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Joining forces: the value of design partnering with operational research to improve healthcare delivery

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Abstract

A wide range of disciplines are directing their methods and tools to help address the challenges of healthcare. Chief among these are design and operational research (OR). Though they have much in common, these two disciplines have existed in isolation for most of their history and there is currently a gulf between the two research communities. In this position paper, we rapidly review the contributions of design and OR in healthcare. We then identify similarities and complementarities between the two disciplines and communities when they consider healthcare systems. Finally, we propose practical steps to enable better collaboration. Our focus is on finding ways in which the two disciplines complement each other. When applying design to healthcare services, designers may wish to learn from OR, which has a long history of supporting improvements in healthcare organisation and services, particularly using quantitative data and analysis and modelling methods. In return, design has distinctive qualities that could augment the OR approach, such as its emphasis on wide and creative search for potential solutions, and iterative co-production and prototyping of solutions with clients. Better collaboration will require a coordinated effort but could yield a more comprehensive and effective approach to improving healthcare systems.

Keywords: healthcare design, interdisciplinarity, operational research, healthcare improvement science

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1. Introduction

Healthcare systems all over the world are facing many challenges because of changes in demand (ageing population, increased prevalence of chronic diseases and emergence of new, often treatment-resistant pathogens) as well as concerns with the adequacy and safety of the care provided and its equal access for all. These challenges are compounded by the rising cost of new medical innovations and pressures to contain the expansion of healthcare budgets.

Some of these problems require new technologies, new treatment strategies or new therapeutics. However, many of these challenges also require rethinking the

Box 1. Examples of applications of design approaches in healthcare.

Application of specific design methods in healthcare:

- (i) Design thinking (Altman, Huang, & Breland 2018; Oliveira, Zancul, & Fleury 2021; Ku & Lupton 2022)
- (ii) Systems approaches (Clarkson *et al.* 2017; Komashie *et al.* 2021)
- (iii) Service design (Pfannstiel & Rasche 2019)
- (iv) Systems engineering (Rouse & Cortese 2010; Griffin *et al.* 2016)
- (v) Experience-based co-design (Donetto *et al.* 2015; Green *et al.* 2020)
- (vi) Human factors and ergonomics (Catchpole 2013)
- (vii) Human-centred design (Melles, Albayrak, & Goossens 2020)
- (viii) Healthcare environment design (Ulrich *et al.* 2008; Cama 2009)

Applications of design to specific areas of healthcare:

- (i) P4 (Predictive, Preventive, Personalised and Participative) healthcare (Patou *et al.* 2020)
- (ii) Medical technology innovation (Zenios *et al.* 2010)
- (iii) Global health (Bazzano *et al.* 2017)
- (iv) Medical education (McLaughlin *et al.* 2019)
- (v) Medical simulation (Petrosoniak *et al.* 2020)
- (vi) Patient safety (Xie & Carayon 2015)
- (vii) Person-centred care (Bhattacharyya *et al.* 2019)
- (viii) Patient work (Werner *et al.* 2020)

way healthcare is delivered. There is great potential for design to contribute to this endeavour (Clarkson 2018). In general, the contribution of design in health has tended to focus on medical products and devices, or medical IT. Its contribution towards designing healthcare services is relatively young, witnessing the small number of papers in key journals like *Design Studies*, the *Journal of Engineering Design* or *Research in Engineering Design*.

We make the argument that when applying design to healthcare services, designers may wish to learn from the experience of design's sister discipline, operational research (OR), which has a longer history of trying to improve healthcare organisation and services. Since its inception just before World War II, OR has developed methods and approaches aimed at improving the performance of complex systems and processes (which health services certainly are), often relying on quantitative modelling, but including also more qualitative but still disciplined methods that facilitate stakeholder engagement and participation. The desirability of better integration between OR and design has been noted over the years (Holzman 1979; Levary 1994; O'Keefe 1995, 2014; Royston 2013). What remains to be seen is how these complementarities can best be operationalised in a healthcare context. In what follows, we propose a partnership and consider how the two disciplines might complement each other in contributing to (re)designing healthcare services. First, we provide some background about the involvement of OR and design in healthcare. We then describe some of the similarities and complementarities of design and OR as we begin to set out how they might join forces in tackling challenges in healthcare.

2. Design and healthcare

In this paper, we use the term design in the broadest sense, as envisioned by the *Design Science Journal* (Papalambros *et al.* 2015). This, therefore, covers aspects of design from cognitive design through to service design and parts of human factors/ergonomics and systems engineering. For this reason, it is impossible to be exhaustive in describing design and healthcare in this short section. It is also important to point out that industrial designers and design engineers are not the only professional designers (Simon 1996): arguably, all professionals design (although some may be more conscious of this fact than others). At the heart of design is the desire to realise functional products and systems and the belief that ‘systems [or products] that work do not just happen – they have to be planned, designed and built’ (Elliott & Deasley 2007).

Design researchers have tackled issues in health services, for example, to better integrate users in product development (Weightman *et al.* 2010), to reduce errors and increase patient safety (Roesler *et al.* 2019) or to use design as a problem-solving strategy to effectively manage indeterminate problem situations (Van Stralen 2008). No comprehensive review of the application of design in healthcare has been published to date, but the literature shows that a range of design methods have been applied to various areas of healthcare (Box 1).

However, design in healthcare remains a relatively recent academic discipline, and a simple bibliometric analysis reveals that it has only a limited presence in healthcare (Table 1). Between 2001 and 2020, less than 2.1% of articles published in key design journals focused on healthcare. In absolute terms, this amounted to less than 150 articles. In practice, national institutions have recommended a better use of engineering and design skills in solving healthcare problems (Reid *et al.* 2005; Clarkson *et al.* 2017). Yet, health services have repeatedly been found to be out-of-step with contemporary design thinking. Key characteristics of the design mindset, for example, user-centredness, openness in problem exploration, learning through iteration, creativity in solution generation, robust testing or risk assessment (Dieter & Schmidt 2013; Clarkson 2018), are often missing in practical service development projects (Clarkson *et al.* 2004; Jun, Morrison, & Clarkson 2014).

The amount and share of published healthcare-related research are substantially larger in OR than in design research (Table 1). The first OR papers in healthcare date back to the 1950s (Bailey 1952), and the literature has developed steadily since then (Figure 1). This suggests that the findings, expertise and experience accumulated in the OR community in relation to healthcare are greater than in design.

3. OR and healthcare

The Operational Research Society describes OR as ‘a scientific approach to the solution of problems in the management of complex systems that enables decision makers to make better decisions’ [The OR Society (n.d.)]. A complementary description might be that OR is a discipline focused on supporting people to organise and manage processes and services more effectively and efficiently so as to improve system performance – OR, like medicine or engineering, is an *improvement* science. Traditional applications of OR draw on quantitative methods such as optimisation, queueing models and simulation (Winston 1993). A typical example

Table 1. Articles published on healthcare in OR and design journals between 2001 and 2020

	Design journals			OR journals		
	2001–2010	2011–2020	Total	2001–2010	2011–2020	Total
Total number of articles published	2,956	3,545	6501	14,863	19,606	34,469
Hits for ‘healthcare or health care’ in topic (%)	6 (0.2%)	26 (0.7%)	32 (0.5%)	155 (1.0%)	539 (2.7%)	694 (2.0%)
Hits for ‘health or healthcare or health care or medic* or pharma* or nurs* or hospital or doctor or physician or patient’ in topic (%)	23 (0.8%)	112 (3.2%)	135 (2.1%)	542 (3.6%)	1,259 (6.4%)	1,801 (5.2%)

Note: Search run on 7 February 2022 on ISI Web of Knowledge. Sample of design journals: *Journal of Engineering Design*, *Research in Engineering Design*, *International Journal of Design*, *Design Studies*, *Design Issues*, *Design Science*, *Artificial Intelligence for Engineering Design, Analysis and Manufacturing (AI EDAM)*, *ASME Journal of Mechanical Design*. Sample of OR journals: *European Journal of Operational Research*, *Journal of the Operational Research Society*, *Management Science*, *Operations Research*, *Omega*, *Computers & OR*, *International Transactions in Operational Research*, *Annals of Operations Research*, *IIEE Transactions*. ISI Web of Knowledge’s ‘topic’ field combines title, abstract and keywords.

would be seeking to improve the efficiency and effectiveness of an organisation by optimising the use of a given amount of resources invested (time, money, facilities, staff).

However, many organisational challenges do not lend themselves to reductionist modelling approaches as they are particularly complex, unstructured or have multiple and potentially contested versions of ‘what better looks like’. To assist in such cases, so-called ‘soft’ OR has been developed. This draws largely on qualitative approaches such as soft systems methodology, cognitive mapping, and strategic options and decision analysis and can be used to help improve collective understanding of the aims of a system, to ask questions of it and to facilitate agreement on how to proceed (Mingers & Rosenhead 2001).

