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## Invited Review

## Taking stock of behavioural OR: A review of behavioural studies with an intervention focus

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## ABSTRACT

This review maps the body of behavioural OR studies that focus on interventions. The term ‘intervention’ is used here to refer to a designed problem-solving system in which individuals or groups engage with OR methods, processes and tools in order to complete a set task or address a real-world problem. We surveyed the relevant OR literature covering a 30-year period, and develop a typology to organise our corpus of reviewed studies. The typology is comprised of four types of studies, each type representing a distinctive approach in terms of its assumptions about behaviour (*determinist* or *voluntarist*) and the research methodologies they use (*variance* or *process*), and each type is concerned with different research questions that do not cut across other approaches. By categorising studies in this way, and drawing on research in associated cognate areas where relevant, eight empirically-generated knowledge themes emerge: intervention configurations, individual differences, model-driven support impacts, (un)intended use, model building process, engagement paths and strategies, facilitated modelling practice, and sociomaterial dynamics. Each of these knowledge themes provides important insights into the behavioural factors that affect, or are affected by, OR-supported activity. We conclude our review with ten suggestions for further developing the behavioural OR agenda concerned with interventions.

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## 1. Introduction

The resurgent interest in the study of behavioural phenomena within the OR discipline arises from a renewed appreciation that for OR to make a real difference, focusing on the ‘content’ of OR work –that is, developing technically correct and valid models– is simply not enough. Whereas attention to process (rather than content) within the OR profession has been long standing (e.g. Eden, 1990; Huxham & Cropper, 1994; Phillips and Phillips, 1993), calls to use behavioural insights to inform the design and conduct of OR-supported processes in order to improve their effectiveness are more recent (Franco & Hämäläinen, 2016; Hämäläinen, Luoma, and Saarinen, 2013; Lane, 2017; Royston, 2016). Central to these calls is a concern with ‘unpacking’ OR interventions to scrutinise what actors actually do with the methods and processes they engage with, how they do it, and what implications this has for shaping

OR intervention processes and outcomes. The developing field of behavioural OR (BOR) has taken this concern seriously, bringing actors and their actions and interactions to the foreground of OR studies.

The BOR field has seen rapid growth in recent years, particularly in Europe. There are now regular BOR conference streams at EURO, IFORS and British OR Society conferences, two edited books, two special issues (one in this journal), additional papers in relevant peer-reviewed journals, and two specialist groups: a European Working Group EWG-BOR (<https://www.euro-online.org/websites/bor/>) and a Special Interest Group SIG-BOR (<https://www.theorsociety.com/Pages/SpecialInterest/Behaviouralor.aspx>) in the UK. Given this level of activity it is perhaps a suitable time to review the extant BOR literature, assess the current state-of-the-art knowledge of the BOR field, and outline future directions for the continuing advancement of the behavioural agenda within OR. Our aim here is to produce a map of a growing OR domain that could offer inspiration and guidance to academics and practitioners interested in undertaking empirical BOR studies.

To this end, we conducted a review covering a 30-year period of published behavioural studies that focus on OR interventions.

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In this review, we use the term ‘intervention’ to refer to a designed problem-solving system in which individuals and groups engage with OR methods, processes and tools in order to complete a set task or address a real-world problem. It should be noted that the interventions so defined can take place either in the laboratory or the field, and thus the studies we review here include experimental, quasi-experimental and field research. Another implication of this framing is that we deliberately excluded from the review those studies that focus exclusively on modelling behaviour, as they tend not to be associated with *human* actors engaging with an OR-supported intervention process in the lab or field. There is obviously a long history of developing behavioural models within OR that merits an assessment. However, these works were outside the scope of the present review. Finally, straightforward applications of OR methods, processes and tools whose findings are purely based on anecdotal evidence or self-reports, or where behavioural mechanisms are not specifically addressed, even if only implicitly, were not included in this review.

Our search strategy identified 79 studies out of an initial corpus of 4677 published papers in mainstream OR journals. To organise our review, we developed a typology of four approaches to the study of behavioural phenomena in an OR intervention context. The four approaches reflect differences in how behaviour is (implicitly or explicitly) assumed to be in a given study (*determinist* or *voluntarist*), and the research methodology used to conduct the study (*variance* or *process*). By categorising behavioural studies in this way, and drawing on research in cognate areas, eight empirically-generated knowledge themes emerge: intervention configurations, individual differences, model-driven support impacts, (un)intended use, model building process, engagement paths and strategies, facilitated modelling practice, and sociomaterial dynamics. Each of these knowledge themes provides a set of important insights into the behavioural factors affecting, or affected by, OR-supported activity. Our review provides an opportunity to better understand the current state-of-the-art knowledge of the BOR field concerned with interventions. The findings of our review also allow us to identify gaps in current knowledge, and formulate potentially fruitful directions for advancing the behavioural agenda within OR.

In what follows, we start our review by defining the two dimensions of our typology. For the behavioural assumptions dimension we draw on the work of Keys (1989, 1997, 1998, 2007) in relation to the process of OR. The work of Poole and colleagues (Poole, 2004; Poole & Van de Ven, 2004; Poole et al., 2000) on organisational change informs the research methodology dimension. Next, we use our typology to assess the current body of knowledge emerging from BOR studies, supported by research in cognate areas were relevant. We conclude the review by identifying current gaps and suggesting directions for future research.

## 2. Behavioural assumptions in BOR studies with an intervention focus

Given that understanding the role and impact of behaviour is central to the BOR agenda, it is worth noting the different assumptions about *human* behaviour that underpin BOR studies concerned with interventions. This is important because it will enable us to appreciate the diversity of intervention-type research published within OR, as well as the type of empirically-driven insights they can generate. Here, we are interested in assumptions about the behaviour of an individual human actor as the basis for examining both individual- and collective-level phenomena. We are also concerned with a broader family of OR interventions (as defined in the previous section): simple and complex, involving individuals and groups, and conducted in the lab and field. Our focus

is thus broader than that adopted recently by White, Burger, and Yearworth (2016).

Keys (1997) provides a useful starting point. In discussing the assumptions underpinning alternative approaches to understanding the practice of OR analysts, Keys distinguishes two ontologies of the world. A *realist* ontology views the world surrounding an individual as a concrete entity, and the components of that world exist independently of the individual's ability to be aware of them. Applied to the BOR context, a behavioural study rooted in a realist ontology would assume that the intervention and its components (e.g. methods, models, task, problem) can be understood as independent empirical entities that can be studied and empirically examined in their own right (e.g. Jackson & Keys, 1984; Mingers & Brocklesby, 1997; Ormerod, 1997), including the various (hypothesised) relationships between them and the behaviours observed within the intervention. Such relationships can be understood in the direction of the intervention *causing* the behaviours, or the intervention representing a generative mechanism that governs the behaviours over time. On the other hand, a *nominalist* ontology views the world as being produced by individuals, and the concepts used to describe it are created by individuals to help them make sense of that world and act within it. Applied to the BOR context, a behavioural study rooted in a nominalist ontology would assume that the intervention and its components cannot be investigated separately from the behaviours observed in the intervention (e.g. Franco, 2013; White et al., 2016), because both have agency to shape outcomes. In this case, relationships between intervention components and behaviours must be understood as interactive, dynamic and mutually reinforcing.

Keys also notes two conceptualisations of human behaviour consistent with the realist and nominalist ontologies: *determinist* and *voluntarist*, respectively. The former assumes that the behaviour of individuals is determined exogenously and thus outside their control; whereas the latter gives individuals agency to act and be accountable for their actions. Indeed, a first glance at the extant literature suggests that OR scholars conducting behavioural studies with an intervention focus do hold different assumptions about the nature of behaviour. In the studies we surveyed, we noticed that they broadly assume -implicitly or explicitly- that the behaviour of individuals or groups is either influenced by internal or external factors (i.e. determinist behaviour) or is in itself an influencing factor (i.e. voluntarist behaviour). This characterisation is also consistent with Ackoff's (1989) shrewd observation about the relation between behaviour, self and the environment. For Ackoff, an individual can affect his/her own self-behaviour or environment, and thus show voluntarist behaviour; on the other hand, behaviour can also be affected by an individual's own self or his/her environment, and thus show determinist behaviour.

Consequently, in studies where behaviour is assumed to be determinist, the observed actions of individuals and groups are taken to be affected by various external factors, including the intervention itself, and/or guided by cognitive structures (e.g. individual traits) that get triggered during the intervention. This assumption also applies to studies where there are researchers and practitioners guiding or leading the intervention. In this case, the researcher in the lab or the practitioner in the field are seen to take an instrumental role related to the intervention being implemented, and thus given less importance than the intervention itself. This is because both researchers and practitioners are mainly concerned with ensuring that interventions work as intended and, consequently, their actions are assumed to be determined by their designed chosen intervention.

