Understanding PSM Interventions Through Sense-Making and the Mangle of Practice Lens

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Abstract. In this paper we seek to understand how individuals, as part of a group facilitated modelling setting, commit themselves to a set of actions, as a basis of sense-making, sense-giving and coordinated actions. For this we introduce Pickering's Mangle of Practice to understand the practice of a group facilitated modelling setting. Using video data from a group modelling building exercise, we analyze how individual actors framed their circumstances in communication with one another and how through facilitated model building this affected their subsequent interpretation and decisions as the process unfolds. We show how, through the models as objects enhanced the interaction between verbal communication, expressed and felt emotion and material cues led to collective behavior within the group. With our study we extend prior research and elaborate on the role of objects and materiality as part of group decision making.

Keywords: Group decision making · Problem structuring methods · Sense-making · The mangle · Collective behavior

1 Introduction

Understanding the impact of PSM interventions is problematic because they are complex settings involving the interaction of actors and modelling devices [1]. Specifically, since a great deal of OR interventions are one-off and temporary, it becomes necessary to devise techniques to ensure an appropriate evaluation of the efficacy of the approaches [2, 3].

In this paper, we introduce and explore the use the use of sense-making and sense giving as one means to study interventions as complex interactions of people, models and context. We take as our example a case study on the participatory planning of Smart City experiments for energy efficient city district redevelopment. We apply PSMs in the case, but we are faced with the question: Is there a means for understanding how individuals working together perform effectively as an ensemble? As with all PSM methods the process of the intervention is conducted in a group, where the process is consultative and iterative. Behaviorally, the process provides a succession of models delivering different perspectives, which contribute to a deepening understanding of the problem as new insight emerges. Also, the process uses the sense

of unease among the problem owners about the present representation of the problem as a signal that further modelling may be needed. However, the idea that PSMs and their models can mediate behavior within groups is not a new idea. This has been acknowledged to some degree, for example by [4] who suggested that models in soft OR represents a facilitative device. Also, Franco and Montibeller [5] discuss models as boundary objects. However, these are examples of a loose coupling of models and the actual situation and therefore it is difficult to infer any theory of behavior through representation. Recently, Ackermann and Eden [6] suggested that the PSM is a process of collective sharing, understanding, and negotiation. They explored this via principles suggested by Fisher and Ury [7], and show how PSMs enable cognitive and social negotiation. We build on this research and suggest a sense-making approach may be appropriate.

Addressing how sense-making and structuring shape the outcome of a PSM intervention is important because we will be better able to understand the processes of PSMs. In doing so, our aim is to understand why attempts to enact PSM interventions often fail to bring about desired results or rarely lead to the substantive claims that are intended, but in many cases lead to unintended outcomes. We draw on the Mangle of Practice (henceforth called the Mangle) proposed by Ormerod [8] and based on Pickering [9, 10]) to conceptualize the interactions within a PSM intervention, and thus we explore the multi-dimensional nature of PSM interventions.

Thus, our paper makes the following contributions. First, we build on recent interest in behavior and OR, as a means for understanding how individuals working together perform effectively as an ensemble through the mediating role of the model. Second, we contribute to the literature on methods to evaluate the process of OR, by employing the concepts from the Mangle [9, 10]) to explain the complex outcomes of (collective) OR processes, namely extended learning. Finally, many scholars of OR will agree that the nature of the link between OR processes and outcomes has yet to be definitively proven. In our paper we test the idea that OR interventions creates the conditions for collective behavior evidenced through a sense-making approach [6, 11].

2   Theoretical Considerations

Over the last 20 years or so, OR scholars have devoted significant attention to understanding processes that shape interventions [4]. In this context, PSM interventions may be conceptualized as creating small scale test beds for understanding how better collective decision-making may arise. An increasing interest in gaining access to understanding the dynamics of PSM interventions in situ has led to important insights regarding theory, behavior and outcomes pertaining to (particularly soft) OR processes [2, 3, 12, 13]. However, significant methodological and epistemological challenges remain in the study of OR interventions [3, 14].

