Methodological issues in systems Human Factors and Ergonomics

Methodological issues in human factors and ergonomics: perspectives on the research-practice gap, reliability and validity, and prediction

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Abstract

The changing nature of work and society, and a proliferation of complex global challenges, is increasing the need for Human Factors and Ergonomics (HFE). The discipline is well equipped to respond, but there remain a number of longstanding issues preventing HFE from realizing its full impact. There is a research-practice gap, a lack of reliability and validity evidence associated with HFE methods, and the inability of HFE methods to predict behaviour. In this article we revisit each issue, with each co-author providing their own perspective on the extent and causes of each issue, and their resolution. The perspectives reveal a consensus that the issues exist and are problematic, but are multi-factorial and require various solutions. The findings are subsequently synthesized to form a research roadmap for the wider discipline.

Keywords: Human Factors and Ergonomics, Methods, Research-Practice Gap, Reliability and Validity, Prediction.

1. Introduction

Human Factors and Ergonomics (HFE) is “the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance” (IEA, 2019). The goal of the HFE practitioner is to understand and optimise individual, team, organisational, and system performance, both in work and societal systems. This is achieved through the application of a diverse set of HFE theories and methods which enable practitioners to:

1. describe and understand the behaviour of individuals, teams, organisations, and systems; and
2. direct the design and evaluation of products, tools, devices, work and tasks, environments, training programs, procedures, policy and regulation, and ultimately overall sociotechnical systems.

HFE is therefore about understanding and optimising performance to enhance efficiency,productivity, safety, and ultimately human health and well-being. HFE has had far-reaching impacts on the design of work and societal systems since its emergence shortly after the second World War, (REFS). The demand for HFE is increasing. Work and societal systems are becoming increasingly reliant on new and sophisticated forms of technology. Dramatic changes are being brought about by artificial intelligence, automation, big data, the gig economy, and the internet of things (Holman et al., 2019). HFE can, and should, be playing a leading role in the response to complex global challenges such as climate change and environmental degradation, extreme weather, overpopulation, food and water security, disease, misuse of the internet and social media, terrorism, cybercrime, nuclear warfare,

inequality, human rights breaches, antimicrobial resistance, and instability in the world's economy (Salmon et al., 2019; Thatcher et al., 2018). HFE has a critical role to play in ensuring that work, societal, and global systems are optimised rather than degraded.

The future is bright for HFE but there are fundamental challenges impacting on the contribution HFE can make (Hancock, 2019; Karwowski, 2005; Salmon, 2016; 2019; Shorrock & Williams, 2016; Stanton, 2016).A number of long-standing issues continue to trouble HFE. These are particularly centred on the methods researchers and practitioners use to understand and respond to complex problems. Key issues recently discussed in the HFE literature include:

1. **The research practice gap (Shorrock & Williams, 2016)**. This refers to an alleged gap between the HFE theories and methods being applied by researchers and practitioners. Specifically, that state-of-the art HFE methods used in research are not being applied in practice (Shorrock & Williams, 2016; Salmon, 2016);
2. **The reliability and validity of HFE methods (Stanton, 2016)**. The reliability and validity of HFE methods has long been a cause for concern (Annett, 2002; Stanton & Young, 1999). For many HFE methods it is not clear whether they actually produce valid and reliable outputs. In 1999 HFE was challenged to prove that their methods actually do all what is claimed of them (Stanton and Young 1999a, 1999b). Unfortunately, over two decades later, there has been little response to that challenge (Stanton 2014; 2016).
3. **The capacity for HFE methods to predict behaviour (Moray, 2008; Salmon et al., 2017)**. A major strength of HFE methods is they can usefully describe and analyse the

behaviour of individuals, teams, organisations, and sociotechnical systems. A major limitation is that most methods do not provide the capacity to simulate or predict behaviour. This has been labelled the greatest challenge facing HFE (Moray, 2008; Salmon et al., 2016).

In this article we revisit each issue. The aim was to enable researchers currently applying HFE in a range of domains to construct their own narratives about why these challenges arise, and how they can be resolvedEach co-author provided their own perspective on the three issues described above, based on their diverse experiences in HFE research and practice. The responses to each question are presented in verbatim below. The co-authors were deliberately diverse. They comprise senior HFE researchers, early career HFE researchers (ECR), and also researchers from other domains who are currently working in the area of HFE (see Table 1).

Author	**Current position**	**Year PhD award and topic**	**Years experience applying HFE methods**	**Number of peer-reviewed HFE journal articles, citations, and H Index (Scopus, March 2020)**	**Domains worked in (based on publications)**
Salmon	Professor Human Factors	2008, Human Factors	20	214 H Index = 42 5,850 citations	Defence (Land, Air, Sea), Road, Rail, Aviation, Maritime, Sport, Outdoor recreation, Retail, Freight, Healthcare, Cybersecurity, Mining, Disaster & Emergency response, Urban design, law enforcement
Read	Senior Human Factors Research Fellow				
Hulme	Post-Doctoral Research Fellow in Human Factors	2017, Epidemiology and HFE	3	13 H Index 9 Citations 218	Sports injury Safety in HFE (current focus, multiple domains)
Walker	Professor Human Factors	2002, Human Factors	21	122 H Index = 35 4,155 citations	Defence (Land, Air, Sea), Road, Rail, Aviation, Maritime, Sport, Freight, Disaster & Emergency response, Urban design, law enforcement, Product Design, Infrastructure Resilience, Training, Civil Engineering

McLean	Post-Doctoral Research Fellow in Human Factors	2018, HFE in sports performance		18 H-Index = 4 Citations = 44	Sport (performance, injury), outdoor recreation, road.
Stanton	Professor Human Factors	1852	168		
Stevens	Senior Lecturer, Land use Planning and Urban design	2012, Urban Planning	6	18 H Index = 8 188 citations	Airports, Road, Rail, Urban Design, Infrastructure Planning

2. The research - practice gap

The research - practice gap in HFE is characterised by discrepancies in the theories and methodologies that HFE researchers and practitioners are applying in response to the same issues (Salmon, 2016; Shorrock & Williams, 2016). A key concern is the extent to which tools used by HFE practitioners reflect the theoretical and methodological advances being made in academia. In short, state-of-the-art HFE theories and methods may not be being applied in practice .

