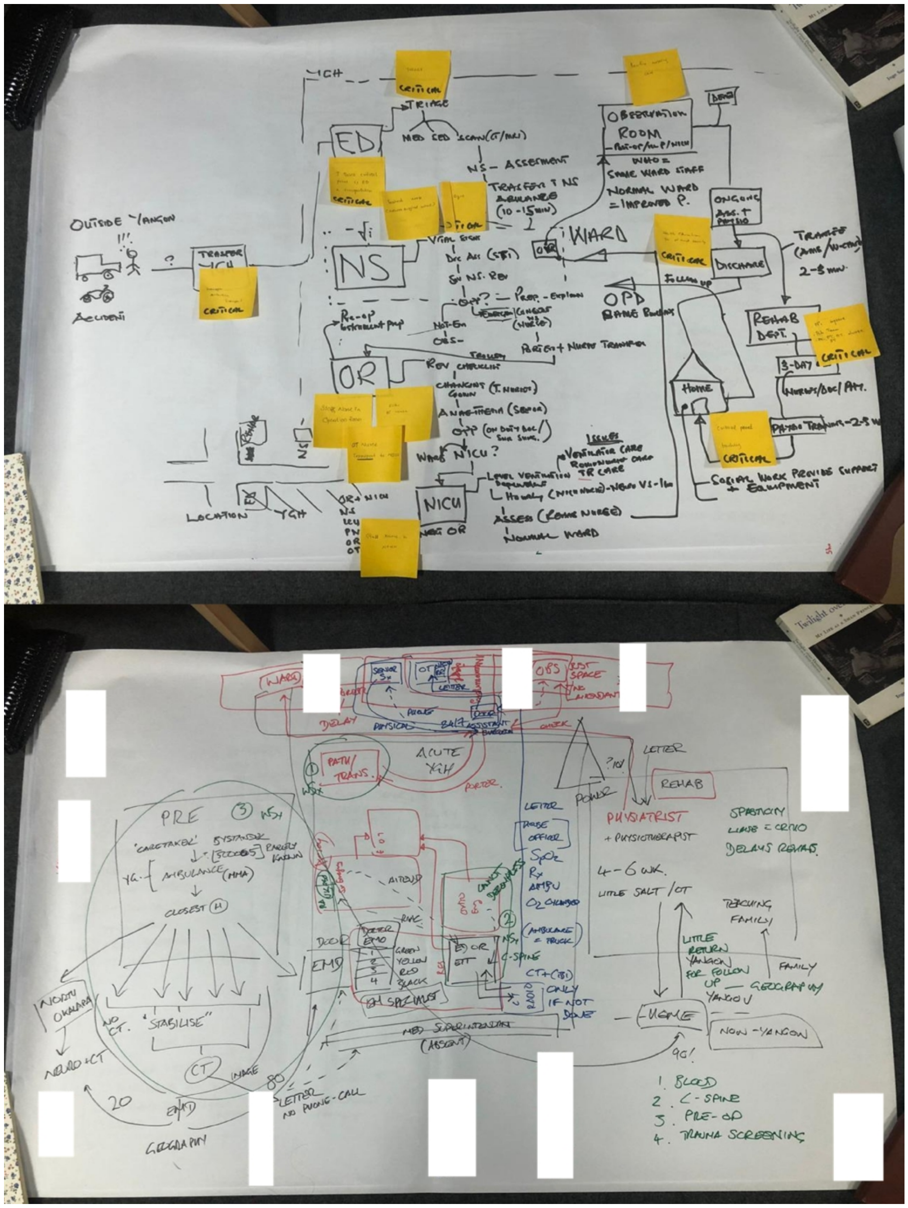
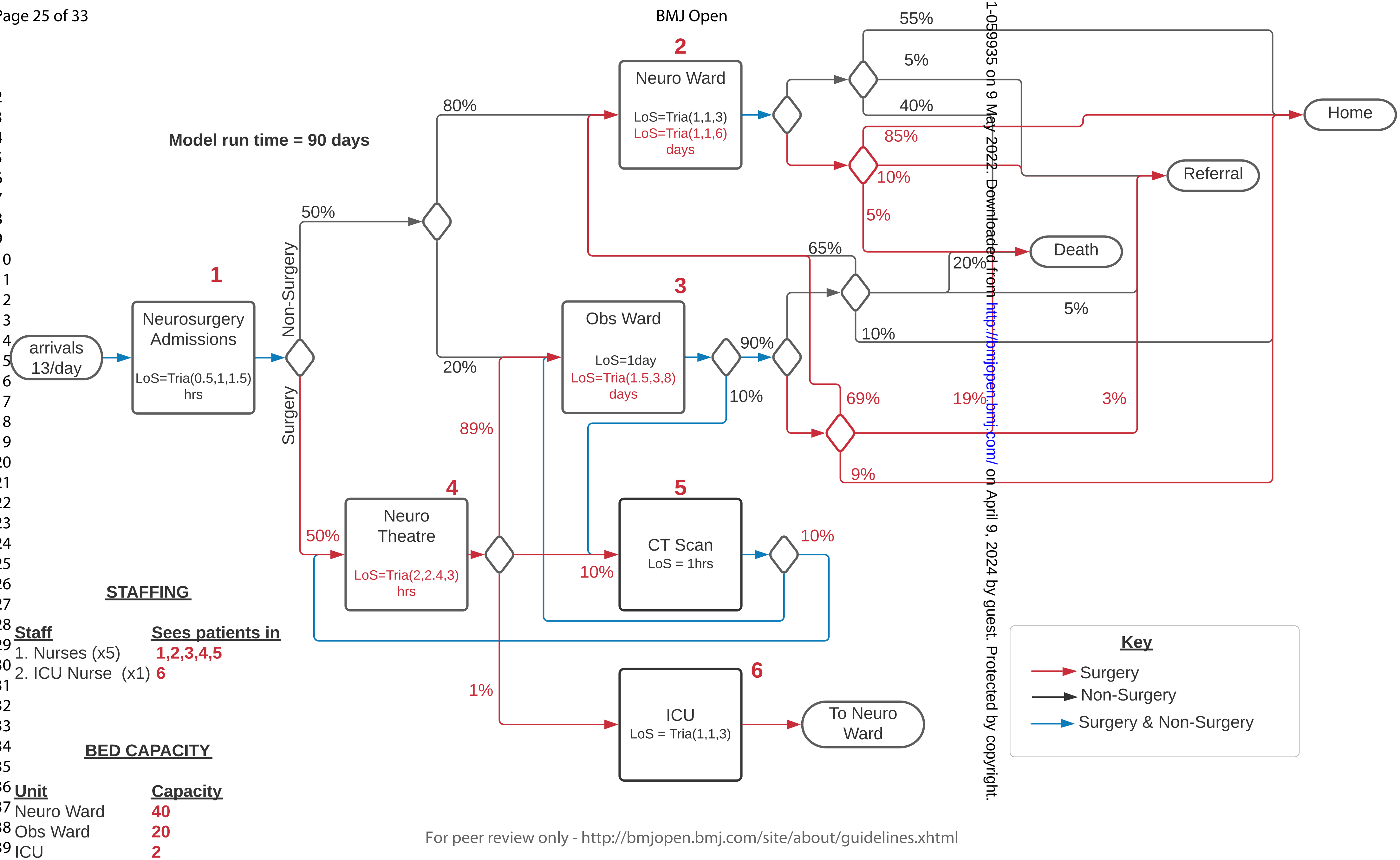


Figure 2. ‘Rich pictures’ generated by workshop data (reproduced from Bashford 2021 with permission of the author, with participant names redacted)

338x451mm (300 x 300 DPI)


Model run time = 90 days
arrivals 13/day
1
Neurosurgery Admissions
LoS=Tria(0.5,1,1.5) hrs
Non-Surgery
Surgery
50%
80%
20%
2
Neuro Ward
LoS=Tria(1,1,3)
LoS=Tria(1,1,6) days
55%
5%
40%
85%
10%
5%
Home
Referral
Death
65%
20%
5%
10%
3
Obs Ward
LoS=1day
LoS=Tria(1.5,3,8) days
90%
10%
69%
19%
3%
9%
89%
4
Neuro Theatre
LoS=Tria(2,2.4,3) hrs
50%
10%
1%
5
CT Scan
LoS = 1hrs
10%
6
ICU
LoS = Tria(1,1,3)
To Neuro Ward
Key
Surgery
Non-Surgery
Surgery & Non-Surgery
STAFFING
Staff
Sees patients in
1. Nurses (x5)
1,2,3,4,5
2. ICU Nurse (x1)
6
BED CAPACITY
Unit
Capacity
Neuro Ward
40
Obs Ward
20
ICU
2

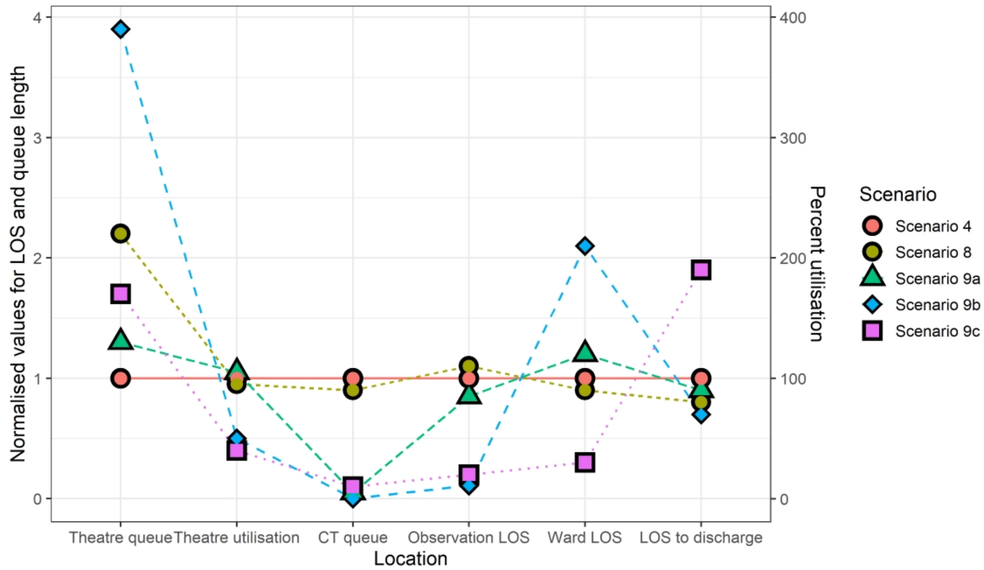


Figure 4 illustrates the effects of changing staff priorities on the patient load in different locations. To improve CT flow in a high patient volume scenario (Scenario 4) we adjusted the CT capacity (Scenario 8) or the nursing staff task priorities (Scenario 9a – priority to CT, Scenario 9b – priority to CT and observation ward, Scenario 9c priority to CT, observation and neuro ward). The figure shows the queues waiting for theatre, CT and the observation ward, the LOS for neuro ward and to discharge with the values normalised to Scenario 4. Additionally, we show percent theatre utilisation. The locations are arranged in the order of patient flow.

