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# Sustainability as a “super wicked” problem; opportunities and limits for engineering methodology

**Abstract:** Characterising sustainability as a “super-wicked” problem alerts us to issues beyond where current thinking about problem structuring enables engineers to deal with the merely wicked. Time is running out, no-one authority is in control, we are the cause of the problem anyway, and we inherently discount the future in our every day decision-making. When these are added to the usual definitions of wicked and messy problems, which only now are we addressing in engineering education, what are the potential limits and opportunities for the methodology of engineering in sustainability? Some modest extrapolations are discussed, based on the results from a recent research project in addressing energy planning in a city development zone. Analysis from another case study is also presented, which provides some triangulation of the ideas developed in this paper.
**Key words:** super-wicked problems, messy problems, problem structuring methods (PSMs), engineering education, sustainability

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## 1 Introduction

When confronted by the challenge of delivering an EU FP7 Smart-Cities project to address the problem of *comprehensive* energy planning in a city district how might an engineer respond? What *methodologies* from engineering might be appropriate? The specific context for the questions is the STEEP project (Systems Thinking for comprehensive city Efficient Energy Planning), which is a two year project that started in October 2013 and focussed on energy planning in three city development zones in Bristol (Temple Quarter Enterprise Zone), San Sebastián (Urumea Riverside), and Florence (Cascine Park). I have attempted to answer these questions based on the ideas of wicked and messy problems and the use of Problem Structuring Methods (PSMs). Whilst these ideas are well known in the Management Science and Soft Operational Research communities’ (Ranyard, Fildes, & Hu, 2015) engineers rarely know anything about them. There is a certain irony here in that one of the key researchers who developed perhaps the pre-eminent PSM, Soft Systems Methodology (SSM), was himself originally an engineer (Checkland, 1981a, 2000; Checkland & Jenkins, 1974). In order to provide some triangulation an analysis is presented from another case study in sustainability, in this case flood risk management. This illustrates problem structuring in action, albeit presented using different terminology in an example of what is call non-codified PSM use. Whilst reassuring in terms of demonstrating the fundamental concepts of dealing with messy problems it does highlight the problem that knowledge about use of these techniques is difficult to find. Another consideration addressed in this paper is pedagogy; how does research like this impact the training of future engineers? Therefore, a further purpose for this opinion piece is to present a guide through a literature that is likely to be unfamiliar in the hope of promoting the wider uptake of PSMs by engineers, and stimulating further methodological development in response to the challenge of super-wicked problems. The structure of the paper reflects the order with which ideas have been presented to STEEP project partners, the implementation of the STEEP methodology, and then its evaluation. The latter has provided the main contribution to the discussion in §4.

## 2 Method

In this section I present critical self-reflection on the use of problem structuring methodology applied in the context of the STEEP project in which I have been involved. In this section I construct the overall framework for this self reflection from i) a definition of wicked/messy and super-wicked problems, ii) a discussion of the appropriateness of Problem Structuring Methods (PSMs) as a valid response to the need to intervene in these problem contexts, iii) a brief review of methods for evaluating the use of such methods[1], iv) consideration of the role of the 'expert' modeller and modelling, and v) extra concerns presented by super-wicked problems. Once these elements have been introduced I present an example of so called non-codified PSM use that illustrates the principles in operation, albeit in a distinctly different field.

Presentation in this rhetorical and critical style is due to influence by Ormerod (2014) who has constructed a well-reasoned argument for "*more informative case studies of 'technical' projects*" to aid future researchers in the difficult endeavour of facilitating interventions in these messy problem contexts. The framework is presented in a similar order to the way in which these topics have been introduced to postgraduate engineers on the EngD in Systems Programme at the University of Bristol since 2009. This also matches the way in which the problem structuring methodology has been taught to the project partners in the STEEP project. The entire training course (as videos and slides) was made open and is available from the project website[2]. If anything is not clear in this section of the paper then I refer the reader to this website for clarification. In sections §2.1 to §2.4 I set out the essential elements of the framework and in §2.5 introduce the specific issues of super-wicked problems as described by Bernstein, Cashore, Levin, and Auld (2007).