OR has a long history of working on healthcare issues, with an acceleration of research and applications in this field over recent decades (Pitt *et al.* 2016). OR has been applied at different decision levels (strategic planning, tactical planning, advance operational decision-making and real-time reactive operational decision-making) and in a variety of services: ambulatory care services; emergency care services; surgical care services; inpatient care services; home care services and residential care services (Hulshof *et al.* 2012). Multiple literature reviews have summarised how different OR techniques have been applied in healthcare and/or summarise OR applications published in specific areas of healthcare (Box 2).

In terms of methods, a comprehensive review of the healthcare OR literature by Brailsford *et al.* (2009) shows that the majority of publications in healthcare OR have been found to employ statistical analysis (e.g., regression analysis), statistical modelling (e.g., Markov models, structural equation modelling), simulation (discrete event, system dynamics, Monte Carlo) or qualitative modelling (e.g., process mapping, cognitive modelling). They also find that the rate of healthcare OR

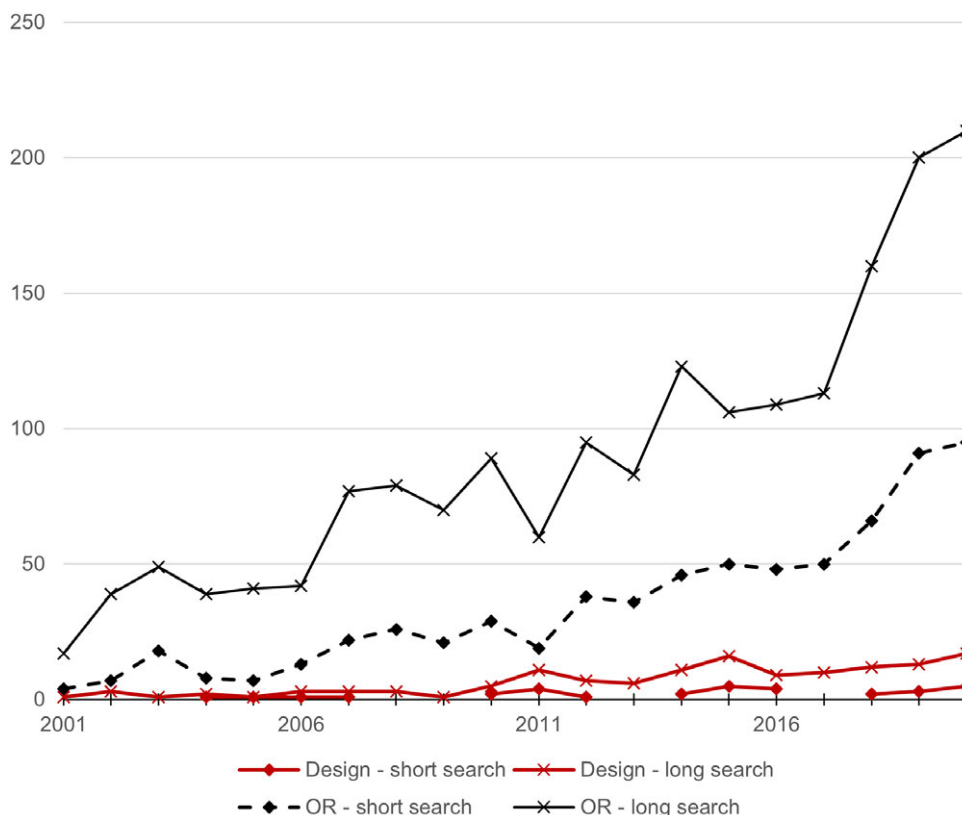


Figure 1. Number of healthcare-related publications per year, in design and OR, in the same selection of journals as Table 1. Short search: ‘healthcare or health care’ in topic. Long search: ‘health or healthcare or health care or medic* or pharma* or nurs* or hospital or doctor or physician or patient’ in topic.

publications is steadily increasing, with a particularly prominent rise in simulation and qualitative (soft) methods.

When it comes to areas of application, Brailsford & Vissers (2011) review papers presented at the meetings of the Operational Research Applied to Health Services European Working Group from 1975 to 2009 and categorise them according to the nine stages of the product life cycle, that is, stages of developing and managing a service. By far the most common categories for OR applications were ‘managing the performance of service delivery’ (39% of papers), ‘developing programs and plans for using resources’ (24%) and ‘evaluating the performance of service delivery’ (18%). Hardly any papers were categorised as ‘identifying customer requirements’ or ‘developing a new service’, which are both key areas where one might expect design to make major contributions.

Increasing attention is also paid to the best ways of engaging and working with healthcare organisations and stakeholders in healthcare OR projects (Brailsford *et al.* 2013; Pearson *et al.* 2013). However, there are still very few published examples of successful implementations of OR (Brailsford *et al.* 2009; Brailsford & Vissers 2011), and few published empirical evaluations of the impact of OR on health services (Lamé, Crowe, & Barclay 2022). This shows that despite a steady

Box 2. Examples of applications of OR in healthcare.

Applications of specific OR techniques in healthcare:

- (i) Modelling and simulation (Wilson 1981; Fone *et al.* 2003; Brailsford *et al.* 2009; Jahangirian *et al.* 2012; van Lent, VanBerkel, & van Harten 2012; Mohiuddin *et al.* 2017; Long & Meadows 2018)
- (ii) Multi-criteria decision analysis (Marsh *et al.* 2014)
- (iii) Scheduling (Samudra *et al.* 2016; Marynissen & Demeulemeester 2019)
- (iv) Optimisation (Ahmadi-Javid, Jalali, & Klassen 2017)
- (v) Soft systems methodology (Augustsson, Churruca, & Braithwaite 2020)
- (vi) Behavioural OR (Kunc, Harper, & Katsikopoulos 2018)

Applications of OR to specific areas of healthcare:

- (i) Emergency departments (Mohiuddin *et al.* 2017)
- (ii) Outpatient clinics (Lamé, Jouini, & Stal-Le Cardinal 2016; Ahmadi-Javid *et al.* 2017)
- (iii) Operating rooms (Cardoen, Demeulemeester, & Beliën 2010; Samudra *et al.* 2016)
- (iv) Staff rostering and scheduling (Ernst *et al.* 2004; Van den Bergh *et al.* 2013)
- (v) Community care (Palmer, Fulop, & Utley 2018)
- (vi) Mental health (Long & Meadows 2018)
- (vii) Cancer care (Saville, Smith, & Bijak 2019)
- (viii) Home healthcare (Cissé *et al.* 2017; Fikar & Hirsch 2017; Grieco, Utley, & Crowe 2020)
- (ix) Global health (Royston 2011; Bradley *et al.* 2017)

growth in academic healthcare OR over a number of years, its overall influence over healthcare in practice remains uncertain. There is more indication of influence where teams of OR analysts have been *embedded* in healthcare organisations (e.g., Royston *et al.* 1999; Royston *et al.* 2003; Marshall *et al.* 2014; Crowe *et al.* 2019; Harper 2020), but there is still a long way to go, and we suggest that combining design's strengths with OR's expertise and experience in healthcare could be particularly fruitful.

4. Joining forces

Although they have grown separately, OR and design have much in common. 'Everyone designs who devises courses of action aimed at changing existing situations into preferred ones', wrote Herbert Simon, a leading figure in both OR and design (Simon 1996). Churchman, one of the early pioneers of OR, defined OR as 'the securing of improvement in social systems by means of scientific method' (Churchman 1970). One of the other key figures in the postwar development of OR, Russel Ackoff, argued (albeit without much success) that the discipline needed to focus much more on design issues and later wrote a book about design for management (Ackoff, Magidson, & Addison 2006). With these definitions, design and OR belong to a broader ensemble of design disciplines that aim to improve the world rather than explain it, much like medicine or architecture in their respective domains (Royston & Komashie 2016).

Previous publications have discussed how OR and design could complement each other. In the OR community, in a brief letter to the editor, Holzman (1979) acknowledged the rift between engineering design and OR and highlighted common denominators (the formulation of objectives, a systems perspective, the choice between alternatives and optimisation) between them. A decade later, Levary (1988, 1994) reviewed the potential for OR contributions to engineering, mentioning computer communications engineering, structural engineering or chemical engineering. O’Keefe (1995) discussed how systems design could improve OR’s impact by focusing on designing better systems rather than improving existing ones. In a series of articles, Evans (1991, 1992, 1993, 1997a,b) argued for the key role of creativity in OR, soon followed by Keys (2000) with a framework for examining the role of creativity and design in OR practice. Fifteen years later, O’Keefe (2014) extended his argument by proposing a design science approach to OR projects, in order to better embed OR solutions into organisational and information systems. Around the same time, Royston (2013) argued that OR was often involved in designing systems, for example, through scenario analysis or simulation, as well as in the complementary task of assisting decisions. This, in his view, meant that OR needed to pay better attention to design thinking.