304x177mm (300 x 300 DPI)

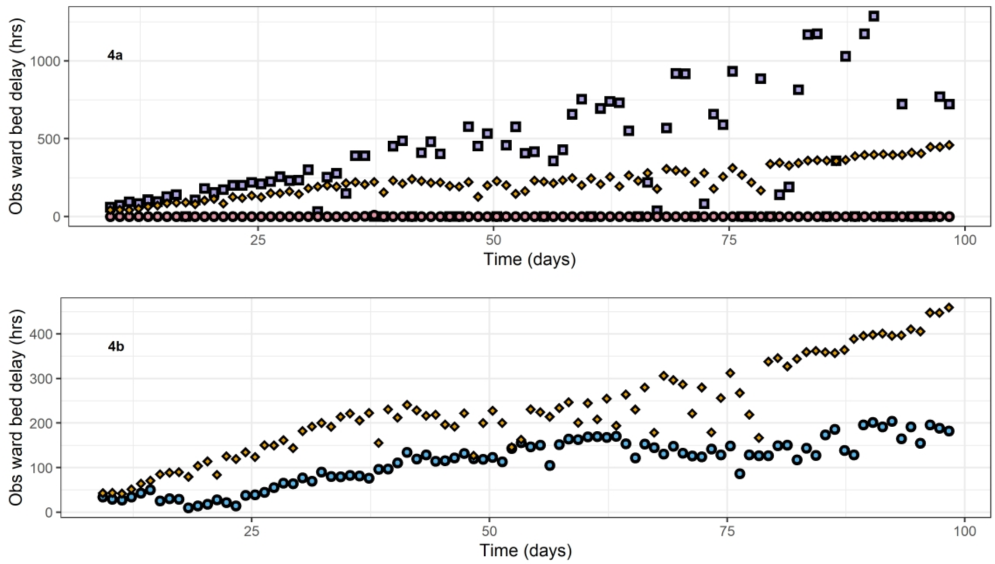


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Figure 5b: Illustrates the effect of varying patient arrival rate. With increased arrivals the waiting time for the observation ward bed increases. Again, in yellow is the baseline scenario 4 (15 patients/day), in blue we show scenario 7 (13 patients/day).

304x177mm (300 x 300 DPI)

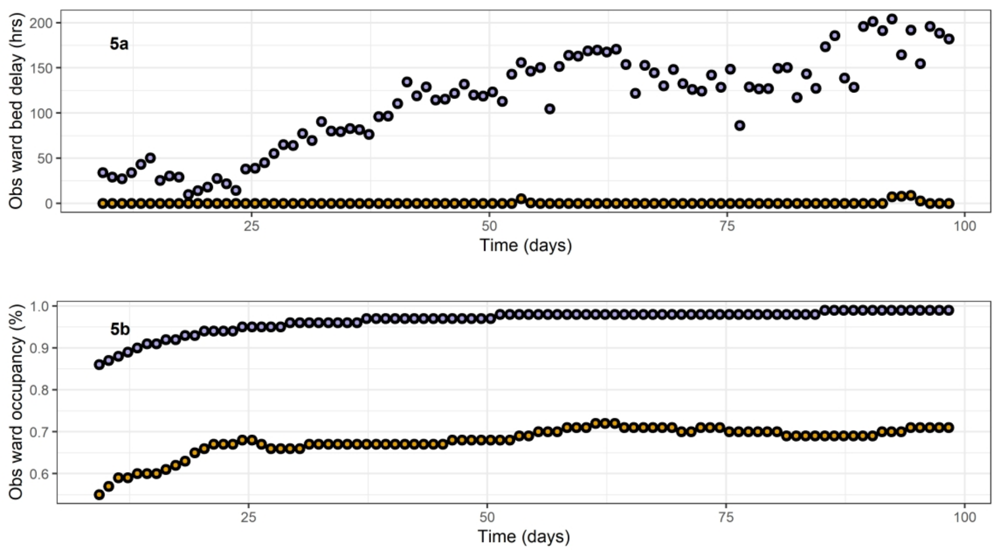

Figure 6: Illustrates the change in patient load on the observation ward when the capacity is increased. In purple is the baseline scenario 0 (20 beds) and in yellow scenario 6 (30 beds). Figure 5a shows the delay to an observation ward bed, 5b shows the observation ward occupancy through the simulation period. The moderate increase in bed capacity clearly reduces the pressure on observation ward beds.

304x177mm (300 x 300 DPI)

Good Reporting of A Mixed Methods Study (GRAMMS)

(1) Describe the justification for using a mixed methods approach to the research question

The study used a mixed method approach to explore the system of neurotrauma care. Mixed methods were employed to maximise the understanding of the system and allow development of a discrete-event simulation. Different aspects of the system were captured via different methods – the process and system structure, broad system understanding and staff/patient experiences were best explored with a participatory story-telling approach, but the specifics needed for fully populating the simulation were addressed with a quantitative prospective data collection. Extensive quantitative data collection was not a possibility and we show that a mixed methods approach can give a more comprehensive understanding compared to each method on their own.

Reasons for the mixed-methods approach are described in the last three paragraphs of the introduction.

(2) Describe the design in terms of the purpose, priority and sequence of methods

The initial methods employed were qualitative participatory methods to gain a broad expansive understanding of the system and its components. This was then supplemented by a smaller targeted quantitative data collection and analysis. The combination of data was used to design and populate the discrete event simulation and explore a range of scenarios.

Described in *Methods: Qualitative data*, *Methods: Quantitative data* and then *Methods: Model* building for the purpose, priority and sequence of methods.

(3) Describe each method in terms of sampling, data collection and analysis

Qualitative: Workshops and one-to-one interviews were conducted
Quantitative: One month prospective patient data collection by local staff, de-identified, analysed for resource usage and patient outcomes. Used to populate the discrete even simulation.

Described in the two subsections *Methods: Qualitative data* and *Methods: Quantitative data*

(4) Describe where integration has occurred, how it has occurred and who has participated in it

Integration of methods occurred in the analysis stage – to analyse the structure and load on the system. Additionally in the simulation stage results from the various methods were used to develop the scenarios.

Described in the results section In paragraph 2 and 3 – explaining the use of qualitative data to inform the simulation model structure and population.

(5) Describe any limitation of one method associated with the presence of the other method

The presence of the quantitative data collection may have reduced the richness and reported variability within the qualitative assessment of patient pathways. Due to structural limitations we only collected 1 month snapshot of quantitative data whereas the qualitative approach explored experiences that span significantly longer timescales and therefore contain more variability and circumstances.
Ideally we would have performed a model review with local stakeholders, but this was impossible due to the pandemic and political circumstances.

Limitations of the mixed method approaches and their influences are described in the 7th and 8th paragraph of the results section.

(6) Describe any insights gained from mixing or integrating methods

Stakeholder data can be supplemented with a quantitative survey to allow for balancing of experiences. Quantitative data collection in a low-resource setting with limited data fields is not sufficient to gain an understanding of the system, the importance of a stakeholder based process map and local knowledge are essential in designing a simulation.

Described in the first paragraph of the conclusions.

Good Reporting of A Mixed Methods Study (GRAMMS)

1. Describe the justification for using a mixed methods approach to the research question

This study seeks to understand traumatic brain injury (TBI) care in Yangon, Myanmar, and explore specific potential improvements to that care. TBI care is a complex process involving an array of people, processes, and institutions. Furthermore, this research was conducted by an international research team with complicating issues around culture, language, and clinical experience in the setting under study.

Improving complex systems first requires an understanding of the system of interest. Qualitative techniques facilitate a rich understanding of the system, from the perspectives of a range of stakeholders. However the exploration of tangible interventions requires predictive quantitative models. In order for these models to be representative of the lived experience of stakeholders, the qualitative and quantitative aspects need to be tightly integrated. This study selected a mixed methods approach in order to focus the rich, contextual insights provided by qualitative study toward specific, discrete, interventions which can be modelled using quantitative techniques.

2. Describe the design in terms of the purpose, priority and sequence of methods

Mixed methods were employed to maximise the understanding of the system and allow the development of a discrete-event simulation based on lived experience. Different aspects of the system were captured via different methods – the process and system structure, broad system understanding and staff/patient experiences were best explored with a participatory storytelling approach, but to explore specific areas for improvement a discrete event simulation model was selected. Participatory diagramming was used to bridge the gap between these two, allowing a system architecture to be co-created by participants as opposed to being imposed by the research team. This architecture was then populated with a prospectively collected dataset, a model built and then refined with the research team in light of the initial narrative analysis. In this way qualitative exploration was used to frame, bound, and understand the quantitative model derived.

The design of this study follow the systems approach outlined by the Royal Academy of Engineering, the Royal College of Physicians and the Academy of Medical Sciences in their 2017 report *Engineering Better Care* (www.raeng.org.uk/publications/reports/engineering-

better-care). This approach can be defined as a series of questions, which were addressed by the different aspects of this integrated mixed methods design. Broadly, the quantitative and qualitative components addressed the following questions:

Narrative analysis and participatory diagramming: *Who will use the system? Where is the system? What affects the system? Who are the stakeholders? What are the elements? What are the needs?*

Discrete Event Simulation: *How does the system perform? What is going on? What could go wrong? How can we make it better? How can the needs be met? How well are the needs met?*

3. Describe each method in terms of sampling, data collection and analysis

Qualitative data

A combination of narrative data supplemented by participatory diagramming was used to understand the lived experience of research participants. This was based upon the Soft Systems Methodology (SSM), adapted for use by a multiprofessional, cross-cultural research team. (17) Narrative inquiry and SSM are positioned within a constructivist paradigm in which the data are co-created by the research team and research participants. The data is a function of the context in which it is created, both on the micro (individual conversation) and macro (society, culture, and language) levels. The research team consisted of both UK and Burmese researchers, trained in the *Engineering Better Care* systems approach, SSM, narrative, and diagramming techniques, and with an expert knowledge of the clinical context under study.

A half-day workshop was held in February 2019 at YGH which was attended by 40 participants including neurosurgeons, neurosurgical nursing staff (ward and theatres), anaesthetists, emergency physicians, and physiatrists. Participants were grouped by both clinical speciality and seniority to encourage active participation and story-sharing, and facilitated in a mixture of Burmese and English by members of the research team. During the workshop, participants were encouraged to create visual maps of their accounts, identifying a mixture of physical structures, clinical processes, patient flow, and lines of communication. These visual maps were often supplemented by numerical figures to reinforce particular points.

