Soft OR and Practice: The Contribution of the Founders of OR

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Abstract

This paper explores the work of some 43 Founders of operations research. In particular it considers the links between soft OR and these Founders. Several of the Founders were direct influencers of the soft OR proponents whilst others related to the context, process and content of soft OR. Coupled with the deductive and inductive reasoning approaches of soft OR, it is argued that soft OR is a legitimate branch of OR. The paper also focuses on the embeddedness of the Founders, and the soft OR proponents, in practice and argues that, for academics, engagement with practice has been and will continue to be an important driver for the health and development of operations research.

Key words: practice, problem structuring, mixed-modeling

Area of review: OR Practice

Introduction

The profiles of some 43 Founders of operations research are presented in the book 'Profiles in Operations Research, Pioneers and Innovators', edited by Assad & Gass (2011). These Founders' pioneering work was carried out mainly in the 40s, 50s and 60s of the last century and in this paper, we explore the link between the Founders and soft OR/problem structuring and the importance of their embeddedness in practice. We then consider implications for the current OR community.

These Founders were selected by Assad and Gass as a result of their interest in the history of OR. They consulted widely and came up with a selection of 50 people 'all of whom had a seminal or major influence on the development and growth of OR'. Eventually for various practical reasons they were only able to obtain 43 profiles for their book.

The research is concerned with soft OR and a derivation of its relationship to the Founders, given that soft OR is to some extent controversial and there is a view that an intervention not involving quantitative modelling should not be classed as OR. Some members of the OR community, particularly in the US, therefore, implicitly (and explicitly e.g. Machol (1980)) deny that soft OR is a legitimate component of OR. Mingers (2011) raises and addresses this issue and argues that the editorial policies of the leading US (and international) journals in ORMS i.e. Operations Research and Management Science, militate against the publication of soft OR papers and thus deny the legitimacy of soft OR; one possible notable exception to this is the work of Siebert and Keeney (2015). Preliminary research by one of the authors also suggests that even in Interfaces (recently rebranded as the Journal on Applied Analytics), the most practice orientated OR journal, there is little discussion of how the problem formulation/structuring phase of OR was conducted and what methods were used.

Mingers goes on to argue that soft OR is well-established in the UK and to some extent elsewhere and has demonstrated its effectiveness in resolving complex ill-structured (wicked) problems. We explore the extent to which the Founders were antecedents of the soft OR movement.

The Founders and the soft OR pioneers were all engaged in practice and we also explore the importance of this engagement in driving the development of OR.

Our methodology involved an initial reading of the book from which we theorized a strong connection between the Founders and soft OR. We then carried out a rigorous directed content analysis (Hsieh and Shannon (2005)) which involved reading the whole Assad and Gass book first documenting connections to various soft OR characteristics and then evidence of the impact of practice on OR developments. Where appropriate we enriched the analysis by studying primary articles or books authored by the Founders.

We first explore the nature of soft OR; we then review some of the many definitions of OR to see to what extent they support the inclusion of soft OR in OR. The next section identifies the Founders who were direct influencers of soft OR. The following sections consider the extent to which the Founders recognized the characteristics of soft OR and to some extent practiced it, followed by some observations on the role of hard (quantitative) OR in solving wicked problems. We then consider the engagement of the Founders with practice and the impact on the development of OR. Finally, we draw some conclusions and implications for the OR community.

Soft OR and Problem Structuring

The motivation for the development of Soft OR stemmed from a concern that hard (quantitative) OR could not solve wicked (ill-structured, complex) problems (Rittel and Weber, 1973) or engage effectively with swamp conditions (messy, confusing problems, Schon, 1987). Rosenhead (1989) discusses this concern in his edited book, that brought together a number of problem structuring

methods (PSMs) that was arguably the first attempt to bring coherence to the field of soft OR. Churchman (1967) argued that mathematical models could only partially and dangerously solve wicked problems and Mingers (2011) in discussing the development of soft OR observed that 'The methods (or methodologies) are not mathematical. He suggests that the characteristics of soft OR methods which might help deal with these problem situations are:

• The methods (or methodologies) are not mathematical, but they are nevertheless structured and rigorous. They are based on qualitative and often diagrammatic modelling procedures. Numerical information may be included, but not complex equations.

• They allow a range of distinctive views to be expressed and explored and embrace multiple and conflicting objectives without collapsing them into a single, often financial, measure.

• They encourage the active participation of stakeholders in the modelling process often through facilitated workshops of those affected by the problem. In order to encourage participation, models should be transparent to participants. This is aided by the first bullet point that they are generally non-mathematical.

• Significant uncertainty is expected and tolerated as is a lack of reliable quantitative data.

• They aim for exploration, learning and commitment rather than optimization.

Rosenhead and Mingers (2001) contribute further to the debate by distinguishing between the process and technical requirements for methods needed to address problem situations exhibiting what have been termed 'swamp conditions' (Schon, 1987) (Table 1).

INSERT TABLE 1 HERE

Pidd (2004) argues that the nature of decisions, particularly strategic ones, is typically messy and complex, involving interactions amongst different participants with diverse views. Because of these

interactions he argues that there is a need to pay attention to the methods and their processes. In particular, he argues that such methods should support 'procedural rationality' where the focus is on the process of choosing rather than rational choice itself.