In parallel, in the design research community, Cross (2001) noted how OR impacted the origins of design methods. Indeed, design engineering courses included OR modules (Fenves & Grossmann 1992), and optimal design developed as a strong stream of engineering design research (Cagan, Grossmann, & Hooker 1997; Papalambros & Wilde 2000). Examples of combining human factors engineering and OR have also appeared (Ryan *et al.* 2011) but have remained limited. In the systems engineering community, some authors go as far as considering OR as a subset of the methods available to systems engineers (Rouse & Cortese 2010).

Many complementarities between OR and design could be harnessed in responding to the numerous complex challenges facing modern healthcare delivery systems, but practical steps are needed (Box 3).

4.1. Complementarities

Because of a shared ethos of improving the world around us, methods and techniques are both a major research output and a core element of practice in OR and design (Ackoff 1956; Gericke *et al.* 2020). By providing practitioners with methods, tools and techniques, OR and design both seek to achieve improvement – but traditionally on different objects and through different routes. OR works at supporting better organisational decision-making and performance, while design aims at improving design processes and products or technologies.

However, these domains are not independent. Technology and organisation both have a key role to play in the future sustainability of healthcare, and they are intertwined: changes in technology often demand changes in the organisation of processes and services, and conversely, organisational changes could often benefit from technological innovations. For instance, to make the most of developments in medical technologies (including data-driven artificial intelligence) requires a refined understanding of human behaviour with technology and product-service development (both of which design has a long history of dealing with), the implications for demand and workforce planning (a core expertise in OR) and a

Box 3: Complementarities between OR and design, and the steps needed to capitalise on them in the context of improving healthcare

Complementarities:

- (i) Technology (a key focus of design) and organisation (a key focus of OR) are increasingly entangled and convergent, requiring a holistic approach that considers them together
- (ii) Design's distinct strengths include a wide-ranging and creative search for potential solutions and a pragmatic concern for workable solutions through frequent prototyping
- (iii) OR's unique contribution lies in its unparalleled developments for quantitative and qualitative analysis and modelling for improving organisational decision-making and system performance
- (iv) OR and design have developed different approaches to stakeholder engagement, which could benefit from cross-learning
- (v) OR and design share a common challenge in evidencing their impact in healthcare
- (vi) OR and design could both learn from other research communities who have successfully engaged with healthcare systems

Steps needed to bring design and OR together to improve healthcare:

- (i) Strategic reflection on how to collaborate better, with joint initiatives between learned societies and professional bodies to launch common projects
- (ii) Promoting the emergence of healthcare specialists in design research and practice, who are devoted to the application and development of design in this sector
- (iii) Identifying common (grand) challenges in health that OR and design could tackle together
- (iv) Breaking down perceived differences and preconceptions about the disciplines
- (v) Training cross-disciplinary researchers and practitioners, apt in both OR and design methods
- (vi) Learning from the experience of other disciplines that have collaborated effectively across boundaries, such as health economics, social sciences or human factors and ergonomics
- (vii) Generating empirical evidence for the impact of OR and design in healthcare

robust model of value flows throughout the service (where both design and OR have elements to contribute).

More generally, it can be argued that design takes a more holistic approach to solving problems than OR, which often focuses on improving the efficiency of a particular process or aspect of a system. That said, problem structuring methods in OR support a wider system view of a problematic situation (Ackermann 2012). These 'soft' methods also help operational researchers to incorporate the views of different stakeholders, but nonetheless much could be learnt in this regard from the more explicit detailing of user requirements that is standard practice in design. Similarly, greater attention could be given in OR to the more explicit, traceable and

systematic process for making decisions that design adopts, for example, about priorities between requirements and solution characteristics.

Another strength of design that complements OR is in the way it tackles risk analysis. While ‘what does good, or better, look like?’ and ‘what could go wrong?’ (Clarkson 2018) are important aspects in both disciplines, design covers so-called ‘human factors’ (Karsh *et al.* 2006; Mumma *et al.* 2018) which tend to be overlooked in OR [despite recent but growing interest in Behavioural OR (Kunc, Malpass, & White 2016; Kunc *et al.* 2018)], while OR tends to focus on quantitative risk modelling.

Although both disciplines have a background of engaging with stakeholders in order to elicit their needs and collaborate towards solutions, the methods differ. OR has developed a tradition of model-supported participative workshops. In addition to workshops, design has adopted a broader range of methods, for example, design ethnography (Hughes *et al.* 1994) and living labs. These methods have evolved and been refined in line with the objectives and interests of each discipline. Their combination could enrich interactions with stakeholders.

Related to this, design could offer rich insights to OR practitioners in relation to prototyping. While OR modelling is iterative and models typically progress through several stages in collaboration with users, there is rarely the early and rapid testing that would generate a wider range of ideas to be trialled and more creative adaptation to meet user needs. Indeed, although design thinking and creativity, key elements of design, also play a role in OR practice, this is often downplayed, naïve or even unconscious (Evans 1997a,b; Keys 2000; Royston 2013, 2016), and better links with design could support this key process.

At the same time, OR can support many areas of design with its optimisation and decision-making techniques (Barish 1963; Levary 1994). OR is well recognised for its numerous approaches to finding quantitative solutions to sometimes fairly complex real-world problems. It also has a rigorous approach to understanding variability or stochasticity and hence can make a good contribution to designing resilient systems. For similar reasons, through its use of models and forecasts it plays a key role in understanding the immediate future in complex chaotic situations such as a pandemic where it may be desired to explore a wide range of scenarios of capacity requirement or disease progression (Currie *et al.* 2020; Kaplan 2020).

Soft OR could also prove complementary to standard stakeholder engagement in design (which focuses on a good understanding of user needs), because techniques such as Rich Pictures (Checkland & Scholes 1990; Crowe *et al.* 2017) help the OR practitioner to go deeper than expressed needs to understand worldviews, concerns and values that are relevant to the complex situation and not just the system. Through years of engagement with issues in health services, OR has also developed specific insights on how best to engage with its stakeholders (Pearson *et al.* 2013; Jahangirian *et al.* 2015), which design could learn from.

Here, both disciplines might benefit from the more in-depth qualitative research methods developed in the social sciences such as ethnography, which can help to establish a far richer and contextually nuanced understanding of a socially constructed system and situation. More generally, OR and design could learn from the broader health services research community which has, for example, developed a strong track record in evaluation of interventions in healthcare. In 1993, Pope and Mays (1993) discussed the integration of qualitative research in

health services research. Thirty years later, quantitative methods remain the norm, but qualitative research has made definite progress. Similarly, human factors and ergonomics researchers have long wondered about the best way to make an impact in healthcare and generated useful insights about the need to tailor the discipline to the requirements of healthcare (Catchpole 2013).

OR and design could also partner with emerging sub-disciplines in health services research that have shown successful integration with other health disciplines. For example, the growing field of ‘improvement science’ in healthcare has made a large impact in healthcare by transferring industrial engineering and quality engineering principles (Berwick 1989). Although OR and design are not absent in this field (Clarkson *et al.* 2017, 2018; Crowe *et al.* 2017), they still have much to contribute. Another area where OR and design could make a contribution is implementation science, ‘the scientific study of methods to promote the systematic uptake of research findings and other evidence-based practices into routine practice, and, hence, to improve the quality and effectiveness of health services’ (Eccles & Mittman 2006). Through modelling and human-centred design of existing and new services, OR and design could help bridge translation gaps between scientific evidence and clinical practice (Cooksey 2006; Morris, Wooding, & Grant 2011).

Finally, design and OR share a common challenge in relating to the evaluation-driven tradition of medical disciplines. Published evaluations of OR and design methods remain very rare (Frey & Dym 2006; Gericke *et al.* 2020; Lamé *et al.* 2022): a recent systematic review and meta-analysis of evaluations of systems approaches to improving healthcare delivery did not find any suitable study to include from either a design or OR journal (Komashie *et al.* 2021). This attests to the dearth of rigorous evaluation of the impact of our approaches in improving healthcare delivery. Yet, being ‘evidence-based’ is a growing concern and key expectation in healthcare (Lamé 2018). Design and OR could benefit from a shared conversation on how to overcome this challenge and to draw on each other’s strengths.

