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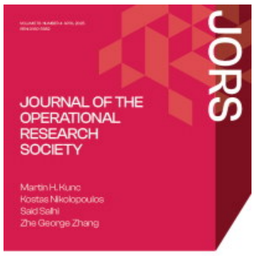

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RESEARCH ARTICLE

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A new approach to getting simulation models used in healthcare: An example from emergency care

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ABSTRACT
While simulation is routinely used by practitioners in many sectors, it is still not part of the hospital manager's standard toolkit. One of the barriers to adoption often described is lack of trust: people trust models that they were involved in developing, but not necessarily those developed for other hospitals, no matter how similar. However, generic models designed to be applicable anywhere also face challenges, as potential users may distrust this one-size-fits-all approach. This paper presents a new approach to tackling this problem. Initially a "semi-generic" model is developed, namely a model that is applicable to a small group of hospitals that have some particular feature in common, e.g., geographical location/size. The semi-generic version is then tested extensively with stakeholders, first from within the initial group of hospitals and later from outside it. Finally, based on feedback from all the stakeholders, the model is adapted to make it fully generic, i.e., applicable to any hospital. The approach is illustrated by a system dynamics model which allows users to test the system-wide impact of five evidence-based interventions for older people in hospital Emergency Departments. Initially developed for one specific region, the fully generic version can be used anywhere in England.

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System dynamics; simulation; semi-generic; emergency care

1. Introduction

Academic researchers have been developing computer simulation models for healthcare applications for over sixty years, but despite this rich history and a vast literature, simulation has not had the same practical impact in healthcare as it has in other sectors (Jahangirian et al., 2012). While simulation is routinely used by practitioners in manufacturing, logistics and defence, it is not part of the hospital manager's standard toolkit. Of course, simulation models are developed by business consultancies for healthcare clients, but such models are rarely reported in the academic literature. One of the many barriers to adoption reported in the literature (Bowers et al., 2012; Fletcher et al., 2007; Jahangirian et al., 2015) is the "not invented here" problem. Clinicians and planners are more likely to trust a model and believe its results if it was developed specifically for their own hospital and they were involved in the whole process. Indeed, in their "proposed project life cycle for successful implementation," Harper and Pitt (2004) emphasise the importance of "involving end users at all stages," for example by forming a steering committee of key hospital staff, spending time working on site, and demonstrating prototype models to "targeted individuals." People are much less likely to trust a model developed for another hospital, even if that hospital is very similar to their own and the only significant difference lies in the parameter values. Modellers often hear claims of "That's not how it works here" or "Our patients are very different" when the results of a model developed for another hospital are shared. However, models designed from the outset to be generic, and based on no particular named site, can also run into problems. Potential users may distrust this one-size-fits-all approach, which can make potential users even less likely to trust the model and its results (Bowers et al., 2012).

This paper describes a novel approach to tackling the "not invented here" problem, illustrated by a case study which focuses on one particular class of models: simulation models designed to be run, potentially with minor changes to the input parameters, by staff in the UK National Health Service

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(NHS) with no prior knowledge of simulation. We introduce the concept of a "semi-generic" model, namely a model that does not represent a specific named hospital but is applicable to a small group of hospitals that have some feature in common. This shared feature could be anything that stakeholders from these hospitals recognise; for example location within the same geographical region, or size, or location in similar areas (e.g., rural "cottage" hospitals), or serving specific patient groups (e.g., children's hospitals). The semi-generic version is tested extensively with stakeholders, first from within the initial group of hospitals and then from outside it. Finally, based on feedback from both sets of stakeholders, the model is adapted to make it fully generic, i.e., applicable to any hospital.

In our case study, a semi-generic system dynamics model of Emergency Departments (EDs) was developed for one particular region, Yorkshire and the Humber (Y&H). Y&H is a large region in the northeast of England, containing approximately 5.5 million people and served by 13 acute Hospital Trusts. Although the model was developed for hospitals within Y&H, using NHS data from Y&H and population data for 25 named localities in that region, it is not specific to any named hospital within Y&H; instead, it uses a set of five "archetypes" based on the average number of daily ED attendances. After testing within Y&H, the model was then adapted to make it fully generic, i.e., applicable to any hospital in England. The model was developed as part of a multidisciplinary, multi-institution research project (Emergency Care for Older People, ECOP; Conroy et al., 2023) involving health services researchers, clinicians and health economists as well as simulation modellers.