### *2.1 Wicked and Messy Problems*

Research Engineers[2] (REs) are introduced to the notion of wicked and messy problems early in the EngD in Systems Programme (Yearworth, Edwards, Davis, Burger, & Terry, 2013). The purpose is to get REs used to the idea that engineers in general are increasingly involved in projects where the notion of a *unique* or *optimal solution* is misguided. I would suggest that most projects in the broad domain of sustainability fall into this category. I use Rittel and Webber (1973) as my starting point on this journey. They provide the original characterisation of a wicked problem. My interpretation of their definitions is as follows:

1. No definitive formulation
2. No stopping rule
3. Solutions are not right or wrong, there is no immediate or ultimate test of a solution, but can only be viewed as good or bad
4. Solutions are 'one-shot', there can be no trial-and-error (experiments); every intervention counts significantly, they are essentially unique
5. No enumerable, exhaustively describable, set of solutions
6. Can be considered as symptoms of other problems
7. Can be contested at the level of explanation, there is likely to be conflicting evidence/data
8. Aim is intervention, not knowledge gathering for its own sake

There are other similar characterisations of such problem contexts as messes by Ackoff (1981), and as swamps by Rosenhead (1992). These definitions are all mirrored in more recent work from Mingers (2011), who provides a similar rendering of the problem space as:

1. Problem situations involving many interested parties with different perspectives (worldviews)
2. Problem situation not well defined

3. Difficulty agreeing objectives
4. Success requires creating agreement amongst parties involved
5. Many uncertainties and lack of reliable (or any) data

The intention is to paint a picture of problem contexts that need to be recognised for what they are, and a trigger for a different response to taking action[4]. Pedagogically, it is sometimes useful to present examples of project failures from other domains and pose the question of whether an adequate approach was taken with the clarity of hindsight into what was clearly a wicked problem context. The learning objective is to engender a sense for these problem contexts and an awareness that an appropriate response is to use a Problem Structuring Method (PSM) with stakeholders.

## *2.2 Problem Structuring Methods (PSMs)*

PSMs are presented as valid response to intervention in wicked/messy problem contexts. There is extensive literature on this justification, see for example (Ackermann, 2012; Eden & Ackermann, 2006; Keys, 2006; Mingers, 2011; Mingers & Rosenhead, 2004, 2011; Rosenhead, 1996, 2006; White, 2009). For teaching purposes I summarise the key features for PSMs as follows based on a subset of this literature (Mingers, 2011; Mingers & Rosenhead, 2004; Rosenhead, 1996). PSMs are:

1. Methods, not mathematical, but structured and rigorous and based on qualitative, diagrammatic modelling
2. Allow for a range of distinctive views to be expressed/explored/accommodated and allow for multiple and conflicting objectives
3. Encourage active participation of stakeholders in the modelling process, through facilitated workshops and cognitive accessibility
4. Can facilitate negotiating a joint agenda and ownership of implications of action
5. Significant uncertainty is expected and tolerated
6. Operate iteratively
7. Aim is for exploration, learning, and commitment from stakeholders

It has also been possible to categorise PSMs based on answering the practical question "*what is it we are actually doing when we use a PSM?*" (Yearworth & White, 2014). This has led to the formulation of a generic constitutive definition (GCD) of a PSM with 9 Aspects as shown in Table 1.

Part of the original motivation for this work was the proposal by Yearworth and Edwards (2014) to provide an axiomatic formulation for PSMs that would appeal to an engineering audience more used to working with pragmatic principles. Examples of non-codified PSM use have been found with relevance to practicing engineers, for example see the work of Lane et al. (2011) in the domain of flood risk management and this example is analysed in detail as a further case study in §3.

