What is System Dynamics? A Paradigmatic Inquiry

Erik Pruyt
Vrije Universiteit Brussel, Business School Solvay
Dept. for Maths, OR, Stats and IS for Management
Pleinlaan 2, 1050 Brussels, Belgium, epruyt@vub.ac.be

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Abstract

There is not one single system dynamics approach. Apart from 'mainstream' system dynamics, there are several distinctive practices in use. In this explorative paper, an attempt is made to reveal basic assumptions of different practices and to classify them in a paradigmatic classification framework on the basis of these basic assumptions. Revealing its basic assumptions might be important for increasing the acceptance and use of system dynamics. It will be shown here that mainstream system dynamics corresponds well with critical pluralism, that other approaches are more postpositivist, pragmatist or constructivist, and that still other paradigmatic approaches might potentially be interesting. The classification framework might be used furthermore to find (i) approaches that suit issues, circumstances, parties involved and goals, (ii) the basic assumptions of different approaches and hence the interpretation and use of the results, and (iii) consistent matches and mixes of system dynamics approaches with other method(ologie)s.

Keywords: Philosophy of System Dynamics, Paradigms, Basic Assumptions, Paradigmatic Classification

1 Introduction

In this paper, several basic assumptions of system dynamics and classifications of different strands of system dynamics in paradigmatic frameworks will be closely looked at. Exploring these basic assumptions –which comes down to a fundamental philosophical exploration in line with Forrester's call for a 'broader and deeper debate about [the] underlying philosophy [of system dynamics], the contrast with alternative philosophies, the nature of knowledge, the role of subjective and observational information, and the criteria for judging validity' (Forrester 1980, p15)– was part of a broader research project in view of consistently matching and mixing[1] system dynamics with other method(ologie)s –more precisely with multiple criteria decision analysis. The research started with the –at first sight– simple question of what system dynamics is: a paradigm, a philosophy, a theory of structure, a methodology, a method, a set of techniques or tools[2]? This question is addressed in section 2 because it became clear from the system dynamics literature that the system dynamics community itself is unclear about the answer to this question. There, it will be argued that system dynamics is not *a* paradigm, *a* philosophy, *a* methodology or *a* method, and is more than *just* a theory of structure, a set of techniques or tools. Since the paradigmatic lead

[1] The phrase 'matching and mixing' will be used here to refer to all kinds of ways of combining (parts of) methodologies. *Mixing* relates to the partitioning of methodologies and combining some of their parts, whereas *matching* concerns looking for the right combination of several whole methodologies and the issue at hand.

[2] See table 1 for definitions of and the connection or hierarchy between the concepts paradigm, philosophy, meta-methodology, multi-methodology, methodology, method, technique and tool.

seemed to offer most interesting insights, a paradigmatic inquiry was ventured in to explore the paradigmatic basic assumptions of different system dynamics approaches, first –following Lane– within the (rather outdated) framework of Burrell and Morgan (1985) (see section 3), and later on by means of a paradigmatic framework of more recent date (see section 4), heavily influenced by the literature of the social and behavioural sciences on matching and mixing (see subsection 4.2) and the literature of the Critical Systems Thinkers on meta-methodologies (see subsection 4.3). The resulting extended paradigmatic table (see subsection 4.4) is used in subsection 4.5 to look at the system dynamics basic assumptions (see 4.5.1) and to classify system dynamics approaches (see 4.5.2). In section 5, the importance and use of such paradigmatic classifications is discussed briefly. Finally, some conclusive remarks and suggestions for further research are launched in section 6.

2 System Dynamics: a Paradigm, Philosophy, Theory of Structure, Methodology, Method, or a Set of Techniques or Tools?

Consistent sets of basic assumptions about ontology, epistemology, axiology, human nature, methodology, causality and logic, constitute different *paradigms* (see table 1). These paradigms influence *interpretations* and frame *philosophies*, *meta-methodologies*, *multi-methodologies*, *methodologies*, *methods*, *techniques* and *tools* used and through these, outcomes, interpretations and decisions made. *Philosophical or sociological theories* can be classified in terms of *paradigms* (see for example figure 1b on page 5). *Meta-methodologies* are often grounded in such *philosophical or sociological theories*, and tell us in turn which *methodologies* to choose (e.g. to create *multi-methodologies*). The (constituting) *methodologies* in turn contain *methods* used in specific sequences. These *methods* make use of specific *techniques*. Finally, some (software) *tools* can be used to ease the application of these *techniques*.

Table 1: Hierarchy and definition of concepts, from paradigms to tools –partly adapted from (Mingers & Brocklesby, 1997).

concept	***meaning***	***examples***
paradigm	coherent set of meta-theoretical (ontological, epistemological, praxiological, methodological, nature-of-society, human-nature,...) assumptions which constitutes a distinct world-view	Postpositivism
↑ ↓		
(philosophical or sociological) theory	coherent explanation of (social, material, personal,...) life by a distinct philosophical or sociological school of thought	Giddens' structuration theory
↑ ↓		
meta-methodology	framework for choosing between methodologies and for matching and mixing methodologies	Multimethodology
↑ ↓		
multi-methodology	a (new) methodology consisting of the combination of (parts of) other existing methodologies	Adaptive Control Methodology
↑ ↓		
methodology	'structured set of guidelines or activities to assist people in undertaking research or interventions' (Mingers and Brocklesby 1997, p490)	Mainstream SD methodology
↑ ↓		
method	'structured set of processes and activities that includes tools, techniques, and models, that can be used in dealing with the problem or problem situation' (Mingers 2000b, p675)	Mainstream SD method
↑ ↓		
technique	'specific activity that has a clear and well-defined purpose within the context of a methodology' (Mingers and Brocklesby 1997, p491)	Stock-flow diagram, numerical simulation
↑ ↓		
tool	'artefact, often computer software, that can be used in performing a particular technique' (Mingers and Brocklesby 1997, p491)	Vensim, Stella, ...

Many system dynamicists (e.g. Andersen (1980), Randers (1980), Meadows (1980), Meadows and Robinson (1985), Forrester (1994), Richardson (1999, p440), Sterman (2002, p503), Maani and Maharaj (2004, p22)) called system dynamics a (modelling) paradigm. All system dynamics practices do indeed share some explicit and (especially) some implicit assumptions, which Mead-

ows and Robinson (1985) argue to point to a distinctive system dynamics modelling paradigm. But Lane (see among else (Lane 1994), (Lane and Oliva 1998), (Lane 1999), (Lane 2000b), and especially (Lane 2001a) and (Lane 2001b)) concluded –when he tried to classify system dynamics in the well-known paradigmatic framework of Burrell and Morgan (1985)– that the domain of system dynamics is not a paradigm, but belongs to more than one paradigm, which is highly problematic in the Burrell and Morgan framework used in that stream of work, which is characterised by rigid paradigm incommensurability (see subsection 3.1 on page 4). He therefore rejected the Burrell-Morgan framework and suggested embedding system dynamics in lower-level philosophical theories –instead of adapting the 'outmoded' or inappropriate framework of Burrell and Morgan or instead of turning to other, more appropriate high-level paradigmatic frameworks –not specifically characterised by a rigorous incommensurability thesis– which will be done in section 4. Until then, the answer to this question –whether system dynamics practice constitutes a specific paradigm or whether different system dynamics practices belong to different paradigms– will be left open.

The suggestion to embed system dynamics in lower-level philosophical theories brings us to the question whether system dynamics is a philosophy or could be embedded within a philosophical theory. Some authors (e.g. Bailey, Bras, and Allen (2000, p75)) indeed call system dynamics a philosophy. But Lane already concluded that system dynamics does not contain a content theory and is therefore not a philosophy in itself. Now, if one would call *systems thinking* a philosophy, then system dynamics might be seen as a part of such a holistic philosophy instead of being a philosophy in its own right. With a little effort, one could also –again suggested by (Lane 2001b)– try to ground system dynamics in existing content philosophies (worthy of that name), or one could use the system dynamics structural language to support some of those philosophies. Reichel (2004) attempts for example to restructure system dynamics on the basis of Giddens' Structuration Theory. Mingers (2000a) argues for grounding system dynamics in Bhaskar's Critical Realism[3]. Vazquez, Liz, and Aracil (1996) suggest Putnam's Internal Realism. Other potential candidates suggested by Lane (2001b) are Habermas' Theory of Communicative Action, Archer's Morphogenetic Theory, Bourdieu's Constructivist Structuralism, or Luhmann's Autopoietic Systems Theory. But as can be seen from Reichel's attempt to restructure system dynamics on the basis of Giddens' Structuration Theory, adaptations need to be made to specific system dynamics approaches to be able to ground them in such philosophical theories. But these philosophies do not provide a philosophical basis for the *whole domain of system dynamics*. So, although these are indeed interesting attempts and leads to follow if one looks for a solid underlying framework for *specific system dynamics strands*, they are not appropriate for the entire domain of system dynamics –which is too diverse to fit one content philosophy– and even less if the purpose is matching and mixing of methodologies in general, which was the initial goal of this research.

Some system dynamicists suggest that system dynamics is a 'theory of structure' (see for example Forrester (1968b) or Starr (1980, p47)) 'that tells us how the concepts of feedback loop and stock should be used to construct models, which is at most a structural epistemological theory or language' (Lane 2001a, p110) with which system dynamicists see and describe reality, a language that 'guides our perceptions of the problems and our actions, rewriting our mental models' (Vazquez, Liz, and Aracil 1996, p33). But system dynamics approaches contain –as will be discussed in 4.5.1– more than just epistemological basic assumptions, which means that system dynamics is more than just a theory of structure.

Others call system dynamics a methodology (see for example (SDS 2005)) or a (group of) method(s) (see for example Sterman[4] and Wolstenholme[5]). Now, it is quite clear that there is something of a mainstream system dynamics method(ology), but there are also many other differ-

[3] 'It is possible to see [system dynamics] as embodying many of the main tenets of critical realism. It is rooted in a systems-based view that corresponds well with [critical realism]'s description if the domain of the real. The assumption that the events we experience (and wish to explain) are causally generated by the structures of underlying systems' (Mingers 2000a, p1264).