On the other hand, in studies where behaviour is assumed to be voluntarist, the observed actions of individuals and groups are taken to have a key role in determining how the intervention will eventually unfold. As Keys observes, decisions and choices about

**Table 1**  
Determinist and voluntarist behaviour compared -adapted from Keys (1997).

Determinist behaviour	Voluntarist behaviour
Individuals' behaviour is determined by exogenously and thus outside their control.	Individuals have agency to act and are accountable for their decisions.
Individuals' observed actions are affected by intervention and other external factors, and/or guided by cognitive structures that get triggered during intervention.	Individual's observed actions determine how intervention will unfold.
Intervention only provides scripted guidance for interactions, and control over how to enact it resides with those guiding the intervention.	Intervention only provides scripted guidance for interactions, but control over how to enact it resides with individuals or groups: they can choose to either modify their behaviour to adapt to the intervention 'script' or actively try to change it.
Intervention methods, process and tools are used in similar ways by various individuals or groups.	Intervention methods, processes and tools can be used in distinctive ways but various individuals or groups according to their goals and interests.

how to engage with the intervention are made by those participating, and whilst the intervention provides a scripted guidance for interactions between the participants and the intervention's procedures and tools, control over how to enact such guidance in any given moment within the intervention lies ultimately with the participants themselves. This means that participants can choose to either modify their behaviour to adapt to the intervention 'script' or actively try to change it. This raises the practical possibility that the same OR methodology, technique, or model could be used in distinctive ways by various individuals or groups according to their goals and interests (Franco, 2013; Franco & Lord, 2011; Tavella & Franco, 2015). Table 1 summarises the basic differences between the determinist and voluntarist assumptions about behaviour.

We believe that using the proposed determinist-voluntarist dichotomy as a first step in organising the extant literature can help to better appreciate the empirical focus intrinsic in the studies we surveyed. However, Ackoff (1989) warns us about the dangers of using dichotomies, a concern shared by advocates of the critical realist perspective within OR (e.g. Keys, 1997; Midgley, 2000; Mingers, 2000; White, 2016). For critical realists, behaviour is more dynamic and emergent, that is, constrained by internal and external structures, while simultaneously contributing to changing these structures over time. Indeed, an argument can be made that most behaviour in practice is likely to lie somewhere between the determinist and voluntarist extremes presented here. Nonetheless, as it will become apparent when we present the findings of our review later on, in the studies we surveyed there was an explicit or implicit choice to foreground one of the extremes as the focus, while backgrounding the other.

### 3. Research methodologies for studying behavioural phenomena

In this review we are concerned with behaviour and, in particular, behavioural change associated with OR interventions. The notion of change, including behavioural change, has been treated both theoretically and empirically in domains such as history, education, medicine, and management. Here we will refer to the work of Poole and colleagues in the area of organisational change (e.g. Poole, 2004, 2007; Poole & Van de Ven, 2004; Poole et al., 2000; Van de Ven & Poole, 2005). Specifically, Poole (2004) identifies *variance* and *process* research methodologies as two distinct approaches to the study of organisational change. In general terms, variance research seeks explanations of change in terms of relationships amongst independent variables and dependant variables, whereas process research seeks explanations of how a sequence of events leads to an outcome. Variance and process methodologies yield quite different conceptualisations of change, and imply different ways for judging the generalisability of research findings. Below we compare the two methodologies in a little more detail

within the context of BOR, drawing heavily on the work of Poole and colleagues (For an extended discussion of variance and process approaches see Poole, 2004; Poole et al., 2000).

#### 3.1. Variance research methodology

A variance methodology uses variables that represent the important aspects or attributes of the OR intervention under study. Explanations of behavioural change take the form of causal statements captured in a theoretically-informed research model that incorporates these variables (e.g. A causes B, which causes C). The model is then tested with data generated by the intervention, and the model findings are assessed in terms of their generality, that is, "the range of cases, phenomena, or situations the causal explanation applies to" (Poole, 2004, p.10). It is worth highlighting the difference between these research models and the behavioural models found in the OR literature: the latter describe the behaviour of actors in a given situation or system that is typically not associated with an OR intervention as defined here, whereas the former describe behaviour-related factors specifically related to an OR intervention.

The deployment of a variance methodology typically requires the implementation of experimental, quasi-experimental, or survey research designs.<sup>1</sup> This involves careful selection of independent variables, which might be either manipulated (e.g. representation format, information type, method, cognitive style), or left untreated (e.g. experience, demographics). It also requires choosing and measuring dependant variables that act as surrogates for specific behaviours in a study. Within BOR, dependant variables typically capture aspects of decision-making performance, choice, learning, and efficiency. Such aspects can be measured in absolute or relative terms, as well as objectively (e.g. against a known or optimal solution) or subjectively (e.g. against a solution provided by experts). Dependant variables can also include perceptions about intervention outcomes (e.g. commitment, confidence) and the intervention itself (e.g. satisfaction, usefulness), which can only be measured subjectively via self-reports. A few behavioural studies consider variables that act as either covariates or moderators through which independent variables influence the dependant variables (e.g. 'conflict' as moderating the relation between 'method' and 'performance'), although the latter is not very common in the corpus of studies we review here.

Once information about all variables is collected, data is quantitatively analysed using a wide range of statistical techniques (e.g.

<sup>1</sup> It should be noted that a variance approach could also be implemented through field research designs where pre and post intervention measures of key variables are used to assess changes in behaviour or surrogates of behaviour. Studies adopting this approach are common in the System Dynamics field (see, for example, Scott et al. 2013).

analysis of variance, regression, structural equation modelling). Behavioural studies that use a variance research methodology can produce a good picture of the generative mechanisms underpinning behavioural processes if they test hypotheses about those mechanisms. An example of the variance methodology to study behavioural change in an intervention context is the study by Huang, Hsu, and Ku (2012). They conducted an experiment that compared subjects using a model-driven decision support system providing counter-arguments as a form of guidance before making an investment decision, with those without the guidance. Using standard statistical techniques, the researchers found that subjects in the counter-argument treatment moved away from their initial preconceptions and were prevented from developing excessive levels of confidence, hence reducing confirmation bias.

As it will become apparent later when we present the results of our review, variance methodologies have been the dominant choice by OR scholars studying behavioural issues with an OR intervention focus. It should be noted, however, that the use of variance methodologies can only offer a partial understanding of behavioural phenomena. As Poole et al. (2000) observe, the variance approach “overlooks many critical and interesting aspects of change processes” (p.29). By contrast, studies that use a process research methodology attempt to incorporate these issues explicitly, as explained next.

### 3.2. Process research methodology

A process methodology is used to examine an OR intervention as a series of events that bring about or lead to some behaviour-related outcome. Rather than using variables, a process methodology considers an evolving actor (individual, group, organisation) to which events occur or who makes events happen as the unit of analysis (Poole, 2004). Process explanations take the form of “theoretical narratives that account for how one event led to another, and that one to another, and so on to the final outcome” (Poole, 2007, p.184). Thus, what counts as an event, and the temporal ordering of events are both critical in process studies. Furthermore, narrative explanations of behaviour within an OR intervention context tend to be more complex than variance explanations because intervention events are complex due to their interconnectedness and dynamic nature. According to Poole (2004), process narratives may “incorporate several different types of effects into their explanations, including critical events and turning points, contextual influence, formative patterns that give overall direction to the change, and causal factors that influence the sequencing of events” (p.11).

Like variance explanations, process explanations are assessed in terms of their generality. However, generalisation depends on *versatility*, namely, “the degree to which it can encompass a broad domain of developmental patterns without modification of its essential character” (Poole et al. 2002, p.43). Put differently, a process explanation or theory is versatile if it can stretch or shrink to fit specific cases that may differ in their tempo and time span. For example, Adaptive Structuration Theory (DeSanctis & Poole, 1994) is a highly versatile process explanation of how technology is adapted by actors because it can be applied to a wide variety of technologies (e.g. software, decision support systems, OR interventions) and actors (e.g. individuals, collectives, institutions), as well as processes (e.g. problem formulation, decision making, behavioural change) that can take a day, a week, a month, a year, or longer.

Diverse and eclectic research designs are used to implement a process methodology. Central to these designs is the task of identifying or reconstructing the intervention process through the analysis of activity and events taking place over time. For example, Shaw, Ackermann, and Eden (2003) analyse time logs of

participant-entered contributions (i.e. ideas; links between ideas) in a series of computer-supported causal mapping workshops (Bryson, Ackermann, Eden, & Finn, 2004) to identify a typology of knowledge sharing. Represented in casual maps of different (structural) complexity, the typology comprises ‘stories’, ‘expanded sequences’, ‘broadcasts’ and ‘news-flashes’ as the outcomes of different knowledge sharing trajectories. They note that synthesis of stories is the easiest way to produce in-depth-understanding about issues; whereas synthesis of news-flashes is the more difficult, and synthesis of expanded sequences and broadcasts is somewhere in the middle.

Whereas studies that adopt a variance methodology (i.e. ‘variance studies’ hereafter) employ hypothetico-deductive procedures, studies using a process methodology (i.e. ‘process studies’ hereafter) employ a mix of approaches. Poole (2004) observes that most often process studies derive theory from observation, and this requires collecting and analysing large amounts of data from which a process explanation is developed. In some cases, however, process studies “test hypothesised models of the change process, and in others they use abduction or retroduction whereby theories are used to guide observation that further specifies the theories” (Poole, 2004, p.12). It should be noted that process studies using abduction or retroduction are not common in OR despite their apparent advantages (Brocklesby, 2016; Mingers, 2012), although some are beginning to appear (e.g. Ormerod, 2014; White et al., 2016).

In summary, variance research methodologies explore and test the mechanisms that drive process theories, while process research methodologies explore and test the narratives that ground variance theories. Process studies are capable of tapping aspects of processes that variance studies cannot. However, as Poole aptly notes, variance and process methodologies should be considered as complementary, rather than opposite, approaches. Table 2 summarises the basic differences between variance and process research methodologies.