Salmon (2016) describes implications of this in relation to accident analysis and investigation, a core focus of HFE work. In this context researchers are currently applying advanced 'systems thinking' methodologies such as Accimap (Svedung and Rasmussen; 2002), the Systems Theoretic Accident Model and Processes (Leveson; 2004), and the Functional Resonance Analysis Method (FRAM, Hollnagel; 2012), and it is not unusual for studies using older methods to now be rejected by journals. Many practitioners, on the other hand, continue to apply older methods, such as the Human Factors Analysis and Classification Scheme (HFACS, Wiegmann and Shappell; 2003), root cause analysis (Wilson et al., 1993), the BowTIE method (Ruijter & Guldenmund, 2016) and Reason's ubiquitous Swiss cheese model (Reason, 1990). Whilst these methods have known limitations and are

not aligned with current state-of-the-science models, they remain popular with practitioners and risk damaging the credibility of the discipline

The impact of the research-practice gap is highly problematic. HFE methods need to be matched to the problems they are tasked with solving. A rise in systemic problems which is not matched with a corresponding rise in applying systems methods threatens the core validity of HFE as a discipline (Holman et al., In Press). Practitioners may not be describing and rectifying problems as efficiently as they can be. Worse still, the analyses produced may be out of date, invalid, misleading, and even dangerous (Salmon, 2016). The issue is not limited to accident analysis and investigation. Similar patterns are being reported in research and practice in other key HFE domains such as situation awareness (Dekker, 2015), teamwork (Stanton et al., 2013), and risk assessment (Dallat et al., 2018).Each co-author was asked to respond to three questions about the research practice gap, its impact, and its resolution. Here are the narratives:

2.1. Do you see a significant research practice gap in HFE?

Salmon: "Yes. Over the past few years I have seen lots of first hand evidence of a research practice gap in many domains. Much of what I have seen relates to the models and methods used for accident analysis and investigation; however, the gap is also apparent in other areas such as systems analysis, HFE in design, and situation awareness assessment".

Read: "Yes, I believe that a gap exists across a range of areas. I would add that the gap can be seen in the theories and methods applied, but also in relation to the implementation of research findings to support system design. In my experience as a practitioner, our team

would look to apply best practice where possible, but a number of constraints affect the ability to achieve this fully."

Hulme: "At this early stage in my academic career, I can only really speak from the perspective of sports injury prevention research. However, I have my reservations regarding the practical impact that HFE research has – and is having – in the field of sports science and injury prevention research. For example, although STAMP (Leveson, 2004) has been applied to better understand the cause and prevention of sports injury from a holistic perspective (Hulme et al., 2017), there is now an urgent need to extend this work by examining and testing the *specific types* of interventions that might work best within the so-called 'Australian distance running injury system'. In short, systemic HFE models are undoubtedly useful at identifying the interrelationships among multiple agents and factors in a given 'sports system', but how to make a tangible, measurable difference to the lives of athletes is an area of HFE research that should be subjected to further scholarly conversation".

Walker: According to the Oxford dictionary, a practitioner is a person actively engaged in an art, discipline, or profession. I therefore reject the premise of the question…to an extent at least. In an applied discipline surely we are all practitioners? I can't personally think of any pure 'theoretical ergonomists' in the same way we might think of a pure mathematician. We may all be practitioners but what we practice, where, and for whom often varies significantly. There is a gap. A big and fundamental gap, albeit one not related to the false dichotomy of 'research' and 'practice'. It's worse than that.

McLean: Yes. Practitioners applying HFE methods in a sports performance context is rare. The professional and international sporting organisations I have worked with over the past few years do not use HFE methods in practice. However, in my personal experiences via practitioner feedback, when applied, HFE research applications to sporting performance have been well received and practitioners have enjoyed and benefited from what HF methods can bring to sport science.

Stanton: No! As both an academic researcher and consultant, I am able to implement the very latest research into practice in all my consulting activities. Whilst I accept that many practitioners may lag behind the cutting edge of research, there is no reason why they should if they made the effort to keep up-to-date and learn the new theories and methods. In some recent consulting to the Healthcare Safety Investigation Branch, I was able to teach them the Actor Map and AcciMap method relatively quickly (within one day) whilst we investigated an incident together. This is indicative of the work that I have conducted with vehicle manufacturers, energy generation and distribution companies, and safety organisations. In my opinion, there is a professional obligation on behalf of everyone in the discipline to remain current with contemporary trends in research and develop his or her knowledge and skills. I have spent most of my career developing and validating Human Factors methods so that practitioners can use them with confidence.

Stevens: In HFE I am becoming more aware of it. I have certainly recognised it in my own urban development discipline. There, we are in fact largely practice led – which is troubling considering the current social and environmental crises. Practice leading practice is self-fulfilling prophecy of commercial driven outcomes where community and society comes

last. As a recent convert to HFE and its methods, I recognise that these approaches, particularly systems approaches, can offer much for the practical exploration and dismantling of the BAU world we live in. I am a little surprised there is such a gap in HFE.

2.2. Why do you think the research - practice gap exists?

Salmon: "I think there a few reasons. One the one side you have a set of constraints that practitioners face when attempting to apply HFE in practice (see Shorrock & Williams, 2016), and on the other you have a set of constraints which are pushing researchers to advance the science and create new models and methods (see Williams & Salmon, 2017). Added to this is the current popularity of systems thinking in HFE, which invariably leads to more expansive, but more complex and time consuming to apply methods. I think because of these issues practitioners struggle to keep pace with new theories and methods, and so stick with what they know and have used previously.

Read: "It is a multifaceted issue, which as with all HFE challenges involves the interaction between factors at the individual, organisational and wider systems levels. At an individual level, researchers may not have the knowledge and skills to communicate their research in a way that assists practitioners to use it, and practitioners may not have the knowledge or skills to critique and appropriately apply theories, methods or research findings. At an organisational level, practitioners may not be provided with the resources to support them to apply research. For example, it is hardly surprising that negotiating the HFE literature is a challenge for practitioners (indeed it can be a challenge for researchers as well!). A Google Scholar search for "teamwork" provides 41,200 results. These results provide various theoretical and methodological approaches, which potentially conflict. Without ready

access to publications sitting behind a paywall, a lack of time to conduct a thorough literature review nor mentoring from discipline leaders, how would the average practitioner synthesise this literature in a way that allows them to determine the best theoretical or methodological approach to follow to solve the challenges they are facing in their work?