[4] 'System dynamics is a method to enhance learning in complex systems' (Sterman 2000, p4). Sterman nevertheless also calls system dynamics a paradigm.

[5] System dynamics is a 'rigorous method for qualitative description, exploration and analysis of complex systems in terms of their processes, information, organisational boundaries and strategies; which facilitates quantitative simulation modelling and analysis for the design of system structure and control' (Wolstenholme 1990, p3).

ent system dynamics method(ologie)s in use ranging from very quantitative to purely qualitative method(ologie)s, not to mention the many variations resulting from many different procedures, scripts and personal styles for each of them. From this, it should also be clear that system dynamics is not just the assembly of system dynamics techniques and tools.

So, at this point, it is tempting to conclude that system dynamics is not a philosophy, methodology or method, and that it is more than just a theory of structure, set of techniques or tools. Therefore, the inquiry as to what system dynamics really is, will be pursued on the most promising of levels: the paradigmatic level. Lane's attempt to position system dynamics in the Burrell-Morgan framework will first be discussed as starting point of this analysis. Then, a paradigmatic framework based on ideas from the literature of the social and behavioural sciences and the critical systems thinkers on mixing and matching and meta-methodologies will be constructed. The advantages of sticking to the paradigmatic level are (i) that it allows to deal with the whole domain of system dynamics, (ii) that it helps avoid the trap of adapting only specific system dynamics approaches to specific/particularistic philosophies, sociological theories, methodologies, methods, and so on, and (iii) it also leaves open more (potentially interesting) system dynamics strands of practice for mixing and matching with other methodologies.

3 The Paradigmatic Framework of Burrell & Morgan

3.1 The Paradigmatic Framework of Burrell & Morgan explained

Burrell and Morgan (1985) assumed that all social theories are based upon a *philosophy of science* as well as upon a *theory of society*. Crossing these two axes gives their well-known paradigmatic framework. The horizontal *nature of social science* axis describes two positions on a set of four related basic assumptions (the ontological, the epistemological, the human nature and the methodological assumptions), hence creating two diametrically opposed poles: the *objective view* versus the *subjective view* (see table 2 for the opposing poles and for the meaning of the vocabulary used by Burrell and Morgan (1985) and Lane (2001a)).

Table 2: The objective versus the subjective poles on the nature of social science axis and the meaning of the vocabulary used by Burrell & Morgan (1979 (1985)) and Lane (2001a)

	Subjective View	Objective view
Ontology: what is the 'nature' of phenomena?	Nominalist: real world exists as a product of appreciation	Realist: external world exists outside of appreciation
Epistemology: what 'knowledge' can we obtain? and how?	Anti-Positivist (humanistic)†: knowledge is subjective meaning	Positivist: causal laws deducted by objective observer
Human nature: what is the nature of human actions?	Voluntarist: free will allows humans to shape their environment	Determinist: humans react mechanically to their environment
Methodology: how can we obtain knowledge?	Ideographic: access unique individual insights and interpretations	Nomothetic: measurement of general concepts

† Burrell and Morgan use the word 'anti-positivist', Lane uses the word 'humanistic'.

The second *nature of society* axis opposes those theories and methodologies which have a radical change view of society to those that have a regulative view of society. These two axes are not to be interpreted as continua, but rather as discontinuous poles. Burrell and Morgan argue that by crossing them, four sets of fundamentally different assumptions are obtained, which constitute the four irrevocably incommensurable paradigms of table 3.

3.2 Lane's Positioning of System Dynamics in the Paradigmatic Framework of Burrell-Morgan

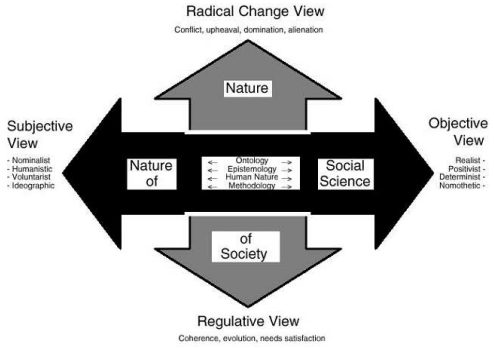
The Burrell-Morgan framework seems to be –at least at first sight– an interesting framework for trying to classify system dynamics practice, especially because it has been used previously by Checkland (1981, p280) and Lane (1994) to classify or position other systems sciences and

Table 3: The four incommensurable paradigms of Burrell & Morgan (1979 (1985))

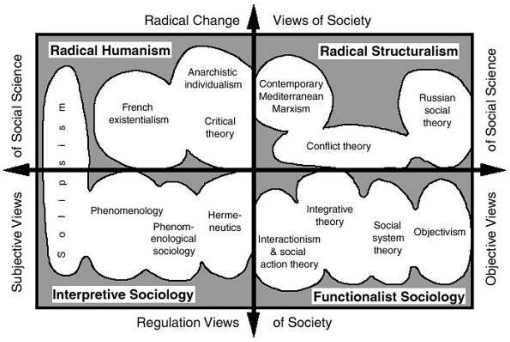
Radical Humanism: social world as a psychological prison of economic alienation	Radical Structuralism: social world as a prison of structural economic forces
Interpretive Sociology: social world is what agents interpret it to be	Functionalist Sociology: external social world exists, can be observed, and laws & structures can be uncovered

operational research methodologies (see figure 1c). Therefore, Lane (1999 and 2001a) used this framework in search for the social theoretic assumptions underlying system dynamics. Figure 1a reproduces the two axes of the Burrell-Morgan framework, and figures 1b and 1c (from (Lane 2001a)) some *schools of social thought* and various systems and operational research approaches in the Burrell-Morgan framework. Figure 1d shows Lane's mapping of different groups of system dynamics practices with the mapping of philosophical theories in the background. These groupings of system dynamics practice will be summarised here (those familiar with this stream of work might want to skip this subsection).

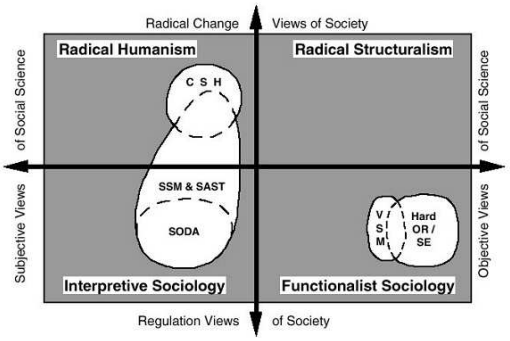
Figure 1: The axes, schools of social theories, operational research and systems approaches, and system dynamics in the Burrell & Morgan (1979 (1985)) framework as in (Lane, 2001a)



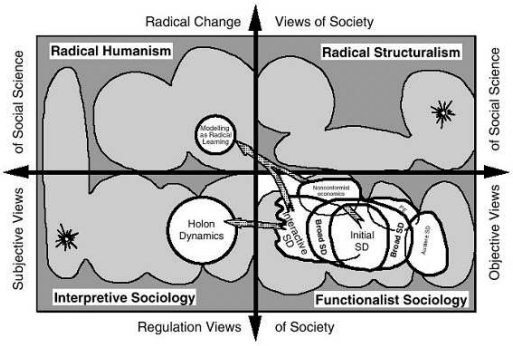
(a) the two core axes of the framework



(b) Schools of Social Theories in the framework



(c) various systems and operational research approaches in the framework



(d) various forms of system dynamics in the framework

He groups practices centered around Forrester's core ideas[6] under the heading *initial system dynamics practice* and locates this group of practices away from the objectivist extreme in the Burrell-Morgan framework because of the importance of subjective elements such as subjective mental models, confidence in the model and insights gained.

[6](Forrester 1958) and (Forrester 1961)

His *broad system dynamics practice* class contains the 'enduring heartland of system dynamics' as delineated by (Sterman 2000), grouping the two subdivisions of the field that were created by the division over the notion of validation of a model: '[t]he more objective interpretation saw confidence as created by rigorous science and therefore emphasised positivistic means (e.g. the refutationism view in (Bell and Bell 1980)) in order to produce results that were tenable. The alternative interpretation saw confidence as arising from social conversations, the emphasis being on ways of bringing modelling closer to users' (see (Meadows 1980) as cited by (Lane 2001a)).

Lane's *interactive system dynamics practice* group (note the uncertain boundary of this region) –still characterised by a realist ontology, but also by a significantly stronger anti-positivist epistemology– comprises group decision support modelling and the promotion of organisational learning which are both focussed on creating a shared interpretation of a problem via personal/group involvement in modelling. He tags the label of *nonconformist economics* to system dynamics in institutional and evolutionary economics, of *policy engineering* to 'the application of system dynamics by expert consultants as a traditional simulation approach', of *austere system dynamics practice* to practices which emphasise more determinist, positivist and objectivist approaches like microworld validation or behavioural decision-making work. Finally he identifies two (embryonal) subjective system dynamics approaches: *holon dynamics* modelling as a personal nominalist experience to make sense of the world (see e.g. (Lane and Oliva 1998)), and *modelling as radical learning* to further open debate in groups and deal with power, ideology and coercion.

This mapping (figure 1d) shows that Lane finds it difficult to position the domain of system dynamics *as a whole* unequivocally on both axes, but especially on the the *human nature* dimension: some forms of system dynamics seem to be determinist and others more voluntarist (Lane 2001a). The placing of system dynamics on the second axis seems to be difficult as well (Lane 1994, p122). On this basis, he concludes that the domain of system dynamics as a whole does not fit in this dichotomous paradigmatic framework –although separate strands of system dynamics practice do. Now, more arguments to reject the adequacy of this framework for classifying system dynamics could be advanced. Suppose one considers only mainstream system dynamics practice (exemplified for example by (Sterman 2000)) and tries to assign this mainstream system dynamics practice to one of the poles of the ontological, epistemological, methodological and nature of society dimensions. Then mainstream system dynamics seems to be –at least at first sight– ontologically realist and epistemologically anti-positivist (e.g. systems exist in the external reality but can only be accessed through subjective mental models). However, nominalist and positivist aspects are also present. The positioning on the methodological dimension is clearer: mainstream system dynamicists make models in close cooperation with their clients on very specific problems which makes the methodological dimension ideographic. Again more problematic is the *nature of society* dimension. Although system dynamics is appropriate to model regulative views of society due to its stock-flow and feedback loop *structures*, it is also appropriate to model the *dynamics* of radical change views of society.