## 4. Review and typology of BOR studies with an intervention focus

Our review covered studies published from 1989 to 2018 in six selected journals (in alphabetical order): *Decision Support Systems (DSS)*, *European Journal of Operational Research (EJOR)*, *Journal of the Operational Research Society (JORS)*, *Management Science (ManScie)*, *Omega*, and *Operations Research (OpsRes)*. Clearly, relevant papers can be found outside our selected group of journals. However, we decided to survey only mainstream OR journals to make our task more manageable. It should be noted that we excluded all behavioural studies related to forecasting from our review, as this is an area that has grown independently into a specialist domain with its own publication outlets (e.g. *Journal of Forecasting*), and where its state-of-the-art is assessed roughly every decade since its inception in the 1980s (e.g. Arvan, Fahimnia, Reisi, & Siemsen, 2019). Overall, we believe that our choice of outlets provides a sound initial picture of the types of behavioural studies with an intervention focus that have developed within OR in the last 30 years.

We used the Elsevier Scopus database combined with Google Scholar as the basis of our search strategy to identify a corpus of 4677 published papers (for further details of our search strategy see the appendix). To organise our review, we build on our foregoing discussion about alternative behavioural assumptions and research methodologies to suggest a typology of four approaches for studying behavioural issues in an OR intervention context. The approaches in the typology result from viewing the behaviour of actors as being determinist or voluntarist, and adopting variance or process methodologies for studying change, includ-



**Table 2**

Variance and process methodologies compared –adapted from Poole (2007).

Variance methodology	Process methodology
Focus on variables that link attributes of entities (e.g. actors, intervention, task, context) to intervention outcomes.	Focus on events in which actors participate during the intervention, both of whom may change over time. Temporal ordering is critical to intervention outcomes.
Used in experimental, survey and field research designs. Data analysis methods are often quantitative, but can also be qualitative.	Used in eclectic research designs, in observational studies in the lab or field. Data analysis methods can be quantitative or qualitative, or both.
Enables testing of causal explanations through hypothesis testing. Generality depends on uniform application of causal explanation across a range of cases and contexts.	Enables production of process explanations or further specification of process theories. Generality depends on the versatility of the process explanation or further specified theory.

ing behavioural-related change. These are: variance studies of determinist behaviour (Approach I); process studies of determinist behaviour (Approach II); process studies of voluntarist behaviour (approach III); and, variance studies of voluntarist behaviour (Approach IV). We believe this categorisation offers a helpful heuristic device for identifying the variety of behavioural studies that have an OR intervention focus.

Using this typology, we identified a final list of 79 relevant studies for review.<sup>2</sup> Table 3a shows that the greatest percentage (71%) of articles published were variance studies, with many more variance studies assuming that behaviour is determinist (Approach I) rather than voluntarist (Approach IV). The remaining are process studies (Approaches II and III) evenly split between the two behaviour assumptions. Interestingly, as Table 3a highlights, process studies are more prominent in UK/EU journals (*Journal of the Operational Research Society*, *European Journal of Operational Research*). Table 3b shows that, overall, the volume of behavioural studies with an intervention focus has significantly increased over time, with as many articles published in the last decade as in the previous two decades altogether.

In what follows we introduce the studies within each category of our typology by briefly describing the broad research questions they aim to address, together with some illustrative examples. This introduction will provide the background for a more detailed discussion, in the subsequent section, of the state-of-the-art knowledge that emerges from our review.

<sup>2</sup> Some studies contain sub-studies and thus may appear under more than one category.

**Table 3a**

BOR studies published during 1989–2018 by journal and approach.

Journal	Approach				Total
	I	II	III	IV	
DSS	18	2	0	1	21
EJOR	15	2	5	0	22
JORS	9	7	5	0	21
ManScie	9	0	0	1	10
Omega	2	0	1	0	3
OpsRes	1	1	0	0	2
Total	54	12	11	2	79
	68%	15%	14%	3%	

**Table 3b**

BOR studies published during 1989–2018 by decade.

Approach	Decade			Total
	1990s	2000s	2010s	
I	17	10	27	54
II	2	6	4	12
III	1	2	8	11
IV	1	1	0	2
Total	21	19	39	79
	27%	24%	49%	

#### 4.1. Approach I: variance studies of determinist behaviour

Variance studies that adopt Approach I are broadly concerned with testing the impact of OR interventions on actors' behaviour, and vice versa. Overall, scholars who adopt Approach I tend to be concerned with the following broad research questions:

- What are the behavioural effects of reconfiguring different aspects of an OR intervention?
- What is the impact of individual differences on the use of, and perceptions about, OR methods, processes and tools?
- What are the behavioural impacts of model-supported interventions?

Approach I studies explore these questions mostly via experiments or quasi-experiments. A significant proportion of studies in this category explore the effects of reconfiguring different aspects on an intervention by, for example, changing the ways in which models or information are displayed and communicated to users (e.g. Bell & O'Keefe, 1995; Gettinger, Kiesling, Stummer, & Vetschera, 2013), designing different types of model-generated information feedback (e.g. Paich & Sterman, 1993; Quadrat-Ullah, 2014; Sengupta & Abdel-Hamid, 1993), and altering the procedures used to elicit preferences and beliefs (e.g. Cavallo, Ishizaka, Olivieri, & Squillante, 2018; Poyhonen, Vrolijk, & Hamalainen, 2001; von Nitzsch & Weber, 1993). A smaller proportion of studies have also examined the impact of differences in cognitive style or ability on the use and perception of OR methods and tools (e.g. Fasolo & Bana e Costa, 2014; Franco, Rouwette, & Korzilius, 2016; Lu, Yu, & Lu, 2001). Finally, there are some studies whose focus is on establish-

ing the behavioural effects attributed to use of model-driven support, including that embedded within individual or group decision support systems (e.g. Barr & Sharda, 1997; Bhandari, Hassanein, & Deaves, 2008; Pala, Vriens, & Vennix, 2015)

Despite their important and sizeable contribution to the BOR agenda, studies adopting Approach I have their limitations. Due to their reliance on the use of variance methodologies, Approach I studies do not reveal the events, activities or phases through which individual and group behaviour changes when engaging with OR methods, processes and tools. Specifically, they cannot address the important question of how OR-supported activity unfolds over time. Studies that adopt Approach II and Approach III are designed to fill this gap, as discussed in the next two sections.

#### 4.2. Approach II: process studies of determinist behaviour

Approach II studies adopt a process methodology to examine the research questions that Approach I studies cannot. Scholars choosing this approach are often concerned with the following broad research questions:

- How do experts and novices build models?
- How do individuals and groups engage with OR methods, processes and tools?

Studies that address the first question have emphasised the importance of understanding the developmental nature of OR-supported activity (e.g. Franco & Rouwette, 2011), and in particular with how the model building process unfolds over time. This group of studies traces the modelling process through think-aloud protocols generated by expert and novices to identify the stages or cycles of modelling activity and the attentional patterns of modellers (e.g. Tako & Robinson, 2010; Willemain, 1995; Willemain & Powell, 2007). On the other hand, studies that deal with the second question have often sought to reveal the behaviour of users engaged in OR-supported activity. Here, OR scholars typically code and analyse time logs of activity and events, captured through video and computer records, to trace the problem solving and decision making trajectories of individuals and groups (e.g. Chung, Willemain, & O'Keefe, 2000; Gogi, Tako, & Robinson, 2016; Shaw, 2003).

#### 4.3. Approach III: process studies of voluntarist behaviour

Process studies in this category assume that actors have agency to act, typically within focused episodes of OR-supported activity. Two main themes have received empirical attention by OR scholars using this approach:

- How is OR-supported activity enacted by those involved in situ?
- How do actors' interactions with the material and conceptual elements of an OR intervention develop over time?

Studies addressing these questions adopt non-experimental research designs to help produce a narrative that reveals and explains the bidirectional relation between OR-supported activity and actors' behaviour. One of the overriding characteristics of studies examining the first question is their focus on uncovering what actually goes on inside the practice of OR 'as it happens'. These studies move away from post-hoc reflections that are common in the OR literature by closely observing the actual work of those engaged with OR methods, processes and tools, using audio and video recordings as empirical materials (e.g. Franco & Greiffenhagen, 2018; Velez-Castiblanco, Brocklesby, & Midgley, 2016; White et al., 2016). Attention to the second question stems from the recognition that OR interventions in the field are complex endeavours, which has led to studies that have brought a closer focus on, for example, the interplay between agency linked to the material

aspects of OR practice such as models and software, and agency linked to its social aspects (e.g. Franco, 2013; White, 2009); or on the dynamic processes by which the material, conceptual and social aspects of OR practice become temporally intertwined, as well as the effects of this intertwining (e.g. Brocklesby, 2009; Ormerod, 2014).

#### 4.4. Approach IV: variance studies of voluntarist behaviour

Our final group of studies is concerned with testing a theory of the impact of actors' behaviour on an OR intervention throughout time. These are variance studies that assume behaviour can adapt to an OR intervention environment in unexpected ways. The main research question addressed by studies using this approach is:

- What behavioural factors explain the (un)intended use of OR methods, processes and tools?

The small number of studies that address this question highlight the importance of adaptation in the use of OR methods, processes and tools by individuals or groups, which is triggered by their need to achieve satisfactory outcomes (Limayem, Banerjee, & Ma, 2006; Poole, Holmes, & DeSanctis, 1991).

In sum, studies within each of the four approaches offer a partial understanding of how behaviour affects, or is affected by, OR-supported activity. Taken together, the insights produced by studies across all four approaches offer a richer understanding of behavioural phenomena in an intervention context than any one approach can offer by itself. Before discussing the state-of-the-art knowledge that emerges from our review, we briefly outline below relevant behavioural research in cognate areas that provide additional support to our findings.