**Table 1.** The 9 Aspects of the generic constitutive definition (GCD) of PSMs adapted from Yearworth and White (2014).

| # | Aspect | Definition |
|---|---|---|
| 1 | Improvement Activity | A structured approach to systemic intervention, *designed* to lead to improvements in a problematic real-world situation |
| 2 | Systemic Approach | The problem structuring approach used systems ideas supported by appropriate systems modelling (amongst other requirements) |
| 3 | Adaptation/ Creativity | Creativity must have gone into how the problem structuring approach was adapted or elements combined for the particular problem situation |
| 4 | Methodological Lessons | Use of the approach led to methodological lessons |
| 5 | Worldviews | Recognition that problems are construct of an individual's mind, they do not exist independently of human thought and are defined by an individual's "worldview" |
| 6 | Messiness | The problem context in which the problem structuring approach was used was recognised as messy following definitions such as contained in this paper |
| 7 | Interactive/ Iterative/ Therapeutic | The intervention has come about through sharing of "*perceptions, persuasion and debate"* in a participative group setting using an interactive and iterative approach. The facilitator adopted a stance that was "*interactive/therapeutic, not expert*" |
| 8 | Subjectivity | In the approach taken it has been recognised that the stakeholders of the problem situation are not *"divorced from the problem*" |
| 9 | Limits | The approach dealt with conceptual limitations of modelling language used |

## *2.3 Evaluation Methods*

The development of the generic constitutive definition (GCD) required an approach to evaluation that could focus on the PSM to the exclusion of the uniqueness of the specific problem context in which they are used, and the equally unique set of actions arising in consequence (Pawson & Tilley, 1997). Whilst this was sufficient to develop the GCD, more specialised techniques are required to fully evaluate a PSM in action such as provided by Midgley et al. (2013), White (2006) as well as Ormerod (2014), as already mentioned. An example of the use of these techniques can be found in the evaluation of the STEEP project methodology (Yearworth, 2014). The STEEP project evaluation has led directly to some of the personal reflection in §4 of the paper below.

### *2.4 Effectiveness of Expert Modelling*

Whilst PSMs make use of systems modelling as a crucial component (Yearworth & White, 2014) it is also important to briefly touch on the role that 'expert' system modelling can take to support intervention in the sustainability context. In this respect having an adequate theoretical framework for assessing *how* models are used and *when* in the project lifecycle by experts is also crucial (Yearworth & Cornell, 2014). It is mentioned here to provide contrast between the expert mode of modelling, which is perhaps the prevalent way in which engineers work, and the participative and facilitative mode that is the subject of this paper. Further exposition on the difference between expert and facilitated modelling can be found in work by Franco and Montibeller (2010). Integration of such 'hard' modelling into PSMs use is not overly difficult (Kotiadis & Mingers, 2006; Pollack, 2009).

### *2.5 Super Wicked Problems*

Whilst Ackoff (1981), Mingers (2011), and Rittel and Webber (1973) provide a useful starting point for thinking about wicked/messy/swampy problem contexts, Bernstein et al. (2007) take the original Rittel and Webber idea forward to a new level of urgency for sustainability by introducing four new concerns i) time is running out, ii) no-one authority is in control, iii) we are the cause of the problem anyway, and iv) we inherently discount the future in our every day decision-making. Whilst their work is explicitly focussed on implications for policy, I attempt to interpret their concerns into my existing work on the application of PSMs to wicked/messy problems in sustainability. This is the "modest extrapolation" to existing methodology and the subject of the discussion that follows.

## 3 Example case study

As mentioned in §2 above, there are examples of uses of PSMs in application domains of relevance to an engineering audience but the presentation of the research uses a different terminology than that routinely used in the PSM academic community. The Generic Constitutive Definition (GCD) of PSMs from Yearworth and White (2014) provides a means of characterising so called *non-codified* uses of PSMs. The original motivation for the development of the GCD was to widen the case study database of PSM usage, primarily to help with the development of methodology. The example of such use by Lane et al. (2011) is analysed here with a view to illustrating the principles of the framework developed in §2.