Lane (2001a) argued that this could lead us to three possible alternative conclusions, namely that (i) system dynamics does not have an underlying 'social theory', or that (ii) system dynamics is grounded in functionalist sociology (in which case different practices are anomalies of the system dynamics field), or that (iii) the domain of system dynamics cannot be located in this paradigmatic framework. However, the analysis above and the analysis in subsection 4.5 makes clear that we can firmly reject the first conclusion: we can distinguish aspects that could be said to have its own paradigm or to be aspects of social theory. And we can also strongly reject the second alternative conclusion (i) because of the fact that even mainstream system dynamics does not genuinely fall within the functionalist sociology paradigm as will be further shown in subsection 4.5, and (ii) because of the gradual shift away from functionalism of mainstream system dynamics (cfr. the theme of this conference). So, system dynamics does not fit well in this restrictive paradigmatic framework where *objective* and *subjective* are rigorously separated as are *radical change views of social science* and *regulation views of social science*, because of the associated irrevocable paradigm incommensurability. In this framework it is simply not an option to claim that system dynamics breaks through the paradigm incommensurability (e.g. the realist ontological position combined with the subjective epistemological position), that it allows discussion at the borders of

the paradigms, or that it unifies the paradigms.

Another argument against the Burrell-Morgan framework is that there is simply no place for structuralist[7] approaches (Jackson 1990, p663) –which system dynamics clearly *is*. One option would be to add a structuralist paradigm, but then we are still confronted with the problem of the rigid paradigm incommensurability. Another option would be to consider a new paradigmatic framework not characterised by irrevocable paradigm incommensurability, which is opted for here.

4 System Dynamics in Another Paradigmatic Framework

So in spite of the appropriate level of the previous framework, it was certainly not appropriate for the initial goal. More recent paradigmatic frameworks, which will be turned to in this section might help. Strangely enough, Lane has not attempted to do this. Instead he dropped the whole idea of positioning system dynamics in a paradigmatic framework and turned to (lower-level) philosophical theories –which could be argued to fall *within* paradigmatic frameworks (see table 1 on page 2). Instead, he could have (i) 'modernised' the Burrell-Morgan framework, by dropping the idea of strict paradigm incommensurability, or by maintaining strict paradigm incommensurability but dropping the incompatibility thesis linking epistemology and methodology, or (ii) turned to other acceptable paradigmatic frameworks, because there is simply not one single eternally 'true' paradigmatic framework. Paradigmatic frameworks evolve just as philosophical and scientific theories and thoughts. They should be seen as devices to structure thinking or tools to classify. In the end, paradigms and paradigmatic frameworks are nothing but artifacts of the human mind[8], which is not to say that they are not important. They influence thinking and hence impact the real world (in)directly, and could be used to do this consistently and also to elicit the basic assumptions used, or as Meadows and Robinson (1985, p20) write: '[d]ifferent modeling paradigms cause their practitioners to define different problems, follow different procedures, and use different criteria to evaluate the results. Paradigms deeply bias the way modelers see the world and thus influence the contents and shapes of models'. This means that different frameworks could be (and are) proposed for specific purposes and in specific contexts, and that these frameworks could be extended and adapted when justified. This is actually what will be done here. In this section, a paradigmatic framework is introduced, which will be extended to suit the initial purpose. However, this will not be done void of any link to the historical scientific context (see subsection 4.1 for a brief historical overview). Therefore, the resulting paradigmatic framework resembles other contemporary paradigmatic frameworks. This is not surprising, because even such abstract things as paradigmatic frameworks have direct links to reality through philosophy, science, and real-world interventions and evolutions.

4.1 A Brief Historical Overview

Until the 1950s, the positivist (functionalist) paradigm was the dominating paradigm in sociological research, management science, operational research and systems sciences. Then in the 1950s-1970s a less extreme form of positivism, namely postpositivism developed from (extreme) positivism in response to the rising criticisms –also from the first system dynamicists– against positivism. Constructivists –who catched up in the 1970-1985– clearly stated their basic constructivist assumptions to distinguish constructivism from (post)positivism and argued that these paradigms and the methods based on them (on the hypothesis that the epistemologies and methodologies were linked) were incompatible, which resulted in the paradigm wars (Tashakkori and Teddlie 2002a, p

[7] 'Structuralism [...] is concerned with uncovering and understanding the underlying structures or systems of relationships which generate the surface phenomena perceived in the world. It demands explanations of the phenomena available to our senses in terms of the underlying, unobservable mechanisms that generate them. Structuralists attempt to provide models of the causal process at work at the deep structural level, which produce observable phenomena and the relationships between surface elements' (Jackson 1993, p567).

[8] 'The highest leverage of all is to keep oneself unattached in the arena of paradigm, to realize that NO paradigm is 'true,' that even the one that sweetly shapes one's comfortable worldview is a tremendously limited understanding of an immense and amazing universe' (Meadows 1997).

ix) and to an (overdrawn) dichotomy between 'hard' and 'soft' methodologies, also in the systems movement (see e.g. (Jackson 2001)). Other intermediary paradigmatic schools emerged at the end of the 1980s from the paradigm wars, like the pragmatist and the transformative-emancipatory-critical paradigms, which rejected rigid paradigm incommensurability and the incompatibility thesis and came up with (different forms of) a paradigm *compatibility thesis*.

4.2 The Initial Paradigmatic Table Explained

The framework started from is the framework of Tashakkori and Teddlie (1998) from the social and behavioral sciences, who describe four distinct paradigms –positivism, postpositivism, pragmatism and constructivism– in terms of specific sets of ontological, epistemological, axiological, methodological, causal and logical assumptions in order to put pragmatism (see 4.2.4) on the map as *the* paradigm for matching and mixing of methodologies (see table 4). Their table is immediately extended here (i) with the transformative-emancipatory paradigm (Mertens 2002) –which Tashakkori and Teddlie (1998) consider to be part of the pragmatist paradigm– and (ii) with some additional characteristics –such as appropriateness of models, results and strategies– which were considered important in view of matching and mixing system dynamics with other method(ologie)s.

Their framework is –at least at first sight– less extreme than the Burrell-Morgan framework in that it allows intermediate positions to be taken[9]. But Tashakkori and Teddlie (1998) do not just present a table containing four paradigms, they also stick a specific paradigmatic position on it –the *single paradigm thesis*– and claim that pragmatism is *the only* appropriate paradigm for matching and mixing of (quantitative and qualitative) methodologies. Their single paradigm thesis is not followed here and it is argued elsewhere (e.g. in (Pruyt 2006)) that there are other possibilities to match and mix, apart from pragmatist matching and mixing. However, their table is interesting as alternative starting point, especially because it could be extended rather easily with more intermediate paradigmatic positions which will be done in subsections 4.3 and 4.4 where the intermediate critical pluralist position is discussed and added. Using this extended table, it will be shown that different strands of system dynamics practice and combinations thereof could be situated in different such paradigms. In what follows, a clear distinction will be made between on the one hand the 'paradigmatic table', and on the other hand the 'paradigmatic framework' (table + single paradigm thesis).

The positivist paradigmatic position corresponds to the objective view in the previous paradigmatic framework, and their constructivist paradigm to the subjective view as discussed in the previous section. These are the two positions generally considered, also in Management Science, Operational Research and the Systems Sciences (MS/OR/S).

These two positions will not be discussed here in great detail since they are already extensively discussed in the (MS/OR/S) literature. Here, two additional intermediate paradigmatic positions will be concentrated on, namely *postpositivism* and *pragmatism*, as described by Tashakkori-Teddlie and to a lesser extent a third additional intermediate paradigmatic position, namely the transformative-emancipatory paradigm as discussed by Mertens (2002). She argues that this transformative-emancipatory paradigm is a third intermediate paradigm on which matching and mixing of methodologies could be based. Here, the transformative-emancipatory paradigm has been added explicitly to the table in order to (i) create a parallel with the critical paradigm (hence the name transformative-emancipatory-critical in tables 4 and 5) considered by several critical systems thinkers (see subsection 4.3), and to (ii) make clear that the Tashakkori-Teddlie table is not considered to be exhaustive: other (intermediate) paradigms might be rightfully added, such as critical pluralism, which is included in the extended table (see table 5 on page 14).

[9] One could raise the question whether a framework from the social and behavioral sciences could be used for system dynamics and the mixing and matching of methodologies. We think that this is fine, because –although system dynamics differs from methods of classic social and behavioral research– sociological research is what system dynamics is all about: system dynamicists 'build models of social systems' (Forrester 1961).

4.2.1 The positivist paradigm:

The positivist ontological-epistemological position is realist-objective, which means there is a single external reality which can be known/accessed by an objective observer. The focus is therefore on value-free facts which are observer-independent (Schwaninger 2004, p412). Methodologies used are purely quantitative and decontextualised, often called 'hard'. Causes are knowable and real and temporarily precedent with the effects. Theories and models are appropriate if they are not refuted, and results and strategies are appropriate if they are optimal.

4.2.2 The constructivist paradigm:

According to the relativist constructivist ontological position, multiple socially constructed realities exist. And observers can only subjectively access these realities, which makes that the inquiry is essentially value-bound and that the focus is on interpretations of phenomena or facts. Mostly (but not necessarily) constructivist approaches are qualitative with an inductive logic and rely on the 'discursive approach, i.e., the interaction between multiple perspectives by means of which consensual domains are negotiated and (new) shared realities created' (Schwaninger 2004, p412). Causes and effects are argued to be indistinguishable. Therefore, theories and models are appropriate if they arouse sufficient confidence and lead to acceptable compromises or agreements.