Ackermann (2012) describes problem structuring methods as follows: 'The basic structure of any PSM comprises the capture and representation of different points of view in some diagrammatic form (e.g. a rich picture, a decision graph or a causal map). These views might be elicited individually or created with a group. This captured material is explored with the group, using various modelling techniques/analyses, to foster development of an enhanced understanding by participants, to enable a shared language to be developed…helping a group negotiate towards a set of improvements and actions to resolve the situation'.

It appears that little distinction is made between soft OR and problem structuring methods. Ackerman suggests that PSMs include, but are not limited to, soft systems methodology (SSM) (Checkland, 1981), strategic options development and analysis (SODA) (Eden & Ackerman (2001)), the strategic choice approach (Friend & Hickling, 1987), as well as drama theory (Bryant, 1997), decision conferencing (Phillips, 1989), robustness analysis (Rosenhead, 1980) and the viable systems model (Beer, 1984). More recent research has explored the identification of characteristics that can be used to determine whether an approach can be classed as a PSM (Yearworth and White, 2014; Smith and Shaw, 2019).

Mingers (2011) has a concern that the term soft OR is seen by many as having negative connotations within OR generally, implying imprecision and lack of rigor' (p730). For example, Machol (1980) asserts that Eden and Jones' case study (1980) of a soft OR application is not OR. Mingers goes on to say that 'another term ''problem structuring methods'' (PSMs), first used by Pidd & Woolley (1980), is sometimes used instead. However, there are also objections to the term PSMs, since it seems to imply that these methods can only structure problems, not actually solve or resolve them and there are many examples of soft methods doing just that p370.'

In considering the use of the terms soft OR and PSMs, we note that soft OR is a complete approach from structuring to decision without the development and solution of a quantitative model and PSMs are methods designed to enact soft OR. We use the term soft OR throughout the paper and it includes PSMs.   However, we do wish to distinguish between soft OR and problem structuring generically. Problem structuring occurs at the initial stages of an intervention to frame the problem and can involve the use of PSMs. A good example of this distinction is the participative development of an influence diagram to structure a problem followed by a system dynamics (quantitative) simulation. The development of the influence diagram is an example of problem structuring but the whole process is not soft OR as it involves a quantitative model. If only the influence diagram were used in a participative process for problem solving, then that would be an instance of soft OR (Wolstenholme and Coyle (1983)). Another example of problem structuring would be Howick & Eden (2011) where the application of a PSM was also followed by the use of a system dynamics simulation model.

From the above contributions we propose below a set of characteristics of Soft OR and their contexts which we will use to gauge the extent of recognition or engagement by the Founders with wicked problems or 'swamp' conditions and soft OR. We can see that the first three characteristics are concerned with the problem situation and its environment and are thus labelled as context. The fourth and fifth characteristics relate to the way that the problem solving is carried out (process) and the final characteristic relates to the nature of the modelling employed. This context/process/content categorization is commonly used to describe strategy interventions (Pettigrew & Whipp, 1991). (Huxham and Cropper, 1994, also used the process/content categories in their paper on facilitation.) The characteristics are:

- An ill-defined problem situation (context).

- The existence of multiple actors or stakeholders with different perspectives and conflicting objectives (context).

- A high degree of uncertainty, intangibles, qualitative and limited quantitative data (context).

- Engagement with and interactions between stakeholders to seek agreement on the nature of the problem, learning and on actions. This may involve the use of facilitated workshops (real or virtual) (process).

- Concern for process issues /procedural rationality (process)

- The use of models as a focus for the discussions which are transparent and understandable. These are typically diagrammatic models such as causal maps, cognitive maps, influence diagrams, decision graphs and rich pictures (content).

Models are key components of both hard and soft OR. Our working definition of the term model is: 'a simplified representation of an aspect of the real world as perceived by its users. Such models may be physical or virtual including symbolic (mathematical), graphical, diagrammatic, or verbal'. In hard OR the models are symbolic, and the analysis is computational, whereas in soft OR the models are typically diagrammatic, and they are the focus of an interactive analysis involving inductive and deductive reasoning between the stakeholders.

What is Operations/Operational Research?

In this section we explore some of the many definitions of OR and the extent to which they encompass soft OR. The terms operational research and operations research are used interchangeably with the former having its origins in the UK and the latter being the US term; here we use the abbreviation OR. Blackett, often referred to as the Father of operational research, writing in 1950, noted that "Many attempts have been made to define operational research and nearly all include some such phrase as 'the application of scientific method.'….In more detail, scientific method may be defined as that combination of observation, experiment and reasoning (both deductive and inductive) which scientists are in the habit of using in their scientific investigations." (Blackett, 1950)

A variety of definitions of OR exist which typically highlight that it involves the scientific method and the development and use of analytical methods and quantitative/mathematical models to improve organizational decision making as the following examples illustrate.

Informs states that 'OR is the application of scientific & mathematical methods to the study & analysis of problems involving complex systems…. Regardless of their chief field of interest, operations researchers have certain methods in common. They begin by immersing themselves in the details of the problem they're studying. They talk with people involved in all aspects of it, learning about their perspectives and needs, and they examine available data, separating that which is truly relevant from that which is not. (INFORMS, 2019).

The early stages of problem solving are also explicit in the analytics framework of the Certified Analytics Professional qualification established by INFORMS where the first two of the seven domains of the analytics process are business problem framing and analytics problem framing, and the fourth stage is methodology selection.

