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Problem Structuring/Soft OR

KEYNOTE

Problem formulation and study design*

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Abstract

This paper provides an overview of principles of Operational Research problem formulation and study design. Problem formulation identifies what the analysis is trying to achieve and what issues it needs to address. The paper examines problem formulation challenges like understanding your customer and stakeholders' needs and deciding on study scope. A number of problem formulation methods are summarised. Study design identifies, in the light of the formulated problem, what analysis we intend carry out and how. We discuss a number of ways of developing the technical design of an OR study. A generic OR study design process is used to highlight key design considerations. Supporting ideas and approaches are also discussed.

Keywords: Problem formulation; problem structuring methods; study design; experimental design; stakeholder analysis

1. Introduction

The aim of this paper is to outline approaches to problem formulation and study design within Operational Research (OR) studies. It is derived from an in-house technical training module run within the Defence Science and Technology Laboratory (Dstl), an agency within the UK's Ministry of Defence (MoD). Dstl's OR studies are often large and relatively complex. However, the principles described are scalable.

In outline, the overall design process for an OR study usually involves four elements:

- **Problem formulation** (also called problem elicitation) identifies what the analysis is trying to achieve and what issues it needs to address.
- **Study design** in the light of the formulated problem, identifies what analysis we intend to carry out and how - the technical specification of the work**.** It may lead to the development of a specific Concept of Analysis (CoA) document.
- **Design of experiments** considers how to design information-gathering exercises where variation is present. Such activities include getting 'real world' data on system performance, questionnaires and surveys, stochastic simulation models, judgement exercises and, of course, more formal experiments (e.g. Randomised Controlled Trials).

It is often an important element in an overall study design process. Outputs of the process may be captured in the Concept of Analysis or a stand-alone document.

- **Project planning:** identifies how, in practice, we shall organize resources over time to carry through the study in line with the design. It results in a project plan.

These activities are heavily inter-related and take place in an iterative way. For example, with a complex study, we might expect a high-level study design and project plan to be developed first. One of the first activities within the project plan would then be to undertake a more detailed problem formulation and study design phase. This would result in a Concept of Analysis. The project plan would then be revised accordingly.

In this paper we focus primarily on problem formulation and study design and provide an overview of experimental design principles. Problem formulation challenges are examined and a number of problem formulation methods are summarised. A generic OR study design process is used to highlight key design considerations. Supporting ideas and approaches are also discussed.

2. The Problem Formulation Challenge: Doing the Right Thing

One of the key challenges OR practitioners face is to ensure that an OR study is tackling the right problem. Why does this pose a significant challenge?

A commonly used definition of OR is "*Use of scientific methods to assist executive decision-makers*". It is a practical discipline with a practical aim. So, the value of analysis depends entirely on tackling the right problem: the one on which the decision-maker(s) need help. A simple approach would therefore be to take the question we have been asked to address at face value. However, underlying an 'exam question' are a range of issues:

- Who actually originated the question and who owns the problem to be addressed?
    - In a large, hierarchical, organisation the question may have been passed down several levels and possibly reinterpreted along the way. It may even be difficult to understand who the decision-makers actually are. In other contexts, the OR practitioner may be engaging directly with the decision-maker on a daily basis.
- What does the decision-maker mean by her question?
- Why is she asking it, and how does that affect what it really means?
- What others think she should have asked?

These questions highlight that decision-making is a political and social process. In addition, Ackoff (1979) highlights: "Managers are not confronted with problems that are independent of each other, but with dynamic situations that consists of complex systems of changing problems that interact with each other. I call such situations messes. Problems are abstractions extracted from messes by analysis."

Often the operational researcher will focus on addressing soluble elements of the decision-makers' 'mess' or wicked problem as it's often known. However, as Pidd (1996) cautions: "One of the greatest mistakes that can be made when dealing with a mess is to carve off part of the mess, treat it as a problem and then solve it as a puzzle - ignoring its links with other aspects of the mess."

Thus we need to understand the mess as a whole as well as the constituent elements that we are being asked to analyse. Divergent customer and stakeholder opinions are important generators of messy problems, so knowing where they are 'coming from' is crucial.

3. Understanding Your Customers and Stakeholders

Table 1 provides an illustrative set of questions we need to ask, some of which might be tactless to ask directly.