Subsequently, two members of the research team (SW and PPNM) conducted 64 one-on-one interviews with a range of stakeholders including patients and their relatives, physicians, surgeons, nursing, and auxiliary staff. These interviews were again structured to encourage story-telling and the elicitation of individual narratives, using a combination of audio recording, note-taking, and participatory diagramming to capture these accounts. These interviews were conducted in Burmese, anonymized at source, and then professionally translated and transcribed.

Both the workshop and subsequent interviews were loosely structured to encourage the elicitation of rich narratives, rather than to address preconceived questions. Facilitators and interviewers referred to the questions posed in *Engineering Better Care* to help guide the discussions, and sought to explore habitual, exceptional, and hypothetical narratives to gain an understanding of the lived experience of respondents. At the same time, techniques of participatory diagramming and graphical elicitation were used to help interviewers and respondents structure this data during the course of the workshop and interviews, with the aim of prompting new insights, clarifying terms, and creating a mutual understanding of the narratives being related.

The resulting qualitative dataset was imported into proprietary software (ATLAS.ti v8 Mac, Scientific Software Development GmbH). Narratives were analysed to identify key areas of concern, along with the development of a consensus understanding of the system features which were central to these: the boundary of the system under study, its physical components and their orientation to each other, the key clinical processes occurring within the system, and the flow of patients through it. A formal thematic analysis of the dataset was not conducted as part of this study.

Quantitative

This qualitative systems model informed the subsequent collection of prospective, targeted, quantitative clinical data. One of the research team (SW) collected a dataset of demographic, inpatient location, discharge destination, and outcome data over a one month period in February 2020. All neurotrauma admissions to the YGH neurosurgical unit who went on to receive a neurosurgical intervention were included, with collection of initial and subsequent Glasgow Coma Scores (GCS) as a measure of outcome.

Model building

Using a combination of the data from the two initial phases, a discrete event simulation was developed to represent a simplified model of the neurotrauma system at YGH. The focus of

the model was on the pre- and post-operative care pathways of the neurotrauma patients including a model of the resource requirements. This focus was grounded in the narrative accounts, which indicated these stages as being the key determinants of overall patient outcome.

The qualitative data was used to structure the care pathway, with the quantitative information used to describe the distributions of resource usage, length of stay and discharge destination of patients moving along specific pathways. The model was developed iteratively using the software package Anylogic (university edition, The Anylogic Company, 2016 v7.3.7). The model was verified through an iterative development process involving the research team members, and critiqued against the existing literature.

4. **Describe where integration has occurred, how it has occurred and who has participated in it**

Integration of methods in this study occurs throughout the philosophy, design and delivery of the research programme. Narrative elicitation, participatory diagramming, and discrete event simulation were all selected due to their epistemological pedigree in understanding complex systems. As such, they represent an integrated suite of approaches by which the *Engineering Better Care* systems approach may be enacted. Narrative elicitation and participatory diagramming were themselves distilled out of the Soft Systems Methodology to better suit a cross-cultural research team. The use of systems thinking as an overarching framework allowed the qualitative work, situated withing a constructivist paradigm, to be then integrated into a more positivist quantitative paradigm. Discrete event simulation provides an accessible graphical interface by which results of the model can be reintegrated into the qualitative data for validation and verification. It might be concluded that the images used in both cases provide the methodological interface between the different methods and their philosophical bases.

5. **Describe any limitation of one method associated with the presence of the other method**

In general, narrative elicitation sits within a constructivist philosophy in which data is co-created between research participants and the researchers. Knowledge is made and remade within the discussion, and no boundaries are placed upon the data created other than those which arise from the interaction of the two. However, the desire to frame this project with a

systems thinking framework, and to employ a quantitative technique to explore system improvements, necessarily biased the narratives toward describing a system. This is a conceptual framework which comes from the research team as opposed to the participants. A series of conceptual devices was then used to abstract this narrative data to render it suitable for modelling: participatory diagramming provided a constructivist approach to describing system architecture which was then further abstracted to build the discrete event simulation. This simulation was then populated with a limited dataset and built to explore those concepts deemed by the research team to represent tangible improvement opportunities within the neurosurgical service.

This approach then bounds both the qualitative and quantitative methodologies on order for them to integrate with each other – the qualitative sacrifices richness and nuance, while the quantitative sacrifices data.

6. Describe any insights gained from mixing or integrating methods

The integration of methods show how it is possible to bridge both methodological and philosophical positions using the overarching concept of systems thinking, and the device of imagery to describe the system under study. Pragmatically, the qualitative data suggested specific areas for improvement in TBI care in Yangon – access to CT scanning and observation ward beds – which could then be modelled using the discrete event simulation. Modelling suggested that while CT access becomes a bottleneck at increasing patient loads, this may be improved by changing the prioritisation of nursing staff but not by increasing the number of patients which the CT scanner can accommodate. However this comes at a cost to other areas of the system, which then show increased queuing times. These insights suggest that increasing overall nursing numbers sits on the critical path to improving CT access, and the simply investing in a further scanner may not deliver the looked-for benefits. Similarly, the simulation suggests that while an increase in the number of observation ward beds does alleviate the queuing seen with high patient numbers, the need for expansion is bounded with ten beds completely reliving queuing and no further benefit seen beyond this. These are powerful insights into system function with real-world impacts on potential resource allocation in an impoverished healthcare system.

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A systems approach to improving traumatic brain injury care in Myanmar: a mixed-methods study from lived experience to discrete event simulation

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Complete List of Authors:	Kohler, Katharina; University of Cambridge, Division of Anaesthesia, Department of Medicine Nwe Myint, Phyu Phyu ; University of Cambridge, Department of Clinical Neurosciences, Box 165 Wynn, Sein; University of Medicine I, Department of Neurosurgery Komashie, Alexander; University of Cambridge School of Technology, Engineering Design Centre, Department of Engineering; THIS Institute Winters, Robyn; Cambridge University Hospitals NHS Foundation Trust, Neurocritical Care Unit Thu, Myat; University of Medicine I, Department of Neurosurgery Naing, Mu Mu; University of Medicine I, Department of Intensive Care Hlaing, Thinn; THET, Myanmar Country Director Burnstein, Rowan; Cambridge University Hospitals NHS Foundation Trust, Department of Anaesthesia Wai Soe, Zaw; University of Medicine I, Rector Clarkson, John; University of Cambridge School of Technology, Department of Enginering Menon, David; University of Cambridge, Division of Anaesthesia, Department of Medicine Hutchinson, Peter; NIHR Global Health Research Group for Neurotrauma, University of Cambridge Bashford, Tom; University of Cambridge , NIHR Global Health Research Group for Neurotrauma
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A systems approach to improving traumatic brain injury care in Myanmar: a mixed-methods study from lived experience to discrete event simulation

Corresponding author:
Katharina Kohler * – kk371@cam.ac.uk
Division of Anaesthesia, Department of Medicine, University of Cambridge, Box 93, Hills Road, Cambridge CB2 0QQ, UK

Further authors:
Phyu Phyu Nwe Myint *
Department of Clinical Neurosciences, Box 165, Addenbrooke's Hospital, Hills Road, Cambridge CB2 0QQ, UK

Sein Wynn
Department of Neurosurgery, University of Medicine 1, 245 Myoma Kyaung Street, Lanmadaw Township, Yangon, Myanmar.

Alexander Komashie
Engineering Design Centre, Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, UK

The Healthcare Improvement Studies (THIS) Institute, University of Cambridge, Clifford Allbutt Building, Cambridge CB2 0AH, UK

Robyn Winters
Neurocritical Care Unit (NCCU), Addenbrooke's Hospital, Hills Road, Cambridge CB2 0QQ, UK

Myat Thu
Department of Neurosurgery, University of Medicine 1, 245 Myoma Kyaung Street, Lanmadaw Township, Yangon, Myanmar.

Mu Mu Naing
Department of Anaesthesia, University of Medicine 1, 245 Myoma Kyaung Street, Lanmadaw Township, Yangon, Myanmar.

Thinn Thinn Hlaing
THET Myanmar, c/o THET, 1 St. Andrews Place Regent's Park, London NW1 4LE, UK

Rowan M Burnstein
Department of Anaesthesia, Addenbrooke's Hospital, Hills Road, Cambridge CB2 0QQ, UK

Zaw Wai Soe

University of Medicine 1, 245 Myoma Kyaung Street, Lanmadaw Township, Yangon, Myanmar.

P John Clarkson
Engineering Design Centre, Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, UK

David K Menon
Division of Anaesthesia, Department of Medicine, University of Cambridge, Box 93, Hills Road, Cambridge CB2 0QQ, UK

Peter JA Hutchinson
Academic Division of Neurosurgery, Box 167, Addenbrooke's Hospital, Hills Road, Cambridge CB2 0QQ, UK

Tom Bashford
Division of Anaesthesia, Department of Medicine, University of Cambridge, Box 93, Hills Road, Cambridge CB2 0QQ, UK.
Engineering Design Centre, Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, UK

*Joint first author

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Tables: 1
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Abstract

Objectives

Traumatic brain injury (TBI) is a global health problem, whose management in low resource settings is hampered by fragile health systems and lack of access to specialist services. Improvement is complex, given the interaction of multiple people, processes, and institutions. We aimed to develop a mixed-method approach to understand the TBI pathway based upon the lived experience of local people, supported by quantitative methodologies, and to determine potential improvement targets.

Design

We describe a systems approach based on narrative exploration, participatory diagramming, data collection, and discrete event simulation (DES), conducted by an international research collaborative.

Setting

The study is set in the tertiary neurotrauma centre in Yangon General Hospital, Myanmar, in 2019 – 2020 (prior to the SARS-CoV2 pandemic).

Participants

The qualitative work involved 40 workshop participants and 64 interviewees to explore the views of a wide range of stakeholders including staff, patients and relatives. The one-month retrospective admission snapshot covered 85 surgical neurotrauma admissions.

Results

The TBI pathway was outlined, with system boundaries defined around the management of TBI once admitted to the neurosurgical unit. Retrospective data showed 18% mortality, 71% discharge to home, and an 11% referral rate. DES was used to investigate the system, showing its vulnerability to small surges in patient numbers, with critical points being CT scanning and observation ward beds. This explorative model indicated that a modest expansion of observation ward beds to 30 would remove the flow-limitations and indicated possible consequences of changes.

Conclusions

A systems approach to improving TBI care in resource-poor settings may be supported by simulation and informed by qualitative work to ground it in the direct experience of those involved. Narrative interviews, participatory diagramming, and DES represent one possible suite of methods deliverable within an international partnership. Findings can support targeted improvement investments despite co-existing resource limitations while indicating concomitant risks.

Strengths and limitations of this study

- This study demonstrates the value of combing discrete event simulation (DES) and narrative-driven participatory diagramming for understanding care pathways in a global health context.
- Narrative enquiry provided a participatory method for data creation which balances power between actors, providing robust qualitative data to inform the development of quantitative DES models.
- The DES model allowed the exploration of a range of scenarios to help understand the impact of key resources on clinical outcomes.
- The combined effects of the SARS CoV2 pandemic and the current pollical climate in Myanmar made it impossible to subsequently validate the model outside of the international research team.
- Quantitative simulation models only account for a limited perspective, with the results requiring careful contextualisation before being used to change clinical practice.