Thinking about the wider system, it is interesting to consider aspects such as the pressures on academics to publish (where quantity may sometimes outweigh quality, leading to a burgeoning literature. Another important consideration is the extent to which research findings are incorporated into standards. Without the background of a requirement within a standard, it can be difficult to implement a HFE approach, let alone one that is aligned with current best practice in HFE research. I would suggest that it is these systemic factors that can help to support 'lags' between research and uptake in practice.

Hulme: "In my opinion, there are two reasons why the HFE research-practice gap exists from a sports injury prevention perspective. First, I think that injury prevention researchers in the sports science and epidemiological fields have simply not been adequately exposed to HFE methods and analyses. After all, HFE approaches can offer an alternative 'systems thinking perspective' to complement more traditional forms of scientific inquiry that focus primarily on individuals (i.e., athletes) and their immediate behaviours (e.g., sports workload applications). For this reason, there is a need to continue to promote HFE methods and analyses among the sports science and injury prevention communities. Second, and somewhat more contentious, I think that sports scientists and epidemiologists, including biostatisticians, might perceive HFE methods and analyses as less rigorous and therefore unfit to be used as a basis to guide injury prevention interventions. This comes back to the

'soft' versus 'hard' science dichotomy, including attitudes towards qualitative and quantitative research approaches. Such attitudes are attributable to differing philosophies and personal perspectives towards how research could (and should) be designed and conducted more generally. For HFE approaches to have practical impact down the line, it may well be necessary to firstly addresses underlying personal biases and predilections towards how reality is understood and the science behind it applied".

Walker: If the so-called 'value proposition' of HFE is as it should be, we would be overwhelmed with demand for state-of-the-art systems methods, with those working in consulting and industry clamouring for them and partnering with academia as fast as they can (and vice versa). It happens in other fields, like engineering and the physical sciences, where the latest scientific developments are converted (commercialised?) into useful things that are perceived to be of value. But generally speaking that is not happening in our world, at least not at any scale, despite some brilliant examples (see below) of what can happen when it does. In the main, the kind of work associated with 'research' is not valued in the same way by the consumers of 'practice', so in my view it's a more fundamental, discipline-wide 'value gap'. Whether, and for whom future values will align is at present unknown, but I often ponder whether a client would ever ask a rocket scientist to distil their entire discipline "into three short, easy to understand bullet points". I somehow doubt it, and therein lies the problem. Faulty perceptions of value, at least right up until the point at which yet another complex emergent phenomenon bounces out of the ether to scare us witless. Unfortunately, at that point it is normally too late for HFE to fully demonstrate its value proposition and the cycle repeats.

McLean: I think the lack of exposure to HFE and systems thinking methods in sport science education is the main issue. No sport science degree that I am aware of has a HFE or systems thinking component teaching the benefits of HFE methods for performance. Personally, I completed a sport science degree and a research Masters degree in exercise physiology before I was even aware of HFE methods and their potential for understanding sports performance. Secondly, I think because sport science is very much a discipline specific domain practised in isolation i.e. physiology, biomechanics, nutrition, etc, the integration of multiple disciplines is difficult to comprehend for many sport scientists. However, I do believe this is slowly changing.

Stanton: I think that the research-practice gap only exists in the minds of people who are not putting research into practice. I am working with many commercial organisations in vehicle automation, flight deck design, control room design, and safety. The benefit of working directly with an original equipment manufacturer is that research is put into practice as a matter of course. One example from the early 1990s, was working with Jaguar Cars (now JaguarLandRover) on adaptive cruise control. We helped Jaguar design the driver interface for the Adaptive Cruise Control (ACC) system that led to a production vehicle in 1999 (making Jaguar the first to market with ACC), winning some design awards along the way. Whilst I accept that it can take some years for the research to lead to practice, research-based evidence can be very persuasive for including Human Factors considerations in design.

Stevens: In my opinion its time and money (motivation). This is the same regardless of discipline. Industry have approaches they understand, they know how much to budget for

them, they get the right political data they were after – so why complicate it. New approaches are seen to cost time and money; they believe they are already getting the right answers. Further, the profile of academics by industry could do with a makeover – there is a perception that much of the work is pie in the sky – unfortunately there is a legacy of academic achievement that has left industry cold.

2.3. How can the research practice gap be closed?

Salmon: "First off its worth stating that it has to be closed. It is an unacceptable feature of our discipline – and our impact is limited as a result. In terms of how to close the gap, I think work is required on both sides. Researchers can be more cognisant of the constraints that practitioners work under, and practitioners can place more emphasis on engaging with researchers and being across the latest research developments. Partnerships between academia and Industry are vital, as they enable researchers and practitioners to work together and co-develop state-of-the-art methods for use in practice. Our Understanding and Preventing Led Outdoor Accidents Data System (UPLOADS; Goode et al., 2018; Salmon et al., 2017) program is a good example of this. Based on an industry partnership we developed an incident reporting and learning system that is underpinned by Rasmussen's risk management framework and involves the use of Accimap to analyse led outdoor activity incidents. The development process was an extensive collaboration between researchers and practitioners, and involved various studies and activities that were designed to identify key end-user needs and to upskill practitioners in the methods (Goode et al., 2018). As a result, UPLOADS is now used by many organisations, whilst at the same time being recognised as state-of-the-art in terms of accident theory and analysis methods. Without the partnership, this would not be the case"

Read: “We often hear that “safety is a shared responsibility” and I think we could expand this concept of a shared responsibility to the translation of HFE research into practice. We need our wider organisational systems (in academia and industry/government) to support us to develop meaningful collaborations whereby sufficient time and resources are available to conduct good quality, leading-edge research which addresses the priority real world issues. While academia is moving towards measuring and rewarding research translation and research impact, there is a delay in the system whereby publications remain a key measure, and academics enter the profession wanting to conduct the research that interests them, perhaps not always aligning with the problems that need to be solved. Further, the rewards for practitioners to engage more with research and researchers are highly dependent on the constraints imposed by their organisations, and the culture of senior management, etc. On a practical level, more industry linked programs, where students and / or early career researchers conduct placements within an organisation might help to close the gap, similar to calls for cross-modal training between cyclists and drivers to improve attitudes and understand why the other party may be behaving in a particular manner. Better understanding each other’s worldviews, constraints and attitudes can only help to move academia and industry towards shared goals.”