Table 1 Probing customers and stakeholders

What's really in the customer's and stakeholders' mind?
What are the key issues to be addressed, hypotheses to be tested, and types of conclusion to be drawn?
Where are the boundaries of the issues to be addressed (scope of study) and what are the priorities within this?
What forms of outputs are required? Qualitative versus quantitative? What level of reliability, precision and accuracy is required?
How will she judge success?
What is the customer aiming to do with the study?
Does she have the sole authority to make decisions and take action in the area concerned.
If not, of whom is she trying to persuade and of what does she have to persuade them?
What arguments is she having with other stakeholders, especially those with powers of (co-)decision and those in formal review or audit positions?
What are their prejudices and preconceptions?
What is she likely to find controversial in potential analytical approaches to this topic?
What conclusions / results would she really like to see?
What (if any) is their relationship with previous or other ongoing work?
What has been done before in this area? Does she know about it? Was she content with it or disappointed?
Why is this not sufficient? Have new issues arisen? Incomplete treatment previously? Not precise enough? Didn't like the answer?
Additional Stakeholder questions:
Who are they?
What 'buy-in', negotiation or validation do we need from them?
Where do they 'come from' ?
What aspects do they think or may be neglected if the customer calls all the shots?
What debates have they been having with the customer?

4. Problem Formulation Methods

4.1. Get out more!

Just as decision-making is a social process, so is conducting an OR study. As highlighted in the previous section, getting to know and understand your customers and stakeholders is critical to ensure that you are tackling the right problem. Engaging with other people who have tackled similar studies in the past, or who are dealing with the same people, is also productive It helps: identify issues that you may not be able to tackle with customers and stakeholders directly; minimises the possibility of 're-inventing the wheel'; and, it can also open up collaboration opportunities.

4.2. Use stakeholder analysis methods

In addition to asking the questions in table 1, more formal approaches to stakeholder analysis can be conducted. A widely used technique is the Power – Interest grid, to which Attitude has been helpfully added[1]. It is illustrated in Figure 1.

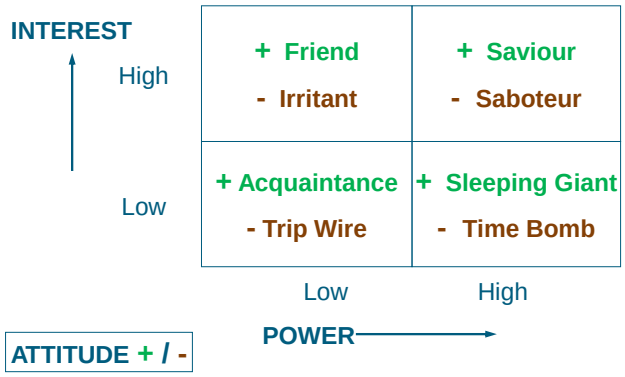

Figure 1 Stakeholder analysis Power - Interest - Attitude grid

Understanding where people and organisations sit within this grid is of use. However, the real value is derived from developing actions to address the findings. Eden and Ackermann (1998) offer useful advice on the stakeholder management process.

4.3. Use 'Soft OR' techniques

Many 'soft OR' / problem structuring methods are designed around the need to understand and address messy problems, elicit stakeholder perceptions and identify the key problems that further (and perhaps 'harder') OR might usefully address. Cognitive / causal mapping and Soft Systems Methodology (SSM) are two commonly used examples. See Rosenhead and Mingers (2001) for introductions to these and other major soft OR methods.

[1] Credited to Lucidus Consulting. See http://www.luciduscconsulting.com/pdf-documents/Lucid-Thoughts/50-Lucid-Thoughts/Chapter-3/Lucid-Thought-24

4.4. Use 'CATWOE' to look at the study itself

Within SSM , the 'CATWOE' construct is used to define systems of interest from different perspectives. This technique can also be extremely useful when it is used to look at the study itself:

- Who are your **C**ustomers?
- Who are the **A**ctors involved?
  - study team; stakeholders; subject matter experts, people affected by the decisions being made ...
- What **T**ransformation(s) do we / they want the study to achieve?
  - What would success look like?
- What are the **W**orldviews of the customer and actors?
- Who is the **O**wner?
  - Who can stop it?
- What are the **E**nvironmental constraints in which the study operates?
  - e.g. time; cost; availability of models, data and subject matter experts?

Dstl experience is that the 'Transformation' question is particularly useful to get a study team to think beyond formal study outputs, to look at how the study can induce outcomes and benefits in the customer's system of interest. This is also discussed in section 7.5.