Lane et al. (2011) present what they call an "*an experiment in radical scientific method*". The experiment they present is essentially a report of the activities of the authors in constituting the Rydale Flood Research Group (RFRG) as an intervention in the flood defences of Pickering, Yorkshire in 2007. The trigger for suspecting non-codified PSM use were the following claims:

> "*By working with the event we harnessed, produced and negotiated a new and collective sense of knowledge, sufficient in our experiment to make a public intervention in flood risk management in our case-study location.*"

And

> "*…the purpose of our experiment became as much about creating a new public capable of making a political intervention in a situation of impasse, as it was about producing the solution itself*".

These claims align with PSM use in that the purpose of the experiment, or *intervention* in PSM language, was taking action rather than generating pure knowledge claims about solutions. This satisfies the Aspect 1 of the GCD in Table 1 above. The fact that the paper exists as a report on *method* that has emerged and been refined through the process of intervention reveals that the authors have *reflected* on what they have achieved and thus achieved what in the GCD would be called methodological learning (Aspect 4 of the GCD); and also presenting research in a style that would be approved of by (Ormerod, 2014). The knowledge claims are thus focussed on the process of intervention rather than the specifics of the interventions. The methodology can thus be transferred from situation to situation, whereas the specific actions taken would be relevant only to the instance of the intervention and thus may not translate. In the authors' words:

> *"What we have done here is moved the idea that a model should travel to one where the* **process** *of model building should travel."* (my emphasis)

This also changed the way in which the research was conducted and reported. Unlike traditional scientific method, which is broadly hypothetico-deductive in nature, this was *radical* in the authors' eyes; although for the PSM community this would obviously be considered as business as usual. This dichotomy between approaches of reporting research into process and more traditional scientific method is usefully characterised into *variance* and *process* methods by de Ven and Poole (2005). Clearly, the reporting of process research caused concerns in the authors as to the validity of the knowledge claims emerging from their work. They drew on Callon (1999) in making the distinction between the different modes of engagement between scientists and publics as follows:

- PEM (Public Engagement Model), where Science and Scientific Knowledge (SK) are seen as authoritative and where the public needs educating
- PDM (Public Debate Model), where the public are viewed as stakeholders in SK and have the right to debate it
- CKM (Co-production of Knowledge Model) where SK is seen as being co-produced through a process of dynamic collective learning

The fact that in the authors' opinion, their work in the RFRG, as a working partnership between lay-expertise and academic expertise, was clearly seen as an example of Callon's CKM mode of working. This suggests that there was recognition that different perspectives were valid and important, although in the limited sense of appreciating that lay-expertise was equivalently valid to academic expertise in the specific case of flooding behaviour in- and around Pickering. However, it suggests sufficient acknowledgement of worldviews to satisfy the Aspect 5 of the GCD. The overall framing of the problem, especially in terms of the recognition that the current approaches of Defra and the Environment Agency had led to an "*impasse*" is ample to convince that there was appreciation that this was a messy problem as characterised in §2.1 above and thus satisfying Aspect 6 of the GCD. It is clear in overall summary that the authors brought a high degree of creativity to their approach (Aspect 3).

Of the remaining Aspects of the GCD, the authors were not explicit about using a systemic approach

(Aspect 2), subjectivity (Aspect 8), or the conceptual limitations of the modelling languages they used (Aspect 9). The question of subjectivity in this type of work is covered by (Voinov, Seppelt, Reis, Nabel, & Shokravi, 2014) and provides a useful adjunct to this case study. We return to questions of the systemicity of their approach and conceptual limitations in the discussion.

## 4 Discussion

The STEEP project has demonstrated some of the practical limitations of applying PSMs to the problem of energy planning in the three cities of Bristol, San Sebastián and Florence. A full articulation of these limitations can be found in the project evaluation document (Yearworth, 2014). A further case study analysed in §3 has further illustrated the principles of problem structuring drawn from another field but of practical relevance to engineering practice.