The remainder of the paper is structured as follows. Section 2 summarises previous work on the linked topics of model adoption and generic modelling in healthcare, in particular the issue of trust. Section 3 provides background information about the ECOP project and the rationale for choosing system dynamics. Section 4 contains a step-by-step description of the proposed methodology, illustrated by the case study. Particular attention is given to conceptual modelling and stakeholder engagement, which are key aspects of the approach. Section 5 discusses how the concept of semi-generic modelling could be applied more widely, and argues that it not only extends the literature on generic modelling but also potentially addresses several of the other known barriers to adoption in healthcare. Finally, some remarks on the limitations of both the ECOP model and of the general approach of semi-generic modelling are followed by a discussion of areas for further research and a summary of the contribution of this paper.

The focus of the paper is on increasing the use of simulation models to support decision making in healthcare. The ECOP model itself is a very basic stock-flow compartmental model; it is a standard application of quantitative system dynamics and contains no technical novelty. Hence although a description of the model is provided in Section 4, this is purposefully brief; for further detail and some illustrative results, see England et al. (2023).

2. Literature review

A succession of reviews of the Operational Research (OR) literature over four decades, from Tunnicliffe Wilson (1981) to Carter and Busby (2023), found no evidence of simulation models having a sustained impact on practice in healthcare. A small minority of papers describe models developed with a collaborating healthcare organisation and state that the model recommendations had been (or were just about to be) implemented in practice, but rarely report the outcomes following implementation. The vast majority of published articles in the academic literature do not mention implementation at all: the focus is entirely on the scientific or technical novelty of the model, not whether it was used in practice.

Carter and Busby (2023) give several possible reasons for this. Papers that describe standard applications of known methods are less likely to be accepted for publication in academic journals, despite being more likely to be used in practice. The pressure on academics to "publish or perish" may lead to papers being written and submitted for publication before there has been time for a model to be used in practice, let alone for an evaluation to be undertaken. Moreover, operational researchers and simulation modellers do not always have the requisite skills to conduct health service evaluations, and historically there have been relatively few incentives for them to do so. Finally, successful implementation is often determined by political, financial and organisational factors which may be beyond the control of the individual healthcare collaborators, no matter how enthusiastic they are about the model.

Brailsford et al. (2013) identified a set of barriers and facilitators for the adoption of simulation models by the NHS. This study focused on one particular generic simulation tool, Simul8 Corporation's Scenario Generator (https://www.simul8healthcare.com/products/scenario-generator), which was designed to be used by NHS staff and did not require advanced modelling expertise; however the findings were applicable to simulation models in general. Facilitating factors included having an enthusiastic clinical "champion" (who need not have any technical knowledge themselves, but who can influence colleagues), working on a business-critical problem, and making effective use of any training provided. The barriers included lack of time and capacity to undertake anything other than urgent tasks, lack of senior management support, lack of trained analyst capability and issues around data availability and quality. Sadly, Scenario Generator itself became a victim of yet another barrier; the ever-changing environment in which the NHS operates. Use fell away completely after 2012 as a result of a major NHS restructure in which former Scenario Generator users moved on to new roles in different organisations (Reid, 2023).

One potential approach to address the lack of adoption is the use of generic models or frameworks of generic building blocks, whose aim is to avoid "reinventing the wheel" and make models more widely accessible (Fletcher et al., 2007; Furian et al., 2018; Robinson et al., 2004; Sinreich & Marmor, 2004). Fletcher and Worthington (2009) reviewed the literature on generic hospital models and identified four levels of genericity. Level 1 models are highly abstract (e.g., using a simple queuing theory model to show the impact of variability) and can be applied to other areas as well as healthcare, while Level 2 is a "toolkit" of generic building blocks that can be assembled into a bespoke model. Level 3, "setting specific generic models," are developed for a given type of unit (e.g., an ED or an intensive care unit) where the structure remains the same and differences between hospitals are captured by the data only. Level 4, "setting specific models," are bespoke to the hospital for which they were developed. Ironically, Fletcher and Worthington found that there was very little difference between levels 3 and 4 in terms of implementation. Furian et al. (2018) present a toolkit of software-independent generic building blocks for ED modelling, based on a set of published ED models; however, they do not apply it to a real-life case study. Boyle et al. (2022) distinguish between generic and "generalisable" models, and propose a generalisable data-driven DES framework for modelling EDs. Their definition of generalisable, models that can represent multiple units and can be customised using local data, is similar to Fletcher and Worthington's Level 3, while the framework approach is similar to Level 2. The framework was implemented in Simul8 and tested for an ED in an Australian hospital. It required quite a lot of tailoring to that setting, and the authors state: "Although there was good communication with hospital staff throughout the project, there were challenges with implementation of the model for long-term use" (p. 346).