Relatedly, scholars have examined how the importance of a theory driven approach helps to understand how patterns of interactions shape the PSM process [3, 15]. This line of research acknowledges that actors through sense-making shape the interactions which in turn shape the structuring of the problem and so on, but there remain two important gaps. First, existing studies have focused on actors' individual characteristics

[16] and, in doing so, have not examined how the group setting shape sense-making and structuring. Second, studies have neglected the multidimensional and interactive nature of PSMs' contexts, typically examining only single dimensions such as group membership. Hence the richness and importance of the interactions remains largely empirically unexplored and under-theorized. To help address these gaps we draw on sense-making concepts and employ Pickering's notion of the Mangle to understand the sense-making structuring cycle in PSM interventions.

2.1   Sense-Making

The concept of sense-making and sense-giving derive from Weick's work [17], with numerous scholars highlighting they are key elements of the problem structuring process (e.g. [3, 6, 15]). Sense-making is the primary site where meanings materialize to inform, and constrain identity and action [17]. It is described as a process which is 'retrospective, social, on-going, and driven by plausibility' [17]. In contrast, sense-giving, a sense-making variant (Weick et al., 2005), involves attempts to influence the sense-making and meaning construction of others towards a preferred re-definition of reality [18, 19]. As such, we suggest that sense-making and sense-giving are concepts central to PSM interventions, particularly in the face of increased complexity, ambiguity and uncertainty that contemporary organizations face, where the need to create and maintain coherent understandings that sustain relationships and enable collective action is especially important and challenging [17].

Weick [17] argues that sense-making and sense-giving are important in any context where there is a need to create and maintain coherent understandings that sustain relationships and enable collective action. Similarly, Maitlis and Lawrence [19] suggest that sense-making and sense-giving are triggered in a broad range of contexts, particularly in environments characterized by uncertainty and complexity, and where issues are deemed to be significant to stakeholders. Therefore, the need for sense-making, and hence the potential for sense-giving, is often heightened under conditions of equivocality [17]. In line with this, we examine the process shaping of a PSM intervention drawing on a case where models were used to increase the group's sense-making. We highlight that the literature is cognitive in orientation, in that on the one hand, through sense-giving efforts, formal group members can work to enact shared meaning to other group members as a basis for organized action [20]. And on the other hand, recipients of sense-making activities do not merely accept new ideas, rather they interpret them through their existing cognitive frames [21].

Sense-making is not to studying OR interventions [6]. In their earlier work, Eden and Ackermann provided guidance on how to explore the relationship between users' sense-making and the negotiation by organizational members drawing on cognitive mapping [22]. Cognitive mapping was a useful approach for eliciting and clarifying users' sensemaking in negotiation [23]). Recently, within a communication frame, Franco [15] perceived structuring as a process of sense-making framework in a cyclical pattern indicating a loop where, as the problem is being structured, participating individuals engage in the sense-making of the problem, and as the change in their understanding is achieved, individuals engage in further structuring. The result of the

cyclical pattern of structuring and sense-making is an agreed accommodation of an understanding of the problem. We regard this as sense-making in the first order. While important, it does not entirely lead us to critically and analytically understand the processes at play in how accommodation is reached. Thus we introduce the Mangle as a socio-cultural learning theory to understand sense-making in the second order.

2.2 Pickering's The Mangle

Ormerod has brought to the attention of the OR community Pickering's theoretical work on the 'Mangle of Practice' [8–10] Following Ormerod's interpretation, Pickering's contribution was to move beyond the representational idiom of understanding 'science-as-knowledge' towards an explanation of scientific practice and culture using a 'performative idiom'. Developed from Latour's Actor Network Theory (ANT) [24] this new idiom does not disregard science-as-knowledge but enhances this perspective with an understanding of science as "*the field of powers, capacities, and performances situated in machinic captures of material agencies*" [10]. Whilst Pickering was primarily concerned with moving the sociology of scientific knowledge (SSK) to a new theoretical foundation, Ormerod's insight was to see that the Mangle was equally applicable to understanding OR interventions. What then is the Mangle, this performative idiom, and how does it apply to improving our understanding of OR interventions?