Hulme: Again I feel that there are two reasons that standout above the others. First, I think there is a lack of an intermediary process of some form connecting academia with the people on the ground. For example, HFE academics working within an higher education institution conduct research, usually as the so-called “experts”, and subsequently aim to publish their findings in a reputable peer reviewed journal. Much of this work can have a

large theoretical component, and is equally written and articulated in such a way that the intended beneficiaries can be left asking: *what are the real implications for me? How can I use these insights and results and translate them to inform practice?* Of course, practitioners and industry need to be exposed to HFE research before such questions are even raised, and potential solutions to encourage greater awareness should be explored. Second, I would like to emphasise the importance of approaching the end-users during the planning phases of research, ascertain what problems require solving and why, and then proceed with HFE research activities. This would facilitate ongoing collaborations, allowing the HFE researcher to understand the specific needs and implementation context that can enable or hinder the implementation of a given solution or intervention. The previous UPLOADS (Salmon et al., 2017) example is a leading case in point of how established industry partnerships can be mutually beneficial to all parties. What is found to be *efficacious* under controlled circumstances is not automatically *effective* in a real-world situation, and so personal insights can help to close this gap.

Walker: There are a number of options, some more depressing than others. Option 1 is to work in partnership, but it is an increasingly naive hope. For a while now the message, tacit or otherwise (Shorrock et al., XXXX; Elon Musk, etc), has been that academic outputs are of little practical value and that 'practice' – where the 'real' ergonomic work is assumed to occur - need types of output that research does not, or cannot deliver. My feeling, and it may be controversial, is that despite efforts made on the research side there is scant movement towards applying latest developments in practice (Ref, XXXX). This article, for example, has a practitioner summary yet few, if any, commercial publications have a 'theoretical' or 'scientific' summary. Industrial advisory panels on projects far out-weigh

scientific or academic advisory panels. The world of research has, by and large, listened and responded to exhortations for practitioner impact but it has not been reciprocated. In practice, methods dating from the 60's and the third industrial revolution (3IR) are in routine use whether they are appropriate or not (Holman et al., In Press; Walker et al., 2010). Let us ask the question we dare not ask: is the discipline slowly ossifying despite a period of unprecedented global change, when human-centred solutions are needed more now than ever? Let's cheer ourselves up (but only slightly) with Option 2, which is to face into the 'value gap'. The dawning fourth industrial revolution (4IR) will rapidly overwhelm the discipline as we know it today, meaning that HFE value will have to be added elsewhere. Many research grand challenges in engineering, for example, are ergonomic and human-centred in all but name. These are where the 'high quality' systems problems (e.g. Dul et al., 2012) increasingly reside, and where a deeply-systemic ergonomic perspective is welcomed. Good bye 3IR ergonomics, it's been nice knowing you. Welcome to the 4IR.

McLean: I believe exposure to HFE and systems thinking methods are key to closing the gap. If HFE and systems thinking methods were introduced to sport science students at an early stage in their education, these methods might well become valuable practitioner tools, which at present is not the case. In addition, as HFE methods eventually become more popular in the elite sports performance there are a few issues to be avoided which could create gaps and reduce practitioner engagement. Firstly, research populations need to match the population where practical applications are intended e.g. research done with an under 12 football team cannot be transferred to a premier league team. Secondly, cut the fluff. HF researchers need to be aware that elite coaches have very limited time (and understanding of HFE methods) and succinct but accurate explanations of outputs are key

to engagement, which can be challenging given the complexity of HFE methods. Lastly, design research as best as possible to avoid major distractions to elite teams, elite sport is very structured and coaches don't like to deviate from plans and training schedules.

Stanton: It seems fairly obvious to me the Human Factors is such a complex subject that one needs a doctorate before beginning to put it into practice. It is all too easy to do Human Factors badly. I am even aware of people in the profession calling themselves Human Factors specialists without any grounding in the subject matter. I am also too well aware that a Bachelors or Masters degree is scant preparation for tackling the complexity of sociotechnical systems. A research doctorate provides excellent training for putting research into practice, providing and apprenticeship in problem analysis and problem-solving, interpersonal and leadership skills, project management and organization, research and information management, self-management and work habits, written and oral communication skills. This means that we need to up-skill the entire profession if we hope to close the perception of the research-practice gap (one which is already closed in my own professional practice). Raising the professional status of our discipline has many benefits, as it should bring researcher and practitioners closer together.

Stevens: It will require academia to lead the process, build trust and demonstrate efficacy in the methods and approaches that industry could be using in their decision-making. It is however a process that can begin when undergraduate teaching is being delivered in a range of disciplines. Students attend universities to gain insight into theory and practice – it is what separates university from technical colleges. Students (practitioners in training) need to understand the value and importance of research and scientific enquiry for

decision-making. Academia, both research and teaching, need to be mutually supportive and articulate to the practitioners of the future that practice that does not draw on science is the fundamentally flawed. To support those practitioners currently making the decisions; standards of quality science and rigour must be mandatory components of government project tendering – a major source of consultant work.

A summary of each perspective is presented in Table 2.

Table 2. A summary of perspectives on the research practice gap in HFE

Author	**Do you see a significant research-practice gap in HFE?**	**Why do you think the research-practice gap exists?**	**How can the research practice gap be closed?**
Salmon	Yes	1. Practitioner constraints preventing uptake of HFE theory & methods; 2. Researcher constraints impacting the design and communication of theory and methods	1. Partnerships between academia and industry; 2. Researchers being more cognisant of practitioner constraints
Read	Yes	1. Researcher lack of knowledge and skills around communication of research; 2. Practitioner lack of knowledge and skills on how to apply state-of-the-art theory and methods; 3. Organisations lack of support for practitioners in implementing new methods.	1. Organisational support for practitioners to engage with researchers and academia; 2. Organisational support for practitioners to implement new theory & methods; 3. Support for development of meaning partnerships between academia and industry.
Hulme	Yes	1. Lack of practitioner exposure to state-of-the-art HFE methods 2. Philosophical and epistemological differences between the natural and social sciences	1. Greater practitioner exposure to research outputs; 2. Involvement of end-users in research planning.
Walker	No	1. Limited value placed on HFE research by practitioners	1. Partnerships between academia and industry; 2. Align more closely with other disciplines / subsume ourselves into them
McLean	Yes	1. Lack of practitioner exposure to state-of-the-art HFE methods	1. Closer alignment between research study samples and end-user populations; 2. More succinct and understandable communication of research outputs and method; 3. Improved research study design to better align with practitioner needs.
Stanton	No	1. Practitioners failure to translate research outputs into practice	1. Upskilling of the profession via the increase of PhD qualified practitioners.
Stevens	Yes	1. Time and financial constraints influencing practitioners' selection of theory and methods.	1. Researchers to better demonstrate the efficacy of state-of-the-art theory and methods. 2. Embed the need for scientific enquiry of practice during higher education studies.