The UK OR Society state that: 'Operational research (OR) is a scientific approach to the solution of problems in the management of complex systems that enables decision makers to make better decisions….' Most of the problems OR tackles are messy and complex, often involving considerable uncertainty. OR uses advanced analytics, modelling, problem structuring, simulation, optimisation and data science to determine the best solution to the problem and the best practical course of action.' (The Operational Research Society, 2019)

EURO state that: "Though there is no "official definition" of Operational Research ("Operations Research" in the US), it can be described as a scientific approach to the solution of problems in the management of complex systems. In a rapidly changing environment, an understanding is sought which will facilitate the choice and the implementation of more effective solutions……Most of the problems OR tackles are complex, often entailing considerable uncertainty. OR can use advanced

quantitative methods, modelling, problem structuring, simulation, and other analytical techniques to examine assumptions, facilitate an in -depth understanding and decide on practical action." (EURO, 2019)

The Canadian OR Society state that: 'Operational research (OR), also called operations research, applies systematic analytic techniques to improve decision-making…..OR uses math, computing, engineering, and business skills to develop efficient and effective solutions to both small and large problems.... Operations researchers generally are strong in both quantitative and interpersonal skills.' (The Canadian OR Society, 2019)

In considering whether Soft OR lies within the realm of OR, the UK & EURO definitions explicitly include problem structuring whilst INFORMS also refers to a scientific approach and to the importance of engaging stakeholders and identifying their needs and perspectives. The Canadian definition includes 'applies systematic analytic techniques to improve decision-making' which encompasses soft OR.   The case for including soft OR in the scope of OR is therefore that: problem structuring is recognized explicitly in Europe; it is a systematic analytical procedure; it stresses the importance of process in the formulation of problems; and that it employs the scientific method of deductive and inductive reasoning in developing diagrammatic models and in its problem structuring and resolution processes.

Soft OR Influences (by Founders)

In this section we consider the influence of the Founders as recognized by the leading proponents of soft OR.

Eden (1988) advocated the use of cognitive mapping as a building block to structure and solve ill-structured problems. The approach was developed into SODA – strategic options development and analysis. His initial expertise was in dynamic programming and simulation, but he found these difficult to use when engaging with managers. His move to the use of cognitive maps was influenced

by Ackoff ('within the OR world Ackoff and Checkland have worked hard to relate coherent theory to their own consulting practice') and Ackoff's ideal design scenario; Saaty's analytic hierarchy process; inverting current assumptions about the situation (Mason & Mitroff, 1981) (not profiled in the book)); and building models that force "counterintuitive" outcomes e.g. Forrester's system dynamics. He also recognized that cognitive mapping as an OR technique depends upon the application of coding principles that relate to hierarchies as enunciated by Simon in his book "The Architecture of Complexity" (Simon, 1962). He also considers that critical path analysis (a topic related to many of the Founders) with PERT overtones works not so much because of the quantitative analysis but because it prompted the consultant to ask sensible questions and the modelling technique was simple, diagrammatic and consequently transparent to the client.

Friend and colleagues developed the strategic choice approach, another pillar of soft OR. The main source is the book 'Planning under Pressure: The Strategic Choice Approach' by Friend and Hickling (1987). The book is an account of the development of the strategic choice approach during a lengthy period of deep engagement with problems at Coventry City Council (a city in the UK). The book has no references so we can conclude inferences about the influence of the Founders from the bibliography which contains the following works of the founders: Ackoff, A Concept of Corporate Planning (1970) and Redesigning the Future (1974); Beer, Decision and Control (1966) and Brain of the Firm (1972); Howard, Paradoxes of Rationality (1971); Raiffa, Decision Analysis (1968) and Mason & Mitroff, Challenging strategic assumptions (1981) – not profiled as observed earlier.

Rosenhead (Rosenhead et al, 1972) developed robustness analysis, a problem structuring method aimed at keeping future options open and refers to Ackoff's idealized design but implicitly questions whether working towards a single future scenario is realistic.

Bennet, Bryant, and Howard (2001) developed drama theory, a modelling approach to resolving conflict which has its origins in game theory developed initially by Von Neumann (a Founder) and Morgenstern.

Checkland developed soft systems methodology (SSM), a systems approach to problem solving. He developed the approach as a consequence of finding limitations to the more mechanistic systems engineering approaches. The approach was developed outside the OR community but has been adopted as a leading PSM. In his early paper on SSM, Checkland (1971) cites Ackoff, Beer and Churchman as influencers.

Phillips (1989) developed decision conferencing, a workshop based approach to problem solving which exhibits many of the characteristics of PSMs although it often leads to quantification. He cites as influencers Keeney and Raiffa (1976) and Howard (1966).

From the above we can see that the direct influencers of the leading soft OR proponents among the Founders were Ackoff, Churchman, Forrester, Beer, Saaty, Simon, Howard, Keeney, Raiffa and Von Neumann.   Perhaps the key influencers were: Churchman (1967) with his concern that mathematical models could only partially and dangerously solve wicked problems; Ackoff (1979a, 1979b) who was concerned about the increasing inappropriateness of OR's methodology in focusing on the concept and practice of optimization and its pursuit of objectivity, and advocated a re-conceptualizing of OR; and Beer with his holistic approach to complexity and his participative approach.