Introduction

Traumatic brain injury (TBI) is a global public health issue, with the 2017 Lancet Commission on Traumatic Brain Injury (LNCTBI) estimating that over half of the world's population will suffer a TBI within their lifetime. (1) TBI is a particular problem in low- and middle-income countries (LMIC) where increasing automobile use, poor regulatory frameworks, and fragile health systems combine to provide not only an increasing risk of TBI, but an environment in which the pre- intra- and post- hospital care which TBI requires cannot be provided. (2)

At the core of TBI management is the provision of surgical intervention, itself a challenge in many LMICs. The 2015 Lancet Commission on Global Surgery found that over 5 billion of the world's population lack access to safe, affordable, timely surgical care, and that surgery itself requires a functional healthcare system to support it. (3) In addition, TBI care depends on time-critical investigations, such as CT scans, which can also be a challenge to access without delay in resource poor environments. The effects of delay are consistent with the known pathophysiology of secondary brain injury and experience from other studies which suggest that delay remains a key determinant of outcome in TBI (1).

The management of TBI is complex and difficult to characterise. (4) While epidemiological studies have been conducted to explore the global picture, mapping practice at the level of the institution to drive service improvement remains a challenge. (5) This is exacerbated in settings which have low levels of routine data collection, or a lack of established clinical and organisational protocols and care pathways. One conceptual framework which has been advocated to help understand the complex environment of clinical care is systems thinking; either as a standalone device or as part of an established corpus of knowledge such as systems engineering. This has been applied in many settings through a variety of methodological approaches and is advocated by the World Health Organisation (WHO) as an approach for understanding healthcare. (6) One model for taking a systems approach to healthcare improvement is described in the 2017 report *Engineering Better Care*, which presents a recursive series of questions to be answered as part of such an approach, and which has been explicitly explored within the context of global health. (7,8)

Accurate and complete quantitative data collection is often considered a prerequisite for operational systems modelling. While data collection and analysis have been shown to be feasible in low- and middle-income countries, there are significant limitations in data collection associated with resource limited settings. (9) This contrasts with high-income settings where electronic health records, implemented to facilitate clinical care, may provide data for operational research and systems analysis. (10) More participatory approaches, such as process mapping, have been described to improve surgical care but these do not have the power of quantitative models. (11)

Healthcare system modelling using discrete event simulation (DES) is a common approach in operational research, supported by quantitative data in combination with local knowledge. It has been shown to be a useful tool to model a complex system and investigate the potential effects of resource reallocation or improvements. (12) However, extension of this type of modelling into LMIC healthcare systems has been sparse to date, with a few notable exceptions. (13,14) The success of DES depends on an appropriate representation of the system to be modelled and its applicability can be limited if the system is not well represented or described.

We describe a mixed-methods systems approach to understanding TBI care in a tertiary neurosurgical centre in Myanmar, to demonstrate the feasibility and utility of this approach to a resource-limited tertiary neurosurgical centre with a significant burden of TBI. This study is the product of an academic institutional health partnership combining the Cambridge Yangon Trauma Intervention Project (CYTIP) and the NIHR Global Health Research Group on Neurotrauma. (15)

Methods

Setting

The study was conducted across 2019-2020, prior to the SARS CoV2 global pandemic, in Yangon General Hospital (YGH), Myanmar. YGH is a tertiary neurotrauma referral centre in Myanmar receiving both local and regional patients and which functions as both the local and national trauma centre. It has a recently established Emergency Department and provides a comprehensive array of surgical services. The neurosurgical centre is physically distant from the main hospital campus, with patients requiring transfer between the two sites. We employed an integrated mixed-methods approach based upon narrative analysis, participatory diagramming, targeted prospective data collection, model refinement, and then model validation and verification. Nested within a wider academic partnership, this work is reported against the Good Reporting of a Mixed Methods Study (GRAMMS) criteria. (16)

Patient and public involvement

This works forms part of a portfolio of research funded by the NIHR Global Health Research Group on Neurotrauma (https://neurotrauma.world), who have partnered with patient representatives in both the UK and around the world to understand the consequences of TBI and set research priorities. This partnership informed the initial study design of this project. In Myanmar we were unable to identify specific patient groups or representatives pertinent to TBI care, and instead chose a participatory research design to include their perspectives within the formal data collection. While this meant patients and the public were not engaged at the outset of the study, the snowball participant sampling allowed them to identify further research participants and shape both the design and findings of the study. Similarly, the choice of narrative methodology allowed patient and public respondents to shape the research data in partnership with the research team. The intention of the research team was to use further patient and public work to understand how the research findings might best be shared with communities, but the cessation of research activity due to the SARS CoV2 pandemic and political events in Myanmar made this latter stage unworkable.

Ethical approval

This work has ethical approval from the Institutional Review Board of the Government of the Republic of the Union of Myanmar Federal Ministry of Health and Sports, Department of Medical Research (Ethics/DMR/2019/082). It also has approval from the University of Cambridge School of Humanities and Social Sciences Ethics Committee (18/181) and is sponsored by the University of Cambridge.

Qualitative data

A combination of narrative data supplemented by participatory diagramming was used to understand the lived experience of research participants. This was based upon the Soft Systems Methodology (SSM), adapted for use by a multiprofessional, cross-cultural research team. (17) Narrative inquiry and SSM are positioned within a constructivist paradigm in which the data are co-created by the research team and research participants. The data is a function of the context in which it is created, both on the micro (individual conversation) and macro (society, culture, and language) levels. The research team consisted of both UK and Burmese researchers, trained in the *Engineering Better Care* systems approach, SSM, narrative, and diagramming techniques, and with an expert knowledge of the clinical context under study.

A half-day workshop was held in February 2019 at YGH which was attended by 40 participants including neurosurgeons, neurosurgical nursing staff (ward and theatres), anaesthetists, emergency physicians, and physiatrists. All participants provided written informed consent. Participants were grouped by both clinical speciality and seniority to encourage active participation and story-sharing and facilitated in a mixture of Burmese and English by members of the research team. During the workshop, participants were encouraged to create visual maps of their accounts, identifying a mixture of physical structures, clinical processes, patient flow, and lines of communication. These visual maps were often supplemented by numerical figures to reinforce particular points.

Subsequently, two members of the research team (SW and PPNM) conducted 64 one-on-one interviews with a range of stakeholders including patients and their relatives, physicians, surgeons, nursing, and auxiliary staff. Again, participants provided written informed consent and were selected through purposive snowball sampling to explore as wide a range of stakeholders' views as possible. Children and those unable to provide written informed consent were excluded. These interviews were again structured to encourage story-telling and the elicitation of individual narratives, using a combination of audio recording, note-taking, and participatory diagramming to capture these accounts. These interviews were conducted in Burmese, anonymized at source, and then professionally translated and transcribed.

Both the workshop and subsequent interviews were loosely structured to encourage the elicitation of rich narratives, rather than to address preconceived questions. Facilitators and interviewers referred to the questions posed in *Engineering Better Care* (**Figure 1**) to help guide the discussions, and sought to explore habitual, exceptional, and hypothetical narratives to gain an understanding of the lived experience of respondents. (18) Prompting questions for these narratives included broad questions such as "what does a normal day look like?", "what is the best experience you have had?", "what was the worst case you have ever seen?". However, interviewers were encouraged to use a variety of approaches to encourage rich and reflective narratives, including sharing personal stories and observations. No fixed interview schema was used, with an emphasis placed on the quality of the data created, rather than its reproducibility. At the same time, techniques of participatory diagramming and graphical elicitation were used to help interviewers and respondents structure this data during the workshop and interviews, with the aim of prompting new insights, clarifying terms, and creating a mutual understanding of the narratives being related. (19)

The resulting qualitative dataset was imported into proprietary software (ATLAS.ti v8 Mac, Scientific Software Development GmbH). Narratives were analysed to identify key areas of concern, along with the development of a consensus understanding of the system features which were central to these: the boundary of the system under study, its physical components and their orientation to each other, the key clinical processes occurring within the system, and the flow of patients through it. A formal thematic analysis of the dataset was not conducted as part of this study.

Quantitative

This qualitative systems model informed the subsequent collection of prospective, targeted, quantitative clinical data. One of the research team (SW) collected a dataset of demographic, inpatient location, discharge destination, and outcome data over a one-month period in February 2020. All neurotrauma admissions to the YGH neurosurgical unit who went on to receive a neurosurgical intervention were included, with collection of initial and subsequent Glasgow Coma Scores (GCS) as a measure of outcome.

Model building

Using a combination of the data from the two initial phases, a discrete event simulation was developed to represent a simplified model of the neurotrauma system at YGH. The focus of the model was on the pre- and post-operative care pathways of the neurotrauma patients including a model of the resource requirements. This focus was grounded in the narrative accounts, which indicated these stages as being the key determinants of overall patient outcome.

The qualitative data was used to structure the care pathway, with the quantitative information used to describe the distributions of resource usage, length of stay and discharge destination of patients moving along specific pathways. The model was developed iteratively using the software package Anylogic (university edition, The Anylogic Company, 2016 v7.3.7). The model was verified through an iterative development process involving the research team members, and critiqued against the existing literature.

Results

Qualitative data

Responses from the 104 respondents (40 workshop participants and 64 interviewees) were supplemented with interview data from workshop facilitators and members of the research team, and combined with field notes and written reflections into a single dataset. The workshops resulted in the creation of meta-narratives constructed as complex images which conveyed a range of information including physical infrastructure, patient flow, clinical decision making, investigations, and clinical interventions. These were closely allied to the 'rich pictures' created when using SSM **(Figure 2)**. The interview data consisted predominantly of either verbal narratives or co-created process flow diagrams.

From these, a formal system structure was synthesized, bounded within the neurosurgical unit and focusing on nodes consisting of neurosurgery admissions, the observation wards, the neurosurgery theatres, the CT scanner, the neuro-intensive care unit, and the neurosurgical wards. This boundary was chosen to facilitate targeted quantitative data collection, but also due to the expertise of the Burmese research team being biased toward this area of the hospital. A patient flow logic model was then superimposed upon these, with outputs chosen as discharge, referral to another centre, or death (**Figure 3**).

Quantitative data

The quantitative data showed 83 admissions with a median age of 33.4 years (range 11 to 66 years). The median length of stay was 3.8 days (range 1-18 days). There was a 18% mortality, 71% discharge to home with an 11% referral rate to another department or hospital upon discharge. This population information was used to inform the static distributions of patient flow in the simulation, as shown in figure 3.