To summarise the complementarities of design and OR, we draw on Royston’s adaptation of the Johari window to OR (Royston 2016). The Johari window was first proposed by Joseph Luft and Harrington Ingham in 1955 to describe how people perceive themselves and how they are in turn perceived by others. Table 2 shows the Johari window adapted to OR and design in healthcare, showing areas that are recognised by one or both disciplines, as well as ‘blind spots’, that is, areas under-recognised by both.

4.2. Practical steps to bridge the gap

Taking advantage of the complementarities between design and OR in tackling problems in healthcare systems is no straightforward task. The disciplines have grown separately and have formed distinct research communities, with almost no interface. Bringing them together requires broadening the vision of their respective perimeters and roles in improving healthcare (Royston 2013). We suggest practical steps to make this happen (Figure 2).

Increasing engagement

This move will require strategic thinking on the part of both communities. Effort has begun in this direction, with a number of initiatives to bring together OR and

Table 2. ‘Johari window’ of OR and design in healthcare

	Strength of design	Less prominent in design
Strength of OR	<ul style="list-style-type: none"> (i) Need to take a systems approach (ii) Problem-solving, improvement-driven ethos (iii) Need for stakeholder engagement 	<ul style="list-style-type: none"> (i) Focus on organisational efficiency (ii) Quantitative modelling of organisations (iii) Need to develop specialists focused on the healthcare context (iv) Data-driven analysis of organisations and services (v) Analysing – understanding how elements of a whole system work
Less prominent in OR	<ul style="list-style-type: none"> (i) Focus on practical, implementable solutions (ii) Role of creativity in improvement (iii) Need for iterative experimentation and prototyping (iv) Observation of users to understand their needs and habits (v) Synthesising – combining elements to form a whole working system 	<ul style="list-style-type: none"> (i) Importance of empirical evaluation of impact in healthcare (ii) Learning from other disciplines who have engaged with healthcare research (e.g., social sciences or health economics)

design researchers, such as between the OR Society and Design Society (Royston 2014) or through other interdisciplinary encounters (Komashie *et al.* 2019; Ciccone *et al.* 2020). Further engagement between the two research communities is required to build on this early momentum and make things happen. One possible outcome of such engagement could be to identify common grand challenges that could be tackled jointly. The recent creation of a Special Interest Group on Health Systems Design at the Design Society is an encouraging sign and could be a vehicle for identifying common challenges.

Increasing health research in design

To enable greater collaboration, design needs to strengthen its healthcare research stream. OR has a strong sub-community of healthcare specialists, with dedicated conferences and journals. In contrast, design’s involvement remains limited and healthcare is often a supplement to work in other sectors for many design researchers. We argue that the specificities of healthcare and its importance as an industrial sector also justify the emergence of specialists in design.

Training a new cohort of improvers

This last point begs the question of appropriate training. A way to bridge the gap between OR and design in healthcare could be to train graduates in design and OR tools and approaches applied to healthcare, thus promoting the emergence of a cohort of cross-disciplinary healthcare improvement specialists. Currently, ‘quality improvement’ in healthcare is often based on principles derived from industrial engineering and quality management by the Institute for Healthcare Improvement,

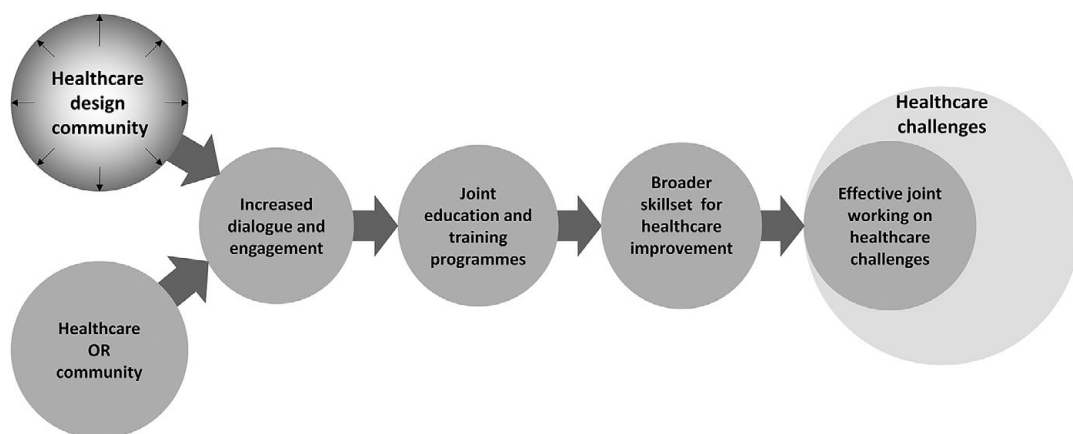


Figure 2. Practical steps to tackling healthcare challenges through OR and design.

such as Plan-Do-Study-Act cycles or statistical process control. Yet, this single perspective can be limiting, and improvement specialists could benefit from a broader toolkit, as proposed and studied in the emerging multidisciplinary field of improvement science/research (Marshall, Pronovost, & Dixon-Woods 2013). Embedding these specialists close to practice, in healthcare organisations, would be one way to understand better the effective ways to make an impact through design or OR methods (Marshall *et al.* 2014; Perry *et al.* 2021). Healthcare professionals are also increasingly encouraged to train in quality improvement (Worsley, Webb, & Vaux 2016). This training could be an opportunity to expose them to elements of systems analysis, modelling and design based on design and OR principles and concepts.

Combining curricula

OR and design curricula are often separate and even hosted in different schools (mathematics, business and management or computer science for OR, engineering for engineering design, arts or technology for industrial design), but combining them in a training programme seems feasible. Recent interdisciplinary workshops with both design and OR participants (as well as human factors and ergonomics specialists, social scientists and clinicians) revealed that much of the gap between disciplines, including that between OR and design, is often due to preconceptions about other disciplines, miscommunication and perceived differences that do not stand up to careful analysis of what gets done in actual projects (Komashie *et al.* 2019). Despite using different vocabulary and mastering different tools, methods and techniques, participants shared a strong common purpose of making a positive impact on the way healthcare is delivered and a sense that the problems warranted collaboration. It quickly emerged that the methods were complementary. A systems-oriented perspective, highlighting the complex interactions between elements of health services, proved to be a fruitful angle to generate common discussions (Komashie *et al.* 2019; Ciccone *et al.* 2020).

Looking beyond OR and design

Finally, it is important to remain conscious that the simple alliance of OR and design is unlikely to transform healthcare on its own. The way issues are defined and presented (Martin *et al.* 2019), leadership or organisational culture are strong factors in the success or failure of improvement projects (Dixon-Woods, McNicol, & Martin 2012). At an individual level, successful healthcare improvers rely on varied habits of mind, including influencing, communication and resilience (Lucas 2016), which are distinct from the methods, tools and disciplinary frameworks that define design and OR. More generally, innovation requires entrepreneurship as well as good design and science to happen (Luo 2015). Therefore, a broader understanding of business, economics and organisations will be required, if OR and design are to affect healthcare delivery. Learning from other disciplines that have engaged with healthcare research (e.g., social sciences, economics) may also help better adapt our approaches to the context of healthcare and complement them, for example, in evaluating the impact of our interventions.

5. Conclusion

This paper explores some of the potential benefits and opportunities for design and OR to join forces in addressing the increasingly complex challenges facing modern day healthcare delivery systems. OR has a long history of engaging with healthcare systems and has developed a strong sub-community around this topic. Design would benefit from learning from this experience and could in return complement OR's approach with its own methods and perspectives on how to improve healthcare systems.

We suggest that a systems perspective, problem solving and stakeholder engagement are all common to design and OR, while design has unique strengths in approaches to creativity, iterative experimentation and prototyping, and OR brings expertise in quantitative and qualitative analytical and modelling techniques for improving organisational decision-making and system performance.

Both disciplines, however, have a challenge in common with regard to generating the empirical evidence of their impact on healthcare delivery. This presents an opportunity for collaborative research into better ways of evaluating systems-informed interventions in healthcare.

Nonetheless, it is recognised that, bringing these two communities together is no simple task and requires a coordinated effort. There would be a practical interest in combining the approaches of OR and design but also a research interest in analysing if and how such collaborations work, and what makes them more or less feasible and effective.