#### 4.5. Research in cognate areas

Behavioural studies undertaken within the context of model-supported interventions can also be found in specialist domains cognate to OR, such as System Dynamics and Group Decision and Negotiation. Within System Dynamics, there is a long tradition of experimental work concerned with improving learning behaviour. Studies that focus on reducing misperceptions of feedback in dynamic environments (Sternan, 1989) with the assistance of management simulators (microworlds) are good examples of this stream of work, and can be related to the studies categorised as Approach I in this review. These studies show that reducing misperceptions of feedback is possible by changing the type and format of the information generated by the simulator (e.g. Borštnar, Kljajić, Škraba, Kofjač, & Rajković, 2011; Gary & Wood, 2016; Howie, Sy, Ford, & Vicente, 2000; Kopainsky & Sawicka, 2011; Moxnes, 2004; Škraba, Kljajić, & Leskova, 2003).

Similar to System Dynamics, experimental behavioural research is also well-established in Group Decision and Negotiation (e.g. Barkhi & Pirkul, 1999; Beroggi, 2000; Krishnaswamy, Pahuja, & Sundarraj, 2016; Melzer & Schoop, 2016; Škraba, Kljajić, & Borštnar, 2007). Perhaps more interestingly, a small but increasing number of process studies is beginning to appear in this domain, with some studies primarily concerned with tracing decision making trajectories within a group support environment, as in Approach II (Ackermann & Eden, 2011; Ackermann, Eden, & Pyrko, 2016; Filzmoser, Hippmann, & Vetschera, 2016; Griessmair, 2017; Hine, Murphy, Weber, & Kersten, 2009); and others mainly focused on unpacking the ebb-and-flow of group decision support practice, as in Approach III (e.g. Burger, White, & Yearworth, 2018; Franco & Nielsen, 2018; McCardle-Keurentjes & Rouwette, 2018; Tavella & Franco, 2015; Velez-Castiblanco, Londono-Correa, & Naranjo-Rivera, 2018). These studies are

beginning to uncover the micropractices (Ackermann, Yearworth, & White, 2018) that unfold as participants seek to model, manage or negotiate issues within a group decision and negotiation support environment in order to reach a conclusion.

Finally, it is worth noting a parallel stream of behavioural studies within Systems Dynamics that is concerned with evaluating the impacts of group model building (GMB), a System Dynamics approach developed by Vennix (1996) and Richardson and Andersen (1995) to facilitate team learning. With notable exceptions (e.g. McCardle-Keurentjes, Rouwette, Vennix, & Jacobs, 2018), these studies adopt a variance methodology through single or multiple case research designs that involve the use of pre and post intervention self-reported evaluations to assess the impact of real-world GMB interventions on learning and other surrogates of behaviour (e.g. Akkermans & Vennix, 1997; Rouwette, Korzilius, Vennix, & Jacobs, 2011; Scott, Cavana, & Cameron, 2013; Vennix, Akkermans, & Rouwette, 1996). This important body of work is unique in attempting to produce a coherent corpus of empirical evaluation studies of model-supported interventions that has no parallel within OR at present.

Table 4 shows an illustrative sample of studies categorised by approach, research question, underpinning theory, research design, data source, and findings. The full list can be found in the supplementary material.

## 5. Current state-of-the-art knowledge

Having introduced each approach and sampled a few illustrative studies, we discuss in this section the current state-of-the-art knowledge of the BOR field concerned with interventions. Table 5 summarises the knowledge emerging from variance studies (Approaches I and IV), whereas Table 6 outlines knowledge emerging from process studies (Approaches II and III). Where appropriate, knowledge supported by research in cognate OR areas is also included. As the tables show, a set of eight distinct empirically-generated knowledge themes equally split between variance and process studies can be identified, with some but not all studies building upon each other. Furthermore, there are no knowledge themes that cut across variance and process studies (except from variance studies that include a short analysis of process data). Below we discuss this emergent body of knowledge.

### 5.1. Knowledge from variance studies (Approaches I and IV)

#### 5.1.1. Intervention configurations

A sizeable body of knowledge emerges from examining the impact of alternative configurations of one or more elements of an intervention. Here we summarise this knowledge along five main sub-themes: representation formats, information type, weight elicitation procedures, external stimuli, and model building involvement.

As Table 5 highlights, the use of appropriate *model representation formats* can lead to better decisions and negotiations. Representation formats include visualisations or statistical information provided as text, tables or graphs. For example, Huysmans, Dejaeger, Mues, Vanthienen, and Baesens (2011) show that people using different representation formats (e.g. decision tables, decision trees, propositional rules, oblique rules) in credit scoring tasks supported by a model-driven system perform differently in terms of how they interpret, use and prefer these formats. The effects of representation formats are consistent with research in System Dynamics and Group Decision and Negotiation (e.g. Beroggi, 2000; Howie et al., 2000), where there is clear evidence that suitable *visualisations* (e.g. model displays, problem representations) can improve performance in terms of accuracy, understanding, reduction

of bias and, in the case of groups, equality of influence. The underlying reasons for the impact of representation formats are broadly grounded in cognitive fit theory (Vessey, 1991), that is, the identified effects are contingent on the fit between the representation format used, the task at hand, and the purpose of modelling. Overall, this line of research has produced strong evidence that people's behaviour is highly sensitive to the ways in which model-related information is represented and communicated.

The *type of information feedback* generated by models can also affect performance, particularly in dynamic decision-making environments. As found in System Dynamics research (e.g. Gary & Wood, 2016; Moxnes, 2004), there is compelling evidence that, irrespective of environmental complexity, model users provided with cognitive feedback (information about existing relations within the environment) perform best and are more consistent in executing their decision strategies, followed by those provided with feedforward (recipes or rules of thumb for acting in the environment). Model users that only receive outcome feedback (information about the state of the environment after strategy implementation) consistently perform poorly. The studies by Paich and Serman (1993) and Sengupta and Abdel-Hamid (1993) provide illustrative examples of these findings. The main reason for these effects is that particular types of information can enhance or hinder actors' ability to develop better mental models of the environment, which in turn will inform their decision strategies and ultimately, performance (Serman, 1994, 2000). Together with the knowledge about representation formats (see above), there is thus strong evidence that OR should develop model-driven systems that offer a combination of appropriate representation formats and feedback information. For example, a model-driven system that generates cognitive feedback through graphs could be more effective rather than one based on just text (e.g. Sengupta & Abdel-Hamid, 1993).

There is also strong evidence that when dealing with multicriteria decision problems, different *elicitation procedures* yield different attribute weights and lead to rankings that exhibit varying levels of consistency and stability (e.g. Borcherting, Eppel, & Von Winterfeldt, 1991; Pöyhönen & Hämäläinen, 2001; Poyhonen et al., 2001). The way in which weight elicitation procedures are deployed also matters. An earlier study by von Nitzsch and Weber (1993) demonstrated what has now become a well-established fact in multicriteria decision analysis: varying the structure of a value tree leads to different weights, and actors exhibit low sensitivity to changes in attribute ranges. More recently, Lahtinen and Hämäläinen (2016) showed that the use of different paths when deploying the Even Swaps procedure can result in different choices. The reasons for the effects of weight elicitation procedures are not yet fully understood and thus variance-type research in this area continues to attract interest amongst OR scholars.

The study of *external stimuli* designed to bring about particular behaviours in a model-supported environment has produced an important cluster of knowledge. This type of enquiry is not uncommon within System Dynamics, where research has explored the impacts of, for example, setting challenging goals or using wrong models to help actors improve model-supported performance (e.g. Wijnen, Mulder, Alessi, & Bollen, 2015; Yang, Jiang, & Gary, 2016). Within OR, the study of external stimuli has been diverse, including changes to the wording of questions in probability distribution elicitation tasks (Connolly & Dean, 1997), adoption of externally generated objectives as prompts for option generation tasks (Siebert & Keeney, 2015), and the use of incentives when operating a model-driven group decision support system (Barkhi, Jacob, & Pirkul, 2004). Broadly, the knowledge that is emerging suggests that the design and implementation of appropriate external stimuli in model-supported environments can improve performance and communication of expert knowledge and beliefs.