The Mangle describes the constant interplay between material and human agency. Pickering's break with pure ANT was the recognition that human agency and material agency are not equivalent things, that human agency is imbued with purpose, whereas material agency is not so; "*Human intentionality…appears to have no counterpart in the material realm*" [10]. This break in symmetry opens up an interpretation of scientific endeavor as the constant drive, the human purpose of science, to wrest knowledge from material whose intrinsic agency can be viewed as resistance to our attempts, the "*dance of agency*" [10]. The Mangle is not about the knowledge that we gain, although this is the ultimate purpose of science, but the *narrative* of the struggle to arrive at that knowledge. The Mangle is a wonderfully descriptive term for this.

Ormerod picks up on this narrative element and reminds us that the practice of 'normal' scientific publishing, including OR, discourages practitioners from writing about the trials and labors to obtain results. Our outputs are generally sanitized accounts of methodology and results. Ormerod's thesis is that the OR practitioner can learn more by reading about the details of how other practitioners obtained their results. His conclusion is a plea for "*more informative case studies of 'technical' projects*". Thus as OR practitioners we should be just as concerned with the analyses of the *process of OR* as in the results of the actual interventions. Perhaps more so since we use OR in the realm of 'wicked problems' [25] or 'messy ones' [26] such as in the case we analyze.

We thus suggest that in order to understand the effectiveness of PSM interventions in the realm of tackling 'wicked problems' it is necessary to gain a deeper understanding of the dynamics of the sense-making processes in groups [15, 17]. More specifically, a critical examination of "sense-making [as] mental activity which involves the interpretation and understanding of [problem structuring as an articulating

framework], and the actions that seem to be suggested by it, mean for an individual in relation to the world in which he/she acts" [15]. We propose sense-making to study the micro processes that form the evolving shape of the collective PSM intervention, which following Pickering we regard as a *narrative* of the struggle to arrive at that knowledge and to sustain the affective aspects of an intervention.

The Mangle provides a theoretical lens for understanding the sense-making in the co-construction of object-oriented agency, which PSMs are an example [27]. The Mangle also presents us with the opportunity to re-establish the sociological under-pinnings of PSMs. As an illustration, Checkland originally developed SSM without reference to any explicit theory [28]. He did however review SSM against Church-man's enquiring systems and Vickers' appreciative systems theories leading to a for-mulation of SSM as an *"...enquiring system whose mode of operation provides a formal means of initiating and consciously reflecting upon the social process of 'appreciation'"*. From this Checkland concluded that SSM is not a version of func-tionalism but rather a "*phenomenological investigation into the meanings which actors in a situation attribute to the reality they perceive*" and thus to the "*philosophical/ sociological tradition of interpretive social science*" [27]. We do not need to delve further into interpretivism (as did Checkland) but seek instead links between Check-land's view of SSM (and hence of perhaps all PSMs) as phenomenological investi-gations into meanings and Pickering's performative idiom. This would simplify things enormously. We believe the link exists; Pickering makes specific reference to the need for "*phenomenal accounts*" as necessary "*conceptualizations of the aspects of the material world*" that are supported by experimentation [10].

We now move on to empirically examine through the Mangle how sense-making and sense-giving underpin PSM interventions. Prior to this, we set out details of our case context and research design.

3 The Case Study: The STEEP Project

Our case study is based on the STEEP (Systems Thinking for Energy Efficient Plan-ning) project, which is an EU FP7 project that seeks to identify innovative policy experiments for city district energy planning in Bristol, South West England and the partnering cities.[1]

The context for the case is the growing concern for securing sustainable, reliable, and affordable energy systems in EU-countries that seek to address climate change risks by meeting EU 2020 carbon reduction targets. Opportunities for change towards lower carbon energy systems arise from the convergence of ubiquitous IT systems with decentralised energy technologies that create new complementarities of small-scale, local technologies with traditional networked infrastructures. Cities are perceived to be ideal test beds due to their limited scale, their diversity hence opportunities for learning about the complexity of socio-cultural practice change that accompanies technology transitions [29].