Soft OR and the Founders

In the following sections, we consider the extent to which the Founders were concerned with the context, process and content characteristics of soft OR. Our principal source of evidence is the Assad and Gass book (2011) with the chapters on each Founder listed in the online appendix. We

shall not make specific references to the book in the text as that would interfere with the flow of the text, but the relevant page numbers appear in Tables 2, 3 and 4, available in the online appendix. Where the evidence comes from other articles or books, we have referenced them in the text.

The Context of Soft OR and the Founders

The context of soft OR includes the complex nature of the problem situation, swamp conditions or wicked problems. Ackoff became concerned about strategic issues which exhibited the soft characteristics and believed that hard (mathematical) OR was not equipped to solve strategic problems. Beale worked on strategic modelling in the highly complex British National Health Service (McDonald et.al. 1974). Beer was concerned with adopting a holistic approach to complex organizational problems and indeed attempted to model the complexities and uncertainties of the Chilean economy. Bellman was concerned with applications in societal problems and new problem areas where qualitative features were important. Much of Blackett's early work explored new and emerging problems in the military field, which by their nature are initially ill-defined and involve a degree of uncertainty and lack of data. Blumstein was concerned with the complexities of the criminal justice system. Churchman was concerned with wicked problems – complex social systems, ill-formulated, confusing information, with many stakeholders with conflicting values and was convinced that providing partial solutions (those parts amenable to mathematical modelling) was morally wrong. Cooper recognized that the oil refinery scheduling problem was inherently probabilistic.

Forrester was concerned with complex business and public policy problems, from start-up companies to urban and global development. Gass recognized the involvement of multiple stakeholders with multiple objectives. Gomory explored the challenging problem of international trade. Goodeve chaired the advisory board of the Institute for Operational Research, set up to tackle complex social problems and the home of strategic choice, one of the early soft OR

techniques. Hertz recognized that uncertainty was the Achilles heel of capital investment appraisal.

Howard was interested in strategic executive decision-making where there was little or no data – the

problems that kept them awake at night. Johnson suggested that the frontiers of OR would be the

complex and unstructured problems arising in regional and world development, the field of

medicine, and the field of charities. Kozmetsky focused his work on large-scale unstructured

problems that required transdisciplinary and collaborative research and methodologies. Miser was

concerned about assisting people responsible for policy or action to develop, understand, select, and

implement what should be done in an uncertain environment to advance human welfare (the

swamp).

Morse focused on the hazy interface between science and high-level policy decisions - the latter

usually dealing with complex objectives that are sometimes jealously guarded by the egos and

financial or political fortunes of decision makers. Raiffa was concerned with the different objectives

and perspectives of the parties to negotiations. Rivett noted that, in general, the problems which

management face are ill-defined; he also developed approaches to policy analysis where problems

were not only ill-defined but where there was additionally only fragmentary information. Roy

focused on complex problems with multiple stakeholders having multiple perspectives and multiple

objectives. Saaty also focused on complex, multi-criteria real world problems, involving different

stakeholder groups with different positions and priorities. Simon (1990) was of the view that the

systems we wished to model were an order of magnitude more complex than could be

computerized; his work on bounded rationality recognized the complexity of the situations facing

decision makers. Vaszonyi recognized that post World War II management problems had increased

in scope and complexity and involved different stakeholder groups.

Of the soft OR influencers who wrestled with the context issues, we would not be surprised to see

Ackoff, Churchman, Forrester, Saaty, Simon, Beer, Howard and Raiffa appear here. However, Beale,

Bellman, Blackett, Blumstein, Cooper, Gass, Goodeve, Gomory, Hertz, Johnson, Kozmetsky, Little,

Miser, Morse, Rivett, Roy and Vazsonyi, like the soft OR pioneers, also recognized the extreme complexities of many problem situations

The Process of Soft OR and the Founders

The process of soft OR involves a deep engagement with multiple stakeholders who may well be from interdisciplinary backgrounds although that is not explicitly stated as a feature of the process design. Ackoff developed an approach involving idealized design, visioning and interactive planning which was process orientated and aligned well with the process aspects of problem structuring and arguably laid the foundation of the field of soft OR. He worked closely with stakeholders in seeking to explore and solve their problems. Additionally, he believed in taking an interdisciplinary approach to decision making.   Arnoff was interested in process issues, probably due to his belief in the importance of social capital. He had a concern for taking a team approach and viewing a study within its contextual environment. Beale showed concern for which models to use and when; he was also concerned with the working relationship with clients. Beer worked on participative methods designed to enable large groups to arrive at solutions to their own problems.   Blackett's pioneering work in military OR was undertaken by a multidisciplinary team, bringing different perspectives, which came to be known as Blackett's circus. His work typically brought him into contact with a variety of decision makers and stakeholder groups such as military leaders and personnel. Blumstein recognized the strong ideological stakeholder perspectives that permeated the criminal justice system. Bonder advocated maintaining close relationships with key stakeholders and clients; he also noted lessons learned from his work with the military that were relevant to the process of OR.