4.5. Basic systems diagrams are particularly useful

Basic systems diagrams are also a useful mind-clearing and discussion tool. In particular, they help to understand the choices to be made around study scope. These diagrams illustrate the entities, interactions and influences, as 'blobs' and 'arrows'. More formal causal loop diagrams and system context diagrams can also be used. Figure 2 is an example of 'homework' from one of Dstl's internal training activities. The hypothetical exam question was: "*How can shoppers in an Afghan market best be protected?"* The boundaries of 3 alternative study possibilities are shown in orange, blue and green. Respectively they are focused on: guarding and defending markets; minimising the effects of attacks; and, engaging with segments of the population to reduce the desire/ incentives to attack the market. Entities and interactions sitting outside of the chosen boundary are often represented within the study as assumptions.

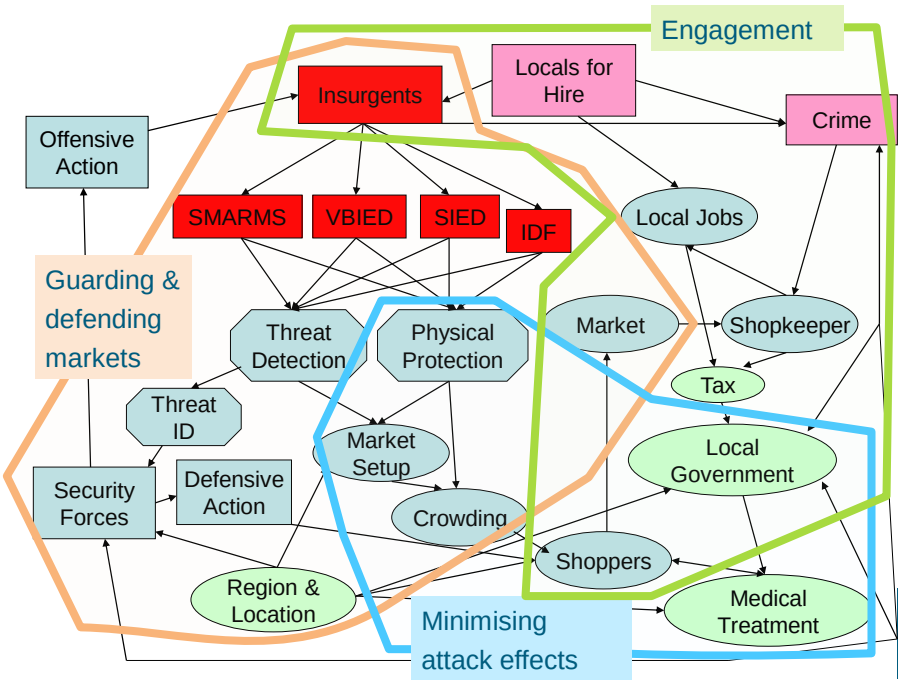

Figure 2 Using systems diagrams to define study scope

5. A General Study Design Process Outline: Doing Things Right

Figure 3 illustrates a generic study design process. The outputs are: a preferred analytical approach; understanding of sources of data and expertise; understanding of risks, opportunities and fallback options; validation and review requirements; and plans for stakeholder engagement and getting the work exploited.

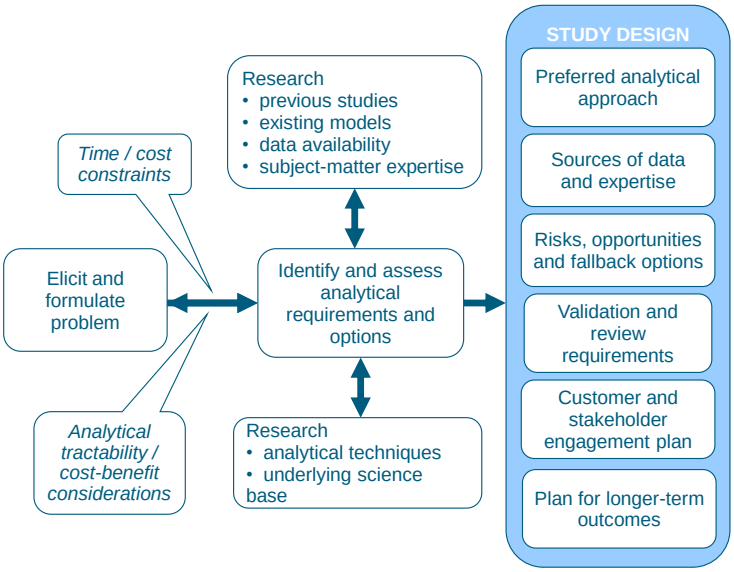

Figure 3 A generic study design process

6. Developing a Preferred Analytical Approach

6.1. Engage experts

Engage your technical and subject matter experts early to develop analysis options. It is likely to be much more productive and cost-effective now than at any other stage of the study.