Personal reflection on the STEEP project evaluation has pointed me towards the following as the key issues:

1. Ownership and definition of the transformation implied by Aspect 1 of the GCD is co-dependent with the membership of the stakeholder group; the two *co-create* each other. The '*who*' and '*what*' of a transformational goal must be defined simultaneously at the outset of a project, before any thought about the '*how*', '*when*' and '*why*' can be discussed
2. There is nothing in the STEEP methodology, which is based on the GCD view of PSMs described in this paper, that specifically deals with power and this has been recognised as a weakness. The methodology assumes a plural problem context and that there is sufficient commitment amongst the stakeholders for them to want to work collectively to arrive at a shared understanding and agreement on actions. Without the power to enforce a specific transformational goal, e.g. through the legal or regulatory environment or financial incentives on the part of governments, then it is inevitable that such a goal will be weakened in the process of encountering the interests of the stakeholders.
3. Planning should be thought of as a transformational process constantly reviewing and negotiating the goal(s) of transformation and modifying and updating plans from time to time. We might even think of planning as the process that tries to reduce the gap between imagined, planned futures and what actually happens on the ground. The notion of iterative gap closing

expressed as a problem suppression loop is explored by Ring (1998) and Yearworth et al. (2015).

Issues 1 and 2 above mirror the characterisation of super-wicked problems that "*no one authority is in control*". In the case of PSMs this is usually considered a weakness in terms of dealing with power, but for Bernstein et al. (2007) the problem is expressed as the absence of power. The idea of interdependent development of transformational goals and formation of stakeholder groups seems a reasonable ambition up to the scale of projects such as STEEP and in the case study example analysed in §3, but difficult to conceive in any larger context suggesting the relevance of PSMs to localism would be appropriate (O'Brien & Hope, 2010; Walker, Hunter, Devine-Wright, Evans, & Fay, 2007). If anything, there is likely to be a constant erosion of goals, a well-known archetype observed by the system dynamics community (Braun, 2007). Issue 3 echoes the aspect of super-wicked problems that "*time is running out*". The constant re-evaluation of transformational goals in the light of our imagined, planned future and current state would highlight the urgency and is the intention of Aspect 7 of the GCD. Bernstein et al. (2007) pose the question "*how might small changes now create enduring path dependent effects in the longer term…*". The idea of path dependency is absent from the GCD and its underpinning literature and is a serious deficiency. The idea that "*we are the cause of the problem anyway*" is certainly touched on in Aspect 8 of the GCD, although not in such a strong form. Rather than cause, the GCD just suggests the impossibility of objectivity on the matter. As mentioned above, recent literature in the domain of expert modelling supports this view (Voinov et al., 2014). In this respect the GCD should perhaps be strengthened. However, given the existence of a challenging messy problem and the desire to take "*action to improve*" it is unlikely that the stakeholders would have no part to play in causes. The inherent discount of the future in our every day decision-making or "*hyperbolic discounting*" (Ainslie, 1991) is not covered in the GCD. Whilst Aspect 7 introduces the time element through iteration and may highlight urgency, it does not deal with this specific economic issue. Aspect 9 of the GCD acts as a sort of catchall for owners of the PSM process to avoid conceptual limitations in their work and this was conceived more as guidance to avoid using a systems modelling approach that does not afford the necessary insight into the problem situation. For the flood risk case study analysed, it was unclear whether there had been any thinking that questioned whether the modelling carried out was adequate to support *problem* *structuring* as such, although the modelling that was discussed was firmly rooted in the domain of the flood risk expertise of the authors. The problem of hyperbolic discounting suggests the need for specific systemic financial modelling tools that may not yet exist. However, as noted in §2.4, and in the general case of dealing with future conceptual limitations in approach, integration of such tools into PSM use is not an issue. Finally, the question of an appropriate systemic approach (Aspect 2 of the GCD) has not really been covered in the presentation of the STEEP methodology or in the analysis of the flood risk case study. In the latter case this was because of its absence, and for STEEP because there is adequate information in the public domain. However, for any method to be really considered as an example of using a PSM a suitable systemic approach must be adopted. This where it would be beneficial for knowledge about PSMs and perhaps Soft Systems Methodology (SSM) in particular would be useful included in the engineering curriculum. For now, the following present a useful range of introductions to the subject (Ackermann, 2012; Checkland, 1981b; Checkland, 2000; Checkland & Scholes, 1999; Mingers, 2011; Rosenhead, 1996, 2006; White, 2009).