3. The reliability and validity of HFE methods

A concerning lack of reliability and validity evidence for HFE methods exists both in academia and in practice (Annett, 2002; Stanton & Young, 1999; Stanton, 2016). It is not actually clear a. that HFE methods measure or describe what they intend to, and b. that the analyses produced are repeatable across different analysts and across different applications. For the present commentary, each co-author was asked to respond to two questions regarding a. the requirement for HFE methods to have evidence demonstrating their reliability and validity, and b. why the reliability and validity of HFE methods is seldom tested.

3.1. Do all HFE methods require evidence of reliability and validity?

Walker: Yes...

Read: I don't agree that all methods must have evidence of standard reliability and validity to be useful. Annett (2002) distinguishes between two types of methods: evaluative and analytical. He argues that the validity of evaluative methods (i.e. tests that aim to measure a parameter, such as workload or fatigue) should be distinguished from the validity standards required of analytical methods (i.e. those that aim to understand complex systems). For evaluative methods, reliability is achieved when results from independent samples agree. For analytic methods, reliability is achieved where data collection conforms to the model that underpins the method. So the purpose of the method being considered should drive the requirements for reliability and validity. It may be that it is inappropriate to hold HFE methods for understanding and modelling complex systems to the same standard as those that set out to measure a construct or parameter.

A good example where I think reliability doesn't apply would be HFE methods to support conceptual design. A design method is neither an evaluative nor analytical method – is it not attempting to measure or to understand an existing system. By its nature, it intends to promote creativity and innovation. Thus, not only would it be unlikely that high levels of reliability would be achieved amongst designs created by different groups, it would actually be undesirable. I do however think that key aspects of validity need to be confirmed – i.e. the method needs to achieve what it sets out to achieve - although I realise it is contentious to argue that a method can be valid without necessarily being reliable!

Salmon: It is definitely important to ensure that HFE methods actually do what they aim to do (validity); however, my feeling is reliability is not so clear cut. For example, we have found recently that inter-rater reliability can be misleading, particular when using systems HFE methods. For example, when either conducting systems analyses (e.g. AcciMap; Svedung & Rasmussen, 2002) or attempting to identify risks across an entire sociotechnical system (e.g. Net-HARMS; Dallat et al., 2018), the analyses are always richer and more comprehensive if we use multiple analysts from different parts of the system (e.g. front line staff, supervisor, manager, COE, regulator, government). Here they produce entirely different analyses based on their own view and experience of their own part of the system in which they work, and when these analyses are combined it becomes extremely comprehensive. This of course represents low inter rater reliability; however, the outputs are more valid as a result.

McLean: Yes, but it can be difficult, especially with subjective data. Also, in a competitive team sport context, reliability and validity can be difficult to formally test as external factors influencing player and team behaviour including match status, different opposition, and playing home/away means that no two matches are identical. As such, test-retest and internal reliability are difficult if not impossible. As a minimum, where instruments are developed for data collection, they should have face validity where the design of the measurement instrument is informed by SMEs". It is my opinion that team sport performance is not a quantitative analysis discipline that gives us frequencies and percentages of actions. Rather, qualitative analysis methods that HFE offer are well suited to understanding the 'how' and 'why' of performance, which is more important. The dilemma that comes with this is the potential bias of qualitative analysis.

Stevens: All methods of research enquiry, HFE or otherwise, are only inherently useful if they are valid and assist in examining and elucidating the challenges to which they were tasked. Further, if the validity of an approach is clearly demonstrated there are greater opportunities for uptake and deployment both in research and practice. However, maintaining the reliability of methods is perhaps more difficult in some domains than others. The use of objective and technically generated data sets will always allow for higher degrees of reliability. Yet, the more subjective and arguably more complex pursuits, of sociotechnical and systems thinking approaches reliability is perhaps less confident. In my opinion this uncertainty is not holistically detrimental or at odds with the generation and pursuit of new knowledge.

3.2. Why is the reliability and validity of HFE methods not often tested? How can this be resolved?

Walker: We need to remember that the ergonomic paradigms we are attempting to measure with our ergonomic methods are just human constructs, not natural phenomena (Rifkin, 2014, p. 2). You could argue that the traditional conception of reliability and validity is deterministic in nature, suited to deterministic problems and methods: if the system being analysed is well understood and formalised, then knowledge of that system can be generated reliably and repeatably. But is ergonomics really like that? Actually, the fundamental ergonomics 'paradigm' is rooted in subtle realism (Bedinger, 2020; Walker, 2016). A physical reality, and its universal properties, are assumed to exist objectively 'behind' human perception, but HFE's ability to know this reality is limited by the methods at our disposal. This is why we have so many! We also operate within an epistemology rooted in transactionalism. We generate conceptual models of reality (i.e. situation awareness, mental work load, etc.) which we reinforce or deselect through an interactive sense-making process within a social context. At the end of the day, then, as HFE participants we are pragmatic, transactional, subtle realists. We are not Newtonian physicists. This makes issues of reliability and validity more complex and nuanced than they appear. It is no wonder they are so rarely subject to explicit testing.

Read: Where the type of method calls for tests of reliability and validity, I think that it is important for this to be undertaken as part of the development process. HFE is a scientific discipline and risks being undermined or ignored when we edge too close to pragmatism and away from scientific robustness. I sometimes wonder about the number of new methods, and adaptations to existing methods, being developed within academia. Perhaps the sheer scale of methods impacts on the ability to fully test methods across different

contexts and domains. Perhaps if we could gain some consensus on a core set of methods and approaches, based on the needs of practitioners, and embark on collaborative, longitudinal program of research to comprehensively test these methods, this could provide a way forward.

Salmon: Formal reliability and validity studies are difficult to run and require a lot of resources. They are complicated to design, it is difficult to recruit a sufficient number of participants (they often have to perform a time consuming analysis twice), you often need an expert panel comprising multiple subject matter experts, or a gold standard set of analyses, and you have to make sure all participants receive the same training in a particular method. On top of this, the analysis of data is resource intensive and time consuming (the data from a study we recently conducted took well over 6 months to analyse). Finally, there is limited guidance on appropriate methods and statistical tests to use.