Both Furian et al.'s and Boyle et al.'s frameworks were designed to be used by expert modellers. The approach closest to that taken for the ECOP model is described by Penn et al. (2020). The purpose of the model, a DES developed in Simul8, was to assist planning decisions on the numbers of beds and configuration (in terms of multi-bed bays) of hospital wards. First, an archetype or setting-specific generic model (in Fletcher and Worthington's terminology) of a ward was developed by expert modellers. The elements of this base model, i.e., essential features common to all hospital wards, were derived through discussions with NHS staff, literature reviews, and the modellers' own experience. The base model was then given an Excel user interface to enable lay users to interact with it easily. The model was initially applied by the modellers themselves to inform a real-world strategic decision about a rehabilitation ward. Later, the base model was applied to a different type of ward, specialised intensive care, by students with limited (but non-zero) knowledge of simulation. However, the authors note that although at the time of writing this second model was still being used by the ICU manager, structural changes had to be made to the base model "to produce sufficiently accurate results to support decision-making". Hence it is not clear how truly generic (or generalisable) the base model is; moreover, users need a Simul8 license to run it.

Client/stakeholder engagement throughout the modelling process is universally cited in the literature as a critical success factor in the use of simulation in healthcare. There is a vast literature on stakeholder engagement, ranging from classification and analysis of stakeholder groups in general (Mitchell et al., 1997) to the development of guidelines for successful stakeholder engagement in healthcare (Brailsford et al., 2009; Harper & Pitt, 2004; Zabell et al., 2021). However, even for bespoke models there are many barriers to such engagement (Jahangirian et al., 2015) and it is clearly not feasible for generic models. Fletcher et al. (2007), who developed a generic DES model for EDs in England, state "… the generic model was found to be a good starting place in the hands of those who had built and understood the model. Our experience of trying to reuse previous models suggests that generic models may be less advantageous as a starting point in the hands of others." (p. 1562). The specific issue of "not invented here" is addressed by Bowers et al. (2012), who state that "An attempt to transfer a model may be viewed as an example of a systemisation of healthcare and top-down reform" (p. 1464) and hence could be seen as an attack on clinical independence. The authors go on to say: "Generic models may always be viewed with suspicion and any modelling needs to plan for considerable effort liaising with local staff" (p. 1464).

Semi-generic models, which are an attempt to address this problem, lie somewhere between levels 3 and 4 in Fletcher and Worthington's taxonomy; they are clearly not bespoke, but neither are they "setting-specific generic models" that are designed from the outset to be applicable to all hospitals. The underlying idea is that stakeholders and/or potential users from the initial small group of hospitals should immediately recognise their shared connection and thereby gain an initial level of trust in the model. Our hypothesis is that it is this threshold level of trust that can be a barrier with many "one-size-fits-all" generic models, and that once this barrier is overcome, users will be more willing to play with the model and develop greater trust in it.

3. Case study: The ECOP model

The overall aim of the ECOP project (Conroy et al., 2023) was to describe best practice in emergency care for older people, describe patient outcomes, and understand how best practice might be delivered. The findings would then be synthesised in a web-based simulation tool, available to ED clinicians and service planners across England, to support planning decisions by testing the system-wide impact of a range of ED-based interventions aimed at older people. These interventions should all be based on reputable clinical studies reported in peer-reviewed journals. The key requirement, aligned with the overall project aim, was that the model should not focus on the ED alone but should consider the "whole system," i.e., what happens to ED patients in other parts of the hospital and after they are discharged. It was not necessary to estimate waiting time metrics or resource use, or capture individual variability. Based on our knowledge (both from our own experience and from the literature) of the barriers to uptake, we specified three further requirements. The tool should be available free of charge to all NHS staff without the need to purchase proprietary software. The user interface had to be intuitive and user-friendly, so that people with limited computing skills and no knowledge of simulation could run it. The model should come with built-in data from a trustworthy source so that it could be run "as-is," but it should also provide the user with a simple way to edit parameters or upload their own data to tailor the model to their own setting.

Both discrete-event simulation (DES) and system dynamics (SD) have been widely used for decades for ED modelling, although DES has always been far more popular; in their survey of ED simulation models, Salmon et al. (2018) found a total of 254 papers, of which 209 used DES as the sole method while only 18 used SD as the sole method. EDs are stochastic queuing systems, and DES is ideally suited to measure performance in terms of waiting times and resource utilisation. Most DES models in the literature are primarily concerned with activity within the ED itself, and many are highly detailed. On the other hand, SD models are typically somewhat simpler in structure and (importantly) often look beyond the ED; Lane et al. (2000), whose SD model illustrates how ED crowding, ward bed shortages and waiting lists for elective surgery are all interconnected, is a classic example. Since the aim of the ECOP model was to understand the system-wide impact of ED-based interventions at population level, and (as noted above) there was no requirement to capture waiting time metrics *via* a stochastic individual-level approach, SD was the natural choice.