6.2. Work backwards

A very effective study design heuristic is to work backwards. In the problem formulation activity, we looked to develop an understanding of the form and precision of the answer that customers and stakeholders want. This can now be used to develop an understanding of the analysis approaches needed. Figure 4 illustrates a highly stylised OR process. Options, objectives, assumptions, data and judgements are input into an analysis process, resulting in implications and deductions and subsequent 'what if' iterations. This conventional analysis flow is shown by the green arrows. The 'working backwards' questions are shown in Blue. The associated logic flow is shown with blue arrows. We start at the bottom right of the diagram by asking: what are the scope and type of outputs being sought? We then consider what sorts of analysis would provide that output and then what inputs are required to perform that analysis. Where there's a shortfall, we might then ask whether we can actually answer the posed 'exam question', or just a sub-set of it. In which case, we need to discuss it with the customer.

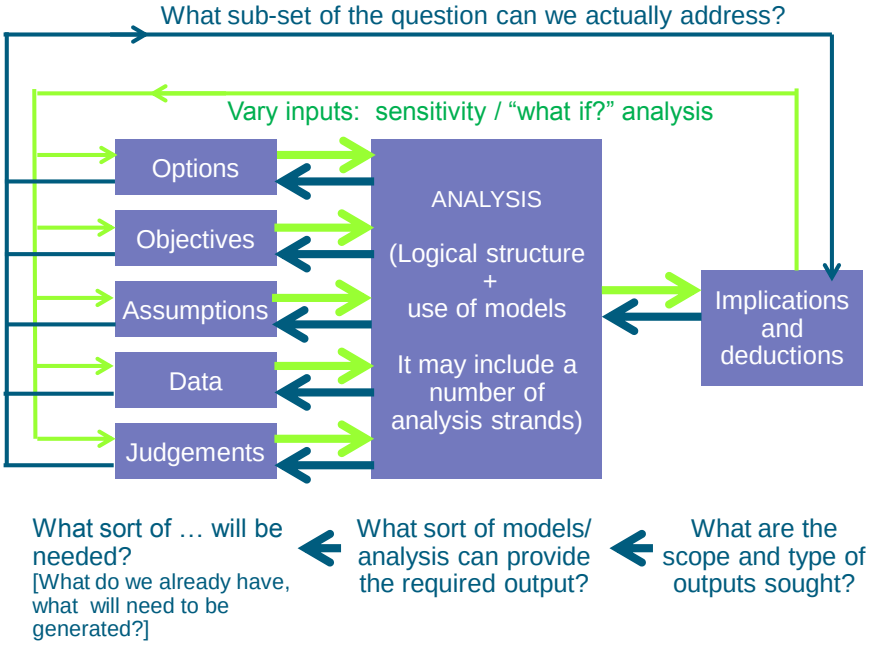

Figure 4 Working backwards to derive a study design

The approach is a good review tool. It will often highlight analysis strands that are otherwise missed. A commonly seen design has many analysis strands all leading into a final ill-defined 'synthesis' or 'fusion' phase. Be wary of this design. It is often an indicator that the design has not been fully thought through. 'Working backwards' can help to identify what that phase needs to involve and the risks associated with it.

6.3. Use experimental design principles

This tutorial does not focus on use of experimental design and many of the ideas overlap with the generic study design principles being developed here. However, a visual overview of experimental design principles is provided in Figure 3 overleaf. This visual knowledge map is part of a series within the Human Environment Analysis Reasoning Tool (HEART) developed by Dstl in collaboration with NATO partners (Jones and Tikuisis, 2011).

The main issues highlighted in Figure 3, which are not covered elsewhere in the paper, include:

- Aim to develop testable hypotheses from the 'exam question'.
- Understand what factors affect the problem and which are inside and outside of our control.
- Develop a formal experimental design if it is appropriate.
- Draw on advice from statisticians.
- Specialist experimental designs exist for design of computer experiments.