**Table 4**  
Illustrative sample of BOR studies.

Illustrative study	Approach	Research question	Main theory	Data source	Findings
<a href="#">Sengupta and Abdel-Hamid (1993)</a>	I	What are the behavioural effects of reconfiguring different aspects of an OR intervention?	Dynamic decision making (Sterman)	Experimental data collected from masters students completing a dynamic decision task.	Subjects provided with cognitive feedback perform best, followed by those provided with feedforward. Subjects provided with outcome feedback perform poorly.
<a href="#">Lu et al. (2001)</a>	I	What is the impact of individual differences on the use of, and perceptions about, OR methods, processes and tools?	Psychological types (Jung)	Experimental data collected from undergraduate students completing a preference task.	Willingness to use models relies heavily on individual preferences and perceived usefulness. Perceived ease of using models has no direct effect on either individual preferences or willingness to use.
<a href="#">Pala et al. (2015)</a>	I	What are the behavioural impacts of model-supported interventions?	Escalation of commitment (Staw)	Experimental data collected from undergraduate students completing a dynamic decision task.	Causal loop diagrams (CLDs) can help to decrease escalating commitment to a failing course of action.
<a href="#">Waisel, Wallace, and Willemain (2008)</a>	II	How do experts and novices build models?	Epistemology of practice (e.g. Schon, Miser); modelling as problem solving (MacCrimmon & Taylor)	Live recordings of experts' verbal descriptions of their modelling process; collected sketches produced during process.	Sketches are used more when the focus is on model structure or realization than on model context or assessment; sentential sketches tend to be started sooner than diagrammatic ones; sketching begins earlier on more difficult problems.
<a href="#">Gogi et al. (2016)</a>	II	How do individuals and groups engage with OR methods, processes and tools?	Gestalt theory (e.g. Maier; Mayer); cognitive psychology (e.g. Sternberg)	Time logs and number of scenarios run by subjects using simulation model to complete a problem solving task; time when insight is achieved by subjects using model.	Insight emerges after subjects overcome implicitly imposed constraints, and then change their understanding of the cause of the problem.
<a href="#">Velez-Castiblanco et al. (2016)</a>	III	How is OR-supported activity enacted by those involved in situ?	Language games (Wittgenstein); boundary critique (e.g. Midgley);	Audio-recordings of a real-world OR intervention design workshop.	Intervention design is shaped by communications concerning boundary judgements about intervention context and methods.
<a href="#">Ormerod (2014)</a>	III	How do actors' interactions with the material and conceptual elements of an OR intervention develop over time?	Mangle of practice (Pickering)	Data generated from a real-world OR project (e.g. notes, meeting minutes, models); researcher's post hoc reflections.	Progress in OR interventions is linked to a dialectic of resistance and accommodation whose outcome changes one or more aspects of the intervention through a dynamic interweaving (a 'mangling').
<a href="#">Limayen et al. (2006)</a>	IV	What behavioural factors explain (un)intended use of OR methods, processes and tools?	Adaptive structuration theory (DeSanctis & Poole)	Experimental data collected from undergraduate students completing a preference task.	Groups provided with decisional guidance show more faithful appropriation of model-driven systems which, in turn, results in better group outcomes and better perceptions of group processes and outcomes.

There is a small but promising group of BOR studies that are concerned with testing the *high involvement* hypothesis, that is, the notion that involving clients in model building has higher benefits than model building without client involvement (e.g. [Alessi, 2000](#); [Robinson, 2004](#)). For the specific case of discrete event simulation models, the evidence so far suggests that involvement improves problem solving behaviour by enabling model users to consider more variables and a greater variety of scenarios than without involvement (i.e. using pre-built models), at least when time pressure is low ([Monks, Robinson, & Kotiadis, 2014](#)). In addition, involvement enables learning transfer, though mainly for similar problems, but involvement also seems to cause overconfidence that results in errors ([Monks, Robinson, & Kotiadis, 2016](#)).

This result is somewhat in contrast with earlier research suggesting a positive relationship between confidence and accuracy ([Bell & O'Keefe, 1995](#); [Chau & Bell, 1995](#)), which warrants further research.

#### 5.1.2. Individual differences

There is some evidence that individual differences can explain actors' preferences for, and attitudes towards, certain elements of an OR intervention. [Fasolo and Bana e Costa \(2014\)](#) found that individuals with higher numeracy (the ability to work with numbers) express value preferences more easily with numerical techniques and people with higher verbal fluency find value elicitation easier with non-numerical techniques. A study by

**Table 5**

State-of-the-art knowledge from variance studies 1989–2018 (Approaches I and IV).

Knowledge theme	Findings	Contributing studies
Intervention configurations	Use of appropriate model representation formats can lead to better decisions and negotiations.	Bell and O'Keefe (1995); Chau and Bell (1995); Sia, Tan, and Wei (1997); Beroggi et al. (2000); Gettinger et al. (2013); Howie et al. (2000); Huysmans et al. (2011); Tan, Tan, and Teo (2012); Kauffman et al. (2013); Akpan and Brooks (2014); Gogi et al. (2016); Scholz, Franz, and Hinz (2017).
	The type of information provided by models affects actors' performance in dynamic environments.	Paich and Serman (1993); Sengupta and Abdel-Hamid (1993); Skraba et al. (2003); Moxnes (2004); Skraba et al. (2007); Borstnar et al. (2011); Kopainski & Sawicka (2011); Gary and Wood (2016); Kumar and Dutt (2018); Qudrat-Ullah (2014).
	Different weight elicitation procedures, and the way in which they are implemented, yield different attribute weights, and lead to rankings or choices with varying levels of consistency and stability.	Borcherding et al. (1991); Bottomley and Doyle (2001); Buchanan (1994); Cavallo et al. (2018); Ishizaka and Siraj (2018); Ishizaka et al. (2011); Lahtinen and Hämäläinen (2016); Lienert, Duygan, and Zheng (2016); Linares (2009); Pöyhönen and Hämäläinen (2001); Poyhonen et al. (2001); von Nitzsch and Weber (1993); Webber, Apostolou, and Hassell (1996);.
	The use of appropriate external stimuli can improve performance and better communication of expert knowledge and beliefs.	Connolly and Dean (1997); Van Bruggen, Smidts, and Wierenga (1998); Barkhi et al. (1999); Willemain, Wallace, Fleischmann, Waisel, and Ganaway (2003); Hamalainen et al. (2013); Gary and Wood (2016); Siebert and Keeney (2015); Wijnen et al. (2015); Yang et al. (2016).
	Model building with actors' involvement produces higher benefits in terms of experimentation and learning than model building without involvement.	Monks et al. (2014); Monks et al. (2016).
Individual differences	Individual differences have little or no direct impact on the outcomes of, and perceptions about, an OR intervention.	O'Keefe and Pitt (1991); Van Bruggen et al. (1998); Panko and Sprague Jr. (1998); Akpan and Brooks (2014); Fasolo and Bana e Costa (2014); Franco et al. (2016); Gettinger et al. (2013); Liu, Lee, and Chen (2011); Lu et al. (2001); Melzer and Schoop (2016); Robinson and Davies (2010).
Model-driven support impacts	Model-driven support systems embedded with appropriate guidance can improve individual and group performance.	Barkhi et al. (1998); Barr and Sharda (1997); Singh (1998); Barkhi et al. (1999); Barkhi et al. (2004); Bhandari et al. (2008); Chung et al. (2000); Guo and Lim (2012); Huang et al. (2012); Pala et al. (2015).
	Problem structuring tools have little or no direct impact on performance, at least in a laboratory setting.	Joldersma and Roelofs (2004); Cuhna & Morais (2016); McCordle-Keurentjes et al. (2018).
(Un)intended use	The degree of actors' faithful 'appropriation' of model-driven support systems affects outcomes, performance and perceptions of the system.	Limayem et al. (2006); Poole et al. (1991)

**Table 6**

State-of-the-art knowledge from process studies 1989–2018 (Approaches II and III).

Knowledge theme	Findings	Contributing studies
Model building process	Model building seems to follow a complex non-linear sequence of stages. There are clear differences between the model building paths and attentional behaviour exhibited by experts versus novices.	Powell and Willemain (2007); Waisel et al. (2008); Willemain (1995); Willemain & Powell (2007); McHaney, Tako, and Robinson (2018); Tako (2015); Tako and Robinson (2010).
Engagement paths and strategies	Effective model-supported problem structuring follows a relatively linear sequence of stages.	Ackermann and Eden (2011); Massey and Wallace (1996); Papamichail, Alves, French, Yang, and Snowdon (2007); Ackermann et al. (2016).
	Actors tend to adopt distinct problem solving and knowledge sharing strategies when engaging with model-supported processes, and it is possible to distinguish between successful and unsuccessful strategies.	Chung et al. (2000); Gogi et al. (2016); Shaw et al. (2003).
Facilitated modelling practice	While there are differences between the facilitated modelling paths and attentional behaviour exhibited by experts versus novices, they also share some common patterns of behaviour regarding process management and the use of domain knowledge.	Tavella and Papadopoulos (2015a, b).
	OR-supported activity is comprised of cognitive and interactional processes that are rarely neutral and require the competent assembling of discursive (e.g. talk, text) and material (e.g. body, models, software) resources.	Franco and Greiffenhagen (2018); Franco and Nielsen (2018) Burger et al. (2018); McCordle-Keurentjes and Rouwette (2018); Tavella and Franco (2015); Velez-Castiblanco et al. (2016); Velez-Castiblanco et al. (2018); White et al. (2016).
Sociomaterial dynamics	The success of an OR intervention in producing change seems to be heavily dependant on the action possibilities afforded by the intervention, the skilful performance of the OR practitioner, and the behaviour of stakeholders.	Brocklesby (2009); Franco (2013); Ormerod (2014, 2017); Overmeer, Corbett, and Van Wassenhove (1998); White (2009).

Franco et al. (2016) found differences in model use, conflict management and satisfaction between groups with high, as opposed to low, need for cognitive closure (Kruglanski, 2004). However, most studies show that individual differences have little or no direct impact on performance or perceptions. For example, O’Keefe and Pitt (1991) found weak evidence that preferences for display type in a visual interactive simulation environment could be explained by individual differences; Lu et al. (2001) found that cognitive style measured on the thinking – sensation dimension did not have an effect on the perceived ease or usefulness of using computerized multi-attribute decision support systems; and Robinson and Davies (2010) show that differences in educational background have little or no difference on the modellers’ performance in a simulation task. Overall, although the notion that individual differences can have an impact on the effective use of, and perceptions about, OR methods, processes and tools has been suggested by a number of scholars (Benbasat & Dexter, 1982; De Waele, 1978; Franco & Meadows, 2007; O’Keefe, 1989), it is yet to be strongly supported empirically. A possible reason is that individual differences are measured using a wide variety of measures (e.g. cognitive style, cognitive ability, education, experience), which makes the comparison of findings difficult.