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[1] Further details can be found at http://smartsteep.eu.

The City of Bristol, in South-West England, is one of the partnering cities in the project, and a representative of the local council manages the project as part of the council's smart city programme portfolio. In its Smart City Programme, the City Council formulates that aim that Bristol aims to be in the top 20 European cities by 2020 and has made a clear commitment to create a world-class and inclusive green-digital economy. The aim is to *"...use smart technologies to meet our ambitious target to reduce CO_2 emissions by 40 % by 2020 from a 2005 baseline, as well as our social and economic objectives"* [39].

The project partners in Bristol comprised the local university, an engineering consultancy, a third sector organisation with expertise in energy modelling, and the local council. The project proposal document states that the project's specific objectives are

– To enable all participants cities and partners to learn from the successful and unsuccessful experiences of other cities and experts
– To integrate all stakeholders in smart city plan definition: public administrations, policy makers, technology providers, financial organisations, enterprises and citizens
– To better understand the complex energy, resources, social and economic flows and their relationships
– To have a clear picture on the number, effectiveness, cost and interdependence of the possible smart city interventions and projects
– To disseminate or application plan to other similar cities at the European scale

The Bristol Temple Quarter Enterprise Zone (TQEZ) was chosen at the city district for the STEEP approach in Bristol. The TQEZ is a designated regeneration area that aims to attract businesses through reduced business (tax) rates, encourages development through a relaxed planning application processes, and enables regeneration through enabling infrastructure such as investment in transport and heating systems.

3.1 PSM Workshop Description

Group model building workshops were held as part of the STEEP project to facilitate the exploration of aspects relevant to systemic energy planning for the District Modelling of Bristol's TQEZ.

STEEP employed a form of Soft Systems Methodology [30] and Hierarchical Process Modelling (HPM) [31, 32] as a Problem Structuring Method following the generic constitutive definition of Yearworth and White [14]. Modelling a transformation as a system using HPM requires a top-level process to be identified that acts as a descriptor, or the purpose of the system [31–33]. A diagrammatic view of the problem structuring method adapted from [31, 32] and originally adapted from [34] is shown in Fig. 1, demonstrating how HPM, which has been enhanced with Issue Based Information System (IBIS) capabilities (referred to in this methodology as Evidential Discourse in ENgineering (EDEN) [35], are integrated in an SSM learning cycle. Detailed information about the methodology in practice can be found at http://smartsteep.eu.
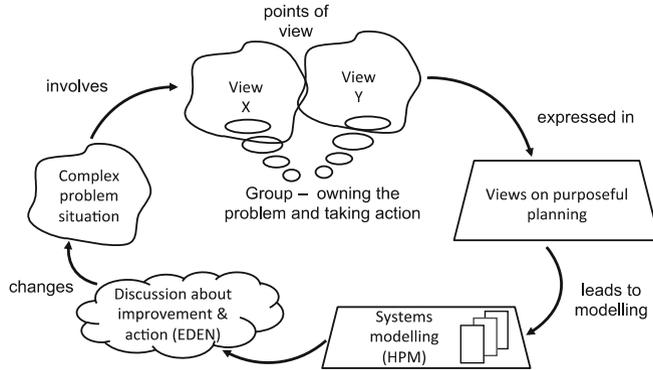
Fig. 1. Diagrammatic view of the problem structuring method. Adapted from [31, 32] and originally adapted from [34]

The workshop was attended by representatives of technology manufacturing companies, infrastructure operators, third-sector organisations with an interest in energy and low carbon development in Bristol, consultancies (multi-disciplinary engineering and architects), local authority employees and University academics. The invitations to participate were sent to a variety of organisations who were known to the project partners as having an interest in redevelopment projects in Bristol. The methodology allowed participants to take a wide view of 'energy', including building types and usage profiles, infrastructure systems and technology, movement/transport mix, thereby considering social practices – the changing nature of work in networking hubs, increasing awareness of sustainable energy behaviours and environmentally, and health-friendly travel choices. The workshop began with a representative from the city council setting the context, followed by an explanation of the methodology by a University academic.