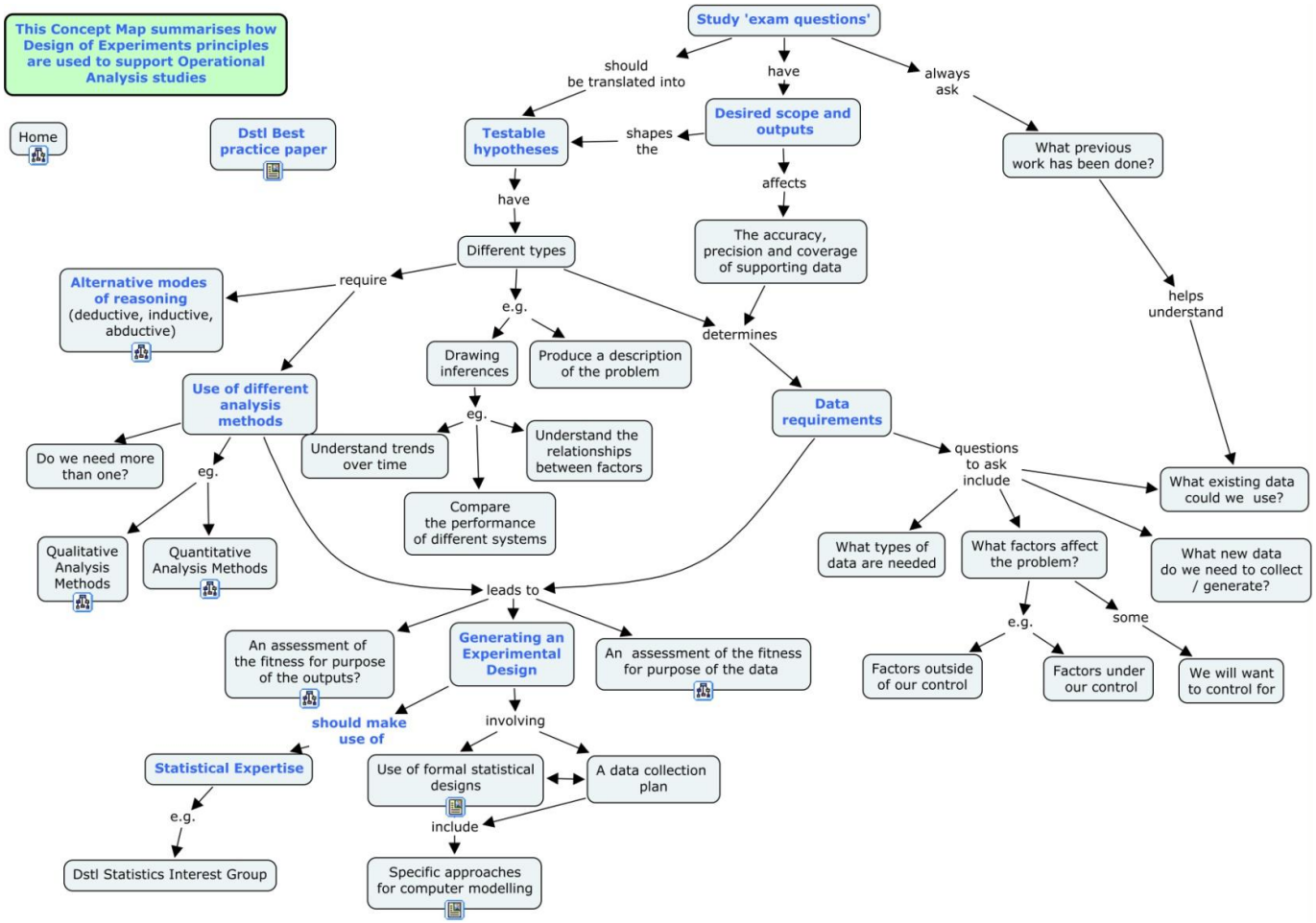

Figure 5 A visual knowledge map showing experimental design principles

7. Other Elements of the General Design Process

7.1. Identifying sources of data and expertise

This is evidently context dependent. However, a general message is to look widely, to reduce the likelihood of 'reinventing the wheel'.