McLean: In my experiences I don't think HFE researchers are as concerned with reliability and validity statistical methods as other disciplines such as sport science, or psychology. A possible recommendation could be for HFE researchers to consult with statisticians in the design of research. EXPAND

Stevens: It is important to note that the testing of the validity and reliability of methods is not a challenge solely attributable to HFE. In the urban development discipline and in particularly within the social sciences studies of urban life there are also apparent deficiencies. In part, I recognise that the challenge lies in the quantity and quality of the doctorate studies and in particular the quality of the supervision being imparted which has underlying implications for the methodological rigour. There is a need for current and

supervising academics, of all disciplines, to ensure they are also research productive academics with knowledge of state of the art approaches.

Hulme: It was during my PhD that I was first exposed to the concepts of reliability and validity in an HFE capacity. After coming to terms with their general meaning, I considered that there was probably just a little bit more reading required before I was well versed on the topic. This couldn't have been further from the truth! After reading in more detail about reliability and validity in the HFE literature during my post-doctoral studies (e.g., Stanton and Young, 1999; Annett and Stanton, 2000; Annett, 2002; Kanis, 2014; Stanton, 2014; Stanton, 2016), it stuck me just how nuanced and particular these concepts can be. For example, I soon realised there was intra- and inter-rater reliability, test-retest reliability, parallel forms reliability, internal consistency reliability, criterion validity, content validity, and construct validity. Each of these terms, of which can be further broken down into subcategories, serve to highlight that reliability and validity training, testing, and practice requires careful consideration on behalf of the researcher. In short, I am not entirely sure why reliability and validity have not been prioritised in the HFE safety science literature, but can only speculate that doing so is viewed as too great a challenge given the knowledge and expertise surrounding it? Even as an ECR with a long career ahead, I can say with confidence that methodological rigor and high-quality scientific research, including the testing of reliability and validity, is something that is looked on positively by all academic disciplines and should be considered in the HFE space.

Stanton: My approach has always been to conduct formal studies of reliability and validity, and to report the findings in the peer-reviewed literature and books (Stanton, 2016). Reliability is a measure of stability of the method over time and stability of the method across analysts. Ideally, it should be possible to demonstrate that the application of a HFE method will result in the same results if it is used by different people or on different occasions by the same people (provided that the system being analysed hasn't changed). A method is generally considered to have minimally acceptable reliability if the method's expert creator could achieve repeatable results on different occasions. At the other extreme would be a method that delivered the same results when used by anyone with even a little training. Between these extremes would be most of the methods used in HFE. Whether any one of these would be considered to have an acceptable degree of reliability would depend on a variety of factors, including: the expertise of those using it; various constraints such as time and resource availability; the type of project; and the problem for which the method was being used. Indeed, when a method is being used creatively then high reliability, either for an individual analyst or across different analysts, may be undesirable, as it could restrict the range of alternatives considered. By way of contrast, in large, safety-critical, projects with a number of analysts, a much higher degree of reliability is necessary, as the results achieved by the different analysts will no doubt need integrating at some stage during the project.

If reliability is not a simple concept, then validation is even more challenging. Stanton and Young (1999a) proposed four types of validity for Ergonomics methods: construct, content, concurrent, and predictive. Construct validity, for example, concerns the underlying theoretical basis of a method. Content validity, according to Stanton and Young, is

concerned with the credibility that a method is likely to gain among its users. They suggest that, ideally, a method should use appropriate terminology and language and seem up to the job of analysis if it is to be taken seriously. Obviously, such validity requires agreement among those using the methods. Finally, Stanton and Young's (1999a,b) argued that concurrent and predictive validity concerns address the extent to which an analyzed performance is representative of the performance that might have been analysed. The difference between concurrent and predictive validity is a matter of time: concurrent validity describes current performance sampled whereas predictive validity concerns the performance of the future. What is important is that the Ergonomics methods possess a level of concurrent or predictive validity suitable for their application. There continues to be debate over the role of validation in Ergonomics (Annett, 2002; Stanton, 2002; Stanton, 2014; Stanton & Young, 1999b), and the issues are by no means resolved. The goal of the discipline for methods should be to meet both reliability and validity criteria. Although laboratory and other research work may be a desirable minimum, it is the perceptions of ultimate users in the design and engineering industries that will be most important.

A summary of each perspective on the issue of HFE methods' reliability and validity is presented in Table 3.

Table 3. A summary of perspectives on the reliability and validity of HFE methods.

	Do HFE methods require evidence of reliability and validity?	Why is the reliability and validity of HFE methods not often tested?	How can this be resolved?
Salmon	Yes (Validity) No (Reliability)	1. Reliability and validity studies are difficult to design and require a high level of resources; 2. There is limited guidance available on how best to design, conduct and analyse reliability and validity studies.	1. Protocols/guidance for conducting reliability and validity studies
Read	Not in all cases (e.g. design methods)	1. There are too many HFE methods	1. Identify a set of core HFE methods and conduct formal reliability and validity studies
Hulme	Yes	1. It is too challenging combined with a lack of knowledge and expertise	
Walker	Yes	1. It is too challenging	1. Develop a shared understanding of HFE's underlying epistemology and ontology
McLean	Yes	1. A lack of knowledge regarding appropriate statistical tests	
Stanton	Yes		1. A stated goal of the HFE discipline should be for its methods to meet set reliability and validity criteria
Stevens	Yes	1. it can be in the too hard basket, but it is not solely a challenge for HFE.	1. Ensure the quality of both doctoral candidates and their supervision.

4. Prediction

Accurately forecasting the behaviour of individuals, teams, organisations, and even entire systems has been labelled one of the greatest challenges facing HFE (Moray, 2008, Salmon et al, 2017, Stanton and Stammers, 2008). The majority of HFE methods cannot predict behaviour beyond the relatively simple case of deterministic error-producing conditions (Embrey, 1986; Kirwan, 1992a, b; 1998; Stanton et al., 2009). This is particularly problematic in the realm of systems HFE. For example, whilst methods such as Cognitive Work Analysis (CWA; Vicente, 1999), the Event Analysis of Systemic Teamwork (Stanton et al., 2018), and the Systems Theoretic Accident Model and Processes (Leveson, 2004) provide the capacity to comprehensively model complex systems, they are incapable of simulating system behaviour, and consequently cannot make valid predictions about the behaviour of a particular system following HFE intervention (Salmon et al., 2020). This is often required by end-users or project stakeholders. Whilst many HFE scholars have emphasised the need for predictive HFE methods, they have not been forthcoming. Here each author was asked if prediction in HFE is possible, and if so, what is required to enable it.