Candidate interventions were identified through a systematic "review of reviews" of ED-based initiatives conducted as part of the ECOP project (Preston et al., 2021). The final set of modelled interventions, selected based on the quality of the evidence by a group of expert clinicians, were proactive care, front door frailty, hospital at home, geriatric emergency medicine, and acute frailty unit. Short descriptions of these, together with their associated effect sizes on various patient outcomes and references to the studies from which they were obtained, can be found in the Appendix. With the exception of mortality rates, the outcomes are all process-based, e.g., length of stay or probability of readmission, rather than clinical.

4. Approach

Described in general terms, our approach has five steps:

1. Develop a "semi-generic" model for a relatively small number of hospitals (termed the *initial group)* that share some additional connection. This step covers all the standard stages of model development; conceptual modelling (deciding on model scope and the appropriate level of detail to achieve the model purpose), developing a computer model, verification and validation, and experimentation. The most critical aspect is conceptual modelling; it is essential to bear in mind that ultimately, the model will be used outside the initial group of hospitals. It is also vital to ensure that the shared connection is obvious to users. This step could potentially involve input from stakeholders within the initial group, but this is not essential since it is important that the resulting model is not

perceived as representing a named hospital in this group.
2. Conduct extensive stakeholder engagement within the initial group by demonstrating the model to people not involved in its development, and obtaining detailed feedback. Check that people recognise the shared connection, explore the extent to which they trust the model (and if not, why not) and identify any potential barriers that might limit its wider use. Modify the model in response to stakeholder feedback.
3. Repeat step 2 until stakeholders are happy with the model and no further modification is deemed necessary.
4. Demonstrate the model to stakeholders outside the initial group, to identify any further barriers to wider adoption. Modify the model in response to stakeholder feedback.
5. Repeat step 4 until the stakeholders are satisfied that the model can be used for any hospital.

In the remainder of this section, we describe how each step was operationalised in the case study, focusing in particular on conceptual modelling, developing the computer model, and stakeholder engagement.

The approach taken in developing the semi-generic version of the ECOP model broadly followed the standard stages of system dynamics model development, with the exception of the traditional second stage, developing a dynamic hypothesis to be explored in the model. As noted earlier, the model is essentially a compartmental, data-driven, quantitative stock-flow model in which the only feedback is numerical, i.e., the fraction of ED attendances that result in reattendances and/or readmissions. These are directly calculated in the model, and hence no causal loop diagram or dynamic hypothesis were developed.

4.1. Conceptual modelling

Conceptual modelling, the process of abstracting a model from a real-world system by defining the purpose and scope of the model, the inputs and outputs, and the data requirements, is a vital aspect of simulation model development (Robinson, 2008). It is particularly important when developing a semi-generic or fully generic model, since (as noted by Fletcher et al., 2007) the model will eventually be used by people who were not involved in developing it and may not have access to the same data. The conceptual modelling stage inevitably raises many issues about the necessary level of detail in the model structure. The less detailed a model, the less likely it is that people will say “That’s not how things work here” but equally, the more likely it is that they will say some vital element is missing which renders the model useless. This is a familiar dilemma for all modellers! In the case of the ECOP model, one member of the research team held a clinical post in a Y&H Trust, the principal investigator was a consultant geriatrician with a national role, and others (the health services researchers) had spent time in some of the EDs within Y&H, observing the operation of these departments and interviewing staff there. This prior qualitative research, together with the personal relationships established as a result, provided insight into the local landscape and enhanced the credibility of the semi-generic version.

Regarding the model structure and scope, all EDs fulfil broadly the same function but their internal organisation and structure can be very different. After discussions with the whole research team, a very high-level approach was taken, as depicted by the patient flow diagram in Figure 1. The arrows represent flows of patients between different locations, represented by rectangles. While real hospitals obviously have a complex internal structure, with different configurations of units, departments and wards (and potential flows between them), this highly simplified structure covers all possible configurations. The primary aim was to prevent potential users immediately rejecting the model because it did not reflect the ED or ward structure in their own Trust. Any local differences should be captured by the input data, and hence the semi-generic model contains five archetypes which all have the same structure as Figure 1 and differ only in their parameters.