### 5.1.3. Model-driven support impacts

There is an extensive decision support systems literature that examines the extent to which individual and group decision support systems can foster individual/group problem solving behaviours that are conducive to high quality decisions. In this review we only focused on those support systems that are model-driven as opposed to technology-driven (Morton, Ackermann, & Belton, 2003; Power & Sharda, 2007). Overall, there is clear evidence that systems containing appropriate model-supported guidance can improve individual and group performance by, for example, reducing biases (Bhandari et al., 2008; Huang et al., 2012; Pala et al., 2015), avoiding coalition formation (Guo & Lim, 2012) or revealing more truthful information (Barkhi et al., 2004; Barkhi, Jacob, Pipino, & Pirkul, 1998). Appropriate model-supported guidance can also increase actors’ performance in implementing strategies, regardless of the complexity of the strategy, by making them less prone to perform unnecessary activities or fail to execute essential planned activities (Singh, 1998). However, it should be noted that whilst model-driven systems can improve performance, such improvement may produce a ‘reliance effect’, namely, actors following the guidance and accepting the recommendations provided by the system without necessarily understanding the problem (Barr & Sharda, 1997). This suggests a strong role for variance research to help understand this phenomenon.

With regard to the impact of model-driven support in a problem structuring context, empirical knowledge is scarce. In the only two variance studies of problem structuring we identified in our corpus, the impacts reported were rather modest. Both Joldersma and Roelofs (2004) and Cunha and Morais (2016) found hardly any positive effects of the problem-structuring method used (causal/cognitive mapping). System Dynamics researchers have also reported modest impacts for problem structuring approaches (e.g. McCardle-Keurentjes et al., 2018). We conclude that the knowledge that is emerging indicates little or no direct impact of model-supported problem structuring on group performance, at least in a laboratory setting. Clearly, more research is needed before reaching firm conclusions.

### 5.1.4. (Un)intended use

The notion of ‘appropriation’ is well-established within studies that view technology as a set of structures whose effects on behaviour is moderated by social interactions (e.g. Barley,

1986; Orlikowski, 1992). According to Adaptive Structuration Theory DeSanctis & Poole (1994), individuals and groups can appropriate the structures of a technology as intended by its designers (i.e. a ‘faithful’ appropriation) or against their intentions (i.e. an ‘ironic’ appropriation). This is clearly relevant for the study of model-driven support technologies such as those employed in OR. However, there are only few variance studies that have used this empirical lens to examine behaviour. Of those we surveyed, the findings suggest that the degree of actors’ faithful ‘appropriation’ of a model-driven support system affects outcomes, performance and perceptions of the system (Limayem et al., 2006; Poole et al., 1991).

## 5.2. Knowledge from process studies (Approaches II and III)

### 5.2.1. Model-building

As Table 6 indicates, there is increasing evidence that model building follows a sequence of stages, with most modellers adopting complex non-linear paths, often recycling to previous stages, and showing varying levels of attention to particular modelling stages. In addition, there are clear differences between the model building paths and attentional behaviour exhibited by expert versus novice modellers. These process studies are descriptive rather than prescriptive, and yet the implications of the findings of expert and novice studies for OR teaching and training are obvious. If we want to develop novices into competent modellers, it is important to design procedures to counter inefficient modelling behaviours and also learn from experts’ modelling practices. Clearly expert modellers differ in their practices, but the studies also suggest the existence of modelling styles that need to be codified. This suggests a strong role for more process research to extend our understanding of the differences between experts and novices with regards to model building.

### 5.2.2. Engagement paths and strategies

Effective model-supported problem structuring follows a relatively linear sequence of phases. This is consistent with the classic unitary sequence model of group decision making (Ellis & Fisher 1993). For self-facilitated groups, building a group model and arriving at a group problem definition is preceded by the elicitation and exploration of group members’ perspectives and/or models. Group Decision and Negotiation research also identifies this linear pattern for facilitated, computer-supported group problem structuring, with group members moving gradually from an initial focus on their own contributions and preferences to attention to the contributions and preferences of others, before integrating their views and producing a group problem definition (Ackermann & Eden, 2011; Ackermann et al., 2016). These results are consistent with the notion of behaviour being guided by a structured process that has been faithfully appropriated by group members (see Section 5.1.6). They are also consistent with process theories based on a teleological model of change (cf. Van de Ven & Poole, 1995), which views the group as an entity that engages in “reflexively monitored action to socially construct and cognitively share a common end state or goal” (p.525).

Some process studies go beyond tracing the ebb-and-flow of model-supported interaction to reveal the problem solving and knowledge sharing strategies that actors use when engaging with model-supported process. Furthermore, these studies are beginning to distinguish successful from unsuccessful strategies. For example, we have learned that there are actors who pay more attention to develop an optimal problem solving approach rather than to computing an optimal solution (Chung et al., 2000). We have also learned that actors can share knowledge with different levels of complexity (Shaw, 2003), and that achieving insight about a

problem is only possible when actors overcome self-imposed constraints (Gogi et al., 2016). The reasons for these observed effects are varied, from the specific features of the model-driven support system used to the particular characteristics of those using the system (but see Section 5.1.4). This knowledge is just beginning to emerge and thus it is still at a speculative stage.

### 5.2.3. Facilitated modelling practice

Similar to the knowledge emerging from model building studies (see Section 5.2.1), there are also differences between the facilitated modelling paths and attentional behaviour exhibited by experts and novices. Compared to novices, expert facilitators mainly focus on, and transit between, structuring and assessing the model by ‘active listening’ and ‘asking the right questions’. However, expert and novice facilitators also share common patterns of behaviour involving process management (e.g. active listening) and the use of domain knowledge where appropriate. The use of scripts by novices has been used to explain these common patterns. There is also an increasing number of process studies that look at wider aspects of facilitated modelling practice *in situ*. The common conclusion emerging from these studies is the notion that facilitated modelling activity is comprised of cognitive and interactional processes that are rarely neutral, and that they require the competent assembling of discursive (e.g. talk, text) and material (e.g. body, models, software) resources. Group Decision and Negotiation research consistently supports this conclusion (e.g. Burger et al., 2018; McCardle-Keurentjes & Rouwette, 2018; Tavella & Franco, 2015). Process explanations for these empirical observations are varied and rooted in a range of theoretical domains (e.g. ethnomethodology, cognitive psychology, embodied affectivity), but have the potential to codify effective *in situ* facilitated modelling practices.

### 5.2.4. Sociomaterial dynamics

The emergent knowledge generated by a few process studies is based on the use of theories to guide empirical observations in order to build a theoretical narrative that further specifies the theories (see Section 3.2). Thus we have learned that OR interventions in the field involve complex social and material micro-practices that enable iteration and adaption (White, 2009). Furthermore, we have learned that the deployment of OR interventions is loaded with contingency, and its success in generating behavioural change is heavily dependant on the action possibilities afforded by the intervention (material agency), and the skilful performance of the OR practitioner along with the behaviour of stakeholders (human/social agency) (Overmeer et al., 1998; Brocklesby, 2009; Franco, 2013; Ormerod, 2014, 2017).

Taken altogether, the knowledge generated by variance and process studies is significant. It should be noted that the relatively large proportion of studies adopting a variance methodology is not unexpected given the nature of our field. However, concerns have been raised about the robustness of variance research within BOR (e.g. O’Keefe, 2016), and thus more work is needed to improve the design of this type of enquiry. In addition, whilst there are areas that continue to attract the attention of BOR scholars, there are others that remain untapped or have just began to be explored empirically. These and other related issues are discussed next.

## 6. Future directions

Following our review, below we propose ten potentially useful avenues of future work to advance the BOR agenda concerned with interventions. Some of these represent extensions of current work, whereas others focus on developing new research. For several topics, we also discuss methodological issues with a view to improving future variance and process studies.

Before we outline our suggested agenda, we should highlight a couple of important issues. Firstly, we underline the role of theory in the programme of work we are proposing below. Without proper theories, it would be challenging for variance studies to explore mechanisms underpinning behavioural processes. Similarly, drawing lessons for OR practice from observed behavioural processes would be difficult without a guiding theory. The theories informing, or emerging from, the studies we reviewed here were not always stated explicitly. We believe that generalisation of findings would be facilitated if both variance and process studies show explicit concern for theory and theory building. Secondly, we note that although the programme or work outlined below seems at first glance aligned with either variance or process approaches, we believe that it is possible to study the same topics using several approaches simultaneously. Indeed, there are a few variance studies reviewed here that have included some process analysis, although we have not seen process studies that included variance-type analysis. By combining multiple approaches in a single study, stronger generalisations can be achieved, which is well worth considering when planning future studies.

### 6.1. Representation formats in problem structuring

The literature already offers an extensive body of experimental evidence about the impact of model representation formats on performance and behaviour. A potentially useful extension of this work would be to focus on the impact of new media. Indeed, due to very rapidly developing technologies, new ways of presenting information are emerging all the time and today we could even embed actors in a virtual reality context. It should also be noted that no variance studies included here have looked at the impact of model representation formats within a *problem structuring* context. This is somewhat surprising, as the use of visuals and text formats is critical to problem structuring methods (Rosenhead & Mingers, 2001). This suggests a strong role for variance research in this area. Researchers interested in pursuing this avenue can find relevant work in other domains such as organisational behaviour and decision making (e.g. Atkins, Wood, & Rutgers, 2002; Butler & Scherer, 1997; Ofir, 2000).