The mean admitting GCS was 10.8 (range 3 to 15) and the mean discharge GCS was 12.6 (range 3 to 15). Six patients were transferred intubated from ED to the neurosurgery department. Location data collected was consistent with the qualitative system mapping, with the most reported locations being the admission unit, observation ward, neurosurgical ward (male and female), neurosurgery theatres and referral destinations. The initial admitting location for the surgical patients was the observation ward with almost all patients (98%) staying for at least 2 days before being transferred to the general neurosurgical ward.

Discrete event simulation

The DES model was structured using the model in figure 3 to explore key activities in a patient's journey from arrival at neurosurgery admissions to discharge home, referral to another hospital, or death. All processing times were modelled as triangular distributions to take account of variations and uncertainty in both the process and data. The distributions were developed based on quantitative information and expert experience. Two separate patient groups were identified - surgical and non-surgical treatment streams - that share the same resources but were assigned different distributions and care pathways.

The narrative data identified two key areas as bottlenecks in patient flow: the availability of CT scanning (a time-critical investigation for neurosurgical patients), and the occupancy of observation ward beds. These were subsequently used as the main targets to investigate through DES. These were explored across a range of patient flows to explore the resilience of the system to sudden changes in surgical burden.

The simulation was run with a warm-up period of 200 hours and over a period of 90 days. In addition to the three kinds of discharge from the system - home, referral and death - the model reported outputs on queue lengths, waiting times and resource utilisation in selected areas (Scenarios summarised in **Table 1**).

Scenario	Patient arrival	Percentage of	Observation	Additional

number	rate	surgical patients	ward capacity	changes
0 (baseline)	13	50	20	-
1	8	20	20	-
2	8	80	20	-
3	15	20	20	-
4	15	80	20	-
5	15	80	30	-
6	13	50	30	-
7	15	50	20	-
8	15	80	20	Increased CT capacity to 2/slot
9a	15	80	20	Priority: CT
9b	15	80	20	Priority: CT & observation ward
9c	15	80	20	Priority: CT & observation & neuro ward

Table 1: Description of the scenarios used to explore the system. Three main variables were modified and the effects investigated. Additional improvement possibilities were explored in Scenario 8 and 9a-c.

Insights from the narrative data led to a decision to explore the effects of changing the admission rate, the percentage of surgical patients, the capacity of the observation ward, and the availability of CT scanning. CT availability was explored by both increasing the capacity of available scanners (increasing from one patient per two-hour time window to two patients per two-hour time window) and by increasing the priority of access to nursing staff for accompanying CT transfers, observation ward and neuro ward. In all, nine scenarios were developed including the baseline. Scenario 9 involved three variations testing different levels of priority access to nursing staff. For model validation, the results of length of stay from the model were within the range of 1 to 21 days estimated by Rock *et al* (20) based on empirical data from across Myanmar and consistent with clinical experience and the quantitative dataset.

The queue to access CT was modelled assuming a 2-hour round-trip based on local experience, with each patient requiring a single nurse escort. In scenario 4 – a high patient volume scenario – we found the wait to access a time-critical CT increased to clinically unacceptable levels of several hours in keeping with the narrative accounts. We explored two potential improvement strategies for reducing wait for CT: increasing the number of patients that can go at the same time to 2 (Scenario 8) and increasing the priority of CT scanning within the tasks for the available nursing staff (Scenario 9a-c).

We found that scenario 8 did not resolve the CT capacity problems with the queue persisting at similar levels to scenario 4. The adjusted prioritisation scenarios where the availability of nurse escorts is increased (9a: CT main priority, 9b: CT and observation ward as priority, 9c: CT, observation ward and neuro wards as priority) resolved the CT queuing and allowed for timely CT processing. However, this impacted on other areas of care as illustrated in **Figure 4**, which shows system performance measures (such as length of stay and queuing) normalised to scenario 4. As an example, the effect of prioritising CT escorts and observation ward staffing in scenario 9b resulted in a long queue for theatres with reduced theatre occupancy and prolonged neuro ward length of stay, all due to the lack of available nursing staff to perform the necessary tasks. Similar complex system effects can be seen for scenario 9a and 9c where the delays have been diverted to admissions and theatres.

In addition to the CT bottleneck, the effect of changing patient numbers on the observation ward bed occupancy was investigated. **Figure 5a** illustrates the effects of a change in population characteristics by changing the percentage of patients classified as “surgical”. Scenario 4 (50% surgical patients) in black, scenario 3 (20% surgical patients) in blue, and scenario 7 (80% surgical patients) in red. The increased number of surgical patients with a longer stay on the observation ward care post-operatively results in an increase in the delay to access an observation ward bed. **Figure 5b** illustrates the effect of varying patient arrival rate. With increased arrivals the waiting time for the observation ward bed increases. In black is the baseline scenario 0 (13 patients/day), in blue is scenario 7 (15 patients/day). It is notable that with an increase in the arrival rate of just 2/day there is a significant increase in the waiting time for a bed, given that the observation ward occupancy is already >90% for the baseline scenario. These results were again consistent with local experience.

Consequently, a possible service change with a moderate expansion of the observation ward capacity from the baseline 20 beds to a potential 30 beds was explored. This was an illustrative change aiming to determine a potential alleviation of a bottleneck. The results are shown in **Figure 6**, with the baseline model (20 beds) shown in purple and scenario 6 (30 beds) in yellow. The delay to access an observation ward bed is shown in the top panel and the percentage occupancy in the bottom panel. The additional bed spaces resolved the near full capacity state of the observation ward and reduced the waiting time for a bed to negligible numbers.

Discussion

We describe a systems approach to understanding the care of neurosurgical patients in a resource-limited setting, based on a combination of qualitative exploration, prospective data collection, and discrete event simulation. The insights gained from this study are both practical and methodological. Practically, we show that changes in staffing allocation and observation ward capacity may improve patient flow despite co-existing resource limitations. Methodologically we show how a mixed-methods approach by a cross-cultural multiprofessional research team can deliver high quality systems modelling which is grounded in both the lived reality of local stakeholders, and in reliable prospectively acquired data.

Understanding healthcare from a systems perspective presents both conceptual and pragmatic challenges. These are best met by marrying robust qualitative and quantitative approaches, however achieving this in resource limited settings where clinical services are stretched and routine data collection may be impossible is challenging. In addition, much of the systems thinking literature comes from a canon of thought developed in high-income countries, and this may not translate readily to other cultures or languages. Indeed, the Burmese members of the research team found translation of the *Engineering Better Care* questions very challenging, both linguistically and conceptually. Furthermore, while the project was conceived within the Soft Systems Methodology, a constructivist approach grounded in systems thinking which has been applied to healthcare in a range of contexts, this was found to be a barrier to participatory research as the terminology and theory was found to be difficult to translate into Burmese.

As a result, the research approach we describe uses narrative as a tool for understanding lived experience to overcome some of these barriers. Storytelling is common to all human society and is a mechanism for people to both conceive and communicate complex ideas.(21) Combining this with participatory diagramming provides a natural form of data creation, without requiring local research partners to engage with complex theoretical models. Narrative research also encourages a degree of transformation on the part of the research team, as they elicit and assimilate a variety of stories from widely different viewpoints. In the words of one of the research team:

"When we started this research I thought that all of our problems came from a lack of resources. Now I can see so many things we can improve without waiting for more money."

The participatory diagramming also provides a starting point for the DES model which is grounded in the primary experience of the research participants, providing reassurance that the model is close to reality, and that the prospective data collected is parsimonious and of maximum utility. Structuring both of these with the systems approach articulated in *Engineering Better Care* provides a degree of methodological rigour and ensures that a focus on the function of the system as a whole, rather than discrete processes, remains at the heart of the data collection. Future work might benefit from a more structured interview tool to help combine narrative inquiry with the systems approach.

The discrete event simulation modelling facilitates the conversion of this rich narrative data into a more abstracted form, which can then be readily manipulated and used to predict changes to system behaviour within specific constraints. Consistent with the experience of the research team, our model explores the resource limitations around access to CT imaging and observation beds. However, the model challenges the narrative data, with access to CT scanning limited less by the access to CT machines, and more by the availability of nurse escorts. The model however agrees with the narrative report that nursing provision is stretched when patient volume increases and changing prioritisation of tasks only shifts the resulting delays to another care area. Similarly, the model indicates that while a modest expansion of observation beds improves patient flow, this does not scale indefinitely. Both insights have consequences for real-life improvement opportunities. Ideally, these insights would have been taken back through a process of qualitative exploration to better understand the findings, but both the SARS CoV2 pandemic and political events in Myanmar prevented this last phase of the research.

However, it is important to note that our DES model was created to look specifically at patient flow, again grounded in the reported experience that most patient complications arise from a delay to care. Traumatic brain injury, like other specific pathologies, is a time critical condition and it seems reasonable that delay is one of the key drivers of patient outcome.(22) However, any number of alternative models could be built to explore communication flow, institutional power, or clinical decision making. More complex concepts such as the quality of care are not addressed in our model. The provision of surgery may be considered at the interface of clinical need, access, and quality and our model currently explores only one of these dimensions. (23)

The DES model was developed to demonstrate the kinds of insight that are possible when the technique is combined with participatory systems mapping and the rich narrative data from qualitative methods. As a result, several assumptions were made that may be considered limitations of the model. For example, all Length of Stay (LoS) durations and processing times were modelled as triangular distributions in the absence of numerical data to allow theoretical curve-fitting. The triangular distribution is pragmatic, intuitive and effective in situations of insufficient numerical data (24). Another assumption made was the absence of priority in the allocation of nurses and beds. Patients were allocated these resources on a First Come First Served (FCFS) basis.

It is important to note that a variety of other models could have been built based upon our qualitative dataset. A different system boundary, such as that of the whole hospital as opposed to the neurosurgical unit, would have required different quantitative metrics and would have been much more complex to build. It would also have required a research team made of different clinical specialities to ground the qualitative and quantitative data within lived expert experience. However, the benefit of good early qualitative work is that it provides the opportunity to explore a variety of different future models, to address a wide range of clinical and operational improvement questions.

Conclusion

Traumatic brain injury is a growing burden in the global south, and efforts to improve care in this area are hampered by its complexity, a lack of access to the necessary services, and the delay this engenders.

Our mixed-methods systems approach which combines rigorous qualitative approaches with discrete event simulation allows for modelling firmly grounded in local context but informed by established mathematical theory. We demonstrate that such research can be carried out by a diverse research team based on the lived experience of a range of stakeholders. The resulting model retains validity when critiqued against this primary qualitative data, provides insights into resource limitations and specific targets for improvement and should be of value across a huge range of clinical and geographical contexts.

Contributors

TB, KK, AK, PPNM, SW, RMB, PJC contributed to the design of the research. TB, SW, PPNM, KK, AK, RW, RMB conducted the data collection, model design and analysis. MT, PJC, PJAH, ZWS aided with project management and data analysis. TB, KK, AK, PPNM took the lead in writing the manuscript. SW, MMN, MT, DKM, PJC and TTH discussed the results and contributed to the writing of the manuscript.