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References

- Ackermann, F.** 2012 Problem structuring methods ‘in the dock’: arguing the case for soft OR. *European Journal of Operational Research* **219** (3), 652–658; doi:[10.1016/j.ejor.2011.11.014](https://doi.org/10.1016/j.ejor.2011.11.014).
- Ackoff, R. L.** 1956 The development of operations research as a science. *Operations Research* **4** (3), 265–295; doi:[10.1287/opre.4.3.265](https://doi.org/10.1287/opre.4.3.265).
- Ackoff, R. L., Magidson, J. & Addison, H. J.** 2006 *Idealized Design: Creating an Organization’s Future*. Wharton School Pub.
- Ahmadi-Javid, A., Jalali, Z. & Klassen, K. J.** 2017 Outpatient appointment systems in healthcare: a review of optimization studies. *European Journal of Operational Research* **258** (1), 3–34; doi:[10.1016/j.ejor.2016.06.064](https://doi.org/10.1016/j.ejor.2016.06.064).
- Altman, M., Huang, T. T. K. & Breland, J. Y.** 2018 Design thinking in health care. *Preventing Chronic Disease* **15**, E117; doi:[10.5888/pcd15.180128](https://doi.org/10.5888/pcd15.180128).
- Augustsson, H., Churrua, K. & Braithwaite, J.** 2020 Change and improvement 50 years in the making: a scoping review of the use of soft systems methodology in healthcare. *BMC Health Services Research* **20** (1), 1063; doi:[10.1186/s12913-020-05929-5](https://doi.org/10.1186/s12913-020-05929-5).
- Bailey, N. T. J.** 1952 A study of queues and appointment systems in hospital outpatient departments, with special reference to waiting-times. *Journal of the Royal Statistical Society A14*, 185–189.
- Barish, N. N.** (1963) ‘Operations Research and Industrial Engineering: The Applied Science and its Engineering’, *Operations Research*, **11**(3), pp. 387–398. doi: [10.1287/opre.11.3.387](https://doi.org/10.1287/opre.11.3.387).
- Bazzano, A. N., Martin, J., Hicks, E., Faughnan, M. & Murphy, L.** 2017 Human-centred design in global health: a scoping review of applications and contexts. *PLoS One* **12** (11), e0186744; doi:[10.1371/journal.pone.0186744](https://doi.org/10.1371/journal.pone.0186744).
- Berwick, D. M.** 1989 Continuous improvement as an ideal in health care. *New England Journal of Medicine* **320** (1), 53–56; doi:[10.1056/nejm198901053200110](https://doi.org/10.1056/nejm198901053200110).
- Bhattacharyya, O., Blumenthal, D., Stoddard, R., Mansell, L., Mossman, K. & Schneider, E. C.** 2019 Redesigning care: adapting new improvement methods to achieve person-centred care. *BMJ Quality & Safety* **28** (3), 242–248; doi:[10.1136/bmjqs-2018-008208](https://doi.org/10.1136/bmjqs-2018-008208).
- Bradley, B. D., Jung, T., Tandon-Verma, A., Khoury, B., Chan, T. C. Y. & Cheng, Y.-L.** 2017 Operations research in global health: a scoping review with a focus on the themes of health equity and impact. *Health Research Policy and Systems* **15** (1), 32; doi:[10.1186/s12961-017-0187-7](https://doi.org/10.1186/s12961-017-0187-7).
- Brailsford, S. C., Bolt, T. B., Bucci, G., Chausalet, T. M., Connell, N. A., Harper, P. R., Klein, J. H., Pitt, M & Taylor, M.** 2013 Overcoming the barriers: a qualitative study of simulation adoption in the NHS. *Journal of the Operational Research Society* **64** (2), 157–168; doi:[10.1057/jors.2011.130](https://doi.org/10.1057/jors.2011.130).
- Brailsford, S. C., Harper, P. R., Patel, B. & Pitt, M.** 2009 An analysis of the academic literature on simulation and modelling in health care. *Journal of Simulation* **3** (3), 130–140; doi:[10.1057/jos.2009.10](https://doi.org/10.1057/jos.2009.10).
- Brailsford, S. C. & Vissers, J.** 2011 OR in healthcare: a European perspective. *European Journal of Operational Research* **212** (2), 223–234; doi:[10.1016/j.ejor.2010.10.026](https://doi.org/10.1016/j.ejor.2010.10.026).

- Cagan, J., Grossmann, I. E. & Hooker, J.** 1997 A conceptual framework for combining artificial intelligence and optimization in engineering design. *Research in Engineering Design* 9 (1), 20–34; doi:[10.1007/BF01607055](https://doi.org/10.1007/BF01607055).
- Cama, R.** 2009 *Evidence-Based Healthcare Design*. Wiley.
- Cardoen, B., Demeulemeester, E. & Beliën, J.** 2010 Operating room planning and scheduling: a literature review. *European Journal of Operational Research* 201 (3), 921–932; doi:[10.1016/j.ejor.2009.04.011](https://doi.org/10.1016/j.ejor.2009.04.011).
- Catchpole, K.** 2013 Spreading human factors expertise in healthcare: untangling the knots in people and systems. *BMJ Quality & Safety* 22 (10), 793–797; doi:[10.1136/bmjqs-2013-002036](https://doi.org/10.1136/bmjqs-2013-002036).
- Checkland, P. & Scholes, J.** 1990 *Soft Systems Methodology in Action*. Wiley.
- Churchman, C. W.** 1970 Operations research as a profession. *Management Science* 17 (2), B-37–B-53; doi:[10.1287/mnsc.17.2.B37](https://doi.org/10.1287/mnsc.17.2.B37).
- Ciccone, N., Patou, F., Komashie, A., Lame, G., Clarkson, P. J. & Maier, A. M.** 2020 Healthcare systems design: a sandbox of current research themes presented at an international meeting. *Proceedings of the Design Society: DESIGN Conference 1*, 1873–1882; doi:[10.1017/dsd.2020.24](https://doi.org/10.1017/dsd.2020.24).
- Cissé, M., Yalçındağ, S., Kergosien, Y., Şahin, E., Lenté, C. & Matta, A.** 2017 OR problems related to home health care: a review of relevant routing and scheduling problems. *Operations Research for Health Care* 13–14, 1–22; doi:[10.1016/j.orhc.2017.06.001](https://doi.org/10.1016/j.orhc.2017.06.001).
- Clarkson, P. J.** 2018 What has engineering design to say about healthcare improvement? *Design Science* 4, e17; doi:[10.1017/dsj.2018.13](https://doi.org/10.1017/dsj.2018.13).
- Clarkson, P. J., Bogle, D., Dean, J., Tooley, M., Trewby, J., Vaughan, L., ... Shelton, P.** 2017 *Engineering Better Care*, online document <http://www.raeng.org.uk/publications/reports/engineering-better-care> Accessed: 1.1.2023.
- Clarkson, P. J., Buckle, P., Coleman, R., Stubbs, D., Ward, J., Jarrett, J., Lane, R. & Bound, J.** 2004 Design for patient safety: a review of the effectiveness of design in the UK health service. *Journal of Engineering Design* 15 (2), 123–140; doi:[10.1080/09544820310001617711](https://doi.org/10.1080/09544820310001617711).
- Clarkson, P. J., Dean, J., Ward, J., Komashie, A. & Bashford, T.** 2018 A systems approach to healthcare: from thinking to -practice. *Future Healthcare Journal* 5 (3), 151–155; doi:[10.7861/futurehosp.5-3-151](https://doi.org/10.7861/futurehosp.5-3-151).
- Cooksey, D. S.** 2006 *A Review of UK Health Research Funding*. Stationery Office.
- Cross, N.** 2001 Designerly ways of knowing: design discipline versus design science. *Design Issues* 17 (3), 49–55; doi:[10.1162/074793601750357196](https://doi.org/10.1162/074793601750357196).
- Crowe, S., Brown, K., Tregay, J., Wray, J., Knowles, R., Ridout, D. A., ... Utley, M.** 2017 Combining qualitative and quantitative operational research methods to inform quality improvement in pathways that span multiple settings. *BMJ Quality & Safety* 26, 641–652; doi:[10.1136/bmjqs-2016-005636](https://doi.org/10.1136/bmjqs-2016-005636).
- Crowe, S., Grieco, L., Vindrola-Padros, C., Elkhodair, S., Walton, H., Fulop, N. J. & Utley, M.** 2019 How can operational research and ethnography help to fix your emergency department? *Journal of the Royal Society of Medicine* 112 (10), 415–419; doi:[10.1177/0141076819856879](https://doi.org/10.1177/0141076819856879).
- Currie, C. S. M., Fowler, J. W., Kotiadis, K., Monks, T., Onggo, B. S., Robertson, D. A. & Tako, A. A.** 2020 How simulation modelling can help reduce the impact of COVID-19. *Journal of Simulation* 14 (2), 83–97; doi:[10.1080/17477778.2020.1751570](https://doi.org/10.1080/17477778.2020.1751570).
- Dieter, G. E. & Schmidt, L. C.** 2013 *Engineering Design* (5th edn.). McGraw-Hill.