4.2. Developing the computer model

The model was implemented in the software AnyLogic (www.anylogic.com), which can be used to build models in DES, SD and agent-based simulation. AnyLogic was chosen because it allows models

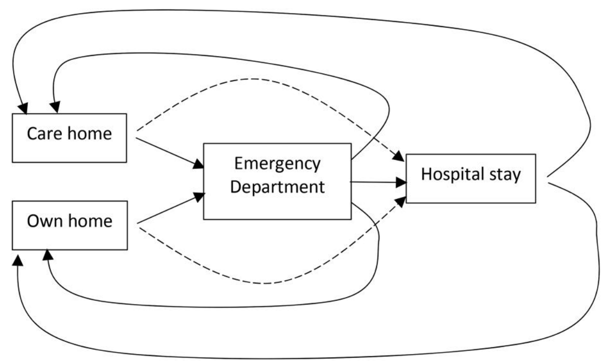

Figure 1. Conceptual model of patient flow. The dashed lines represent new emergency admissions direct to a ward, and also readmissions within 30 days of discharge. Patients may die in any of these locations, but for the sake of clarity this is not shown.

to be accessed online, free of charge, *via* its Private Cloud for which the modellers' institution owns a license. The main benefit of this is that users do not need an AnyLogic licence to run the model but can access it directly through a web link. However, this feature was only used for the fully generic version; the Y&H version was a standalone model.

One of the oft-cited challenges in healthcare modelling is the lack of high-quality data, especially linked data across different care providers. Fortunately the ECOP team had access to the CUREd Research Database[1] which collates routine NHS data for the whole of Y&H. CUREd contains linked patient-level data from NHS111, the Yorkshire Ambulance Service, and the Emergency Department and Inpatient Administration Systems of all hospitals in Y&H. The database makes it possible to track patient journeys from the initial emergency call through conveyance by ambulance to a specific ED and thence to hospital admission or transfer home. CUREd provided most of the baseline parameters for the model, namely the daily flow rates by age group between locations (stocks), and the relevant transition probabilities. These baseline values were derived by the health economists in the research team, who were familiar with the CUREd dataset as they had used it for econometric analysis of patient outcomes in a separate part of the ECOP project (Maynou et al., 2023). Publicly available data from the UK Office for National Statistics (ONS) were used to determine the out-of-hospital death rates and the populations of the counties, cities and large towns within Y&H. For further details, see England et al. (2023).

Three anonymous Trusts in Y&H were selected to represent small, medium and large hospital archetypes; the other two archetypes were a whole county and the whole region. The use of archetypes (crucial for a semi-generic model) would facilitate future adaptation to the fully generic version, but had additional benefits; it ensured that the Y&H version would remain useful in the event of future hospital mergers or closures, and prevented users from making comparisons with identifiable others.

In the model, patients are categorised in five age groups: 75-79, 80-84, 85-89, 90-94 and 95 and over. For each age group, the model captures the flow of patients shown in Figure 1. Daily ED attendances for each of the five archetypes are further broken down by time of day and day of week, based on the average arrival frequency profiles (by age group) derived from the entire CUREd dataset. This makes it possible to test different operating hours for an intervention by calculating the fraction of patients who will receive it. The input parameters for patient flow are all daily averages, broken down by age band: ED attendances, the proportion who are admitted, emergency admissions direct to wards, length of stay, deaths in hospital and 30-day emergency readmissions. The effect size parameters for the interventions are taken from the literature (see Appendix). The model runs for one simulated year with a timestep (dt) of just over one hour. The model outputs include the numbers of ED reattendances, readmissions from a patient's own home or from a care home within 30 days of discharge, and deaths (both inside and outside hospital). The results are presented as graphs which compare the chosen intervention with an as-is baseline. The clinical members of the team conducted face validity tests on the model output, while numerical validation was performed internally against summary data from CUREd and externally against NHS Hospital Episode Statistics data. For further details, see England et al. (2023).

The user interface was designed to be as user-friendly as possible. Having non-modellers in the research team was very helpful in this respect, and they were keen to beta-test the model. To ensure that people would recognise the "shared connection," we first required users to select their own locality from a drop-down list of 25 towns, cities and counties within Y&H. While these are actually only used to derive the background (out of hospital) mortality rates and other basic demographic information, the underlying aim was to provide reassurance that the model represented the user's own locality. Next, users select the archetype that is closest to their own setting, modifying the default parameters if they wish. Finally, they select the intervention they wish to test, specifying its operating hours and target age group(s). A comprehensive set of illustrative results for four different intervention scenarios can be found in England et al. (2023).

4.3. Stakeholder engagement

Stakeholder engagement, both within the initial group and outside it, is a vital element of the semi-generic modelling process. Involving potential model users is clearly important, but it is also important to identify and engage with wider stakeholder groups, such as senior decision-makers who might use the model results but not the model itself, and managers whose "buy-in" is required to allow staff to access the model (Brailsford et al., 2013; Harper & Pitt, 2004). Obviously, it will never be possible to involve every single potential stakeholder in every single hospital, even for the semi-generic version; the decision that the model is fit for purpose and needs no further modification will always be a value judgment. However, this is true even of a highly bespoke model.