4.2.3 The Postpositivist Paradigm:

Postpositivism tones down a bit the extreme positivist position on all dimensions and takes a less extreme position between (but closer to) positivism and constructivism. Ontologically, postpositivism holds on to one external reality that can be known –but now– only within a certain level of probability. Postpositivists are aware that the inquiry is *value-laden* (the inquiry is influenced by the researcher's theories and values), that facts are *theory-laden* (research is influenced by the theories investigators use), and that the same facts can be explained by several theories (also called *underdetermination of theory by fact*). However, they assume that the degree of that influence may be controlled through appropriate methods and procedures. In order to obtain *probably objectively true* findings, (i) observations need to be done from a distant and dispassionate point, (ii) quantitative method(ologie)s are favored, and (iii) the logic is primarily deductive. An important basic assumption of postpositivism for system dynamics is that there are lawful, reasonably stable relationships among social phenomena which may be (probabilistically) known but which change over time. Finally, the most appropriate models for postpositivists are the scientifically validated models with (numerical) outputs in line with the empirical data.

4.2.4 The Pragmatist Paradigm:

Pragmatism could be traced back to philosophical pragmatists like Peirce, James, Dewey, Mead, Bentley, Rorty, Davidson and some neo-pragmatists (Maxcy 2002). Pragmatists consider the research question (Tashakkori and Teddlie 1998, p21) and finding solutions to problems (Creswell, Guttman, and Plano-Clark 2002, p231) to be more important than either the method they use or the paradigms or (ontological/ epistemological/ ...) assumptions that underly the method (Tashakkori and Teddlie 2002b, p679). Hence, they choose their methods on the basis of the criterion of *what will work best* (Rocco, Bliss, Gallgher, and et al. 2002, p596): 'from both [quantitative and qualitative] approaches to answer their research questions' (Tashakkori and Teddlie 1998, px) and they 'do not worry about 'artificial' theoretical distinctions but concentrate on building up a 'toolkit' of methods and techniques, drawn from different strands [of management science], which they are prepared to use together in the course of problem solving if the situation warrants it' (Jackson 1999, p14).

The ontological position is both realist *and* relativist: they accept that there is one external reality, but deny that one single unchanging Truth can be determined and they are 'unsure whether one explanation of reality is better than another' (Tashakkori and Teddlie 1998, p28). Therefore,

	(Logical) Positivism →	Postpositivism	Pragmatism	Transformative- Emancipatory-Critical	Constructivism
Ontology	single external reality that can be known (naive realism)	one external reality that can be known within a certain level of probability (critical or transcendental realism)	acceptance of one external reality, but choice of explanations that best produce desired outcomes (pragmatist realism)	many social realities depending on political, cultural, historical, and economic value systems (relativism)	multiple socially constructed realities exist (relativism)
Epistemology	objective: knower and known are independent	observing from a distant and dispassionate point – findings probably objectively 'true'	objective *and* subjective	objective *and* subjective	subjective: knower and known are inseparable
Axiology	inquiry is value-free	theory & value-laden inquiry: influenced by researcher's theories and values, but degree may be controlled through appropriate methods	aware but not concerned by value-ladenness of choice of research, of inquiry and of the interpretation	knowledge is non-neutral, influenced by human interests, power and social relationships (Tashakkori & Teddlie, 2002a, p677)	inquiry is value-bound
Method[ologie]s	purely quantitative (interventionist and decontextualised)	primarily quantitative (methodological correctness favors quantitative methods)	quantitative *and* qualitative	qualitative, quantitative, or mixed methods	qualitative
Causality	knowable real causes which are temporarily precedent or simultaneous with effects	there are lawful, reasonably stable relationships among social phenomena which may be probabilistically known and which change over time	there may be causal relationships, but we will never be able to completely pin down the exact 'real' causal relations /[no *grand* causality]		causes and effects are indistinguishable because all entities are simultaneously shaping each other
Logic	deductive: from general to particular based on a-priori knowledge	primarily deductive	deductive *and* inductive	deductive *and* inductive	inductive: reasoning from the particular to the general
Appropriateness of model/results	if refutable but not refuted	the model closest to the real world	the model closest to the goal or personal value system	if advancing justice and democracy, specially for oppressed	confidence
Appropriateness of strategies	the optimal strategy	most appropriate, efficient, probably optimal strategy	most appropriate strategy closest goals or to personal value system	appropriate strategy for less advantaged and oppressed	any strategy (good enough for groups)

Table 4: Paradigms adapted (and extended) from (Tashakkori & Teddlie, 1998, table 2.1 p23) and (Mertens, 2002, p140–142)

they cannot determine –when choosing between competing theories– which one is closest to reality, so they support the ones which best produce the desired outcomes or which are closest to the personal value systems of those involved. The pragmatist epistemological position lies on a *continuum* between the objective *and* subjective positions, and changes in different phases of the intervention: 'at some points the knower and the known must be interactive, while at others one may more easily stand apart from what one is studying' (Tashakkori and Teddlie 1998, p26). The axiological position of pragmatism is that research is value-laden (between value-free and value-bound). 'Pragmatists believe that the values of the researcher play a large role in the selection of research topics [, the choice of methodology, in conducting the research] and in the interpretation of results' (Tashakkori and Teddlie 2002b, p677): they select 'topics that are of special interest to [them]' (Tashakkori and Teddlie 2002b, p678), 'study the topic in a way that is congruent with their value system, including variables and units of analysis that they feel are the most appropriate for finding an answer to their research question' (Tashakkori and Teddlie 1998, p26), their 'values play a large role in drawing conclusions from their studies, and they see no reason to be particularly concerned about that influence' (Tashakkori and Teddlie 1998, p26). Finding an answer to their research questions, mostly requires both quantitative *and* qualitative method(ologie)s in the same intervention. Regarding causality, Tashakkori and Teddlie (1998, p29) state that '[b]oth [postpositivism and pragmatism] agree that we should explore causal relationships [at least to some extent, and they] agree on the principle of underdetermination of theory by fact'. However, postpositivists believe 'that we should strive for constantly better explanations of reality and causality', whereas pragmatists believe that 'we should concur with those explanations of causality and reality that are closest to our own values because we will never be able to understand them absolutely' (Tashakkori and Teddlie 1998, p29). The 'at least to some extent' was added here to point to the fact that 'at a general level, pragmatism is a view about the purpose of science –that it is essentially a practical activity aimed at producing useful knowledge rather than understanding the true nature of the world' (Mingers 2004b, p90). Thus, understanding the underlying causality of the real world systems behaviour –which is the main goal of mainstream system dynamics– is not the main goal of pragmatism nor postpositivism. The pragmatist logic in the same research cycle is deductive *as well as* inductive: 'from grounded results (fact, observations) through *inductive logic* to general inferences (abstract generalizations, or theory), then from those general inferences (or theory) through *deductive logic* to tentative hypotheses or predictions of particular events/outcomes' (Tashakkori and Teddlie 1998, p24) which is rather similar to figure 2 on page 18 representing the system dynamics research cycle.

4.2.5 The Transformative-Emancipatory-Critical Paradigm:

Transformative-emancipatory-critical researchers do not base their choices on 'what works' as pragmatists do, but on an explicit value choice to advance justice, democracy and help the oppressed or less advantaged. The intermediary transformative-emancipatory-critical ontological position is that many (social) realities exist, depending on the political, cultural, historical, and economic value systems. The epistemology is both 'objective (providing a balanced and complete view to avoid a bias caused by a lack of understanding of key viewpoints) and subjective (significant involvement of the researcher)' (Mertens 2002, p141). It is acknowledged that knowledge is influenced by human interests and by power and social relationships and is therefore non-neutral. To restore the balance, '[t]he research is conducted with involvement of all relevant communities, especially the least advantaged' (Mertens 2002, p142). They also actively seek topics that may directly help the oppressed or least advantaged (Tashakkori and Teddlie 2002b, p678). So (potential) transformative-emancipatory-critical practice therefore already contains a very specific ethical perspective and pursues the ethical goal, no matter what, and it requires as such the explicit consideration of ethics in all aspects and phases of the research process (beyond and within). In order to do this, they use quantitative, qualitative, as well as mixed methods, and deductive and inductive logic. The more a model, theory, intervention or strategy helps the oppressed or least advantaged or helps forward justice and democracy, the more appropriate it is for transformative-emancipatory-critical inquirers.

4.2.6 Relevance and Consequences of the Extended Tashakkori-Teddlie Paradigmatic Framework for Matching & Mixing and Lessons Learned

A positive aspect of the paradigmatic *table* is that it shows additional intermediary positions between extreme positivism and constructivism with different sets of consistent basic assumptions. A negative aspect of the Tashakkori-Teddlie paradigmatic *framework* (table + single paradigm thesis) is that pragmatism is considered –at least by these pragmatists– to be *the* (only) intermediary position between extreme positivism and extreme constructivism for matching and mixing any number of method(ologie)s if the end (solving the research question) justifies the means (matching and mixing). The legitimateness of their single paradigm thesis and their claim that pragmatism is *the* paradigm for matching and mixing are rather doubtful. Other paradigmatic theses –such as the incompatibility thesis, the a-paradigmatic thesis, the complementary strengths thesis, the multi-paradigm thesis or the dialectic thesis (see (Teddlie and Tashakkori 2002, p17–25) and (Rocco, Bliss, Gallgher, and et al. 2002, p598))– would lead to very different conclusions. Other paradigms might also be considered besides these other paradigmatic positions. The table does for example not contain a typical structuralist position (yet). In the following subsection, the Tashakkori-Teddlie table will be extended with a more structuralist paradigm, which seems to be a more acceptable home for mainstream system dynamics focussed on real understanding of the connection between causal structure, behaviour and action.