Churchman advocated the involvement of multiple stakeholders with their different perspectives in problem formulation, learning and developing action plans, often with the use of facilitated workshops. He saw OR as a 'method of inquiry' and became interested in wider process-related

issues such as OR practice and implementation. Forrester engaged managers in the modelling

process. Gass recognized the use of teams in structuring problems and the possibility that different

stakeholders may be involved. He was also aware of the need to both develop and manage the

modelling process. Gomory recognized the multiple stakeholders concerned with international

trade and their conflicting objectives. Goodeve was conscious of the role of individuals and groups

and worked with Ackoff and Miller to create the Institute for Operational Research (IOR) within the

Tavistock Institute of Human Relations (Friend and colleagues in IOR developed the strategic choice

approach, recognized as a key problem structuring method). Little recognized the place for different

stakeholders in the decision process and recognized that involving clients in the early phases of a

modelling process (e.g. conceptual modelling) was important, particularly when data was

unavailable. Miser, in his paper entitled 'Craft in operations research' (1992) demonstrates a

number of principles of modelling and lessons learned from his experience relevant to the process of

OR.

Morse emphasized the requirement to take account of the needs of different users and was

concerned with the progressive stages of the modelling process noting the importance of a post-

implementation review of the analytical work. Raiffa developed processes for negotiation involving

multiple decision makers and their judgements and key uncertainties, as did Saaty though their

approaches differed, with Saaty developing the analytic hierarchy process. Rivett demonstrated his

concern for process-related issues by identifying nine principles of modelling (Rivett, 1994) as well as

a number of texts on the OR method (e.g. Rivett 1968, 1972). He also signaled his recognition of

multiple stakeholders, noting that there needed to be continual contact with those who would affect

or be affected by the OR work. Roy recognized the importance of multiple objectives and interacting

with stakeholders in his development of the ELECTRE method (1968); his method also explicitly deals

with qualitative information and preferences. Simon's process-related work distinguished between

substantive and procedural rationality; his phases of decision making had a strong influence on Vazsonyi's thinking and approach to problems (Weida et al, 2001, Simon, 1957).

Again, unsurprisingly many of the soft OR influencers appear here - Ackoff, Beer, Churchman, Forrester, Raiffa, Roy, Saaty and Simon. However, many of the other Founders also were concerned about process issues including Arnoff, Beale, Blackett, Blumstein, Bonder, Gass, Gomory, Goodeve, Little, Miser, Morse, Rivett and Vazsonyi.

The Content of Soft OR and the Founders

The content of soft OR focuses on the use of transparent, often diagrammatic, models. Such models typically incorporated qualitative information. Ackoff was concerned to incorporate a range of qualitative variables to capture uncertainty inherent in social and psychological variables. Beer developed the viable systems model which was essentially diagrammatic and indeed is often cited as a soft OR model. Blackett's reframing of the problem of aircraft color, when discussing the issue with one of the stakeholders, illustrates his concern with softer conceptual issues which complemented the quantitative analyses he undertook. Blumstein used diagrammatic flow diagrams of the criminal justice system as a precursor to a quantitative model. Bonder's work led him to develop a diagram of the modelling process and its component activities/elements (Bonder, 1973). Forrester advocated the capturing of mental models and the use of influence diagrams and stock and flow diagrammatic models. Gass was a proponent of the analytic hierarchy process (AHP) which involves the use of diagrammatic hierarchical models to structure problems. Geisler designed a descriptive model of logistics, emphasizing levels, processes, inputs, and outputs. He also used AHP. Howard advocated the use of influence diagrams to represent the structure of decisions.

Kozmetsky often used diagrams to explain problems to others; he called such diagrams typical George diagrams. Little developed a graphical method for profit analysis and was in favor of transparent models; he also used figures to explain arguments about queuing situations. Magee

advocated the use of decision trees to capture uncertainty and structure investment decisions. Raiffa advocated displaying the problem in various ways such as a diagram, a chart, a table or graphically. For example, he describes the use of a decision-flow diagram for presenting "the anatomy or the qualitative structure of the problem" (Raiffa, 1968, p10). Rivett advocated the use of the mapping of multi-dimensional scaling for choosing policies from a range of alternatives. Roy used graphical displays within his ELECTRE method and also research and wrote about graph theory. Saaty was the original developer of AHP which was followed by the analytic network process (ANP), both of which are based around structured processes and make use of diagrammatic models. Simon (1990) raised the issue of whether there are aspects of the situation of interest that are better modelled symbolically, in words or pictures, rather than numerically. Vazsonyi used his GOZINTO (input/output) diagrams showing a pictorial representation of materials requirements to communicate with key stakeholders.

Of the soft OR influencers who used diagrammatic models we have Ackoff, Beer, Forrester, Howard, Raiffa, Saaty and Simon, but again we also have a number of other Founders including Blumstein, Bonder, Gass, Geisler, Kozmetsky, Little, Magee, Rivett, Roy and Vazsonyi. There is no direct evidence that they influenced the soft OR pioneers although the pioneers will have been aware of several of these. Some of the models used by these Founders would have been amenable to further analysis; others served illustrative purposes but still may have acted as facilitative devices to support discussion amongst stakeholders.

Summary of the Relationships of Soft OR Characteristics and the Founders

From the above sections we can see that many of the Founders were very conversant with contexts which are the concern of soft OR. In addition to the soft OR influencers a number also explicitly described or developed processes involving stakeholders and more of them may have done so informally. Many of them also used diagrammatic models although often followed by quantitative

modelling. They therefore to a large extent recognized and practiced problem structuring although apart from the soft OR influencers it was rarely prominent in their writings. Also, there are few instances outside the soft OR influencers, of Founders relying solely on soft OR i.e. coming to an agreement or solution without any quantitative modelling.