Between May 2020 and November 2021, the Y&H model was demonstrated at four external stakeholder events, attended by a total of around 40 people, mainly but not exclusively from Y&H. While this was not strictly in accordance with Steps 2 and 3 above, these events took place during the Covid pandemic and were therefore held online, so we were able to invite people from outside the region. The ECOP project had attracted considerable interest since the chief investigator Simon Conroy, a consultant geriatrician, had a national role leading the NHS Acute Frailty Network[2]. We therefore invited representatives of NHS Elect[3] (a national body that provides improvement support to NHS organisations) as well as members of the British Geriatrics Society. Participants from Y&H included clinicians, planners, and representatives from patient and carer groups. As the cloud-based version was not yet available it was not possible for participants to run the model themselves, but on the other hand online meetings almost certainly enabled more people to attend.

Participants were asked to comment on many aspects in addition to trust. These included the usability of the tool itself and the user interface; the level of detail in the model; the availability of local data to modify the default CUREd data; the usefulness of the model outputs and whether any important metrics were missing; and any other issues people wished to raise. Feedback was collated and summarised in reports that were shared with the meeting attendees as well as the wider ECOP team. This user feedback and its implications was then discussed and changes to the tool made. Usability aspects included a References button that opened a new window showing the relevant cited literature for each intervention, further simplifications of the "plain English" explanations of technical terms like odds ratios and effect sizes, a "traffic light" system to indicate the quality of the evidence in the published studies, and numerous visual changes to the output graphs. The decision to keep the model high-level was vindicated, as some people commented that getting hold of even the limited data required could be difficult and they were grateful for the option to use the default data. Regarding trust, participants clearly recognised that this was a Y&H-specific model and while people within Y&H confirmed that being able to select their own locality in the user interface increased their trust in it, people outside Y&H understandably wanted a tool that related to their own population and hospital setting. Other comments relating to trust included the reliability of local ONS population data, and the option to view (but not modify) the underlying model; one participant stated that this "makes the model less of a black box and I can trust it more—I can see there are real calculations underpinning it. Also useful if showing it to others."

4.4. Development of the fully generic version

This step involves identifying any elements of the semi-generic model that relate solely to the initial group and replacing them with generic equivalents. Although in theory this could involve changes to the model structure, in most cases it will only require changes to variable names and/or model parameters.

In moving to the fully generic (England-wide) version of the ECOP model, the underlying model structure and most of the ED-specific input data, including the intervention effects, did not change; the differences were in the user interface and the population data. The 25 localities within Y&H were replaced by the 42 Integrated Care System (ICS)[4] areas in England. ICSs were established in July 2022 as partnerships between all local health and social care providers, mainly but not exclusively NHS organisations and Local Authorities, with the aim of providing a more "joined up" service to patients. The 42 ICS replaced the 106 former clinical commissioning groups (CCGs), which had a similar role but did not cover social care. In the generic ECOP model, the three hospital archetypes remain unchanged, but the Y&H region archetype is replaced by a user-selected ICS and the county archetype is replaced by an average-sized CCG. The model uses ONS population and mortality data for each ICS, derived by aggregating population data provided by NHS England[5] for the set of CCGs that belong to each ICS. Since the user can edit the input data for the ICS and CCG archetypes, the model is "future-proof" against any further changes in the number, size or names of organizational units.

Towards the end of the project, in spring 2022, the near-final fully generic model was demonstrated at two NHS Elect Measurement Classes attended by around 60 NHS staff from around 35 NHS organisations in England. Only minor changes (all to the user interface) were suggested and the generic model was then made available to NHS users. Registered users are able to access the model *via* a secure web link which provides a temporary private space on the cloud. If they wish, they can download the Excel file containing the default input data, edit it to tailor the input to their own Trust or local area, and then upload it again before running the model. The model takes one or two minutes to run, depending on the speed of the user's internet connection. The raw output data used to create the results graphs in the model can be exported to Excel, saved in the user's private space and then downloaded for further analysis, if required.

5. Discussion

5.1. Contribution to modelling practice

This paper presents a new approach to an old problem, the issue of "not invented here" as a barrier to adoption in healthcare. It also extends approaches used in previous work on generic modelling, which have either adapted a model initially developed for a named location (a setting-specific model, in Fletcher and Worthington's terminology) to make it generic, or used a framework or toolkit to build a model designed from the outset to be generic, such as Boyle et al. (2022) or Penn et al. (2020). Our approach is essentially a hybrid of these two. Developing a fully generic model from scratch is a far more challenging task than developing a semi-generic one, which by definition only has to apply to a relatively small number of hospitals and be accepted by a limited number of stakeholders.