## 5 Conclusions

The STEEP project has provided an opportunity to test the performance of a PSM in a realistic messy problem context. In addition, an example of non-codified PSM use in flood risk mitigation has also been analysed to provide further support for the principles involved in dealing with messy problems. Formal evaluation in the STEEP project has revealed a number of shortcomings despite the original confidence based on work of (Coelho, Antunes, & Martins, 2010; Gezelius & Refsgaard, 2007; Neves, Martins, Antunes, & Dias, 2004; Sheffield, 2004) that PSMs were suitable for this type of problem context. When these shortcomings are also analysed against the concerns of super-wicked problems a number of key issues emerge and it is possible to see where improvements to methodology can be made. This leads to the following focus points for the development of PSMs for use by engineers in sustainability projects:

1. Setting transformational goals, owning stakeholder engagement, and dealing with goal erosion are interdependent problems, which when combined with multi-agency working suggest that conventional workshop-style settings are no longer appropriate.
2. Dealing with worldviews, subjectivity and the fact that we are contributing to the problem in

which we are trying to intervene suggests that we need to extend existing methods to deal with more inclusive and widespread participation.

3. The fact that time is running out suggests that we need to move to methods that are quick and inexpensive to deploy, allow for repeated use, and persist over time.

These three focus points when combined suggest future development of PSMs where they can be implemented and deployed in an online setting. The STEEP project has already moved in this direction by the implementation of the collaborative stakeholder engagement platform, which can be accessed from the STEEP project website. Further developments along these lines are indicated by the work of (Franco, 2007; Morton, Ackermann, & Belton, 2007; Shaw, Westcombe, Hodgkin, & Montibeller, 2004). The enhancements we envision can be summarised by three interrelated strands

1. The ubiquity and inclusivity of social media suggest the idea of a *Platform* with extraordinary reach
2. Specialised expert modelling and access to open data needs to be incorporated into the problem structuring process as *Evidence* that can be debated by stakeholders
3. Problem structuring methodology can be thought of as the essential *Glue* that binds stakeholders together into the process of debating desirable and feasible change enabled by suitable platforms and informed by evidence.

Returning to the co-production of knowledge model (CKM) of Callon (1999) we see problem structuring methodology as an essential, repeatable process at the heart of stakeholders' working together on complex problems to *learn* how to intervene. The presentation of problem structuring methodology in this paper has been made from the perspective of an expert user. However, the idea of platform, expressed above, opens up the prospect of much wider participation but so far with limited views on control over how methodology (process) is implemented nor on the range of experience that would be considered valid contribution to the process. Brown and Harris (2013) describe a "*framework for inquiry*" that suggests the dimensions along which we could see this *opening up* of methodology for the problem of sustainability.

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## Endnotes

1. The evaluation methods used for the STEEP project have contributed a large part towards the reflections on methodology development presented in this paper.
2. Full details of the STEEP methodology including video recordings of the partners' training course can be found at http://smartsteep.eu/resources
3. We use this term to describe students in order to acknowledge their status as equivalent to employees in the companies in which they are carrying out their research. The difference between this setting for engineering doctoral research and 'traditional' university based research is discussed fully by Godfrey (2012).
4. In the sense of different from what might be considered as 'normal' engineering practice. The fact that these participatory approaches are so unusual to normal practice can lead to apparent surprise in research findings – hence the reference to "*radical scientific method*" in the work of Lane et al. (2011).

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