4   Method of Analysis

For the ethnographic fieldwork within our empirical case, observational data was collected through unobtrusive video recordings of the activity during the workshop. Our analysis of the video data focused on key incidents [36]. According to Emerson [36] "*A key incident attracts a particular field researcher's immediate interest, even if what occurred was mundane and ordinary to participants. This 'interest' is not a full-blown, clearly articulated theoretical claim, but a more intuitive, theoretically sensitive conviction that something intriguing has just taken place.*" Incidents of interest were defined by (i) two or more participants explaining terminology, models, or other 'tools for thinking' to each other, thereby transferring knowledge and creating a common semantic space, (ii) two or more participants disagreeing about the representation of a problem in the model, engaging in an argumentation process (issues-options-arguments) and (iii) two or more participants scaffolding collective agency through the co-construction (reciprocal contributions) of

activities targeted at the resolution of a problem. For brevity we focus on one key incident from the study. The incidents illustrate the theoretical lenses presented in the previous sections, i.e. (i) sense-making and structuring loops [15], (ii) the co-construction of object-oriented agency through a mangle of argumentation processes, and (iii) commitment to coordinated action as an indication of collective behaviour. The key incident presented in this paper is taken from the first STEEP workshop, which took place in March 2014.

4.1   Presentation of the Key Incident

The incident we focus on illustrates the resolution of conflict between two participants, seeking each other out in its resolution and is illustrated in Fig. 2. The role of the model and the method (requiring co-constructed ideas to be brought onto post it notes and paper) is relevant in mediating the conversation [15].

Well I can think of a way of carbon offsetting [...] the offsetting actually on the homes of the people who are working in the area.. you know...

...THAT I will accept..

do you see what I'm saying?
***K:** Yes, that was what I was trying to get to*

And, and, and... to come back to that, more K,.., I argue for having the people,... the Green DNA in the building. The DNA has got to be thinking about whole cell. (...) And we were talking about the city region as well[...] At the very least the offsetting has got to be in the city region – but ideally it'd have something to do with the people working in the buildings.

Fig. 2.   Key Incident - Socio-material sense-making and structuring

In our key incident, the first participant strongly disagrees with a suggestion about practice in the enterprise zone, made by another. The second participant, holding the post-it note and thereby expressing his intention to represent (and influence through his wording) the developed ideas, then creates an ultimatum *(we are going to have to do some [offsetting])* for the first participant, requiring a compromise. This may be seen as an incident demonstrating the structuring of an agreement through the use of an abstract

model that extends the problem over a different spatial-temporal realm, invoking materiality outside the workshop: given a shared target (zero carbon), and the perceived collective inability to achieve it in practice in the TQEZ, the model of (carbon offsetting in the community/the region) is employed to produce an acceptable approach for all participants in the group. The extended argument that took place can be represented in an iterative sense-making-structuring process.

4.2 Interpretation of the Incident Through a Combination of Sense-Making and The Mangle

The incident shows a process of identifying a contradiction between the zero carbon vision and the politico-economic purpose of attracting businesses and investment by property developers through the instrument of enterprise zones. In a process of sense-making and structuring (mangling) the participants then find a mutually acceptable way of maintaining the contradicting objectives of zero carbon development and economic friendliness of the investment proposition, by defining a form of 'carbon offsetting in the community' as the shared 'mental model' or tool for thinking. Similar sense-making and structuring processes took place in the different groups regarding different contradictions present in the *problematique* in context. As a result of two STEEP workshops, stakeholders committed themselves to the following top three actions: Understanding property developer business models, Funding models that address local objectives, and Mapping stakeholders [37].