- Dixon-Woods, M., McNicol, S. & Martin, G. 2012 Ten challenges in improving quality in healthcare: lessons from the Health Foundation's programme evaluations and relevant literature. *BMJ Quality & Safety* 21 (10), 876–884; doi:[10.1136/bmjqs-2011-000760](https://doi.org/10.1136/bmjqs-2011-000760).
- Donetto, S., Pierri, P., Tsianakas, V. & Robert, G. 2015 Experience-based co-design and healthcare improvement: realizing participatory design in the public sector. *The Design Journal* 18 (2), 227–248; doi:[10.2752/175630615X14212498964312](https://doi.org/10.2752/175630615X14212498964312).
- Eccles, M. P. & Mittman, B. S. 2006 Welcome to implementation science. *Implementation Science* 1 (1), 1; doi:[10.1186/1748-5908-1-1](https://doi.org/10.1186/1748-5908-1-1).
- Elliott, C. & Deasley, P. 2007 *Creating Systems that Work: Principles of Engineering Systems for the 21st Century*. London: Royal Academy of Engineering.
- Ernst, A. T., Jiang, H., Krishnamoorthy, M. & Sier, D. 2004 Staff scheduling and rostering: a review of applications, methods and models. *European Journal of Operational Research* 153 (1), 3–27; doi:[10.1016/S0377-2217\(03\)00095-X](https://doi.org/10.1016/S0377-2217(03)00095-X).
- Evans, J. R. 1991 Creativity in MS/OR: creative thinking, a basis for MS/OR problem solving. *INFORMS Journal on Applied Analytics* 21 (5), 12–15; doi:[10.1287/inte.21.5.12](https://doi.org/10.1287/inte.21.5.12).
- Evans, J. R. 1992 Creativity in MS/OR: Improving problem solving through creative thinking. *INFORMS Journal on Applied Analytics* 22 (2), 87–91; doi:[10.1287/inte.22.2.87](https://doi.org/10.1287/inte.22.2.87).
- Evans, J. R. 1993 Creativity in MS/OR: The multiple dimensions of creativity. *INFORMS Journal on Applied Analytics* 23 (2), 80–83; doi:[10.1287/inte.23.2.80](https://doi.org/10.1287/inte.23.2.80).
- Evans, J. R. 1997a Creativity in OR/MS: the creative problem-solving process—part 2. *INFORMS Journal on Applied Analytics* 27 (6), 106–111; doi:[10.1287/inte.27.6.106](https://doi.org/10.1287/inte.27.6.106).
- Evans, J. R. 1997b Creativity in OR/MS: the creative problem-solving process, part 1. *INFORMS Journal on Applied Analytics* 27 (5), 78–83; doi:[10.1287/inte.27.5.78](https://doi.org/10.1287/inte.27.5.78).
- Fenves, S. J. & Grossmann, I. E. 1992 An interdisciplinary course in engineering synthesis. *Research in Engineering Design* 3 (4), 223–231; doi:[10.1007/BF01580844](https://doi.org/10.1007/BF01580844).
- Fikar, C. & Hirsch, P. 2017 Home health care routing and scheduling: a review. *Computers & Operations Research* 77, 86–95; doi:[10.1016/j.cor.2016.07.019](https://doi.org/10.1016/j.cor.2016.07.019).
- Fone, D., Hollinghurst, S., Temple, M., Round, A., Lester, N., Weightman, A., Roberts, K., Coyle, E., Bevan, G. & Palmer, S. 2003 Systematic review of the use and value of computer simulation modelling in population health and health care delivery. *Journal of Public Health Medicine* 25 (4), 325–335; doi:[10.1093/pubmed/fdg075](https://doi.org/10.1093/pubmed/fdg075).
- Frey, D. D. & Dym, C. L. 2006 Validation of design methods: lessons from medicine. *Research in Engineering Design* 17 (1), 45–57; doi:[10.1007/s00163-006-0016-4](https://doi.org/10.1007/s00163-006-0016-4).
- Gericke, K., Eckert, C., Campean, F., Clarkson, P. J., Flening, E., Isaksson, O., Kipouros, T., Kokkolaras, M., Köhler, C., Panarotto, M. & Wilmsen, M. 2020 Supporting designers: moving from method menagerie to method ecosystem. *Design Science* 6, e21; doi:[10.1017/dsj.2020.21](https://doi.org/10.1017/dsj.2020.21).
- Green, T., Bonner, A., Teleni, L., Bradford, N., Purtell, L., Douglas, C., Yates, P., MacAndrew, M., Dao, H. Y. & Chan, R. J. 2020 Use and reporting of experience-based codesign studies in the healthcare setting: a systematic review. *BMJ Quality & Safety* 29 (1), 64–76; doi:[10.1136/bmjqs-2019-009570](https://doi.org/10.1136/bmjqs-2019-009570).
- Grieco, L., Utley, M. & Crowe, S. 2020 Operational research applied to decisions in home health care: a systematic literature review. *Journal of the Operational Research Society* 72 (9), 1960–1991; doi:[10.1080/01605682.2020.1750311](https://doi.org/10.1080/01605682.2020.1750311).
- Griffin, P. M., Nembhard, H. B., DeFlicht, C., Bastian, N. D., Kang, H. & Muñoz, D. A. 2016 *Healthcare Systems Engineering*. John Wiley & Sons.
- Harper, P. 2020 Healthy O.R. in Wales. *Impact* 2020 (2), 28–32; doi:[10.1080/2058802x.2020.1768684](https://doi.org/10.1080/2058802x.2020.1768684).

- Holzman, A. G. 1979 Letter to the editor—engineering design and operations research. *Operations Research* 27 (2), 420–422; doi:[10.1287/opre.27.2.420](https://doi.org/10.1287/opre.27.2.420).
- Hughes, J., King, V., Rodden, T. & Andersen, H. 1994 Moving out from the control room: ethnography in system design. In *Paper Presented at the Proceedings of the 1994 ACM Conference on Computer Supported Cooperative Work, Chapel Hill, North Carolina*. Association for Computing Machinery.
- Hulshof, P. J. H., Kortbeek, N., Boucherie, R. J., Hans, E. W. & Bakker, P. J. M. 2012 Taxonomic classification of planning decisions in health care: a structured review of the state of the art in OR/MS. *Health Systems* 1 (2), 129–175; doi:[10.1057/hs.2012.18](https://doi.org/10.1057/hs.2012.18).
- Jahangirian, M., Naseer, A., Stergioulas, L., Young, T., Eldabi, T., Brailsford, S. C., Patel, B. & Harper, P. 2012 Simulation in health-care: lessons from other sectors. *Operational Research* 12 (1), 45–55; doi:[10.1007/s12351-010-0089-8](https://doi.org/10.1007/s12351-010-0089-8).
- Jahangirian, M., Taylor, S. J. E., Eatock, J., Stergioulas, L. K. & Taylor, P. M. 2015 Causal study of low stakeholder engagement in healthcare simulation projects. *Journal of the Operational Research Society* 66 (3), 369–379; doi:[10.1057/jors.2014.1](https://doi.org/10.1057/jors.2014.1).
- Jun, G. T., Morrison, C. & Clarkson, P. J. 2014 Articulating current service development practices: a qualitative analysis of eleven mental health projects. *BMC Health Services Research* 14 (1), 20; doi:[10.1186/1472-6963-14-20](https://doi.org/10.1186/1472-6963-14-20).
- Kaplan, E. H. 2020 OM forum—COVID-19 scratch models to support local decisions. *Manufacturing & Service Operations Management* 22 (4), 645–655; doi:[10.1287/msom.2020.0891](https://doi.org/10.1287/msom.2020.0891).
- Karsh, B. T., Holden, R. J., Alper, S. J. & Or, C. K. L. 2006 A human factors engineering paradigm for patient safety: designing to support the performance of the healthcare professional. *Quality & Safety in Health Care* 15 (Suppl 1), i59–i65; doi:[10.1136/qshc.2005.015974](https://doi.org/10.1136/qshc.2005.015974).
- Keys, P. 2000 Creativity, design and style in MS/OR. *Omega* 28 (3), 303–312; doi:[10.1016/S0305-0483\(99\)00055-9](https://doi.org/10.1016/S0305-0483(99)00055-9).
- Komashie, A., Lamé, G., Patou, F., Ciccone, N., Maier, A. & Clarkson, P. J. 2019 Exploring healthcare systems design research and practice: outcomes of an international meeting. In *Paper Presented at the ICED19 - The 22nd International Conference on Engineering Design, Delft*. University of Cambridge.
- Komashie, A., Ward, J., Bashford, T., Dickerson, T., Kaya, G. K., Liu, Y., Kuhn, I., Günay, A., Kohler, K., Boddy, N., O’Kelly, E., Masters, J., Dean, J., Meads, C. & Clarkson, P. J. 2021 Systems approach to health service design, delivery and improvement: a systematic review and meta-analysis. *BMJ Open* 11 (1), e037667; doi:[10.1136/bmjopen-2020-037667](https://doi.org/10.1136/bmjopen-2020-037667).
- Ku, B. & Lupton, E. 2022 *Health Design Thinking: Creating Products and Services for Better Health* (2nd edn.). The MIT Press.
- Kunc, M., Harper, P. & Katsikopoulos, K. 2018 A review of implementation of behavioural aspects in the application of OR in healthcare. *Journal of the Operational Research Society* 71 (7), 1055–1072; doi:[10.1080/01605682.2018.1489355](https://doi.org/10.1080/01605682.2018.1489355).
- Kunc, M., Malpass, J. & White, L. 2016 *Behavioral Operational Research: Theory, Methodology and Practice*. Palgrave Macmillan.
- Lamé, G. 2018 Position paper: on design research engaging with healthcare systems. In *Paper Presented at the 15th International Design Conference - DESIGN2018, Dubrovnik, Croatia: The Design Society*; doi:[10.21278/idc.2018.0164](https://doi.org/10.21278/idc.2018.0164).
- Lamé, G., Crowe, S. & Barclay, M. 2022 What’s the evidence?—towards more empirical evaluations of the impact of OR interventions in healthcare. *Health Systems* 11 (1), 59–67; doi:[10.1080/20476965.2020.1857663](https://doi.org/10.1080/20476965.2020.1857663).