### 6.2. Model-generated information for groups

There is also compelling evidence about the role and impact of model-generated information feedback on behaviour and performance. For example, we already know that outcome feedback is generally not enough to improve learning behaviour in individuals, and that individuals benefit most when they are provided with model-generated cognitive feedback. However, in the corpus of studies reviewed here, there is little work concerned with *group* learning behaviour and performance, and extending variance research on information type to a group context would thus represent a useful line of future work. Such research can be informed by research in System Dynamics and Group Decision and Negotiation (e.g. Borštnar et al., 2011; Škraba et al., 2003).

### 6.3. Convergence and consistency in preference and priority elicitations

As already noted, the observed instability of priorities and preferences associated with the use of different weight elicitation methods has been studied extensively. Given that these empirical observations are still not fully explained, this continues to be a fruitful area for future work. In particular, studies such as the one by Lahtinen and Hämäläinen (2016) shed light on the impact that different ways of deploying elicitation methods have on priorities and preferences.



It should also be noted that the differences in weights, rankings, or choices produced by elicitation methods take second place when compared with holistic judgments made before using the methods: there is increasing experimental evidence that people are able to reconcile the discrepancies between their pre-method judgments with those produced by the methods, which in turn increases their confidence in the results (Ishizaka & Siraj, 2018; Ishizaka, Balkenborg, & Kaplan, 2011). However, post-decisional confidence is a well-known bias (Snizek, Paese, & Switzer, 1990) and thus further research can help clarify its role in the context of using weight elicitation procedures.

#### 6.4. Developing a typology of external stimuli

A few studies have considered the impact of a range of external stimuli on behaviour and performance (see Section 5.1.1). We have also noted similar work within System Dynamics and Group Decision and Negotiation domains (e.g. Barkhi & Pirkul, 1999; Yang et al., 2016). The potential outcome of this line of work would be a typology of stimuli that could be used for effective OR intervention design and deployment. The use of external stimuli in behavioural research is common in the social sciences (e.g. Baldassarri & Abascal, 2017; Kamenica, 2012; Thaler & Sunstein, 2008), and BOR studies can learn from this type of research and develop ideas appropriate to a model-supported context.

#### 6.5. Model building involvement, model reuse, and learning

A couple of studies have shown that getting involved in building simulation models is more effective than reusing a pre-built model in terms of transfer of learning. The impacts reported are rather modest, however, and model building involvement can lead to overconfidence. There is certainly scope for testing these findings with more and bigger samples, more complex problems, and subjects who are not students. This research can also be extended to other modelling contexts where involvement in model building and the use of pre-built model templates or archetypes are common practice, as in the case of Decision Analysis (e.g. Phillips, 2007; Von Winterfeldt & Fasolo, 2009) and System Dynamics (e.g. Vennix, 1996; Wolstenholme, 2003).

#### 6.6. Problem structuring methods and behavioural change

A common claim about the use of problem structuring methods is that they change behaviour through the development of increased understanding, consensus and commitment. Yet we only identified two variance studies in our corpus that explicitly examined the impact of a problem structuring tool, and these studies reported very modest impacts. It should be noted, however, that these studies involved very small samples so firm conclusions cannot be reached. The scarcity of variance research in this area is perhaps not surprising, given the rejection of the experimental approach by a problem structuring community that always favoured a case study or action research strategy for testing impacts (Eden, 1995; Finlay, 1998). However, a case study strategy is problematic because findings are difficult to generalise - but see attempts to produce empirical knowledge from case study research by System Dynamic scholars (e.g. Rouwette et al., 2011; Rouwette, Vennix, & Van Mullekom, 2002; Scott et al., 2013). Similarly, an action research strategy is challenging because it requires a long-term programme of work involving a significant number of case studies (Eden & Huxham, 1996; Huxham & Vangen, 2003). We argue that variance research has a significant role to play in examining the behavioural impacts of problem structuring methods because experimental findings can inform case study and action

research designs, and findings from case study and action research programmes can also inform variance research studies.

#### 6.7. Progressing the debiasing agenda

The corpus reviewed here offers some evidence about the debiasing effects of OR interventions activities. For example, we know that it is possible to reduce escalation of commitment (Pala et al., 2015), outcome bias (Kaufmann, Weber, & Haisley, 2013), and confirmation bias (Huang et al., 2012). However, there is still potential to extend this type of work, and here we suggest two needed clarifications before progressing this research agenda. Firstly, we need to clarify the terminology used to distinguish between heuristics and the biases that arise from applying them. A good example is anchoring and adjustment: when carrying out estimations we anchor on a quantity and then make an adjustment (a heuristic), but often this adjustment is insufficient, resulting in an estimation too close to the original anchor (a bias). Such a distinction would help us better understand the behavioural mechanisms that explain the debiasing potential of OR interventions activity.

Secondly, we need to distinguish the biases that matter in an OR intervention context from those that do not. The work initiated by Montibeller and von Winterfeldt (2015) is an important first step in this direction. Establishing the debiasing impact of particular OR methods and tools, as well as developing and incorporating new debiasing procedures are certainly important for OR practice. In addition, as noted by Barr and Sharda (1997), regular use of model-driven support can produce over-reliance effects that could trigger biases, and this aspect could also be investigated further.

#### 6.8. Clarifying the role and impact of individual differences

When the focus is on behaviour, one would expect a strong interest in studying the effects produced by individual differences. Yet the number of studies reviewed with this focus was small and, perhaps surprisingly, their results show little or no impact. One possible reason is the variety of measures used to study individual differences. We certainly need more studies around the impact of demographics (e.g. gender, nationality) and background (e.g. expertise, education, role). We also need more studies about cognitive abilities and style. With respect to cognitive abilities, we should note that earlier research findings in this area may have become outdated. It does not seem too far-fetched to assume that younger generations have improved cognitive skills due to living in today's much more versatile and media-rich world than that in which people lived before.

As to the study of cognitive styles, we should note that the few studies we surveyed used cognitive style constructs (e.g. Myers Briggs Type Indicator) that are no longer considered robust given the emergence of dual process theories of cognition (Chaiken & Trope, 1999; Epstein, Pacini, Denes-Raj, & Heier, 1996). Such theories pose that individuals think about problems by adopting analytic and intuitive processes that operate in parallel, as opposed to the unimodal assumption that one of these processes dominates the other. Thus, cognitive style measurements based on dual process theories are likely to provide a more appropriate basis for estimating effects of individual differences across BOR studies. Furthermore, the recent emergence of new psycho-physical measurement techniques opens up new ways to study the impact of individual differences in different settings (e.g. Leppänen, Hämäläinen, Saarinen, & Viinikainen, 2018). Insights from these studies will help BOR scholars gain a better understanding of individual differences that matter, enabling them to develop tailored procedures to ensure that their interventions (in the field, the lab, or the classroom) achieve their intended purpose.

### 6.9. Developmental aspects of OR-supported activity

Process studies have brought to light developmental aspects of OR-supported activity (Franco & Rouwette, 2011) that have largely passed unnoticed in the mainstream literature. In this sense, they have therefore extended the behavioural research agenda adopted by variance studies and revealed the ebb-and-flow of OR-supported activity. We have learned how experts and novices build models and facilitate groups, and about the problem-solving strategies and trajectories of model users engaged in OR-supported activity. There is clearly a case for continuing this line of work in order to codify what does and does not work well and use that knowledge for OR training and education.

In addition, and notwithstanding the insights that can be gained by research into individual differences (see above), perhaps it would be simpler to find ways to improve OR practice so that the impact of individual characteristics becomes less critical. Specifically, there remains a clear need for more process studies to identify modelling and interaction procedures that would follow paths on which individual differences would not matter - e.g. see Lahtinen, Hämäläinen, and Jenytin (2019) for a recent paper in this direction. Ideally the comparison and testing of these new procedures is performed in real-world applications. This will be very challenging, as repeating problem-solving processes in real situations and by real problem owners will not be easy. However, conducting designed experiments in the field is not impossible, as demonstrated elsewhere (e.g. Herrera, McCardle-Keurentjes, & Videira, 2016).

### 6.10. Voluntarist behaviour in model-supported processes

Finally, most BOR scholars are concerned with understanding the factors that shape the behaviour of individual and groups engaged in model-supported problem solving. A very small proportion of studies are beginning to show that these factors are not fully deterministic. Indeed, both variance and process studies that consider behaviour as voluntarist highlight the extent to which individuals and groups can adapt OR-supported activity to suit their needs in unexpected ways (e.g. Franco, 2013; Franco et al., 2016; Poole et al., 1991). These studies also bring to light the interactional and non-neutral nature of OR-supported activity, in which the agency of actors (e.g. clients, analysts, facilitators, model users) and 'non-actors' (e.g. models, text, language, software) play a mutually reinforcing role (Franco & Greiffenhagen, 2018; Ormerod, 2014; Velez-Castiblanco et al., 2016; White et al., 2016). The implications for training and the role of the OR expert are clear: without proper training or guidance in situ, individuals and groups may end up using OR methods, processes and tools in ways that are opposite to their intended design. Whether this is a good or a bad thing remains an empirical question, and thus more variance and process research is needed in this area. In addition to controlled studies, research in field settings that have not yet received much attention such as elicitation sessions (e.g. interviews, workshops), team meetings, presentations, and entire OR projects would particularly help to build our understanding of behavioural issues in actually deploying OR-supported activity.