The incident demonstrates how tensions introduced through the existence of a power base (current policy) influence the structuring of the *problematique* (a low carbon zone) and shape problem structure, as well as feasible and desirable commitments to collective behaviour (developing funding models that address local objectives). The material reality of policy thus influences the sense-making process in the workshop through introduction of boundaries, e.g. by suggesting something is unavoidable (we'll have to), and by establishing criteria for a desirable solution (resilient and flexible) in the structuring process. This is further explored in a more detailed application of the mangle to the incident in the following section.

Armed with the Mangle as an analytical framework it is tempting to take it at face value and view the process of OR enacted in the workshop as our target of analysis. The *dance of agency* certainly seems to capture the busy activity in the workshop as participants are modelling. However, we need to be careful here. Pickering's development of the Mangle was in response to a need to re-theorise SSK and originates in an *asymmetric* interpretation of ANT. The dance is in fact the interplay of human *intentional* agency and material agency, which is devoid of intention. This direct interaction between human and material agency is certainly the stuff of the experimental scientist, but not the OR practitioner. Therefore, it would be inappropriate to apply the Mangle as an analytical lens on the interplay of human-to-human agency in the workshop as this would deviate from its theoretical intentions.

The application of the Mangle in this case requires more effort. Certainly we can think in terms of the performative idiom by focussing on the *actions* within the workshop, literally examining the *doing*, the process of OR, and ignoring for now the

epistemic gains that resulted. However, how is the interaction with material agency to be brought into the workshop? The answer seems to be that the material world, the eventual implementation of interventions leading to energy efficiencies in the target development zone, are represented in the workshop in the form of a *proxy*. The stakeholders are bringing into the workshop their own expertise and knowledge about the difficulties, challenges and actual physical limitations of achieving the agreed transformation. So each participant represents symbolically, and in terms of actual knowledge, an aspect of the material world, which must be voiced to other workshop participants in order to not mislead the workshop about the feasibility, or otherwise of processes that are being discussed in the modelling as possible answers to the question "*how is this to be achieved*?" Therefore, based on the Mangle the atomic unit of analysis would thus be exchanges of this form

Participant 1 "we should try to do this"
Participant 2 either "yes, this is feasible" or "no, this would not work"

Here, Participant 1 is expressing a possible performative act imbued with human agency and representing a creative, exploratory attempt to shape the world. Participant 2 counters with expertise of the material world and represents it to the group, knowing that the putative action is either possible or not.

The incident presented above illustrates the proxy representation of material agency into the conversation. The participant **P** asserts

"*If you're going to say that it's a zero carbon development, then you're only going to take on developers who are committed to zero carbon development…*"

and participant **K** responds with

"*(shaking his head) It's just not possible.. I mean, I love the idea and I think it'd be amazing if you could, but it's just not possible. Understanding planning and unless you want the HCA to go against its own government… Network Rail,… power station…*"

P is taking a position aligned with the original goal of the transformation "*Achieving a **zero carbon** development of the TQEZ*" by asserting an intention to shape the world that requires developers to be similarly aligned. Participant **K** states the material agency limitation concretely by a very clear assertion that this is not possible. Participant **P** receives this push-back from material agency and repeats it to show that the message has been heard. However, the dance is not over yet. **P** now asserts intentionality again, by saying that the obstacle must be removed.

"*…So, so, that's interesting, that's good… I want to hear somebody say 'we can't get there from here', and then I would say 'well then we will have to remove the obstacle'*"

From here, the direct physical achievement of zero carbon is now pushed to one side and another aspect of material agency enters the discussion, that of carbon offsetting.

We can thus see that the *dance of agency* that Pickering describes is actually taking place, with the participants behaving like *avatars* of material agency as well as asserting their own intentional agency. On each occasion where material agency needs to assert itself to the group in response to human intentionality, it was enacted in proxy