4.1. From a HFE perspective, is accurate prediction actually possible?

Stanton: As Niels Bohr (the Nobel prize willing theoretical physicist) once observed: "Prediction is very difficult, especially if it's about the future." That is especially true in HFE, with the complexities of the interactions in sociotechnical systems. It is probably fair to say, the simpler the system and the narrower the prediction, the easier it is to anticipate behaviour (Stanton, 2016). HFE methods have had some notable successes and failures in

this regard (Stanton and Young, 1999). For example, studies of Human Error Identification methods using methods such as SHERPA, HET and TAFEI have been able to predict some of the errors that are observed in system use (Stanton and Stevenage, 1998; Stanton et al, 2006; Stanton et al, 2009). Making predictions about the performance of broader aspects of more complex systems is another matter. Method such as STAMP-STPA, EAST-BL, NET-HARMS have not yet been formally validated, but this should be an important goal for a discipline that operates in the world of engineering.

Walker: If your HFE problem is well understood with relatively slow rates of change and few component parts, prediction is eminently possible. If your HFE problem is of strategic importance to the discipline (Dul et al., 2012), i.e. not fully understood, with high rates of change, and multiple components, then the range of existing HFE methods is surprisingly limited, and the methods capable of meaningful prediction is virtually nil. Even those currently available to tackle these systems problems are largely restricted to pen and paper, or the most basic desktop software, so scale poorly. This is a distinct disadvantage when the future direction is 'massive sociotechnical systems' (Holman & Walker, 2019). There is a subtlety of course. Insight derived from HFE methods can lead to a form of prediction which manifests itself as decision-support. Prediction in a very loose sense.

McLean: From a team sports perspective, No. I think HFE methods have great potential in this area though. At present, HFE methods can help explain recurring patterns of behaviours at a team level that will occur during a match, which can assist the design of training practice. However, predicting what the opposition and individuals will do across an entire match is out of reach at this point. I think the match analysis technology we currently

have combined with the expertise of coaches are equal or better than what any HFE methods can do at this point. Coaches will design training to prepare for the behaviours and patterns of other teams at a macro level, but prediction at the micro and meso levels are not possible at this point. Big data is currently being used in sport science to understand the variables that supposedly predict successful outcomes. However, the problem is that the innumerable interactions and influences to performance are being reduced down to one or two variables. It is impossible to understand sports performance by reducing the complexity of sport into a few variables (salmon & Macca). I think this is where systems HFE will have a big impact in the coming years, by moving the discipline away from reductionism. . The unpredictability inherent in sport is why billions of people watch, I personally hope we never get to the point of accurate prediction.

Stevens: Not in any work that I have been involved in first-hand. While the term 'accurately' is contestable; there does however exist the ability to identify a range of plausible futures for anticipated individuals, teams, organisations, and even systems. Does it only move toward prediction if those futures are played out as exactly anticipated? Is it perhaps enough to be able to identify aspects of anticipated or expected behaviour? Then via appropriately designed systems it is possible to influence humans in those systems that they do not behave in any unanticipated ways – in essence a well-designed space will afford predictable behaviour and that is sufficient. I can imagine that this is possibly a true scenario for some designs in my domain of urban development. Start small and design a purposeful path.

From a HFE and sociotechnical systems perspective some degree of prediction is possible. Humans interacting with artefacts in a setting as designed and anticipated. It is an exercise

in scoping the expectations for prediction – however the more complex the system, the more ways in which emergent behaviours can eventuate.

Hulme: In other academic disciplines, be it the epidemiologic, public health, or business and economic fields, there has been such a thing as "behavioural prediction" for some time. For example, statistical techniques such as multiple regression analyses can help researchers to 'predict' the value of outcome *y* given the value of exposure *x* whilst accounting for the influence of several other explanatory variables. Indeed, regression modelling is frequently used in sports injury aetiology and prevention research to better understand which biologic and behavioural exposures best explain injury occurrence. If following the analysis, a linear pattern is observed, and the coefficient of determination is nearing 1.0, we can say that the model fits the data well and can be useful for making predictions about some unknown phenomenon or value (e.g., what is the risk of injury if an athlete is heavier, faster, or switches footwear?). More advanced forms of statistical analyses, probability modelling require the disclosure of any underlying model assumptions and error. In addition, whilst prediction is the estimation of an outcome based on observed association, causality is the identification of the *mechanisms* and *processes* by which the outcome is generated. Thus, 'accurate' prediction requires that we can also *explain* the aetiological basis of phenomena. Prediction may be possible depending on the context, research purpose,, adopted analytical approach, and the extent to which study limitations have been accounted for and reported. What this all means is that HFE research may have to explore other methods and analytical approaches in which to attempt to predict the behaviour of individuals, teams and systems.

Read: I think 'prediction' needs some definition. Are we talking about prediction of specific behaviours? Or broad predictions that certain behaviours or classes of behaviours could emerge over time or contexts?

If the former, then my answer is no. If we accept that much of our work is investigating complex systems, where we know that performance is variable and adaptive, changing to cope with the changing constraints of our environments, the notion of being about to predict a specific behaviour occurring at a specific point in time seems incongruous with complex systems approaches.

If the latter, then we do have methods that can identify possibilities for behaviour – such as CWA.

I think if we take a complex systems perspective, any form of accurate, specific prediction is not possible, and indeed not useful. Systems theory tells us that systems are dynamic, we build models to describe them, but by the time the model is finalised, the system has likely changed already. Even the process of building the model and having it say, validated by subject matter experts who operate in the system, while only a small intervention, can create non-linear effects that propagate throughout the system (the butterfly flapping its wings). Thus, any predictions made on the basis of that model in fact no longer apply and could in fact lead to a focus on dealing with the wrong issues.

I do agree that it is useful for organisations and governments to have a better understanding of risk and the ways in which risk may play out, but I would advocate less for

specific predictions, and more for better understanding of risk from a systemic perspective and better strategies for managing risk. I wonder if accurate prediction could lead us to a false sense of security, and to have blind spots where the context changes. Instead, we should be building a mindset of uncertainty, and supporting adaptation and flexibility to deal with new risks and issues as they emerge.