7.2. Examining analytical risks, opportunities and fallbacks

Project Management systems usually place a lot of emphasis on risk management and mitigation. However it is worth exploring risks that might arise from analytical processes. For example, where might it be difficult to carry through the design through lack of data, non-availability of Subject Matter Experts, model development problems, etc? Explicitly thinking about opportunities is also valuable. What opportunities are there to do the work more quickly or cheaply or to adopt a technically innovative approach?

In all the above, what fallback options do we have? Another useful de-risking activity is to perform a pilot study or even a 'quick and dirty' walk-through of the study approach to understand where the pinch-points might be.

7.3. Validation and review

MoD operates a 'fitness for purpose' approach to validation and verification of OR (MoD 2002). This approach does not prescribe a specific 'accreditation' standard, in contrast to the US Department of Defence. However, it is incumbent on analysts to assess fitness for purpose on an individual study basis:

- If existing models are being used, is the existing validation state good enough for a potentially new purpose?
- If we are developing new models, what do we need to do to establish that they are fit for purpose?
- What will the customer and other stakeholders expect?

Regular technical review should also be seen as an integral part of its design. It usually adds considerable value to the analysis and the final products. Reviews may simply consist of a walk-through with colleagues, as well as more formal review processes for documents such as the Concept of Analysis, project plan and study outputs. In Dstl, there is a tendency for such reviews to be 'loaded' towards the end of a study as part of the deliverable production process, or as a reaction to things going wrong. However, greater value is added when they occur up-front to shape design and execution.

7.4. Customer and stakeholder engagement

In section 3 we highlighted the value of understanding customer and stakeholders and in section 4.2 the use of stakeholder analysis was considered. These activities should result in a

through-life engagement plan. This needs to be a two-way process. So, for example, we will want to get customer and stakeholder reactions to emerging results, especially in terms of identifying "what ifs?". We will also want to know what they find easy to understand / accept and what is going to require more explanation.

Reporting (progress reports, informal and formal deliverables) is a key component of the customer and stakeholder engagement process. Again it should be considered as an integral part of study design and engagement process, not just a 'routine' component of project plans. These communications should be tailored to customer / stakeholders' needs. Thus, several outputs may be required. Finally, formal reporting should be 'surprise-free'!

7.5. Having an outcome focus to study design

Within the study design process, we should continue strive to focus on outcomes - the 'transformation' described in section 4.4. Questions like "what would study success look like?" help to focus the design around getting study recommendations adopted and efficiency / effectiveness improved as predicted. Otherwise, we may simply concentrate on production of formal deliverables to meet a decision point, or end of financial year deadline. However, OR should also play an important role advising on post-decision implementation, monitoring and evaluation. An analysis of MoD research projects with an exploitation plan showed that they are "more than three times as likely to show evidence of impact." (MoD, 2004)

A good example of an exploitation / communications plan, was a Dstl study looking at how soldiers engage with local nationals. Rather than producing a report just before the study's end date, it was published 3 months earlier, so that it could be widely socialised. The work was presented, via 'soldier-friendly' briefings, to a large number of audiences. An academic paper was also produced for good measure (Tomlinson, 2009). The use of multiple, tailored mechanisms to communicate study results created the appetite for follow-on work, with Dstl playing a major role in setting up MoD's Defence Cultural Specialists Unit.

8. Other Study Design Approaches

In sections 5, 6, and 7 we have illustrated the use of a number of activities which help develop a study design. For completeness, we now look at a number of other ideas which can also be used to do so.

8.1. Different modes of scientific reasoning

Different modes of scientific reasoning can give rise to different styles of study design:

- **Deduction** is the classical, top-down scientific approach. Stated facts are assumed to be true. They are tested by developing hypotheses that may be proved, disproved or modified. Experimental design principles are based on a deductive approach.
- **Induction** works bottom-up to identify general conclusions from looking at specific cases.

- **Abduction** is a pragmatic hybrid. The process begins with observed results and tentative explanations and hypotheses. These explanations, and possible alternatives, are examined to assess which are the most plausible ones.

It can also be useful to review an emergent study design to see what mode(s) we are adopting and whether that seems appropriate.

8.2. Use generic OR frameworks

A number of generic OR frameworks exist which may be used to develop a study design. Two frameworks are considered briefly: D^{5}IME and a study phase / 'world' matrix.