Competing interests

None declared.

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Data availability statement

Access to an anonymised, redacted dataset will be entertained upon reasonable request, but due to the sensitive nature data cannot be made publicly available.

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Figures:

Figure 1. A systems approach to health and care improvement framed as a series of recursive questions

Reproduced with permission from *Engineering Better Care*, Royal Academy of Engineering, 2017).

Figure 2. 'Rich pictures' generated by workshop data

Reproduced from Bashford 2021 with permission of the author, with participant names redacted).

Figure 3. DES model structure showing the variables, patient flow and proportions

The surgical patient pathway is denoted in red, the conservative/medical treatment pathway in black. Patients enter the DES on the left at "arrivals" and exit on the right into "Home", "Referral" or "Death".

Figure 4. Effects of changing staff priorities on the patient load in different locations

To improve CT flow in a high patient volume scenario (Scenario 4) we adjusted the CT capacity (Scenario 8) or the nursing staff task priorities (Scenario 9a – priority to CT, Scenario 9b – priority to CT and observation ward, Scenario 9c priority to CT, observation and neuro ward). The figure shows the queues waiting for theatre, CT and the observation ward, the LOS for neuro ward and to discharge with the values normalised to Scenario 4. Additionally, we show percent theatre utilisation. The locations are arranged in the order of patient flow.

Figure 5a. Effect of a change in population by changing the percentage of patients classified as "surgical"

The increased length of stay on the observation ward is seen as an increase in delay for observation ward bed access. In yellow scenario 4 (50% surgical patients), in pink scenario 3 (20% surgical patients) and in purple is scenario 7 (80% surgical patients).

Figure 5b. Effect of varying patient arrival rate

With increased arrivals the waiting time for the observation ward bed increases. Again, in yellow is the baseline scenario 4 (15 patients/day), in blue we show scenario 7 (13 patients/day).

Figure 6. Change in patient load on the observation ward when the capacity is increased

In purple is the baseline scenario 0 (20 beds) and in yellow scenario 6 (30 beds). Figure 5a shows the delay to an observation ward bed, 5b shows the observation ward occupancy through the simulation period. The moderate increase in bed capacity clearly reduces the pressure on observation ward beds.

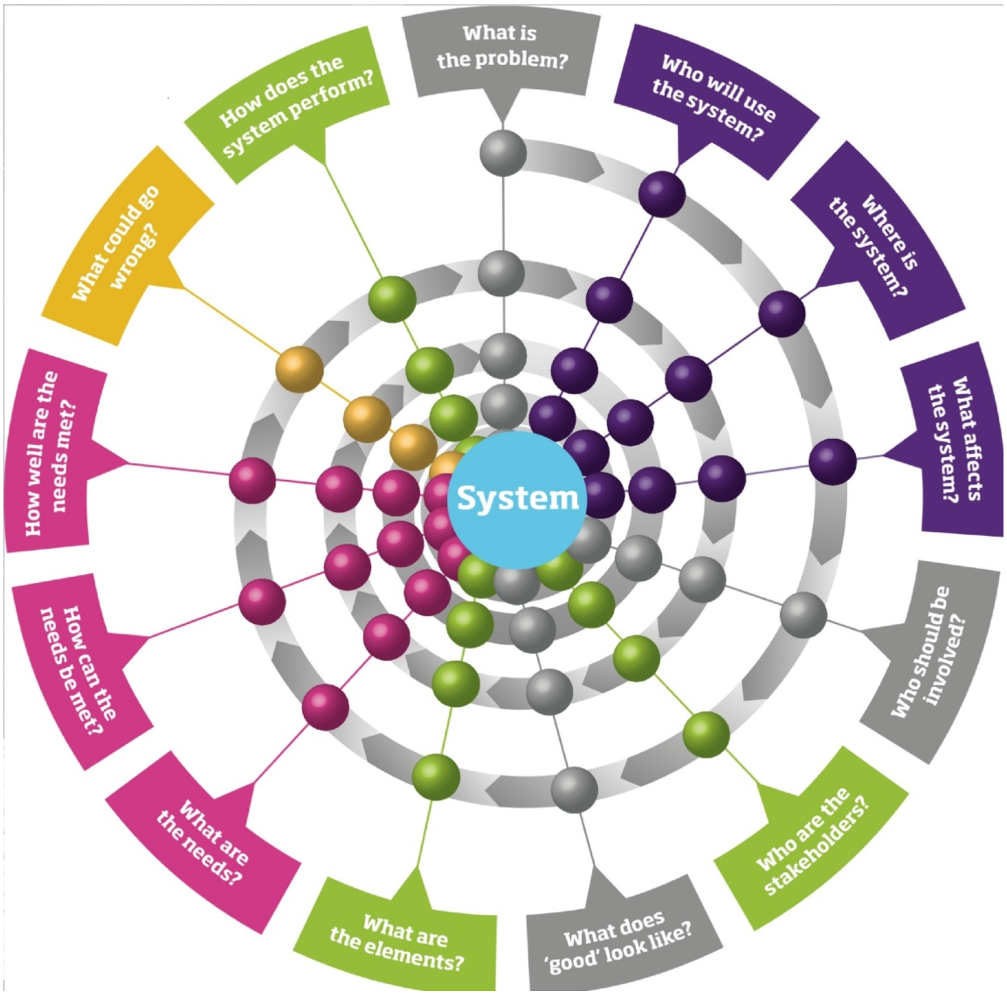


Figure 1 A systems approach to health and care improvement framed as a series of recursive questions (reproduced with permission from Engineering Better Care, Royal Academy of Engineering, 2017).

231x228mm (300 x 300 DPI)

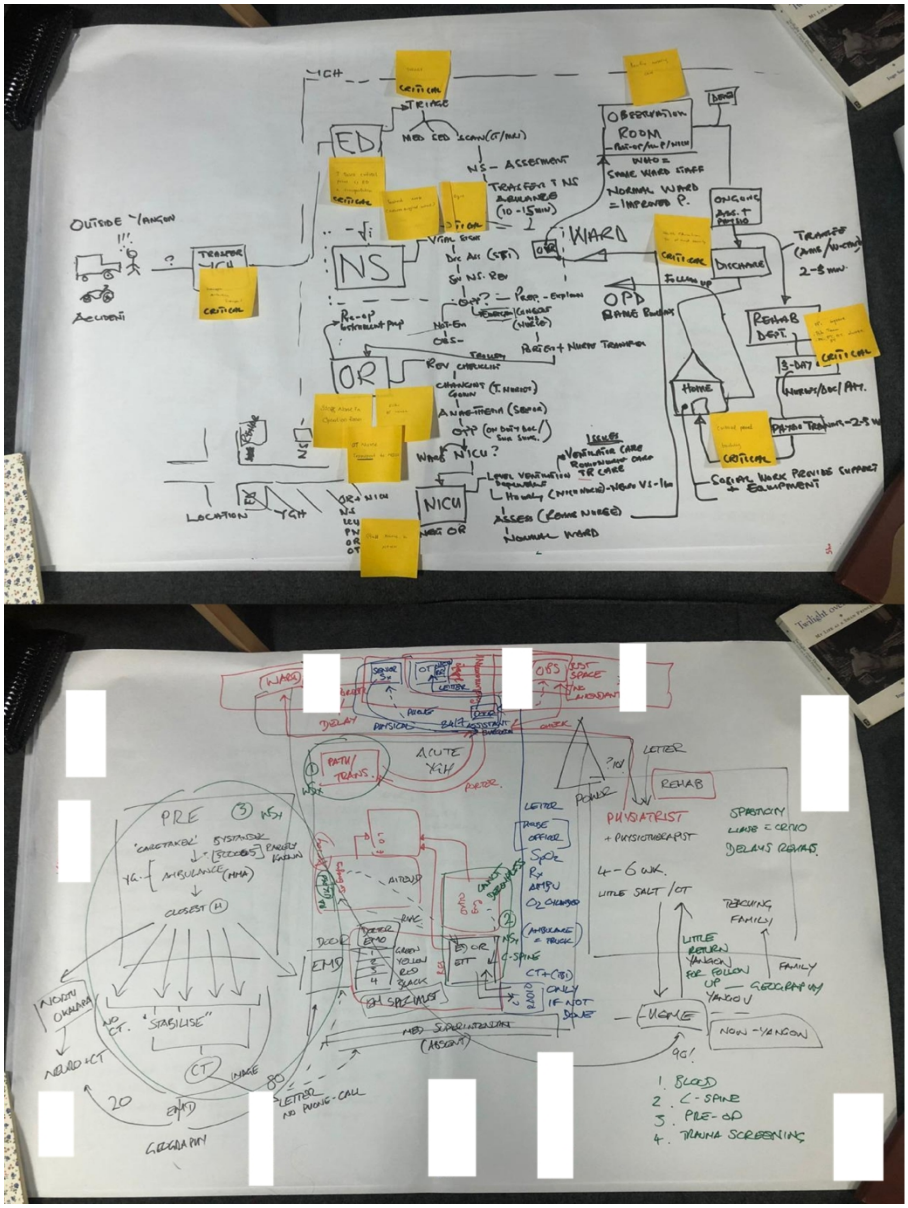
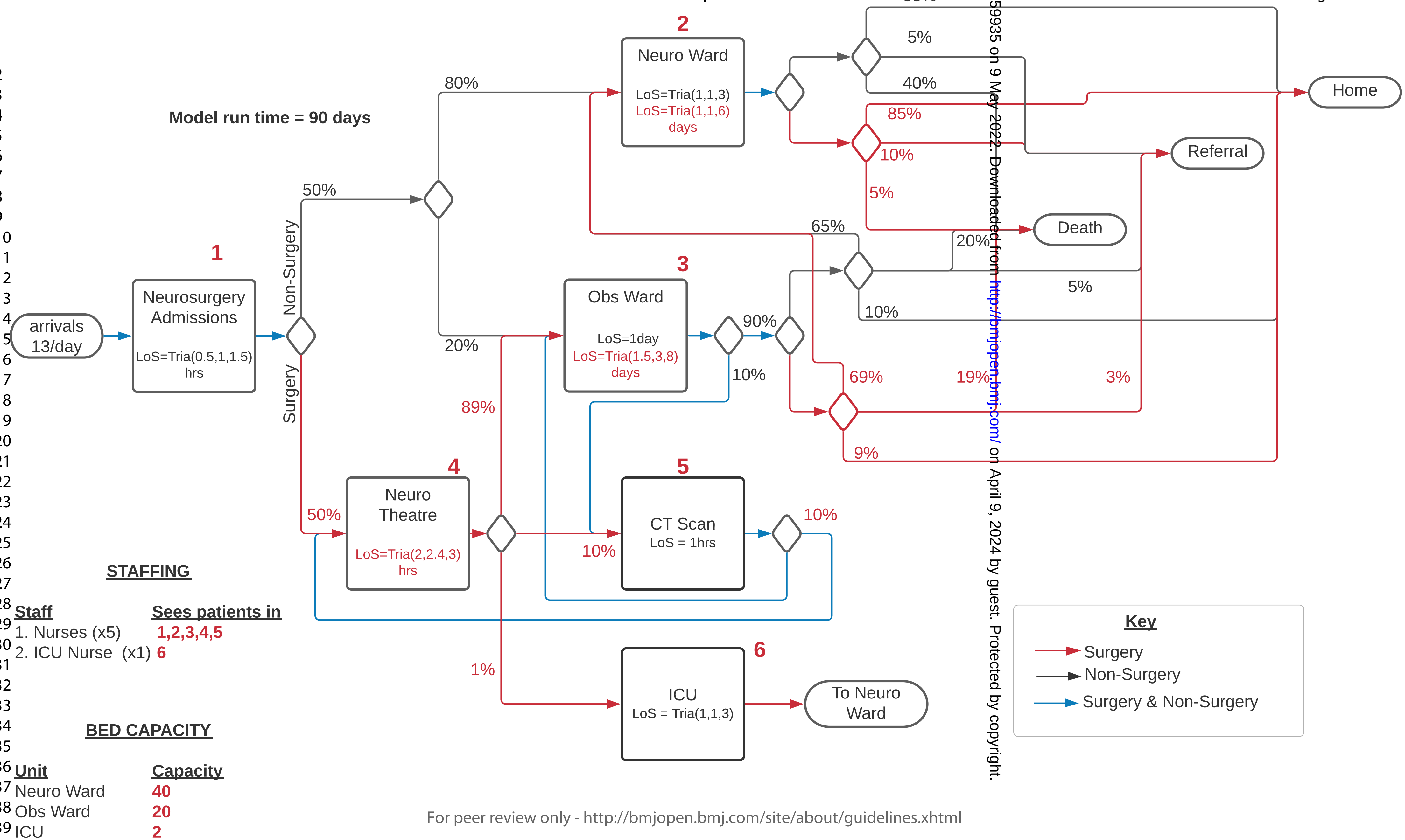