4.3 Critical Systems Thinkers

The so-called Critical Systems Thinkers have been working for more than 20 years –among else– on the meta-methodologies, matching and mixing of method(ologie)s in the domains of management science, operational research and systems sciences. Relevant insights –for the classification of system dynamics– from their frameworks are among else (i) that all frameworks should be tools not to be applied without critical reflection (which is also true for the framework proposed in the next section), (ii) that such things as issues (and their characteristics such as their complexity), the divergence/convergence of the views, the different research phases, different spheres, and the method(ologie)s should be matched critically and appropriately, (iii) that system dynamics is quite differently perceived and classified by outsiders (as a hard, quantitative tool) and insiders (as a much softer tool) of the system dynamics field, (iv) that there are still potential system dynamics uses to be explored, and (v) that system dynamics is not appropriate for all aspects of research, which means that matching and mixing with other method(ologie)s is most of the time required.

When it comes to matching and matching, the Critical Systems Thinkers movement has evolved recently towards (several versions of) coherent pluralism: they welcome and recommend the use of a diversity of paradigms, method(ologie)s, techniques and tools. At first sight this might look like (pluralist) pragmatism. However, one of the major differences with pragmatism is that pluralism needs to be philosophically and theoretically well-founded such that methodologies, tools and abilities to tackle diverse and difficult problem situations are continually improved (Jackson 1999, p17). This is also one of the reason why Critical Systems Thinkers generally dismiss pragmatist approaches (see e.g. (Jackson 1987)).

But pluralism is also based on very specific underlying assumptions and could therefore be seen –just as pragmatism– as a separate paradigm. If we would follow that lead, then we could extend the paradigmatic table with pluralism, such that it includes six different paradigms, namely the positivist, postpositivist, pragmatist, pluralist, transformative-emancipatory(-critical), and constructivist paradigms. However, the underlying assumptions are not unambiguous, since different authors propose different forms of pluralism with different underlying assumptions and theories, and supplemented with different paradigm theses and different resulting views on interparadigm mixing and matching. A possible set of ontological, epistemological, axiological, methodological assumptions underlying pluralism –as advocated by Mingers– will be considered and discussed here.

Mingers (2000a, p1264–1265)[10] suggests that Critical Realism might be a possibly interesting

[10]This subsection is based predominantly on (Mingers 2004b) and (Mingers 2004a).

underlying philosophy for system dynamics. Now, Critical Realism could be seen as a philosophical theory which 'successfully addresses the major divisive issues within the philosophy of science –natural [versus] social, positivist [versus] critical, realist [versus] constructivist, structure [versus] agency', but also as a consistent set of intermediary basic assumptions which makes it an interesting intermediary *paradigm* between (post)positivism and constructivism. It combines a realist ontology with a relativist/subjective epistemology –knowledge as socially and historically conditioned– (Mingers 2004b, p91). This seeming opposition between ontology and epistemology is possible through the acknowledgement by the critical realist of the 'mediation of 'the mental' in our cognitive grasp of the physical world' (Audi 1999, p194). The axiological position is that practitioners are aware of *and* concerned by the value-ladenness of the research: 'the inevitable fallibility of observation [...] requires the researcher to be particularly aware of the assumptions and limitation of their research' (Mingers 2004b, p99-100). The methodology is quantitative *and* qualitative. Concerning causality, this perspective assumes that it is of primordial importance to 'get beneath the surface to understand and explain why things are as they are, to hypothesise the structures and mechanisms that shape observable events' (Mingers 2004b, p99-100). The logic is deductive *and* inductive. Models are appropriate if they lead to real insight in and understanding of the underlying structures, and strategies are appropriate if they have the potential to change mental models and through these structurally change the situation.

4.4 Extending the Paradigmatic Table

Hence, a new intermediary paradigm between the two outer poles of positivism and constructivism is added to the paradigmatic table, which will be called the *critical pluralist* paradigm here. We could also have called it the 'critical realist' paradigm, but that name might actually focus too much on the ontological position and philosophy, or it could be given a completely different name like the 'mainstream system dynamics paradigm' with which it corresponds rather well (see section 4.5). The point is that this precise set of (intermediary) basic assumptions is interesting in view of the classification of mainstream system dynamics (and the consistent matching and mixing of mainstream system dynamics with other methodologies). This critical realist philosophy does not need to be *the* basis of this paradigm, and other philosophical bases are welcomed, but here it was selected as point of departure because of its convenience for the goals at hand, namely (i) to find a paradigmatic home for mainstream system dynamics practice, and (ii) to develop a paradigmatic framework to support the matching and mixing of methodologies, more precisely of system dynamics and multiple criteria decision analysis. Therefore, the precise philosophy underpinning the paradigm is of minor importance and will not be explored in depth.

Table 5 summarises this critical pluralist position –which was discussed as critical realism in the previous subsection– and contrasts it to the other paradigmatic positions discussed in the (already extended) paradigmatic table. It is particularly interesting and revealing to compare the critical pluralist with the postpositivist and pragmatist positions.

The critical pluralist and pragmatist assumptions about axiology, causality, and appropriateness of models, results and strategies are almost opposites. Critical pluralism is concerned about the value-ladenness and related theoretical soundness of their research, whereas pragmatism is not. Causality is of fundamental importance for critical pluralism because the goal is to *learn about and understand* the underlying causal structure and the resulting behaviour, whereas pragmatism is not interested in the underlying causal structures to enhance understanding as long as this does not help to solve the research questions. Related to this are the criteria as to what models, results, strategies and mixes and matches of method(ologie)s are appropriate. In the critical pluralist paradigm, a model is appropriate if it leads to real learning, insight and understanding, whereas in the pragmatist paradigm, a model is appropriate if it helps solving the research questions and if it closely fits the values of those involved. In the critical pluralist paradigm, strategies resulting from increased insight, learning and understanding are appropriate if they embody the potential to structurally transform the underlying mental models and structures and consequently the resulting behaviour, whereas in the pragmatist paradigm, strategies are appropriate if they closely fit the values of the decision-makers or lead to the desired results and their implementation.

	Positivism	Postpositivism	Critical Pluralism	Pragmatism	Transformative-Emancipatory-Critical	Constructivism
Ontology	(naive) realism	(transcendental) realism	(critical) realism	(pragmatist) realism	relativism	relativism
Epistemology	objective	('probably') objective	subjective	objective *and* subjective	subjective (and objective)	subjective
Axiology	value-free	controllable value-ladenness	concerned by value-ladenness	unconcerned by value-ladenness	non-neutral, value-ladenness	value-bound
Method[ologie]s	purely quantitative	primarily quantitative	quantitative *and* qualitative	quantitative *and* qualitative	qualitative, quantitative, mixed	qualitative
Causality	knowable real causes	reasonably stable causal relationships (not necessarily used)	causality is key to understanding of real world	maybe causal relationships but not exactly knowable		indistinguishable causes and effect
Logic	deductive	primarily deductive	deductive *and* inductive	deductive *and* inductive	deductive *and* inductive	inductive
Appropriateness of model/results	refutable but not refuted	validated models, results closest to real world	do models lead to real insight & understanding?	closest to goal or own value system?	advancing justice, democracy & oppressed?	confidence in constructed model
Appropriateness of strategies	optimal strategy	probably optimal or most appropriate strategy	potential to structural transformation?	close to goal or own value system	advancing justice, democracy & oppressed?	any strategy (if agreed to)

Table 5: The extended paradigm table representing the positivist, postpositivist, critical pluralist, pragmatist, transformative-emancipatory-critical, and constructivist paradigms

The first striking difference with important consequences –when comparing the postpositivist and the critical pluralist positions– is their very different epistemological stance. Postpositivist epistemology assumes that the real-world can be accessed (probably) objectively, whereas critical pluralist epistemology assumes that this is only possible *via subjective mental models*. A consequence is that postpositivism assumes to start from and deal foremost with the real world, and that critical pluralism assumes to start from and deal with mental models. This also influences the goals of their modelling and research which is for postpositivism the modelling and projection of and intervention in the real world, and for critical pluralism the learning, i.e. the improvement of the understanding of the connection between structure-behaviour and the intervention based on improved understanding. Another marked difference is that causal relationships are assumed by postpositivism to be rather stable and this assumption is not per definition *explicitly* used (correlations instead of causal relations might for example be considered sufficient), whereas causal relationships are for critical pluralism *the* key to understanding the real world and are therefore *explicitly* focussed on, correlations are simply not sufficient. From this, it follows that postpositivism and critical pluralism also differently interpret modelling results. Postpositivist models are supposed (and validated) to closely represent the specific real-world aspects of interest. The quantitative modelling results are therefore thought to correspond directly to the real-world. Critical pluralists do not assume such a direct correspondence and first interpret (quantitative) results and try to *learn* from them in a qualitative way, and only act on the basis of the improved mental models (increased understanding), and not on the basis of the crude model output. This results in different objects of study, different boundaries, different degrees of aggregation,... and finally different interpretations, conclusions and actions.

Now, these very different assumptions and resulting objects of study, starting points, boundaries, focusses, goals, model uses, and interpretations of modelling results are of fundamental importance, but often terribly misunderstood, especially by those who are rigidly set in their paradigmatic ways and are convinced that their paradigm the only right one. Many confirmed believers of (post)positivist modelling (e.g. classical economics) think for example that critical pluralist models (e.g. mainstream system dynamics) are used in the same way as their own and consequently reject these models because of the fact that such models are flawed if seen from within their (post)positivist paradigm. And many confirmed believers of critical pluralist modelling do not understand the postpositivist drive for hard validation and quantitative results which are used as if they correspond directly to the real world because of their own basic assumptions. Hodges (1991, p355) defines for example a *bad model* as 'one that appeals to the analyst as adequately realistic but which is either: [i] contradicted by some data or is grossly implausible in some aspect it purports to represent, or [i] conjectural, that is, neither supported nor contradicted by data, either because data do not exist or because they are equivocal'. The latter is often true for critical pluralist models used for learning. From a typical postpositivist stance, he warns that such 'bad model[s] can suggest, but [they] cannot reveal truth' (Hodges 1991, p360) as opposed to postpositivist models –at least in his view– which is in turn totally implausible to and rejected by critical pluralist practitioners. He correctly warns against directly using the numbers produced by such 'bad' models which he argues do no more than suggest. But real critical pluralist practitioners would never even think of using these numbers directly: they would use them for increasing understanding, which involves learning from these 'suggestions' before taking action.