by one of the participants. Of course, we have been liberal in our interpretation of material agency. This is not just the *physical* properties of the world, the known physical laws that govern such things as (say) the possible energy efficiency of a given technical solution. There is also the material agency of such things as available capital, interest rates, regulations, and so forth and in this case the notion of zero carbon and carbon offsetting. They all need to be represented in proxy form at appropriate points in the discussion. The net effect is to shape the overall direction of exploration by the group as it runs up against the material limits of the world it is trying to *shape*. Note that we keep returning to the notion of shaping as an intentional act. This particular project is firmly in the realm of *engineering*, the physical limits in the broad sense discussed here limit the scope of intentional engineering action focussed on the technologies associated with the carbon emissions of the TQEZ development. However, engineering is a necessary but still not sufficient element needed to enact transformation. The project is also undoubtedly political; the scope for taking action is more likely to be constrained by the full gamut of PESTEL realities than by technical feasibility. Whilst human agency was focussed on achieving the desired transformation "*Achieving a zero carbon development of the TQEZ*", the Mangle can thus explain why the group emerged from the first workshop with the modified transformational goal of "*Achieving an operational low carbon development of the TQEZ*". The atomic unit of analysis carried out above illustrated just one of the individual incidents during the workshop where participants' representations of the material limitations exerted themselves in the direction which modelling was taken and thus, eventually, in the change in goal.

5   Discussion

The objectives of our paper were to explore how sense-making and structuring shape an intervention and to understand the processes of PSMs. Ormerod [8] has directed us towards the Mangle as a potential useful analytical device to better understand the process of OR. Ormerod's interpretation of the Mangle led him to propose the need for more informative case studies with an "*emphasis on the interaction through time of material, human and conceptual components of a research programme*". To aid the OR researcher, Ormerod has proposed a set of desirable characteristics of case studies that would help draw out and reveal these interactions. Indeed, the STEEP project has already taken Ormerod's suggestion on board in the design and implementation of its evaluation and have collected a number of such narratives for the benefit of other researchers [37].

However, our contribution is to go beyond this narrative over time and have demonstrated the value of the Mangle for the micro-level analysis of participant interaction in-group model building workshops. This has been achieved by returning to Pickering's original theoretical conception of the Mangle as an asymmetric interpretation of ANT and his proposal for a shift to the ontological performative idiom. In doing so we have recognized that material agency enters the discussion in the workshop in proxy form. Participants represent material agency as avatars and literally pushback on other participants when they recognize that assertions of human intent are not possible based on their expert knowledge of limitations. Pickering's image of the

Mangle as a dance of material and human agency is actually observable, as we have demonstrated in our analysis of the incident from the case.

Reflecting on our micro-level analysis using the Mangle we can see that the notion of the performative idiom provides insight into workshop participants' commitment to action. The 'dance' in fact reveals viable action as the process of participants searching for pathways forward in a complex landscape *bounded* by material agency. Pickering stresses "the temporal *emergence* of plans and goals and their transformability in encounters with material agency" [10]; the avatars of material agency are literally saying "no, not that way" and the path forward emerges as a consequence. This adds further support for our claim that action is an emergent property and is not a result of the facilitator leading or suggesting the way forward.

Consistent with more recent studies (e.g. [14, 38]) our research demonstrates the possibilities of a theory informed view of the micro-processes of PSM practice. We argue therefore that it is important to look beyond group membership to understand how sense-making and structuring shape an intervention and, in doing so, it is possible to describes the conditions that lead to intended and unintended effects. This position also means that it is possible to study the collective intent of an intervention [6], opening up the possibility to study PSMs as collective phenomena. PSMs have been applied widely to scaffold the resolution of multi-voiced, multi-perspectival problem situations. However, their emphasis on consensus seeking dialogue as a requisite principle for change and the associated lack of a critical examination of representations that mediate discussions, results in concerns around their adequacy for contested social innovation processes. Specifically, the possibility of accommodating foundational conflict and the constant struggle for dispositional power amongst the participants involved in integrative negotiation is not explicitly considered. We introduce the Mangle as a specific means to address the multi-dimensional aspect of PSM interventions.

Having used the mangle and sensemaking lenses to gain insight into the dynamics in a micro-episode within a soft OR intervention, it seems relevant to position the episode in the multi-layered context of socio-technical transitions: as part of the workshop, the intervention project (STEEP), the smart city Bristol programme, and the national policy of devolution. In the UK context a traditionally very powerful central government, is beginning to devolve some control to local authorities, thereby increasing their agency to develop locally sustainable solutions for transitions.