## 7. Conclusion

This is the first systematic attempt at reviewing empirical research that examines behavioural phenomena within the context of OR interventions. Unlike research that focuses exclusively on developing and testing models of behaviour, we were concerned here within unpacking behavioural issues associated with OR-supported activity designed to cause change that leads to action in laboratory and field settings. This is not to say that behavioural mod-

els are not important or useful. Indeed, the insights generated by these models can be used to feed into the design of the type of studies we have reviewed here. Furthermore, by paying attention to OR interventions we draw clear boundaries with work in areas such as Behavioural Operations, Behavioural Finance, and Behavioural Economics that, with notable exemptions (e.g. Thaler & Sunstein, 2008), are more concerned with highlighting human flaws in decision making processes than with causing change and action through designed interventions.

Our assessment of the relevant literature spanning the past 30 years has produced a first overview of the current state-of-the-art of the BOR field concerned with interventions. Using a systematic search strategy (see appendix), we were able to categorize BOR studies by the approach adopted to study behavioural phenomena in an OR intervention context. Each of the four approaches identified here is distinct in the assumptions it makes about behaviour (determinist, voluntarist) and the research methodology (variance, process) it uses to conduct a study. Furthermore, studies within each approach address different research questions and thus only provide partial understandings of behavioural phenomena. However, taken together, studies across the four approaches offer complementary views of complex behavioural mechanisms that affect, or are affected by OR-supported activity.

Given the different approaches that can be adopted to examine behaviour in an OR intervention context it should be apparent that there is no one correct way of conducting a BOR study (there are many bad ways of conducting a study though!). In addition, even though the highest proportion of studies reviewed here were variance studies, we should refrain from the temptation to associate BOR with a variance approach. The typology articulated here has highlighted the important contribution that the process approach is beginning to make within BOR. However, OR scholars considering a process approach need to be aware of the level of effort required. As Franco and Rouwette (2011) note, process studies can be quite resource intensive and thus we suggest that such studies are undertaken by a team of researchers rather than individuals. Furthermore, a team of researchers would be a stronger position to combine more than one approach within a single study to generate a more holistic appreciation of complex behavioural phenomena.

We set out ten potentially fruitful directions for furthering the BOR agenda concerned with interventions. This agenda implies special challenges for BOR scholars. It is demanding to unpack empirically the behavioural mechanisms affecting, or triggered by, designed OR interventions. It is hard to study behaviour without drawing on formal behavioural theories. It is difficult to develop a macro-level understanding of behavioural phenomena associated with OR interventions while studying micro-level behaviours. Yet the rewards of meeting these challenges are significant for improving the practice of our profession and, as demonstrated in the studies we presented here, there are multiple ways to address these challenges.

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The responsibility for presenting the arguments in this way is, however, entirely ours.

### Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:[10.1016/j.ejor.2020.11.031](https://doi.org/10.1016/j.ejor.2020.11.031).

### Appendix: Search strategy and results

Our systematic literature search consisted of two stages. In the first stage, we searched the Elsevier Scopus database using search queries tailored to each approach in the typology. Each search query contained Boolean statements to limit the search to the journals and years as specified in the paper. The specific terms (such as 'behavioural' or 'intervention') were searched from the title, abstract, or author-provided keyword fields. We also used specific terms to screen out certain papers (such as those with 'computational experiments'). The search query strings are presented in [Table A1](#) below.

Explanation:

- Each query consisted of a search to titles, abstracts and author-provided keywords combining the lists of terms in the columns.
- Search terms 1–3 were combined with Boolean AND statements and exclusion terms were joined to the search query with AND NOT statement.

- As an example, a paper with words 'behaviour', 'influence' and 'emergence' would be captured into Approach IV, but only if it did not include the word 'computational'.

This first stage of the search identified a total of 4677 studies for further analysis. We then reviewed each study and determined whether or not the study should be included in the typology. Because there were duplicates (papers that appeared in two or more typologies), we re-evaluated the category in which a study should be allocated. Disagreements were resolved through discussions between the four authors. The search also served to identify and separate studies whose focus was on developing models of behaviour, as opposed to studying human behaviour within the context of an OR intervention (as defined above).

In the second stage of the search we aimed to find papers that were cited by the papers identified in the first stage ('backward citations'), as well as papers that cited the papers identified in the first stage ('forward citations'), limiting to the range of years and journals as specified above. This stage was needed to make sure that we did not miss any relevant papers from our review. We used Google Scholar to identify the forward citations. Then we reviewed and classified all the papers in a similar manner as in the first stage. At the end of the second stage, the final list of empirical studies consisted of 79 papers, 36 of which were from the original search and 43 from the additional backward/forward citations searches.

**Table A1**  
Search query strings used in the survey.

Approach	Search terms 1	Search terms 2	Search terms 3	Exclusion terms
I	intervention OR cognitive OR ability OR bias OR expert OR novice OR behavio* OR actor	change OR impact OR influence OR difference OR effect		optimal* OR programming OR algorithm* OR computational
II	intervention OR cognitive OR ability OR bias OR expert OR novice OR behavio* OR actor	longitudinal OR development OR dependen* OR path OR sequence OR phase OR cycle OR stage OR typology OR practice		optimal* OR programming OR algorithm* OR computational
III	behavio* OR actor OR intervention OR workshop	longitudinal OR development OR pattern OR structuration OR appropriation OR adapt* OR adopt* OR network OR activity OR material OR object OR affordance OR micro OR facilitat* OR consultant OR client OR practice		optimal* OR programming OR algorithm* OR computational
IV	behavio* OR actor OR intervention OR cognitive	change OR impact OR influence OR difference OR effect	emergence OR longitudinal OR development OR pattern OR appropriation OR adapt* OR adopt* OR network	optimal* OR programming OR algorithm* OR computational

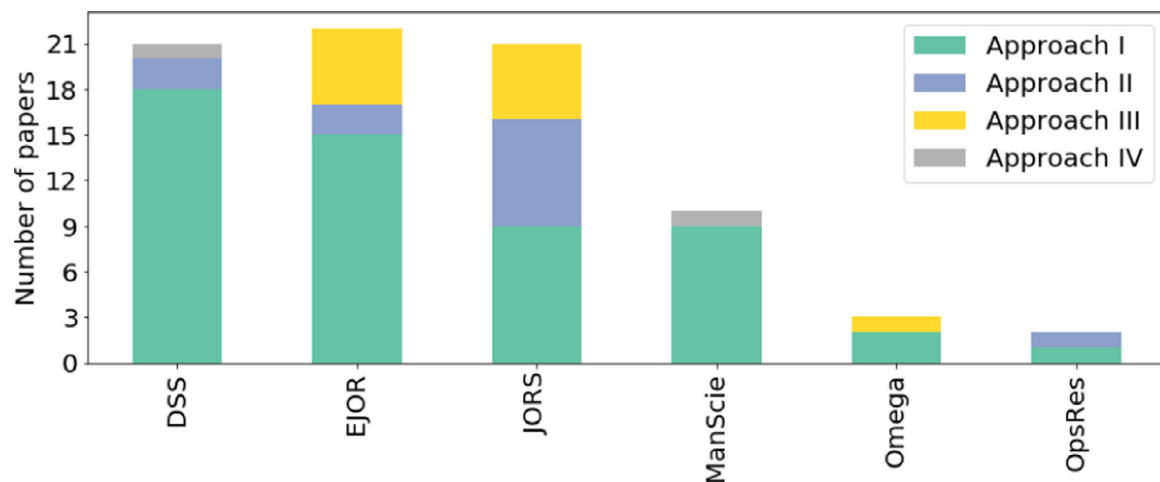


Fig. A1. Number of papers in each approach by journal.

We all read the selected studies and checked each other's understanding and interpretation of them. As shown in Table 3a, most of the studies were found in DSS, EJOR, and JORS.

The rate of published OR intervention studies with a behavioural focus has been changing over the past 30 years. Whilst the number of publications in technology-focused journals (such as *Decision Support Systems*) has remained relatively stable throughout the period, our results show a decreasing trend in journals that are general in scope (such as *Management Science*) but an upward trend in journals that focus exclusively on OR (such as *European Journal of Operational Research*). The former can be linked to a gradual shift towards publications that examine behavioural issues via formal modelling; the latter is consistent with recent calls concerning the importance of re-assessing the role and impact of human behaviour in OR practice (e.g. Franco & Hämäläinen, 2016; Hämäläinen et al., 2013). Studies that adopt a variance approach represent the largest group of publications across all the journals surveyed.

A citation analysis using Google Scholar revealed 5433 citations of the 79 studies. The median number of citations per study was 38. As older studies are more likely on average to have larger citation counts than more recent ones, we also calculated the number of citations per number of years out for each study. There were on average 6.85 (standard deviation=9.43) citations per year.

As shown in Fig. A1, by far the greatest percentage of articles published (68%) were variance studies of determinist behaviour (Approach I). By comparison, only 15%, 14% and 3% of all the remaining articles were process studies of determinist behaviour (Approach II), process studies of voluntarist behaviour (Approach III), and variance studies of voluntarist behaviour (Approach IV), respectively. Overall, process studies (Approach II and Approach III) are more prominent in what some may considered broadly 'European' journals (such as *Journal of the Operational Research Society* and *European Journal of Operational Research*).

In total there were 187 authors in the 79 papers. The top authors in terms of number of papers in our list were Willemain, Hämäläinen, Robinson and Tako who each appeared as authors in 4 papers. The authors in our sample were affiliated in 26 different countries. The top countries were United Kingdom (42 authors), United States of America (38 authors), Germany (8 authors), Taiwan (6 authors), and Netherlands and Canada (both 5 authors).

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