The same is true for the misunderstanding between the other paradigmatic stances. It should be clear that models with different paradigmatic bases differ, and that they cannot be used in the same ways and for the same purposes. As long as this understanding lacks, we are confronted with paradigm incommensurability resulting from misunderstanding. The solution might be to become multi-paradigm literate, not only multi-method(ology) literate. The extended paradigmatic table is useful in this respect, but only if used in a critical sense.

The extended paradigmatic table might also provide an answer to the question posed by Warren (2004) as to why system dynamics –although believed by its proponents to be of great value to management– is not embraced on a large scale by the management community. The answer might be found –at least partially– in the fact that system dynamics has not been, and still is not, clear about its very basic assumptions, which constitute its very essence, and determine its form

and use. Much confusion exists about what system dynamics really is, what its bases are and what it could be used for, even to system dynamics practitioners. The paradigmatic inquiry and classification of system dynamics in the following subsection explains partly why system dynamics models have always encountered much criticisms from (post)positivist modelers and disciplines. Hopefully, this paper contributes somewhat more to the understanding of what system dynamics actually is and what it could be used for.

4.5 Classification of System Dynamics in the Extended Paradigmatic Table

4.5.1 Paradigmatic Inquiry of System Dynamics

In section 2, it has already been noted that many system dynamicists see system dynamics as a specific modelling paradigm. If this were true, then this would make it easier for system dynamicists to clarify their basic assumptions to outsiders.

But system dynamics practices are also characterised by some very divergent assumptions, which seems to indicate that these practices belong to different paradigms (in the sense of philosophy of science) such as the ones in the extended paradigmatic table. In order to support one of these hypotheses, some of the basic assumptions will be looked at now in order to find out whether a single system dynamics paradigm with a consistent set of distinctive basic assumptions exists or not.

System Dynamics Ontology? Is system dynamics characterised by a set of specific assumptions about what the world is? (Forrester 1961, p60) argues in this respect that '[a]ll constants and variables of [a system dynamics] model can and should be counterparts of corresponding quantities and concepts in the actual system'. Meadows and Robinson (1985, p34) argue that the 'primary [ontological] assumption of the system dynamics paradigm is that the persistent dynamic tendencies of any complex social system arise from its internal causal structure – from the pattern of physical constraints and social goals, rewards, and pressures that cause people to behave the way they do and to generate cumulatively the dominant dynamic tendencies of the total system', or in other words that 'things are interconnected in complex patterns, [...] the world is made up of rates, levels and feedback loops, [...] information flows are intrinsically different from physical flows, [...] non-linearities and delays are important elements in systems, and [...] behaviour arises out of system structure' (Meadows 1989) or at least that the dynamic behavior of complex systems can be explained in terms of positive and negative feedback loops consisting of linked stock/flow structures and delays (Mingers and Rosenhead 2001, p299). As such, it might be tempting to conclude that there is a specific (mainstream) system dynamics ontology and that this (mainstream) system dynamics ontology is realist.

But at the 2004 System Dynamics Conference in Oxford, a plenary discussion took place over whether systems exist in the real world or not. From the discussions it became clear that system dynamics models are indeed often seen (by insiders and certainly by most outsiders of the field such as for example Jackson (1992) and Brocklesby (1993)) as hard, realist models of external reality.

However, many system dynamicists raise(d) that system dynamics models could also be used in a more relativist way, or as Mingers and Rosenhead (2001, p299) expressed it 'as models of concepts, i.e., as models of how things might be from a particular viewpoint in a similar way to cognitive maps'. Then there may not be systems in the real world (although many system dynamicists would not fully agree with this), but systems of stocks and flows with feedback loops, non-linearities and delays might then be thought of as good means of description, construction of meaning and explanation (Lane and Oliva 1998, p219). These are also called *holons* (Lane and Oliva 1998). However, such system dynamics practices are not mainstream (yet).

A more moderate position between these two views seems to be adopted by most system dynamicists, namely that systems, stocks, and so on, may sometimes really exist, and may sometimes

be interesting devises to structure, describe and make sense of perceptions of complex real-world issues in the world around us, which brings us actually to the epistemology of system dynamics.

System Dynamics Epistemology? If system dynamics has a specific epistemology, then this would tell us what type of knowledge could be obtained and what the relationship between knower and known is. Mainstream system dynamics does indeed seem to have a specific epistemology, namely a moderately subjective epistemology, and *not* an objective epistemology as could be expected given the (moderately) realist ontology and as very often misperceived by many outsiders. Mainstream system dynamicists believe namely that human beings can only grasp the external world via their mental models. This ontological/epistemological position bears a strong resemblance to the critical realist or critical pluralist position discussed in subsection 4.3.

So, there seems to be a mainstream relativist system dynamics epistemology. But there is also a broad range of less mainstream positions with epistemological positions ranging from moderately objective (e.g. policy engineering) to subjective (e.g. Holon Dynamics).

System Dynamics Axiology? Dana Meadows and some other inspired system dynamicists have always been very much aware of and concerned by the value-ladenness of the choice of research. The choice of their research is a function of what they think is important which depends on their values and world-views, and is not necessarily a function of the tools at their disposal. They are aware of the influence of their paradigms and method(ologie)s on what they consider to be important and vice versa.

Many system dynamicists on the other hand do not seem to be aware of or concerned by the value-ladenness of their (choice of) research and of their interpretation. These are the more pragmatist system dynamicists. There are also system dynamicists who recognise the influence of theories and values and try to eliminate these influences as much as possible. Finally, there seem to arise new forms of system dynamics that recognise that the inquiry is inextricable value-bound. Hence, the system dynamics axiology ranges again from postpositivism to constructivism.

System Dynamics Methodology? Most system dynamics practices (among which mainstream system dynamics practice) combine *quantitative and qualitative* techniques and variables. However, there are also system dynamics practices which are either primarily quantitative or purely qualitative. See for example (Richardson 1996), (Homer 1997, p307), (Richardson 1999, p441), (Warren and Langley 1999), (Homer and Oliva 2001, p349), (Oliva 2003) versus (Coyle and Alexander 1997, p206), (Coyle 1998, p356-357), (Wolstenholme 1999, p424), (Coyle 2000), (Coyle 2001, p357) for an extensive polemic between those practitioners that favour a purely quantitative model and numerical computer simulation at any time and reject isolated qualitative modelling, and those that believe that quantitative models could be dangerous in case of many uncertainties and believe that isolated qualitative models would do in some cases. A final remark concerning system dynamics methodologies is that models are developed in close interaction with the decision-makers and stakeholders and are therefore ideographic.

System Dynamics Causality? Direct causality seems to be one of the basic assumptions of system dynamics. The positivist[11], postpositivist[12], pragmatist[13] and especially the critical pluralist[14] assumptions of causality (see table 5 on page 14) are in this respect compatible with different forms of system dynamics practice. On first sight, the constructivist view on causality seems to pose problems, since it assumes that causes and effects are *indistinguishable because all entities are simultaneously shaping each other*. However, there is no problem if we accept this,

[11] knowable real causes which are temporarily precedent or simultaneous with effects

[12] there are lawful, reasonably stable relationships among social phenomena which may be probabilistically known and which change over time

[13] there may be causal relationships, but we will never be able to completely pin down the exact 'real' causal relations and there is no *grand* causality

[14] causality is key to understanding of the real world

but also that individuals may develop their own causal theories of this jumble. In that case, constructivist causal models are models of perceptions or interpretations of this jumble and give meaning to it.

System Dynamics Logic? System dynamics is based on different types of logic in the different phases of the system dynamics research cycle (see figure 2): first micro-theories are induced (inductive logic), which are later on used to simulate (deductive logic). This specific induction/deduction loop is however not limited to system dynamics alone. Most system dynamics practice could be classified –as far as the logic is concerned– as either critical pluralist or pragmatist, because of the equal emphasis on deduction and induction in most system dynamics practice. And system dynamics practice where there is only induction (qualitative modelling) and no deduction (purely quantitative simulation) could also –in a sense– be called constructivist. In this kind of practice, a structural micro-theory leads to a new micro-theory on the behavior of the system. And (post)positivist system dynamics approaches are primarily based on deduction (simulation) which could only be the case if the micro-theory (the model) has already been induced and validated and one real world is assumed to exist and be accessible.

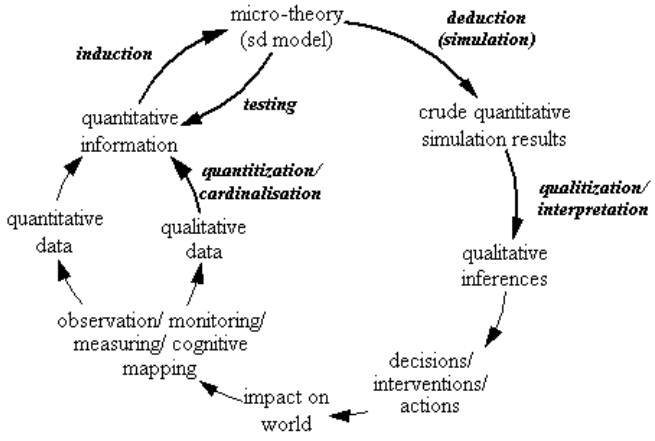


Figure 2: The system dynamics research cycle

Appropriateness of System Dynamics Models, Results and Strategies? There is a very small group of system dynamicists (e.g. Bell and Bell (1980) and Bell and Senge (1980)) who see validation as a scientific process of refutation, and consider refutable models –or conjectures– that are not refuted yet as appropriate, which corresponds to the positivist paradigmatic position. A slightly bigger –but still marginal– slice of system dynamics practice could be considered postpositivist in that models are considered more appropriate the closer their results –not necessarily the model!– are to reality. For these practitioners, validation remains important.