D^{5}IME is a generic framework being used by the OR Society for its training activities (Royston, 2013). The framework consists of: discovery, diagnosis, desires, design, decision, implementation, monitoring and evaluation. Making a conscious effort to think of activities required in each element of the framework helps to derive a holistic design, for example by:

- Avoiding the temptation to jump to adopting specific analysis methods, before having an adequate understanding of the problem.
- Considering the need for post-decision involvement to promote effective implementation of the decision. For instance, Jones (2012) highlights the use of behavioural sciences to promote desired individual and organisational change. Monitoring and evaluation also help the decision-maker(s) understand whether planned benefits are being realised and enables course correction.

The study phase / 'world' matrix is used by John Mingers in Rosenhead and Mingers (2001) to examine OR multi-methodologies. It provides a useful means to think about how to 'mix and match' different methods. Figure 6 shows the basic matrix.

	Appreciation of	Analysis of	Assessment of	Action to
Social World	social power	conflicts, interests	ways to change power	change power
Personal World	individual beliefs, emotions	differing perceptions	alternative ways of seeing the world	generate consensus
Physical World	physical circumstances	underlying causal structure	alternative structures	Select best alternatives

Figure 6 Study phase / 'World' matrix

The matrix can be used to ensure that you have methods that adequately cover the entire space. Methods are overlaid on the matrix to understand where they contribute. For example, Hard OR methods tend to focus on the Physical World, so do they need to be supplemented by Soft methods to address Social and Personal World issues? The matrix can also be used to review a design, for example, to understand whether methods are compatible and /or are covering the same ground.

Figure 7 is a simple illustration of its use. In this instance, the study aim is to choose options for an enjoyable, and cost-effective, set of OR Society conference events. The study begins with a brainstorm of ideas. A Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis examines the options and wider issues, such as whether any sponsorship is needed. A stakeholder analysis is conducted to help explore who needs to be involved (e.g. the venue organisers, OR Society officials, the Conference committee, sponsors and attendees). A number of options are developed and evaluated using a Multi-Criteria Decision Analysis (MCDA).

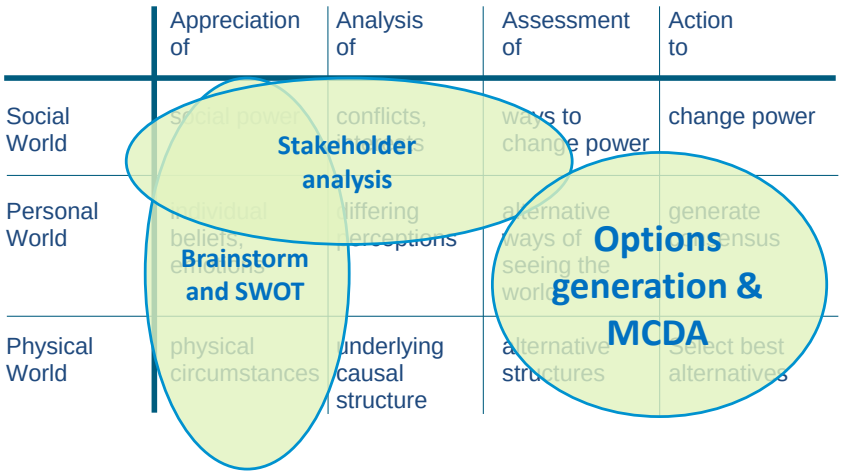

Figure 7 OR Society Conference events options analysis

8.3. Other OR design heuristics

This paper has already covered a number of design heuristics, including 'working backwards', use of scientific reasoning approaches and generic OR frameworks. A number of other heuristics have also been identified which can also be used to help develop elements of a study design (Basnett, Medhurst and Irwin, 2013).

- **Variation of the problem**. Can you vary or change your problem to create a new problem (or set of problems) whose solution(s) will help you solve your original problem?
- **Analogy**. Can you find a problem analogous to your problem and solve that?
- **Generalisation**. Can you find a problem more general than your problem?

- **Auxiliary Problem.** Can you find a sub-problem or side problem whose solution will help you solve your problem?
- **Do you know a related problem?** Can you find a problem related to yours that has already been solved and use that to solve your problem
- **Auxiliary elements.** Can you add some new element to your problem to get closer to a solution?

9. Conclusion

This paper has provided guidance on problem formulation and study design of OR studies. Following the principles set out in the paper should result in higher quality, lower risk studies which deliver long-term benefits for customers and stakeholders.

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