- Lamé, G., Jouini, O. & Stal-Le Cardinal, J. 2016 Outpatient chemotherapy planning: a literature review with insights from a case study. *IIE Transactions on Healthcare Systems Engineering* **6** (3), 127–139; doi:[10.1080/19488300.2016.1189469](https://doi.org/10.1080/19488300.2016.1189469).
- Levary, R. R. 1988 *Engineering Design: Better Results through Operations Research Methods*. North-Holland.
- Levary, R. R. 1994 Engineering applications of operations research. *European Journal of Operational Research* **72** (1), 32–42; doi:[10.1016/0377-2217\(94\)90327-1](https://doi.org/10.1016/0377-2217(94)90327-1).
- Long, K. M. & Meadows, G. N. 2018 Simulation modelling in mental health: a systematic review. *Journal of Simulation* **12** (1), 76–85; doi:[10.1057/s41273-017-0062-0](https://doi.org/10.1057/s41273-017-0062-0).
- Lucas, B. 2016 Getting the improvement habit. *BMJ Quality & Safety* **25** (6), 400–403; doi:[10.1136/bmjqs-2015-005086](https://doi.org/10.1136/bmjqs-2015-005086).
- Luo, J. 2015 The united innovation process: Integrating science, design, and entrepreneurship as sub-processes. *Design Science* **1**, e2; doi:[10.1017/dsj.2015.2](https://doi.org/10.1017/dsj.2015.2).
- Marsh, K., Lanitis, T., Neasham, D., Orfanos, P. & Caro, J. 2014 Assessing the value of healthcare interventions using multi-criteria decision analysis: a review of the literature. *Pharmacoeconomics* **32** (4), 345–365; doi:[10.1007/s40273-014-0135-0](https://doi.org/10.1007/s40273-014-0135-0).
- Marshall, M., Pagel, C., French, C., Utley, M., Allwood, D., Fulop, N., Pope, C., Banks, V. & Goldmann, A. 2014 Moving improvement research closer to practice: the researcher-in-residence model. *BMJ Quality & Safety* **23** (10), 801–805; doi:[10.1136/bmjqs-2013-002779](https://doi.org/10.1136/bmjqs-2013-002779).
- Marshall, M., Pronovost, P. & Dixon-Woods, M. 2013 Promotion of improvement as a science. *The Lancet* **381** (9864), 419–421; doi:[10.1016/S0140-6736\(12\)61850-9](https://doi.org/10.1016/S0140-6736(12)61850-9).
- Martin, G., Ozieranski, P., Leslie, M. & Dixon-Woods, M. 2019 How not to waste a crisis: a qualitative study of problem definition and its consequences in three hospitals. *Journal of Health Services Research & Policy* **24** (3), 145–154; doi:[10.1177/1355819619828403](https://doi.org/10.1177/1355819619828403).
- Marynissen, J. & Demeulemeester, E. 2019 Literature review on multi-appointment scheduling problems in hospitals. *European Journal of Operational Research* **272** (2), 407–419; doi:[10.1016/j.ejor.2018.03.001](https://doi.org/10.1016/j.ejor.2018.03.001).
- McLaughlin, J. E., Wolcott, M. D., Hubbard, D., Umstead, K. & Rider, T. R. 2019 A qualitative review of the design thinking framework in health professions education. *BMC Medical Education* **19** (1), 98; doi:[10.1186/s12909-019-1528-8](https://doi.org/10.1186/s12909-019-1528-8).
- Melles, M., Albayrak, A. & Goossens, R. 2020 Innovating health care: key characteristics of human-centered design. *International Journal for Quality in Health Care* **33** (Suppl 1), 37–44; doi:[10.1093/intqhc/mzaa127](https://doi.org/10.1093/intqhc/mzaa127).
- Mingers, J. & Rosenhead, J. (2001). *Rational Analysis for a Problematic World Revisited: Problem Structuring Methods for Complexity, Uncertainty and Conflict* (ed. J. Rosenhead & J. Mingers) (2nd edn.). Wiley.
- Mohiuddin, S., Busby, J., Savović, J., Richards, A., Northstone, K., Hollingworth, W., Donovan, J. L. & Vasilakis, C. 2017 Patient flow within UK emergency departments: a systematic review of the use of computer simulation modelling methods. *BMJ Open* **7** (5), e015007; doi:[10.1136/bmjopen-2016-015007](https://doi.org/10.1136/bmjopen-2016-015007).
- Morris, Z. S., Wooding, S. & Grant, J. 2011 The answer is 17 years, what is the question: understanding time lags in translational research. *Journal of the Royal Society of Medicine* **104** (12), 510–520; doi:[10.1258/jrsm.2011.110180](https://doi.org/10.1258/jrsm.2011.110180).
- Mumma, J. M., Durso, F. T., Ferguson, A. N., Gipson, C. L., Casanova, L., Erukunakpor, K., Kraft, C. S., Walsh, V. L., Zimring, C., DuBose, J. & Jacob, J. T. 2018 Human factors risk analyses of a doffing protocol for Ebola-level personal protective equipment: mapping errors to contamination. *Clinical Infectious Diseases* **66** (6), 950–958; doi:[10.1093/cid/cix957](https://doi.org/10.1093/cid/cix957).