Figure 2. ‘Rich pictures’ generated by workshop data (reproduced from Bashford 2021 with permission of the author, with participant names redacted)

338x451mm (300 x 300 DPI)


Model run time = 90 days
arrivals 13/day
1
Neurosurgery Admissions
LoS=Tria(0.5,1,1.5) hrs
Non-Surgery
Surgery
50%
80%
20%
2
Neuro Ward
LoS=Tria(1,1,3)
LoS=Tria(1,1,6) days
55%
5%
40%
85%
10%
5%
Home
Referral
Death
65%
20%
5%
10%
3
Obs Ward
LoS=1day
LoS=Tria(1.5,3,8) days
90%
10%
69%
19%
3%
9%
89%
4
Neuro Theatre
LoS=Tria(2,2.4,3) hrs
50%
10%
1%
5
CT Scan
LoS = 1hrs
10%
6
ICU
LoS = Tria(1,1,3)
To Neuro Ward
Key
Surgery
Non-Surgery
Surgery & Non-Surgery
STAFFING
Staff
Sees patients in
1. Nurses (x5) 1,2,3,4,5
2. ICU Nurse (x1) 6
BED CAPACITY
Unit
Capacity
Neuro Ward 40
Obs Ward 20
ICU 2

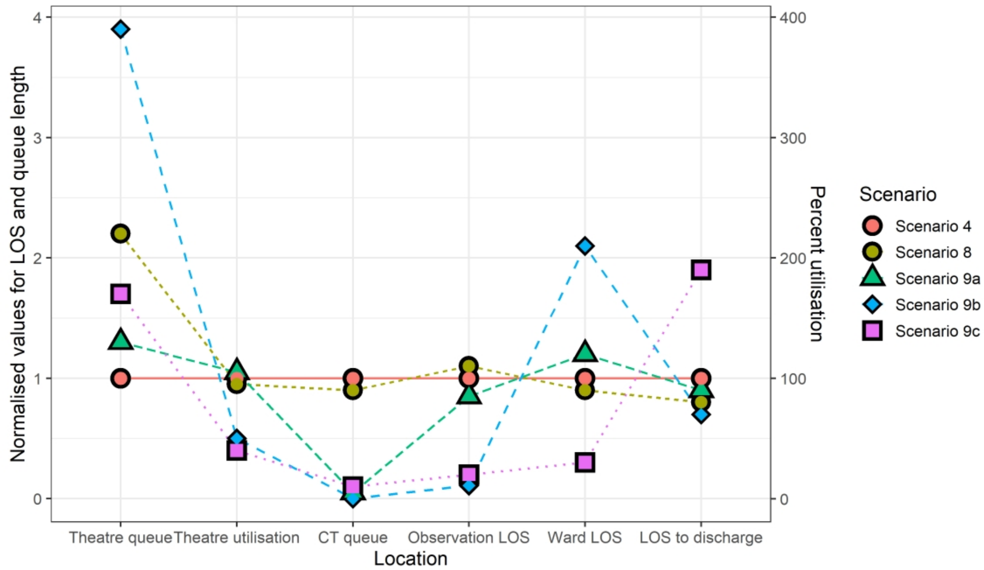


Figure 4 illustrates the effects of changing staff priorities on the patient load in different locations. To improve CT flow in a high patient volume scenario (Scenario 4) we adjusted the CT capacity (Scenario 8) or the nursing staff task priorities (Scenario 9a – priority to CT, Scenario 9b – priority to CT and observation ward, Scenario 9c priority to CT, observation and neuro ward). The figure shows the queues waiting for theatre, CT and the observation ward, the LOS for neuro ward and to discharge with the values normalised to Scenario 4. Additionally, we show percent theatre utilisation. The locations are arranged in the order of patient flow.

304x177mm (300 x 300 DPI)

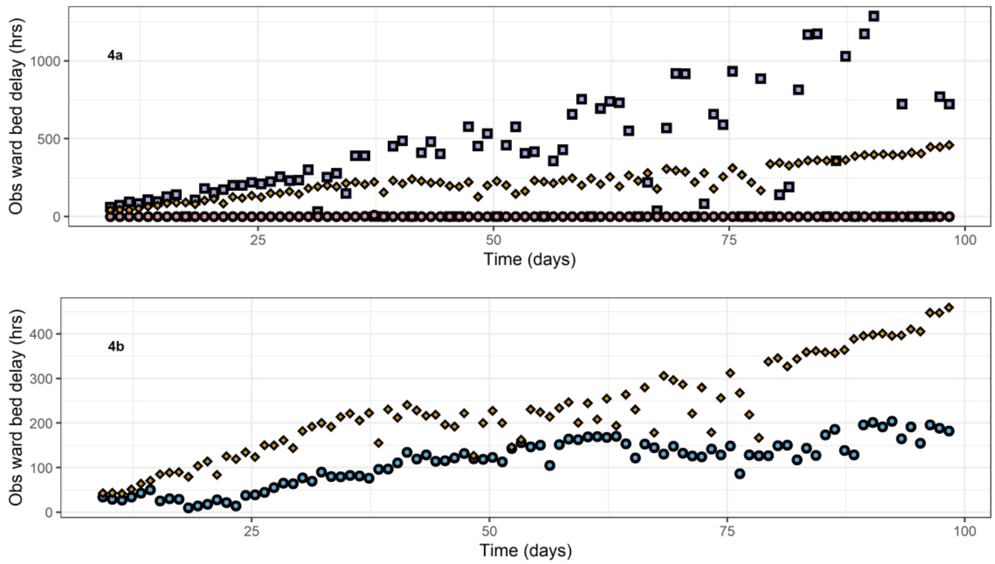


Figure 5a illustrates the effect of a change in population by changing the percentage of patients classified as "surgical". The increased length of stay on the observation ward is seen as an increase in delay for observation ward bed access. In yellow scenario 4 (50% surgical patients), in pink scenario 3 (20% surgical patients) and in purple is scenario 7 (80% surgical patients).
Figure 5b: Illustrates the effect of varying patient arrival rate. With increased arrivals the waiting time for the observation ward bed increases. Again, in yellow is the baseline scenario 4 (15 patients/day), in blue we show scenario 7 (13 patients/day).

304x177mm (300 x 300 DPI)

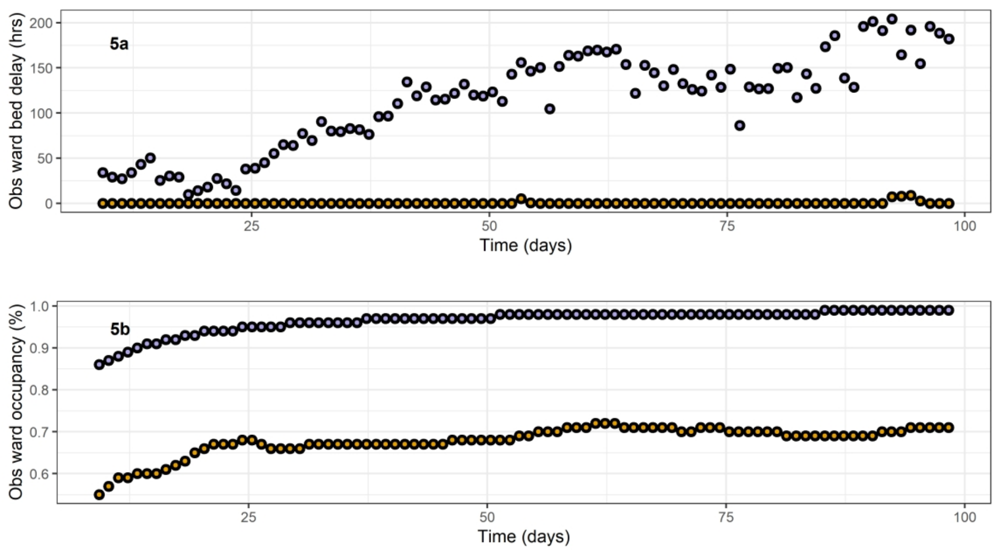


Figure 6: Illustrates the change in patient load on the observation ward when the capacity is increased. In purple is the baseline scenario 0 (20 beds) and in yellow scenario 6 (30 beds). Figure 5a shows the delay to an observation ward bed, 5b shows the observation ward occupancy through the simulation period. The moderate increase in bed capacity clearly reduces the pressure on observation ward beds.

304x177mm (300 x 300 DPI)

Good Reporting of A Mixed Methods Study (GRAMMS)

(1) Describe the justification for using a mixed methods approach to the research question

The study used a mixed method approach to explore the system of neurotrauma care. Mixed methods were employed to maximise the understanding of the system and allow development of a discrete-event simulation. Different aspects of the system were captured via different methods – the process and system structure, broad system understanding and staff/patient experiences were best explored with a participatory story-telling approach, but the specifics needed for fully populating the simulation were addressed with a quantitative prospective data collection. Extensive quantitative data collection was not a possibility and we show that a mixed methods approach can give a more comprehensive understanding compared to each method on their own.