Tables 2-4, available in the online appendix, summarize the sources of the evidence that we have found of each of the Founders engaging with the six characteristics of Soft OR identified previously. We have organized the tables such that table 2 shows the Founders for whom there was evidence of engaging with 5-6 of the characteristics; table 3 shows the Founders for whom 3-4 of the characteristics were satisfied and table 4 where only 1 or 2 criteria were satisfied.

We have ten Founders whose work is aligned to 5 or 6 of the 6 soft OR characteristics). Six of them of them were soft OR influencers but four (Blackett, Little, Roy and Rivett) were not, or at least were not explicitly cited by the soft OR pioneers. Most of the Founders work aligns with at least some of the characteristics.

Many of the Founders can thus be aligned with several of the soft OR characteristics although they mainly stopped at problem structuring and only one or two (e.g. Churchman, Ackoff) ventured to decision making without quantitative analysis. Several Founders appear to have little connection with soft OR, but their engagement in practice opens the possibility that they did recognize the process issues but chose to focus in their writing on hard modelling.

Wicked Problems and Hard OR

The context of soft OR is an ill-defined or wicked problem situation, or swamp conditions, and the proponents of soft OR suggested that mathematical models are not useful, or have limited use, in such situations. Churchman went even further to suggest that providing partial solutions by mathematical modelling was morally wrong.   The soft OR proponents however preferred to try and

influence the OR community but their denial initially of the potential for mathematical modelling to solve wicked problems led to a significant part of the hard OR community ignoring or disowning soft OR. Although trying to model a wicked problem wholly by an optimization model would be highly problematic it is hard to see why a hard model of part of a system if used in a decision support mode has necessarily to be ruled out on the grounds of either feasibility or morality.

The idea of mixed modelling was explored first by Mingers and Brocklesby (1997) who argued that real-world problems are inevitably very complex, having both relatively hard and quantifiable aspects but also soft unquantifiable aspects, thus requiring both hard and soft methods.

At the University of Warwick at both the University corporately and the Business School, soft methods such as cognitive mapping, SWOT analysis and brainstorming have been used to develop strategic options, but in each case, they were tested by a corporate financial model (e.g. Dyson, 2004). The latter model is hard if in mathematical terms relatively simple but nevertheless surely the use of a corporate financial model is a valid exercise in helping to tackle strategic issues which are necessarily ill-defined. In supporting litigation for over-runs in the costs of the channel tunnel, surely a wicked problem, Ackermann et al (1997) use cognitive maps to structure the situation followed by a system dynamics simulation, a hard modelling technique. Lane and Oliva (1998) argued for combining SSM and system dynamics. Scheubrein & Zionts (2006) use problem structuring as a front end to a multi-criteria analysis. Howick and Ackerman (2011) survey the use of mixed methods and Kotiadis and her team advocate and then use a problem structuring method (SSM) to support the development of discrete event simulation modelling (Kotiadis et al, 2013; Tako and Kotiadis, 2015). Franco and Montibeller (2010) advocate facilitated modelling.

Given the emergence of mixed soft and hard modelling, we can see that the soft OR community recognize that hard models can have an important role to play in resolving wicked problems. As the early stages of hard modelling involve the processes of problem framing and formulation, although

they are rarely articulated in accounts of hard modelling, it would strengthen OR if the hard and soft

communities came to recognize the contribution that soft OR can make to the general development

of OR by bringing greater rigor to these processes. One could also imagine hard modelers using a

soft OR process to help develop a range of different mathematical models of a situation reflecting

stakeholders' differing viewpoints. For example, Sarrico and Dyson developed separate data

envelopment analysis (DEA) models of universities from the perspectives of the student (Sarrico et al

1997) and the institution (Sarrico and Dyson, 2000).

The Impact of Practice on Developments in OR.

The Founders were mainly practitioners turned academics or academics who engaged substantially

with practice (as were most of the pioneers of soft OR as noted earlier). A few of the Founders were

practitioners who researched and developed methods. Many of the Founders made significant

theoretical developments and produced seminal articles, which stemmed from their experiences in

practice. Balas developed an approach to solving the travelling salesman problem as a result of his

work at LTV Steel on scheduling their steel rolling mill (Balas, 1989). His interest in forest harvesting

led to his development of the additive algorithm for 0-1 programming (Balas, 1965). Cooper coined

the term 'application-driven theory' to characterize this kind of work (Cooper & McAlister, 1999).

(The phrase 'necessity is the mother of invention' also resonates with this approach.) Data

envelopment analysis was developed to evaluate an educational program as a part of Rhodes' PhD

with the resulting seminal article 'Measuring the efficiency of decision-making units' by Charnes,

Cooper and Rhodes (1978).

Beale, a practitioner, was engaged in scholarly research and also authored a book entitled

'Mathematical Programming in Practice' (Beale, 1968). Dantzig's work at the Pentagon which

focused on the allocation of air force resources led to his interest in linear programming and the

development of the simplex method (Dantzig, 1963, 1988). Forrester's interest in large fluctuations

in production, inventories, employment, and profit at GE led to the development of system dynamics modelling (Forrester, 1961, 2007). Gomory's work for the navy, where fractional numbers of aircraft carriers were not an option, led to the development of the cutting plane method of integer programming. With Gilmore he visited steel plants, glass plants and paper mills to develop an understanding of their manufacturing problems which led to their seminal work on cutting-stock problems (Gilmore & Gomory, 1961; 1963). Hertz worked as a consultant in the 50s and 60s and his experience led him to develop the field of risk analysis with the initial seminal paper 'Risk analysis in capital investment' (Hertz, 1964). Raiffa became interested in public policy problems which led to his pioneering work first published in 'Preferences for multi-attributed alternatives' (Raiffa, 1969), which laid the foundations of multi-criteria analysis.