- National Academy of Engineering (US) and Institute of Medicine (US) Committee on Engineering and the Health Care System.** *Building a Better Delivery System: A New Engineering/Health Care Partnership*. Reid PP, Compton WD, Grossman JH, Fanjiang G, editors. Washington (DC): National Academies Press (US); 2005.
- O’Keefe, R. M.** 1995 MS/OR enabled systems design. *Operations Research* **43** (2), 199–207; doi:[10.1287/opre.43.2.199](https://doi.org/10.1287/opre.43.2.199).
- O’Keefe, R. M.** 2014 Design science, the design of systems and operational research: back to the future? *Journal of the Operational Research Society* **65** (5), 673–684; doi:[10.1057/jors.2012.175](https://doi.org/10.1057/jors.2012.175).
- Oliveira, M., Zancul, E. & Fleury, A. L.** 2021 Design thinking as an approach for innovation in healthcare: systematic review and research avenues. *BMJ Innovations* **7** (2), 491–498; doi:[10.1136/bmjinnov-2020-000428](https://doi.org/10.1136/bmjinnov-2020-000428).
- Palmer, R., Fulop, N. J. & Utley, M.** 2018 A systematic literature review of operational research methods for modelling patient flow and outcomes within community health-care and other settings. *Health Systems* **7** (1), 29–50; doi:[10.1057/s41306-017-0024-9](https://doi.org/10.1057/s41306-017-0024-9).
- Papalambros, P. Y., Ahmed-Kristensen, S., Badke-Schaub, P., Bauerly, K., Boujut, J.-F., Cagan, J., Cantamessa, M., Chakrabarti, A., Chen, L.-L., Chen, W., Clarkson, P. J., Duffy, A., Goel, A. K., Hanna, S., Jin, Y., Kim, Y. S., Knight, T., Lindemann, U., Louviere, J. J., McMahon, C., Nagai, Y., Reich, Y., Seifert, C., Smith, S. M., Tseng, M. M., Vermaas, P. E., Wood, K. L., Yannou, B. & Gero, J.** 2015 Design science: why, what and how. *Design Science* **1**, E1; doi:[10.1017/dsj.2015.1](https://doi.org/10.1017/dsj.2015.1).
- Papalambros, P. Y. & Wilde, D. J.** 2000 *Principles of Optimal Design: Modeling and Computation*. Cambridge University Press.
- Patou, F., Ciccone, N., Thorpe, J. & Maier, A.** 2020 Designing P4 healthcare interventions for managing cognitive decline and dementia: where are we at? *Journal of Engineering Design* **31** (7), 379–398; doi:[10.1080/09544828.2020.1763272](https://doi.org/10.1080/09544828.2020.1763272).
- Pearson, M., Monks, T., Gibson, A., Allen, M., Komashie, A., Fordyce, A., Harris-Golesworthy, F., Pitt, M. A., Brailsford, S. C. & Stein, K.** 2013 Involving patients and the public in healthcare operational research—the challenges and opportunities. *Operations Research for Health Care* **2** (4), 86–89; doi:[10.1016/j.orhc.2013.09.001](https://doi.org/10.1016/j.orhc.2013.09.001).
- Perry, S. J., Catchpole, K., Rivera, A. J., Henrickson Parker, S. & Gosbee, J.** 2021 ‘Strangers in a strange land’: understanding professional challenges for human factors/ergonomics and healthcare. *Applied Ergonomics* **94**, 103040; doi:[10.1016/j.apergo.2019.103040](https://doi.org/10.1016/j.apergo.2019.103040).
- Petrosoniak, A., Hicks, C., Barratt, L., Gascon, D., Kokoski, C., Campbell, D., White, K., Bandiera, G., Lum-Kwong, M. M., Nemoy, L. & Brydges, R.** 2020 Design thinking-informed simulation: an innovative framework to test, evaluate, and modify new clinical infrastructure. *Simulation in Healthcare* **15** (3), 205–213; doi:[10.1097/sih.0000000000000408](https://doi.org/10.1097/sih.0000000000000408).
- Pfannstiel, M. A. & Rasche, C.** (eds.) 2019 *Service Design and Service Thinking in Healthcare and Hospital Management Theory, Concepts, Practice*. Springer; doi:[10.1007/978-3-030-00749-2](https://doi.org/10.1007/978-3-030-00749-2).
- Pitt, M., Monks, T., Crowe, S. & Vasilakis, C.** 2016 Systems modelling and simulation in health service design, delivery and decision making. *BMJ Quality & Safety* **25** (1), 38–45; doi:[10.1136/bmjqs-2015-004430](https://doi.org/10.1136/bmjqs-2015-004430).
- Pope, C. & Mays, N.** 1993 Opening the black box: an encounter in the corridors of health services research. *British Medical Journal* **306** (6873), 315–318; doi:[10.1136/bmj.306.6873.315](https://doi.org/10.1136/bmj.306.6873.315).
- Roesler, A., Grigg, E. B., Martin, L. D., Ross, F. J., Feil, M., Rampersad, S. E., Haberkern, C. M. & Martin, L. D.** 2019 Practice-centered design of an anesthesia medication template to

- reduce medication handling errors in the operating room. *International Journal of Design* 13 (1), 53–68.
- Rouse, W. B. & Cortese, D. A.** 2010 *Engineering the System of Healthcare*. IOS Press.
- Royston, G.** 2011 Meeting global health challenges through operational research and management science. *Bulletin of the World Health Organization* 89 (9), 683–688; doi:10.2471/blt.11.086066.
- Royston, G.** 2013 Operational research for the real world: big questions from a small island. *Journal of the Operational Research Society* 64 (6), 793–804; doi:10.1057/jors.2012.188.
- Royston, G.** 2014 Operational research and design. In *Paper Presented at the Joint Initial Meeting of the Operational Research Society and the Design Society*, London, UK: The OR Society & The Design Society.
- Royston, G.** 2016 The past, present and futures of behavioral operational research. In *Behavioral Operational Research: Theory, Methodology and Practice* (ed. M. Kunc, J. Malpass & L. White), pp. 359–381. Palgrave Macmillan.
- Royston, G., Dost, A., Townshend, J. & Turner, H.** 1999 Using system dynamics to help develop and implement policies and programmes in health care in England. *System Dynamics Review* 15 (3), 293–313; doi:10.1002/(SICI)1099-1727(199923)15:3<293::AID-SDR169>3.0.CO;2-1.
- Royston, G., Halsall, J., Halsall, D. & Braithwaite, C.** 2003 Operational research for informed innovation: NHS direct as a case study in the design, implementation and evaluation of a new public service. *Journal of the Operational Research Society* 54 (10), 1022–1028; doi:10.1057/palgrave.jors.2601617.
- Royston, G. & Komashie, A.** 2016 Full STEAM ahead for operational research and design? In *Paper Presented at the OR58*, Portsmouth, UK: The OR Society.
- Ryan, B., Qu, R., Schock, A. & Parry, T.** 2011 Integrating human factors and operational research in a multidisciplinary investigation of road maintenance. *Ergonomics* 54 (5), 436–452; doi:10.1080/00140139.2011.562983.
- Samudra, M., Van Riet, C., Demeulemeester, E., Cardoen, B., Vansteenkiste, N. & Rademakers, F. E.** 2016 Scheduling operating rooms: achievements, challenges and pitfalls. *Journal of Scheduling* 19 (5), 493–525; doi:10.1007/s10951-016-0489-6.
- Saville, C. E., Smith, H. K. & Bijak, K.** 2019 Operational research techniques applied throughout cancer care services: a review. *Health Systems* 8 (1), 52–73; doi:10.1080/20476965.2017.1414741.
- Simon, H. A.** 1996 *The Sciences of the Artificial* (3rd edn.). MIT Press.
- The OR Society.** (n.d.) *What is Operational Research?* online document <https://www.theorsociety.com/about-or/> Accessed: 1.1.2023.
- Ulrich, R. S., Zimring, C., Zhu, X., DuBose, J., Seo, H.-B., Choi, Y.-S., et al.** 2008 A review of the research literature on evidence-based healthcare design. *HERD: Health Environments Research & Design Journal* 1 (3), 61–125; doi:10.1177/193758670800100306.
- Van den Bergh, J., Beliën, J., De Bruecker, P., Demeulemeester, E. & De Boeck, L.** 2013 Personnel scheduling: a literature review. *European Journal of Operational Research* 226 (3), 367–385; doi:10.1016/j.ejor.2012.11.029.
- van Lent, W. A. M., VanBerkel, P. & van Harten, W. H.** 2012 A review on the relation between simulation and improvement in hospitals. *BMC Medical Informatics and Decision Making* 12 (1), 18; doi:10.1186/1472-6947-12-18.
- van Stralen, D. M. D.** (2008) ‘High-Reliability Organizations: Changing the Culture of Care in Two Medical Units’, *Design Issues*, 24(1), pp. 78–90. doi: 10.1162/desi.2008.24.1.78.
- Weightman, A. P. H., Preston, N., Holt, R., Allsop, M., Levesley, M. & Bhakta, B.** 2010 Engaging children in healthcare technology design: developing rehabilitation

technology for children with cerebral palsy. *Journal of Engineering Design* **21** (5), 579–600; doi:[10.1080/09544820802441092](https://doi.org/10.1080/09544820802441092).

- Werner, N. E., Ponnala, S., Doutcheva, N., & Holden, R. J.** 2020 Human factors/ergonomics work system analysis of patient work: state of the science and future directions. *International Journal for Quality in Health Care* **33**, 60–71; doi:[10.1093/intqhc/mzaa099](https://doi.org/10.1093/intqhc/mzaa099).
- Wilson, J. C. T.** 1981 Implementation of computer simulation projects in health care. *Journal of the Operational Research Society* **32** (9), 825–832; doi:[10.1057/jors.1981.161](https://doi.org/10.1057/jors.1981.161).
- Winston, W. L.** (1993). *Operations Research: Applications and Algorithms* (3rd edn.). Duxbury Press.
- Worsley, C., Webb, S. & Vaux, E.** 2016 Training healthcare professionals in quality improvement. *Future Hospital Journal* **3** (3), 207–210; doi:[10.7861/futurehosp.3-3-207](https://doi.org/10.7861/futurehosp.3-3-207).
- Xie, A. & Carayon, P.** 2015 A systematic review of human factors and ergonomics (HFE)-based healthcare system redesign for quality of care and patient safety. *Ergonomics* **58** (1), 33–49; doi:[10.1080/00140139.2014.959070](https://doi.org/10.1080/00140139.2014.959070).
- Zenios, S., Makower, J., Yock, P., Denend, L., Brinton, T. J., Kumar, U. N. & Krummel, T. M.** 2010 *Biodesign: The Process of Innovating Medical Technologies*. Cambridge University Press.