Reasons for the mixed-methods approach are described in the last three paragraphs of the introduction.

(2) Describe the design in terms of the purpose, priority and sequence of methods

The initial methods employed were qualitative participatory methods to gain a broad expansive understanding of the system and its components. This was then supplemented by a smaller targeted quantitative data collection and analysis. The combination of data was used to design and populate the discrete event simulation and explore a range of scenarios.

Described in *Methods: Qualitative data*, *Methods: Quantitative data* and then *Methods: Model* building for the purpose, priority and sequence of methods.

(3) Describe each method in terms of sampling, data collection and analysis

Qualitative: Workshops and one-to-one interviews were conducted
Quantitative: One month prospective patient data collection by local staff, de-identified, analysed for resource usage and patient outcomes. Used to populate the discrete even simulation.

Described in the two subsections *Methods: Qualitative data* and *Methods: Quantitative data*

(4) Describe where integration has occurred, how it has occurred and who has participated in it

Integration of methods occurred in the analysis stage – to analyse the structure and load on the system. Additionally in the simulation stage results from the various methods were used to develop the scenarios.

Described in the results section In paragraph 2 and 3 – explaining the use of qualitative data to inform the simulation model structure and population.

(5) Describe any limitation of one method associated with the presence of the other method

The presence of the quantitative data collection may have reduced the richness and reported variability within the qualitative assessment of patient pathways. Due to structural limitations we only collected 1 month snapshot of quantitative data whereas the qualitative approach explored experiences that span significantly longer timescales and therefore contain more variability and circumstances.
Ideally we would have performed a model review with local stakeholders, but this was impossible due to the pandemic and political circumstances.

Limitations of the mixed method approaches and their influences are described in the 7th and 8th paragraph of the results section.

(6) Describe any insights gained from mixing or integrating methods

Stakeholder data can be supplemented with a quantitative survey to allow for balancing of experiences. Quantitative data collection in a low-resource setting with limited data fields is not sufficient to gain an understanding of the system, the importance of a stakeholder based process map and local knowledge are essential in designing a simulation.

Described in the first paragraph of the conclusions.

Good Reporting of A Mixed Methods Study (GRAMMS)

1. Describe the justification for using a mixed methods approach to the research question

This study seeks to understand traumatic brain injury (TBI) care in Yangon, Myanmar, and explore specific potential improvements to that care. TBI care is a complex process involving an array of people, processes, and institutions. Furthermore, this research was conducted by an international research team with complicating issues around culture, language, and clinical experience in the setting under study.

Improving complex systems first requires an understanding of the system of interest. Qualitative techniques facilitate a rich understanding of the system, from the perspectives of a range of stakeholders. However the exploration of tangible interventions requires predictive quantitative models. In order for these models to be representative of the lived experience of stakeholders, the qualitative and quantitative aspects need to be tightly integrated. This study selected a mixed methods approach in order to focus the rich, contextual insights provided by qualitative study toward specific, discrete, interventions which can be modelled using quantitative techniques.

2. Describe the design in terms of the purpose, priority and sequence of methods

Mixed methods were employed to maximise the understanding of the system and allow the development of a discrete-event simulation based on lived experience. Different aspects of the system were captured via different methods – the process and system structure, broad system understanding and staff/patient experiences were best explored with a participatory storytelling approach, but to explore specific areas for improvement a discrete event simulation model was selected. Participatory diagramming was used to bridge the gap between these two, allowing a system architecture to be co-created by participants as opposed to being imposed by the research team. This architecture was then populated with a prospectively collected dataset, a model built and then refined with the research team in light of the initial narrative analysis. In this way qualitative exploration was used to frame, bound, and understand the quantitative model derived.

The design of this study follow the systems approach outlined by the Royal Academy of Engineering, the Royal College of Physicians and the Academy of Medical Sciences in their 2017 report *Engineering Better Care* (www.raeng.org.uk/publications/reports/engineering-

better-care). This approach can be defined as a series of questions, which were addressed by the different aspects of this integrated mixed methods design. Broadly, the quantitative and qualitative components addressed the following questions:

Narrative analysis and participatory diagramming: *Who will use the system? Where is the system? What affects the system? Who are the stakeholders? What are the elements? What are the needs?*

Discrete Event Simulation: *How does the system perform? What is going on? What could go wrong? How can we make it better? How can the needs be met? How well are the needs met?*

3. Describe each method in terms of sampling, data collection and analysis

Qualitative data

A combination of narrative data supplemented by participatory diagramming was used to understand the lived experience of research participants. This was based upon the Soft Systems Methodology (SSM), adapted for use by a multiprofessional, cross-cultural research team. (17) Narrative inquiry and SSM are positioned within a constructivist paradigm in which the data are co-created by the research team and research participants. The data is a function of the context in which it is created, both on the micro (individual conversation) and macro (society, culture, and language) levels. The research team consisted of both UK and Burmese researchers, trained in the *Engineering Better Care* systems approach, SSM, narrative, and diagramming techniques, and with an expert knowledge of the clinical context under study.

A half-day workshop was held in February 2019 at YGH which was attended by 40 participants including neurosurgeons, neurosurgical nursing staff (ward and theatres), anaesthetists, emergency physicians, and physiatrists. Participants were grouped by both clinical speciality and seniority to encourage active participation and story-sharing, and facilitated in a mixture of Burmese and English by members of the research team. During the workshop, participants were encouraged to create visual maps of their accounts, identifying a mixture of physical structures, clinical processes, patient flow, and lines of communication. These visual maps were often supplemented by numerical figures to reinforce particular points.

Subsequently, two members of the research team (SW and PPNM) conducted 64 one-on-one interviews with a range of stakeholders including patients and their relatives, physicians, surgeons, nursing, and auxiliary staff. These interviews were again structured to encourage story-telling and the elicitation of individual narratives, using a combination of audio recording, note-taking, and participatory diagramming to capture these accounts. These interviews were conducted in Burmese, anonymized at source, and then professionally translated and transcribed.

Both the workshop and subsequent interviews were loosely structured to encourage the elicitation of rich narratives, rather than to address preconceived questions. Facilitators and interviewers referred to the questions posed in *Engineering Better Care* to help guide the discussions, and sought to explore habitual, exceptional, and hypothetical narratives to gain an understanding of the lived experience of respondents. At the same time, techniques of participatory diagramming and graphical elicitation were used to help interviewers and respondents structure this data during the course of the workshop and interviews, with the aim of prompting new insights, clarifying terms, and creating a mutual understanding of the narratives being related.

The resulting qualitative dataset was imported into proprietary software (ATLAS.ti v8 Mac, Scientific Software Development GmbH). Narratives were analysed to identify key areas of concern, along with the development of a consensus understanding of the system features which were central to these: the boundary of the system under study, its physical components and their orientation to each other, the key clinical processes occurring within the system, and the flow of patients through it. A formal thematic analysis of the dataset was not conducted as part of this study.

Quantitative

This qualitative systems model informed the subsequent collection of prospective, targeted, quantitative clinical data. One of the research team (SW) collected a dataset of demographic, inpatient location, discharge destination, and outcome data over a one month period in February 2020. All neurotrauma admissions to the YGH neurosurgical unit who went on to receive a neurosurgical intervention were included, with collection of initial and subsequent Glasgow Coma Scores (GCS) as a measure of outcome.

Model building

Using a combination of the data from the two initial phases, a discrete event simulation was developed to represent a simplified model of the neurotrauma system at YGH. The focus of

the model was on the pre- and post-operative care pathways of the neurotrauma patients including a model of the resource requirements. This focus was grounded in the narrative accounts, which indicated these stages as being the key determinants of overall patient outcome.

The qualitative data was used to structure the care pathway, with the quantitative information used to describe the distributions of resource usage, length of stay and discharge destination of patients moving along specific pathways. The model was developed iteratively using the software package Anylogic (university edition, The Anylogic Company, 2016 v7.3.7). The model was verified through an iterative development process involving the research team members, and critiqued against the existing literature.

4. Describe where integration has occurred, how it has occurred and who has participated in it

Integration of methods in this study occurs throughout the philosophy, design and delivery of the research programme. Narrative elicitation, participatory diagramming, and discrete event simulation were all selected due to their epistemological pedigree in understanding complex systems. As such, they represent an integrated suite of approaches by which the *Engineering Better Care* systems approach may be enacted. Narrative elicitation and participatory diagramming were themselves distilled out of the Soft Systems Methodology to better suit a cross-cultural research team. The use of systems thinking as an overarching framework allowed the qualitative work, situated withing a constructivist paradigm, to be then integrated into a more positivist quantitative paradigm. Discrete event simulation provides an accessible graphical interface by which results of the model can be reintegrated into the qualitative data for validation and verification. It might be concluded that the images used in both cases provide the methodological interface between the different methods and their philosophical bases.

5. Describe any limitation of one method associated with the presence of the other method

In general, narrative elicitation sits within a constructivist philosophy in which data is co-created between research participants and the researchers. Knowledge is made and remade within the discussion, and no boundaries are placed upon the data created other than those which arise from the interaction of the two. However, the desire to frame this project with a

systems thinking framework, and to employ a quantitative technique to explore system improvements, necessarily biased the narratives toward describing a system. This is a conceptual framework which comes from the research team as opposed to the participants. A series of conceptual devices was then used to abstract this narrative data to render it suitable for modelling: participatory diagramming provided a constructivist approach to describing system architecture which was then further abstracted to build the discrete event simulation. This simulation was then populated with a limited dataset and built to explore those concepts deemed by the research team to represent tangible improvement opportunities within the neurosurgical service.

This approach then bounds both the qualitative and quantitative methodologies on order for them to integrate with each other – the qualitative sacrifices richness and nuance, while the quantitative sacrifices data.

6. Describe any insights gained from mixing or integrating methods

The integration of methods show how it is possible to bridge both methodological and philosophical positions using the overarching concept of systems thinking, and the device of imagery to describe the system under study. Pragmatically, the qualitative data suggested specific areas for improvement in TBI care in Yangon – access to CT scanning and observation ward beds – which could then be modelled using the discrete event simulation. Modelling suggested that while CT access becomes a bottleneck at increasing patient loads, this may be improved by changing the prioritisation of nursing staff but not by increasing the number of patients which the CT scanner can accommodate. However this comes at a cost to other areas of the system, which then show increased queuing times. These insights suggest that increasing overall nursing numbers sits on the critical path to improving CT access, and the simply investing in a further scanner may not deliver the looked-for benefits. Similarly, the simulation suggests that while an increase in the number of observation ward beds does alleviate the queuing seen with high patient numbers, the need for expansion is bounded with ten beds completely reliving queuing and no further benefit seen beyond this. These are powerful insights into system function with real-world impacts on potential resource allocation in an impoverished healthcare system.