Fulkerson in collaboration with Ford laid the foundation of the field of network flows in their paper 'Maximal flow through a network, Research Memorandum' (Ford & Fulkerson, 1954), which was inspired by a military application focused on the Eastern European railway network. Roy developed the ELECTRE method to solve a range of real-world multi-criteria problems which was first published in 'Classement et choix en présence de points de vue multiples (la méthode ELECTRE)' (Roy, 1968).

The Founders were thus all engaged in practice. They sought out new problem areas for the application of OR methods and most significantly many key theoretical and methodological developments stemmed from their immersion in practice.

Conclusions and Discussion

It has been argued that soft OR is not a legitimate branch of OR as it does not involve the use of a quantitative model in problem solving. However, there is strong evidence both from the Founders of OR and from the pronouncements of North American and European societies that soft OR is a legitimate subset of OR.

A study of the Founders of OR shows that several them were direct influencers of the early soft OR proponents. Additionally, many other Founders, not usually seen as being associated with soft OR, nevertheless recognized some, if not all, of the context, process and content characteristics of soft OR. This evidence alone should be sufficient to establish the legitimacy of problem structuring at the early stages of an intervention, if not necessarily soft OR (i.e. coming to a decision without a quantitative model). Furthermore, the UK OR Society and EURO explicitly recognize soft OR or problem structuring and INFORMS characterizes OR by the use of the scientific method and the importance of process in problem formulation. Soft OR with its emphasis on process in the framing and formulation of problems and its inductive and deductive reasoning should therefore be universally recognized as a legitimate branch of OR even if some members of the OR community would not wish to proceed to a decision without a quantitative model.

Although an early stance of soft OR was that mathematical models are not useful in resolving wicked problems the emergence of mixed soft and hard modelling indicates that hard models can have an important decision support role in such contexts.

A further common link between the proponents of soft OR and the Founders is that both groups were heavily engaged in practice. Many of the key modelling developments such as the simplex method, integer programming, data envelopment analysis, system dynamics, multi-criteria analysis, network analysis and risk analysis all stemmed from the engagement of the Founders in wrestling with practical problems, and Eden, Friend and Checkland developed their problem structuring methods due to a perceived practical need.

The early disconnect between the soft and hard OR communities stemmed from the unwillingness of the hard community to recognize soft OR as OR due to the lack of quantitative modelling and analysis whilst the soft community considered that wicked problems could not be solved by quantitative models. But by denying the legitimacy of soft OR the hard community have also largely

ignored, or not been concerned about, the process of problem structuring at least in their publications. However even for hard modelling the exploration with stakeholders, the structuring of the problem, the development of diagrammatic representations and the choice of methodologies are crucial stages which deserve the explicit systematic exploration of problem structuring rather than ad hoc approaches which are not open to scrutiny and may well lack rigor. This structuring may not involve specific problem structuring methods but should certainly involve the process characteristics of soft OR and often diagrammatic models. (Following some of the Founders, a report by Waisel et al (1997) explored the use of diagrammatic representations of mathematical models, although the paper was largely ignored.)

We are thus advocating that hard OR should embrace the rigorous and transparent approach of soft OR in problem formulation and address problem structuring in their publications where appropriate. One could also imagine developing a range of different mathematical models of a situation reflecting stakeholders' differing viewpoints. Conversely, one could imagine using SSM in a hard manner to design a system. Implementation is often raised as a problem in enacting hard OR models, and the deep engagement with stakeholders and the transparency of soft OR may well help to resolve that issue.

The soft OR community, whilst retaining their belief that hard modelling is rarely sufficient to solve wicked problems, do now recognize that quantitative models can have an important supporting role to play. However, they should perhaps be less concerned about the purity of problem structuring methods and more concerned about generic problem structuring. It may also be the case that there is no black and white distinction between wicked problems and the others. For example, even in production scheduling and capacity planning there are uncertainties and multiple stakeholders with competing perspectives. We thus advocate that the soft OR community, whilst retaining their concern with specific problem structuring methods, should additionally embrace generic problem structuring, applying their process and transparency approaches to all problems. One consequence

of this perhaps is that the teaching of soft OR could be within a generic problem structuring framework.

Many current OR academics do engage with practice as did the Founders and the soft OR proponents, but many others also focus purely on developing mathematical methods to solve stylized problems (puzzles) without reference to any real problem situation. This is a consequence of the need to publish in highly ranked journals whose main criterion for publication is theoretical development. (This publishing need is also a potential pressure on soft OR academics). Articles on model development are more likely to be cited by other academics and citations are a key driver of journal rankings. Hence a vicious circle can develop where some academics know more and more about less and less and can become disconnected from the real world. (This issue has been a concern in the Academy of Management for some years e.g. Vishwanath et al (2017)). The potential danger of this trend is that much of OR could become ossified, focusing mainly on an historical problem set that has increasingly limited economic or social impact thus denying its heritage.