Our approach contrasts with the process of facilitated or participatory DES modelling (Kotiadis et al., 2014; Tako & Kotiadis, 2015) in which a model for a specific client organization is developed jointly with decision makers, technical experts, users/customers and other stakeholders. Likewise, our approach also differs from the traditional group model building (GMB) approach in system dynamics (Vennix, 1996) where the aim is to capture and reflect the knowledge (both tacit and explicit) of a range of stakeholders, expose and clarify assumptions, arrive at a shared understanding of the problem, and increase the chances of successful implementation. In both participatory modelling and GMB, stakeholders are directly involved in model-building. However, as noted in Section 4 (Step 1), this is not necessarily the case for semi-generic modelling, where the fundamental aim is that the model will ultimately be used by people who were NOT involved in model development. Stakeholders from the initial group could be involved in model-building, but this is not essential. In the case of ECOP, the model-building process solely involved other members of the research team, albeit some with local knowledge of Y&H, and the stakeholder engagement sessions involved demonstrations of an existing prototype model, not model building.

In our case study, a semi-generic system dynamics model developed for a specific region and tested with potential users in that region was extended to a fully generic model that can, in theory, be used anywhere in England. An additional key feature was the multidisciplinary nature of the research team and the significant roles played by all team members, the project Steering Committee, and external NHS stakeholders. Having clinicians, qualitative health services researchers, and health economists in the ECOP team was hugely helpful for the modellers. Previous OR research on model implementation and the modellers' own extensive experience guided the design of the user interface and the process of user engagement; see for example Harper and Pitt (2004), which describes factors for successful engagement; Brailsford et al. (2009), which includes a taxonomy of NHS stakeholders and presents some practical guidelines on engaging with them; and Carter and Busby (2023). Moreover, in the case of the ECOP model, our approach addresses many of the other issues with adoption identified in the literature (Carter & Busby, 2023). These include avoiding the need for user modelling expertise, licences for proprietary software, and volumes of high-quality data, while providing an easy way for users to tailor the model to their own setting using a familiar tool, MS Excel.

It is important to note that while the ECOP model uses system dynamics, the general concept of first developing a semi-generic model and then extending it to a fully generic version is equally valid for DES. While it is true that SD is typically higher-level and less detailed than DES, which in theory should make SD more amenable to generic modelling, none of the numerous literature reviews on simulation in health found any examples of widely used generic SD models. All the generic models described in Section 2 (Boyle et al., 2022; Fletcher et al., 2007; Penn et al., 2020; Sinreich & Marmor, 2004) used DES. DES models are not necessarily hugely detailed; perhaps the best known and most influential example of a generic model is Bagust et al. (1999), who present a simple DES which, although not intended to be used by anyone else, was designed to show the impact of variability in the arrival rate and length of stay of emergency patients in a "typical" hospital. Indeed, Fletcher et al. (2007) discuss the need for simplicity when modelling a "typical" Emergency Department: "Designing the model so it was not overspecific to particular A&E departments, but detailed enough to explain national issues to an appropriate level" (p. 1561).

A critical aspect of developing a semi-generic model is first to identify the feature(s) that all the modelled settings have in common, and then to make this sufficiently obvious to users to overcome their initial "trust threshold." Arguably, allowing users of the Y&H version to select their own locality before choosing an archetype was largely window-dressing, as the demographic characteristics in each location were not significantly different. However the process of stakeholder engagement within Y&H provided concrete evidence of the psychological benefit of being able to select from a list of recognized towns and cities and use reliable ONS data relating to the population in these locations, and helped us understand what might enable the fully generic version to be accepted more widely.

5.2. Limitations

In terms of the case study, there are a number of limitations to the model itself. The focus of the main ECOP project was care delivered in hospital, and so the model only contains limited pre-hospital interventions and no post-hospital interventions. Moreover, it only contains interventions for which there was a strong evidence base in the literature at the time. If future clinical studies were to find that these interventions were more (or less) successful than reported at the time, the model parameters could easily be modified to take this into account, but if a new intervention were to be rigorously evaluated and found to have a beneficial effect, it would need to be added to the tool. Updating the tool to include new interventions would require additional programming effort, for which funding would need to be found. This is another reason why models developed by academics as part of funded healthcare research projects do not always have very long lifespans.

It would have been possible to avoid the need for users to purchase proprietary software by coding the model in an open-source programming language such as Python. For various reasons, mainly related to the skillsets of the modellers at the time when the proposal for the ECOP project was being written and the fact that their institution already had an AnyLogic licence, we chose not to do this. There are drawbacks to using proprietary software and we might take a different approach today, but the same issues would arise if new interventions had to be added in future. For this reason, we recommend that modellers interested in using the semi-generic approach for other applications should actively explore the feasibility of an open-source option.