But those readers familiar with the system dynamics literature are aware of a schism in the system dynamics community over the issue of validity of system dynamics models and results[15]. Most system dynamicists see validation as 'the process by which we establish sufficient confidence in a model to be prepared to use it for some particular purpose' (Coyle and Exelby 2000, p28) (Coyle 1977). They do not actually fall back on standard statistical tests of model structure because 'some widely used tests, such as standard statistical hypothesis tests, are either inappropriate or,

[15]See among else (Forrester 1968a) (Forrester and Senge 1980), (Barlas and Carpenter 1990), (Barlas 1996), (Lane 1995), (Richardson 1996), (Barlas 1989), (Sterman 2000), (Coyle and Exelby 2000), (Oliva 2003), (Bell and Bell 1980), (Meadows and Robinson 1985).

at best, supplementary for system dynamics models' (Forrester and Senge 1980, p209)[16]. Hence, validity is not exactly the right word[17].

So, mainstream system dynamicists consider system dynamics models and results appropriate if they are *useful*: '[t]he question facing clients and modelers is never whether a model is true but whether it is useful' (Sterman 2000, p890). Mainstream system dynamics models are appropriate if they generate insight and understanding (concerning the structure-dynamics link and/or the real world), which corresponds to the critical pluralist paradigmatic position. 'Useful' could also imply –in more pragmatist and transformative-emancipatory-critical practices– that appropriate models are models that help reach the specific goals such as solving the research question or leading to desired changes or compromises (pragmatism) or advancing democracy, justice, or the oppressed (the transformative-emancipatory-critical paradigm).

Many system dynamicists also emphasise –apart from the importance of usefulness– the importance of *confidence* in the models build and results obtained throughout the modelling process. And some system dynamics practices focus completely on confidence in models and results, which inclines to constructivism or interpretivism.

Intermediary Conclusion: System Dynamics – A Paradigm or Not? So where Meadows and Robinson (1985) argue that system dynamics practice has its own specific modelling paradigm[18], and Lane (2001a) reveals that there are system dynamics practices with different basic assumptions, it could be concluded here that:

- system dynamics practices could be classified in a high level paradigmatic framework;
- mainstream system dynamics practice has a specific paradigmatic position which corresponds well with the critical pluralist paradigm;
- there are also system dynamics practices which could be argued to belong to the pragmatist, postpositivist, constructivist and (potentially to the) transformative-emancipatory-critical paradigms.

These conclusions are especially important for (i) the appropriate use of system dynamics approaches given the issue, context, parties involved, et cetera, (ii) the correct interpretation of system dynamics modelling results, (iii) the formulation of policy conclusions[19], and for (iv) matching and mixing system dynamics with other method(ologie)s.

Now, one could rightly argue that these paradigms are but constructs or names. They are however constructs or names of consistent sets of basic assumptions (about what the world is, how and what we can know, how our values influence our research, et cetera). So what really matters is that different system dynamics practices *are* characterised by different basic assumptions, and that these basic assumptions should therefore be acknowledged and revealed. This variety or diversity might be a danger if it is not recognised and clearly communicated, but it might also be an advantage if it is recognised and used accordingly. Currently, most system dynamics practice contains some critical pluralist, some postpositivist and some pragmatist elements, which renders the understanding of what system dynamics is and what it could be used for rather difficult, and consequently harm the usefulness and acceptability of the modelling and results.

[16] This does however not mean that system dynamics completely shuns tests. See for example the 17 validity and confidence tests proposed by Forrester and Senge (1980).

[17] 'The word validation should be struck from the vocabulary of modelers. All models are wrong, so no models are valid or verifiable in the sense of establishing their truth' (Sterman 2000, p890). Forrester and Senge (1980, 211) and Sterman (2000, p850) argue in that respect that 'validity is inherently a relative concept relative to a particular purpose'.

[18] Their claim is very natural when put into perspective: their purpose was to clarify the difference in basic assumptions between four different modelling techniques (system dynamics, econometrics, Input-Output modelling, and optimisation).

[19] Andersen (1980) demonstrates 'that differences in analytic paradigms may lead to differences in policy conclusions' which 'places a responsibility upon the analyst to examine continually his selection of technique as well as his specification and execution of a study from within a given technique'.

4.5.2 Different Resulting Strands of System Dynamics

The extended paradigmatic table will now be used to discuss different possible strands of system dynamics practice, depending on their inclination (sometimes not clear-cut) towards one of these paradigms.

Positivist system dynamics: Examples of this type of practice are the rather marginal practices of austere system dynamics, policy engineering, optimisation based simulation, purely quantitative (foresight) system dynamics and micro-world modelling (Zagonel 2004, p10). They are mostly referred to as positivist/ functionalist/ hard/ objectivist/ objective system dynamics practices. Their ontological position is that the modelled systems correspond to existing systems in the real world. Their epistemological position is that stock-and-flow diagrams and causal loop diagrams are good objective representations of the external reality, and that quantitative system dynamics simulation is a way to replicate the dynamics of these real-world systems. Axiologically, they assume that values should and could be avoided as much as possible which is achieved (i) by modelling especially the physical flows, and (ii) by rigorously following 'the scientific method'. The assumed (aggregate) human nature as represented *in* models is mostly determinist and somewhat voluntarist in the sense that individuals might change their behaviours when they get insight in the structure-behaviour dynamics, changing the system structure and future system behaviour. A major assumption of this type of practice is that the real causes, which are temporarily precedent or simultaneous with effects, may be pinned down. The operations and measurement scales are quantitative (ratio scales and ratio scale operations); qualitative scales are quantified 'objectively'. The interpretation of the (mainly quantitative) results is positivist, quantitative and 'objective'. Models should be refutable and models should be refuted if not corresponding to reality, which implies that model validation is a scientific process of comparing real-world facts with simulation results. Typical manifestations of this type of modelling are optimisation, forecasting, neo-classical economics modelling, and engineering for control of real-world (social) system structures.

Postpositivist system dynamics: A small part of contemporary system dynamics practice is postpositivist. Part of initial system dynamics practice, the subgroup of broad system dynamics focussed on validity, calibration and hard data (as for example in (Homer 1997)[20]) and pure stock-flow modelling, part of policy engineering, purely quantitative system dynamics, the subgroup of mainstream quantitative-qualitative system dynamics focussed on validity, and quantitative-qualitative system dynamics focussed on foresight and trajectories could be classified as postpositivist system dynamics. Their ontological/epistemological position is above all realist/objective and contains to a lesser extent some nominalist/subjective elements. The 'scientific method' and rigorous scientific modelling (Homer 1996) are assumed to help postpositivists get as close as possible to probably objectively true findings. The best model is the one closest to the real-world. In this sense, models are micro-hypotheses or minor content theories (Lane 2000a, p12) to be tested, validated or refuted. Axiologically, it is acknowledged that the knowledge is influenced by the researcher's theories and values, that modelling and interpretation are value-laden[21], but that its degree may be controlled through the use of the scientific method and skillful modelling. The methodology is primarily quantitative: the small amount of qualitative data is quantified (soft variables), qualitative models (influence diagrams or causal loop diagrams) are used with the aim of developing fully-fledged quantitative models, and quantitative modelling and simulation are considered by postpositivist system dynamicists to be the core of system dynamics. The simulation results of predominantly quantitative models are interpreted quantitatively. Time and context-free generalisations are not thought to be possible for content related findings. Generalisations could however be made in terms of structure, e.g. system archetypes (structurally nomothetic).

[20] Homer (1997, p296) in particular argues in favor of 'a potent stock and flow structure and a rich fabric of numerical data for calibrating that structure', preferably 'hard data [which] can materially affect the final structure and key parameter values of a model, and, consequently, its predictions and even its policy results' (Homer 1997, p297).

[21] 'There are no value-free theories and no value free models' (Sterman 2000, p851).

Postpositivist system dynamics practice assumes that there are lawful, reasonably stable causal relationships among social phenomena which may be probabilistically known and which change (only slightly) over time, requiring causal micro-theories for its study. This '[c]ausality is unidirectional from element to element around a loop [and] is not ambiguous or reversible' (Forrester 1980, p15). The logic is primarily deductive: the essence of postpositivist system dynamics is the deduction of the simulation results from validated micro-theories. The best model is the one which produces the results closest to the real world. And finally, the human nature is assumed to be rather determinist on the aggregated level.

Critical pluralist system dynamics: In short it could be said that the ontological position of such critical pluralist system dynamics is realist (an external real world exists), whereas its epistemological position is subjective (the real world can only be accessed via subjective mental models). So, it is assumed that there is an external reality that could only be known to a certain extent, because it is necessarily approached by means of subjective mental models. The axiological position is one of awareness *and* concern by the value-ladenness of the methodologies and choice of research and method(ologie)s, basic assumptions, boundaries, et cetera. Such system dynamics models are context and time dependent and are developed in close contact with decision-makers and are therefore ideographic. And the methodology is qualitative *and* quantitative. But the quantitative simulation results are to be interpreted in a qualitative way because of the interest in *increasing understanding* concerning the general dynamics of the assumed/perceived underlying structures. In mainstream system dynamics, causality is of primordial importance, because it allows one to link elements together in holistic structures which generate model behaviour through simulation which in turn could be related to reality: '[c]ritical realism [proceed] by trying to discover underlying structures that generate particular patterns of events (or non-events)' (Mingers 2000a, p1266). Hence, it allows the exploration of our understanding of reality. Since the modelling process is an iterative process of construction, simulation, and interpretation, it is both inductive and deductive: the models –which are micro-hypotheses concerning structure and behaviour– are induced from mental models and other information which are subsequently used to deduce simulation results which are interpreted in order to generate understanding. Such models are appropriate if they are useful in changing mental models and real world structures and generate confidence. Now, the main goal of such system dynamics is to increase the understanding, and usefulness is therefore to be interpreted as increasing understanding of the link between underlying structures and resulting dynamics. And strategies are appropriate if they seem to have the real potential to structurally improve behaviour. Mainstream system dynamics, the subgroup of broad system dynamics practice, the subgroup of mainstream quantitative-qualitative system dynamics practice focussed on increasing understanding, and the subgroup of interactive system dynamics focussed on generating understanding could be seen as critical pluralist system dynamics.