The Founders, however, were all engaged in practice. They sought out new problem areas for the application of OR methods and most significantly many key methodological developments stemmed from their immersion in practice. Eden and Ackerman (2019) discuss the importance of the interplay between theory and practice in the context of soft OR showing it can both support practice and develop theory. The implication for all OR academics therefore is to engage with practice as a fertile source of stimulation and ideas and like the Founders expand the problem domain to increasingly encompass the new challenges presented by, for example, climate change, sustainability, social networks, big data and the increasing global turbulence many of which are wicked problems. OR in general should therefore retain its problem-solving focus rather than focusing predominantly on methods and models. Nevertheless, it should be recognized that theoretical developments of, for example, the travelling salesman problem leading to solutions involving large numbers of cities has also led to improved practice in real sequencing and scheduling problems. (In the sixties when

wishing to sequence glass cutting patterns, we could only sequence 20 or so optimally although we were typically dealing with over a hundred (Dyson & Gregory, 1974)).

There may also be a message for practitioners. The early practitioners often found the time to develop their work for publication making an important contribution to the development of OR. This source of innovation seems to be less prevalent these days, perhaps due to time pressures on practitioners. If that is the barrier then a way forward may be for greater collaboration between practitioners and academics to further the advance of OR.

Rather than seeing the mathematical modelers and the soft OR adherents as separate schools, a way forward for the development of OR would be to recognize the commonalities and to build on the strengths of the different approaches. This may involve a broader engagement with practice, greater academic practitioner collaboration, a recognition of the value of formal problem structuring in solving the vast majority of problems and collaboration between hard modelers and soft OR experts. The developing field of mixed modelling, has a key role to play here and offers opportunities for collaboration between the two communities.

Acknowledgements

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'Swamp' conditions	Process requirements for appropriate methods	Technical requirements for appropriate methods
Multiple actors	Permitting alternative perspectives	Diagrammatic
Multiple perspectives	Participative/interactive	Exploration of solution space
Incommensurate/conflicting interests	Iterative	Discrete options
Prominent intangibles	Supporting partial commitment	Possibilities
		Scenarios

Table 1: Swamp conditions – process and technical requirements (Rosenhead and Mingers, 2001, P15)

Online Appendix

Assad AA, Gass SI (2011) Profiles in Operations Research, Pioneers and Innovators. The International Series in Operations Research & Management Science, Springer.

Chapters:

Founder	1. Ill-defined problem	2. Existence of multiple stakeholders	3. Uncertainty and limited quantitative data	4. Engagement with stakeholders	5.Concern for process issues	6. The use of diagrammatic models
Russell L Ackoff	p395/398	p394	p395-397	p394	p395&397	
Anthony Stafford Beer	p603-4	P604 & 606	p604-5	p606	P604	p604-5
Patrick Blackett	P5-10	p6&12	P10&22	p8/12	P8&13	
C West Churchman	p188	p185/188	p181	p183	p178 & 181-2	
Jay Wright Forrester	p375-8	p369		p373	P371-4	p373/377
John DC Little		p664	p668	p664	p668	p663
Howard Raiffa	p499	p499	p502-3	p499	p502-3	Raiffa 1968, p10
Patrick Rivett	1Rivett, 1968 p159	Rivett, 1974 p 273	p479	Rivett, 1968 p160, 161	p487	Rivett, 1977
Bernard Roy	p767	767	p762/767	p767	p767	P762/765
Thomas L Saaty	p581	p581	p583	p584	p583	p584/586

Table 2 – Founders who satisfy 5-6 criteria

Founder	1. Ill-defined problem	2. Existence of multiple stakeholders	3. Uncertainty and limited quantitative data	4. Engagement with stakeholders	5.Concern for process issues	6. The use of diagrammatic models
Alfred Blumenstein	p711	p712/715				P714
Seth Bonder		p748	P747		p747	p743
Saul I Gass		p564		p564	p563-5	p563
Charles Frederick Goodeve	p93	p93		p93		
Ronald A Howard	p783		p783			p787
Hugh Jordan Miser	p317		p316		p312 & 318-9	
Phillip Morse	p62	p62		p62	p52&62	
Herbert A Simon	p262				p260 &282	Simon, 1990
Andrew Vazsonyi	p281	p280			p282	p280

Table 3 – Founders who satisfy 3-4 criteria

Founder	1. Ill-defined problem	2. Existence of multiple stakeholders	3. Uncertainty and limited quantitative data	4. Engagement with stakeholders	5.Concern for process issues	6. The use of diagrammatic models
E Leonard Arnoff				p466	p466-7	
Egon Balas						
Evelyn Martin Lansdowne Beale	McDonald et al,1974				p683/5	
Richard E Bellman	p435-6		p435-6			
Abraham Charnes						
William W Cooper			p211			
George Dantzig						

D Ray Fulkerson				
Murray Aaron Geisler				p304-5
Ralph E Gomory	p702	p702		
David Bendel Hertz			p407	
Ellis A Johnson	p153			
Leonid Vital'evicj Kantorovicj				
George F Kimball				
George Kozmetsky	p357			p337
Harold W Kuhn				
John F Magee			p619/621	p621
Harry Markowitz				
John von Neumann				
Jacinto Steinhardt				
Albert W Tucker				
Stephen Vajda				
Philip Starr Wolfe				
Harvey M Wagner				

Table 4 – Founders who satisfy 0-2 criteria