Salmon: Given the complexity of HFE problem spaces our methods are never going to be 100% accurate in predicting behaviour (no method can be if the system is truly complex); however, I feel strongly that HFE methods, particularly systems HFE methods, can be used to provide extremely useful predictions of behaviour. There is no doubt, for example, that methods such as CWA, EAST and Net-HARMS can provide useful predictions about individual, team, organisational or system behaviour. We cannot predict when and where something will occur, but we can identify the kinds of behaviours that a system might exhibit.

On top of this, I think methods from other areas can also be usefully applied in HFE – for example computational modelling approaches such as agent-based modelling and system dynamics (e.g. Salmon et al., 2020; Thompson et al., 2020). These methods bring a useful quantitative aspect to system modelling, enabling us to assess the likely dynamics of a system's behaviour over time.

4.2. What is required to enable accurate prediction in HFE?

Walker: A radical systems agenda. Without the rapid development of appropriate methodology, HFE is in serious danger of becoming an afterthought in global trends

surrounding the current Fourth Industrial Revolution (4IR). The complexity created by 4IR technologies seems to be rapidly outpacing the realisation of Dul et. al's strategic direction for the discipline, a direction which seems increasingly timid and parochial. New types of HFE methods are needed now more than ever. Specifically:

- Methods with capability to model the interaction between humans and autonomous agents for effective allocation of function in post-dualistic sociotechnical systems (i.e. where AI might mean the human is no longer the 'prime agent').
- The capability of modelling emergence in complex interconnected 4IR systems to understand and predict latent risks and opportunities.
- The capability to perform multilevel analysis of truly massive sociotechnical systems.
- Methods which can be implemented with more than a pen and some paper(!).

Good luck with all that.

Read: As above, I am not sure that accurate prediction is ever possible or even desirable.

Stanton: If it isn't possible to validate methods we should not be making predictions. The purpose of predictions is to anticipate future behaviour of the sociotechnical system and make decisions to improve performance (such as safety, effectiveness, and work satisfaction). No prediction will be perfect, but is should be good enough for the job at hand. For example, when making predictions about driver performance with in-vehicle technology, we were able to demonstrate that the predictions were reasonable when compared with drivers performing the tasks in a driving simulator (Harvey and Stanton,

2013). If the predictions of system performance are not proven to be valid, then the assumptions upon which decisions to improve performance will be false. This could, potentially at least, result in making the system worse rather than better. When dealing with engineering colleagues in a wide variety of industries (aviation, defence, energy distribution, ground transportation, and maritime) the gravitas with which Human Factors methods are treated very much depends upon proof that they actually work.

Salmon: Further development of systems HFE methods as well as exploration of methods from other disciplines. For example, we have been exploring the integration of computational modelling methods such as ABM and system dynamics with systems HFE methods (See Salmon & Read, 2019; Salmon et al., 2020).

Stevens: Well-designed systems that are the result of interdisciplinary knowledge and experience. Splitting one atom is enough to begin the chain reaction – why are we trying to eat an elephant?

Hulme: Regarding the prediction of individual behaviour, the HFE research thematic would benefit from applying or integrating traditional statistical approaches (e.g., General Linear Models, regression analyses) more frequently into its methodological toolkit if and where necessary. Paul and the other co-authors have touched on prediction in relation to teams and organisations, and so the remainder of this answer will focus exclusively on predicting the behaviour(s) of complex systems. Consequently, HFE methods currently cannot fully predict complex systems behaviours, which by definition, means that accurate prediction is not yet possible either. In short, and from a methods perspective, there are two required

steps that are to occur before the prediction of complex systems is close to possible: (i) that a system is characterised by a set of tenets, principles or characteristics (e.g., Grant et al., 2018; Hulme et al., 2018), and it is these tenets that are to be subject to modelling activities; and, (ii) that the said modelling occurs in a dynamic, time continuous fashion which can be achieved with computational systems science modelling methods (i.e., simulation-based approaches). At present, a select group are the only HFE researchers to explicitly promote the use of Agent-Based Modelling (ABM) and System Dynamics (SD) modelling in the HFE space (e.g. Hettinger et al , 2015; Salmon et al., 2020; Thompson et al., 2020), and more work is required to understand how dynamic computer-based modelling methods can be used to capture the 'emergent' nature of complex (sociotechnical) systems. In doing so, prediction – however accurate – might be within reach as such approaches are generally programmed with different types of inputs or variables that directly correspond to the system under analysis. By manipulating the value of these variables, computer simulations can be run hundreds or thousands of times to theoretically evaluate the short or long-term effects that are associated with a range of potential outcomes. I would like to see the HFE research field move in this direction and embrace the possibilities of what Guy has coined a radical systems agenda!

McLean: I am reluctant to provide any suggestions as I don't want sport performance to be predictable. Although, I think the best chance is potentially with computational modelling methods such as systems dynamics and agent-based modelling integrated with HFE methods where thousands of simulations can be run. This area is where I think sport and HFE researchers and practitioners can learn from each other. Accurate prediction is paramount for safety critical domains, and the increasing availability of big data in sport

could help HFE with its prediction efforts. However, transdisciplinary research is another issue altogether.

A summary of each perspective on the issue of prediction is presented in Table 4.

Table 4. A summary of perspectives on the reliability and validity of HFE methods.

Author	**From a HFE perspective, is accurate prediction actually possible?**	**What is required to enable accurate prediction in HFE?**
Salmon	Yes	1. Development and testing of new predictive HFE methods; 2. Integration of computational modelling methods with systems HFE methods.
Read	Yes (Broad predictions)	N/A (Prediction not desirable)
Hulme	Yes, depending on the context and aims of study	1. Identification of the set of features which influence behaviour; 2. Use of computational modelling methods such as ABM and System Dynamics.
Walker	Yes, for deterministic systems and in the provision of insight to support decisions.	1. Development and testing of new predictive HFE methods
Stanton	Yes, but extremely difficult	1. Further reliability and validity testing of HFE methods in a predictive context.
Stevens	No	1. Development and testing of new predictive HFE methods;
McLean	No	1. Integration of computational modelling methods with systems HFE methods.

5. Conclusion

To be added (PS)

Methods from the 1960's rendered invalid by their routine application to systems problems; a practitioner focus which values 'practice' over research and theory (a form of anti-intellectualisation); methods which are completed on pen and paper (in the year 2020), and

don't scale well; methods with scant reliability or validity evidence… Not sounding so good is it!

6. References

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