More generally, there are clearly limitations to the concept of semi-generic modelling. It may not always be possible to identify a suitable common feature shared by a specific group of hospitals. Individual hospitals, even if only small in number, may differ too much in structure, context or purpose for a common conceptual model to be developed. Equally, stakeholder engagement (either at the semi-generic stage or at the fully generic stage) may lead to the conclusion that a "one size fits all" approach simply will not work, as the barriers to trust are too high.

5.3. Further research

Of course, as the saying goes, the proof of the pudding is in the eating: will the ECOP tool ultimately be used in practice, and will it influence decision-making? This paper is no different from many others in that it was written at the end of a research project and at the time of writing, wider dissemination had only just started. While there is evidence (albeit limited) that the England-wide generic version is trusted by people outside Y&H, we have no concrete proof that it will achieve sustained adoption, let alone that the semi-generic approach would work for other problems. To judge the success or otherwise of this approach and its impact on implementation will require a robust evaluation over several years, addressing not merely uptake and reception of the model but also its impact on management/clinical decision-making and (most importantly of all) on patient outcomes. This is beyond the scope of this paper—and indeed of the ECOP project—and will be the topic of future research. However anecdotal feedback to date has been very promising, both from Trusts and at national level. NHS England requested access to the tool in December 2022 and included several of the modelled interventions in its Urgent and Emergency Care Plan, announced by the UK Government in January 2023[6].

6. Conclusion

We have described here the extensive multidisciplinary approach and coproduction that seem to be key elements of success when developing models for healthcare settings. In particular, we have developed an approach that we have reason to believe begins to address the thorny "not invented here" issue that has been a barrier to adoption in the past. Whilst an evaluation is needed of the implementation approach, our experience to date suggests that this development process might be useful not only on other healthcare modelling projects but modelling in a range of sectors.

Notes

1. https://www.sheffield.ac.uk/scharr/sections/hsr/cure/projects/cured-rd/home.
2. https://acutefrailtynetwork.org.uk/.
3. https://www.nhselect.nhs.uk.
4. https://www.england.nhs.uk/integratedcare/what-is-integrated-care/.
5. Clinical commissioning group population estimates (National Statistics) - Office for National Statistics (ons.gov.uk).
6. https://www.bbc.co.uk/news/health-64448354.

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Appendix
Interventions: references to studies and documented effect sizes

Intervention	Description	Effect size	References
PRE-ED			
Proactive care	Primary care led population risk stratification and nurse-led care program consisting of CGA*, care planning and care coordination for high-risk individuals.	• Negligible effects on mortality, admissions to hospitals or care homes.	(Bleijenberg et al., 2016; Blom et al., 2016; Smit et al., 2018)
Hospital-at-home	Providing holistic care to people with urgent care crises in their own homes, rather than admitting them to hospital	• Hospital at Home with CGA led to similar mortality compared to hospital delivered CGA*. • Mortality (Risk ratio = 0.98, CI = [0.65, 1.47]). • Older people living at home at six months (affecting readmissions) (Risk ratio = 1.05, CI = [0.95,1.15]). • Reduction in admissions to long term residential care at six months (Risk ratio = 0.58, CI = [0.45, 0.76]).	(Shepperd et al., 2021)
In-ED			
Geriatric emergency medicine	Consultant geriatrician led CGA*	• Reduced admissions (absolute risk reduction 2.6%-19.7%) • Reduced readmissions (Risk ratio = 0.74, CI = [0.55,1.00]).	(Conroy et al., 2011; Hughes et al., 2019; Jay et al., 2017; Lowthian et al., 2015; Malik et al., 2018)
Front door frailty	Nurse or allied health professional led CGA*, often involving community in-reach.	• Reduced mortality (risk ratio = 0.92, CI = [0.55, 1.52]), • Reduced admissions (risk ratio = 0.9, CI = [0.7, 1.16]), • Reduced readmissions (risk ratio = 0.95, CI = [0.83, 1.08]), • Reduced institutionalisation (risk ratio = 0.75, CI = [0.44, 1.29]).	(Conroy et al., 2011; & Heflin 2005; Karam et al., 2015; Lowthian et al., 2015; Malik et al., 2018; Sinha et al., 2011)
POST-ED			
Acute frailty unit	Geriatrician led CGA* delivered in short stay areas for admitted patients.	• Reduced mortality (risk ratio = 0.86, CI = [0.68, 1.1]), • Reduced readmissions (risk ratio = 0.78, CI = [0.67, 0.92])	(National Institute for Health & Care Excellence NICE Guideline 94, 94, 2018)

*CGA = Comprehensive Geriatric Assessment.