The City of Bristol thus pursues its own Smart City Bristol Programme with the aim to be "*in the top 20 European cities [that use smart technologies to help deliver a cleaner environment, a higher quality of life and a vibrant economy] by 2020 [having] made a clear commitment to create a world-class and inclusive green-digital economy*" [39]. Furthermore, in Bristol, voters have expressed their desire to be involved in and shape a 'Bristolian' future by choosing a directly elected Mayor in Bristol.

Thus, considering the sense-making and mangle episode from the perspective of local stakeholders striving for greater self-determination of transition policies, it becomes possible to interpret the collective learning facilitated through the problem structuring workshop in the context of socio-technical transition theory (e.g. [29]). The need to further develop collective steering competence [40] is explicitly stated as the following quote by a representative of an engineering consultancy (also a STEEP project partner) at a University collaboration facilitation meeting exemplifies:

"There is no panacea for the challenges Bristol as a city is facing. A range of multi-agency, multi-faceted programmes is needed to tackle these" (March 2014).

To facilitate the emergence of goal-oriented collective steering competence, the dynamic ability to interact on the basis of collectively developed desirable futures and adaptive collective behaviour through self-evaluation processes, need to be scaffolded (Kemp et al., 2007). The following quote illustrates how sensemaking and mangling in the workshop were effective in identifying shared areas to focus collective effort for change:

"If we hadn't have gone through the process of modelling, if we hadn't have got stakeholders into the room, we wouldn't have discovered that [...] there was lack or lack at the moment of a coherent vision around carbon reduction. So the modelling process itself flagged up what these barriers were, what these issues were, as it is supposed to do as a model. It doesn't assume that there is consensus but it highlights where the issues or the gaps might be in that consensus". (City Council Project Representative at STEEP Consortium meeting, September 2014).

In order for goal-directed collective agency to arise in sustainability transitions, such as for the energy efficient planning of the enterprise zone that is the aim of the STEEP project, processes of "*goal-oriented modulation: between planning and incrementalism*" [40] take place. Hence, as a next step to inform practice change through the STEEP workshop learning processes, goal-oriented collective behaviour is foreseen.

Considering this process in the context of the smart city programme, further evidence for the emergence of this collective steering competence is seen through the increasing number of formalised cross-organisational projects for transitions in Bristol between stakeholders from the local authority, the University, businesses and NGOs. Several real-world' laboratories for socio-technical sensemaking and mangling are being set up with new technologies in people's homes in Bristol (e.g. SPHERE (e-health)) and scaled-up IT test-beds (Bristol is Open). Zooming back in to the micro-episode presented in this paper we thus suggest that it offers a in-depth view of the collective sensemaking and mangling processes that – embedded in programmes of projects with related problem structuring interventions in Bristol – facilitate the development of collective steering competence. Over time, policy influence and integration may thus result from locally developed shared notions, ideas and instruments for transitions that emerged from micro-episodes of the problem structuring in workshops.

As such, collective sensemaking and the mangle may effectively challenge unsustainable routines and practices, especially when the resulting adaptive collective behaviour is maintained in wider programmes of goal-directed problem structuring practice, such as in the context of the collaborative projects cited above, which include developmental monitoring and evaluation processes in the pursuit of a locally sustainable approach to transition management.

Finally, there are various implications and benefits to OR practice that we can see from our work. Our first contribution is that our approach enables a more dynamic interpretation of the problem structuring setting. Rather than taking a static view we can see that the problem context naturally enters dynamically in group model building in a proxy form as participants represent material agency as avatars. Our second contribution has been to show the need for awareness by the facilitator of the possibility of the transformation being modelled changing as individual participants each represent a

partial embodiment of material agency, the group thus collectively recognising after some time what limits are placed on their collective intention by material agency. We thus conclude with the suggestion that in order to understand the effectiveness of such complex PSM processes, it is necessary to gain a deeper understanding of the dynamics of negotiations in co-learning processes in groups.

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