This type of system dynamics is often misunderstood by non-mainstream system dynamcists and outsiders of the field who often look at it from the (post)positivist paradigm(s). Rabins and Harris (1997) for example strongly condemn Forrester's urban and world dynamics models, because they consider the simulated trajectories to be predictions or forecasts, where Forrester and mainstream system dynamcists only use them qualitatively for learning and general understanding.

Pragmatist system dynamics: There is also system dynamics practice along the pragmatist lines. First, there are at least important pragmatist elements in most system dynamics practices, such as the use of soft variables and reference modes. Barton (2002) even suggests that pragmatism might provide *the* underlying philosophy to systems thinking. The ontological/epistemological position is more realist/objective –e.g. in the simulation phase– and sometimes more nominalist/subjective –e.g. in the modelling and interpretation phases: external reality exists, but is interpreted and partially (re)constructed. Pragmatist system dynamics assumes that it is impossible to know which model is closest to reality. Therefore, models are chosen that produce the desired outcomes, or models that are closest to the personal perceptions, world-views and value systems. Furthermore, the underdetermination of theory by fact is accepted. Pragmatists also

accept that the choice of research, the theory used, the modelling, models and the interpretation are value-laden, but they attach different consequences to it: they are aware of it, but not concerned by it whereas postpositivist modelers try to suppress these values as much as possible, and critical pluralists are aware of it *and* concerned by it. The logic is also inductive *and* deductive: the model is induced from perceptions and assumptions and the simulation deduces the simulation results. System dynamics could indeed be seen as an iterative and interactive methodology in which real-world observations/perceptions, facts, previous findings and theories are induced to construct an ad hoc structural micro-theory (the system dynamics model) which is then deduced to obtain simulation results, which are compared to perceptions, expectations, values and theories in order to adapt the ad hoc structural micro-theory (the system dynamics model) which is then deduced to obtain simulation results, etcetera. The methodology is ideographic.

When turning to the –for system dynamics– important issue of *causality*, *pragmatist philosophical theory* seems to be –at first sight– incompatible with system dynamics in that it questions causality, more precisely: (i) a 'universal causality' (Maxcy 2002), (ii) unidirectional and temporal causality, (iii) which, moreover, could be studied by a single method (in casu system dynamics). At second sight, pragmatist and constructivist practices of system dynamics are not concerned by these criticisms because (i) system dynamics does not assume a 'universal causality' or 'general laws' as argued by Lane (2001a), because (ii) system dynamics is based on feedback loops[22], because (iii) the potential criticism of a single method does not hold out as system dynamicists recognise that their method is only appropriate for very specific issues (time-dynamic issues caused by (perceived) circular causality). So, pragmatist system dynamics practitioners assume that the real causality in social-economic systems can never be pinned down exactly. Besides, there is no grand causality: cultures, societies and institutions change, changing existing causality. The real problematic distinguishing feature and inconsistency with mainstream system dynamics is that pragmatist system dynamics is not really interested in structural causality to help understand, but rather in the system dynamics language, techniques, tools and models to make models that just work or help reach a goal or correspond to values.

Operations and measurement scales are quantitative *and* qualitative. Qualitative aspects might be quantified without any problem for purposes of calculation. However, the interpretation is *not* constructivist, because a micro-hypothesis is chosen that best fits the research question, the desired results and the values of the stakeholders and modelers.

Constructivist system dynamics: Examples of this type of practice are Holon Dynamics (Lane and Oliva 1998), Modelling as Radical Learning, or other possible subjectivist, interpretative (Hsiao 2001), soft or constructivist system dynamics modelling practices, 'boundary object models for negotiating a social order' (Zagonel 2004) and the subgroup of interactive system dynamics which either focusses on shared interpretation or which considers all interpretations to be equally valid could be classified as constructivist system dynamics, not those focussed on creating shared understanding or just obtaining a solution. The ontological position is relativist in the sense that 'systems' do not exist in reality, and that only holons or concepts can be described that are intimately linked to the knower. This means that the epistemological position is subjective: models are concepts and describe 'how things might be from a particular viewpoint' (Mingers and Rosenhead 2001, p299). The axiology is unescapably value-bound, the human nature is assumed to be voluntarist, and the methodology is ideographic and mostly qualitative, but could also be quantitative. Quantitative modelling and simulation might help to understand the dynamics of views or the understanding of holons. Furthermore, these strands of system dynamics practice assume that real-world causality is not distinguishable, but that subjective causal interpretations give meaning to the world. Operations and measurement scales are mostly qualitative: quantitative measurement scales are rendered qualitative through interpretation. The interpretation of the results is always qualitative and constructivist. Quantitative and qualitative modelling

[22]Feedback loops imply that if A (in)directly causes B, B in turn (in)directly causes A. Besides, system dynamics does not per definition exclude concurrent causation (the cause is simultaneous with its effect), or backward causation (the cause is temporally posterior to its effect which could be seen as anticipation) although these are difficult to implement.

might help to understand interpretations or meanings. But a holon of one individual is not better than a holon of another individual. Choosing between them makes no sense. Evolution to commonly shared models is sometimes possible. Only the (common) journey can in this case raise confidence and commitment. Possible uses of constructivist system dynamics are modelling for learning and understanding about other points of view, modelling for assumptions and holon hypotheses surfacing, modelling to gain insight in possible evolutions, modelling to build shared interpretation, modelling to find compromises between fundamentally different views, which lead to better-informed decisions and actions in specific domains, commitment to structural changes, etcetera. Emphasised techniques and tools are subjective articulated mental model of a dynamic system, subjective influence diagrams, subjective causal loop diagrams, and qualitative/mental simulation.

Transformative-Emancipatory-Critical system dynamics: This system dynamics practice has the specific goal of helping the disadvantaged and oppressed and to advance democracy and justice using system dynamics tools. Examples are the stream of *modelling as radical learning* which groups modelling approaches to further open debate in groups and deal with power, ideology and coercion, part of qualitative system dynamics like the QPID method (see (Liddell and Powell 2004) and (Howard, Vidgen, Powell, and Powell 2005)), and specific instances of system dynamics and efforts focussed on advancing justice and democracy, and helping the least advantaged. But transformative-emancipatory system dynamics is only marginally developed, which points to a general weakness of system dynamics, namely its poor capacity for representing interpersonal power and social relationships, and the disaggregated level.

5 Use and Importance of the Classification of System Dynamics in the Extended Paradigmatic Table

Many classification frameworks exist, but not all of them are appropriate for classifying the domain of system dynamics because of the fact that system dynamics is quite a specific domain. All such classification frameworks have been developed in specific contexts for specific purposes, and are only to be used what they could be used for. However, they should not be considered and used as invariant or True frameworks. Generally speaking, they could be very useful if used in a critical manner.

The classification framework discussed here, based on paradigmatic basic assumptions, has been developed more specifically in view of consistent matching and mixing of system dynamics approaches, multiple criteria decision analysis methods and other method(ologie)s (see also (Pruyt 2006)). This classification framework could possibly also be used in a critical sense for:

- reflection on the system dynamics domain, its philosophy/paradigms and basic assumptions;
- classification of different system dynamics approaches such that the similarities and dissimilarities between them become clear;
- choice of appropriate assumptions and selection of method(ologie)s or (paradigmatic) approaches in function of the issues and their characteristics, the particular circumstances, the parties involved and impacted, and the goals;
- consistent matching and mixing with other method(ologie)s;
- correct –respecting the basic assumptions– application of the method(ologie)s or approaches chosen;
- correct interpretation of the results;
- clear communication of the approach, the basic assumptions, the results, et cetera.

Now, the use of such classifications is all the more important in the case of system dynamics because of the fact that most system dynamics studies are *not* clear about their basic assumptions. Mostsystem dynamics papers and researchers *are* critical pluralist in that they start from mental models and focus on understanding while recognizing the existence of the real world. *But* they are also very often characterised by postpositivist, pragmatist and other elements. Such mixing up is detrimental to the understanding of the particular studies and the field of system dynamics as a whole because it leads to ambiguous practices, results and interpretations with unclear strength and possible applications. It might therefore be recommended to stick –per system dynamics study– to one philosophical-paradigmatic basic position in function of the particular issues and context at hand, parties involved, and goals, such that the assumptions are clear, that it is used correctly, that it is matched and mixed consistently, that the results are interpreted correctly and communicated clearly. This might add to a better understanding of what system dynamics is and what the results could be used for.

6 Concluding Remarks and Suggestions for Further Research

Little research has been done to reveal the basic system dynamics assumptions. Further research into the (philosophical) basic assumptions of system dynamics theory and practice is therefore needed, not only for deepening the understanding of system dynamics practitioners and outsiders of the field of what system dynamics is and could be used for, but also for increasing the general acceptance of system dynamics and improving it.

In this paper, it has been demonstrated that –although there seems to be one specific mainstream system dynamics approach based on very specific basic assumptions– there are also several system dynamics practices that are characterised by very divergent basic assumptions, which indicates that these system dynamics practices belong to different paradigms: mainstream system dynamics practice could be said to be critical pluralist, but other system dynamics practices are sometimes rather constructivist, postpositivist, pragmatist and potentially transformative-emancipatory-critical. There are indeed various system dynamics practices with ontological, epistemological, causal, logical and methodological assumptions spanning the range all the way from (post)positivism to constructivism. And most (applied) system dynamics practices contain some critical pluralist, some postpositivist and some pragmatist elements. But such paradigmatic inconsistent use weakens the usefulness and acceptability.

Now, a precise classification of these different system dynamics practices or names given to these different system dynamics practices is not what really matters, nor does it really matter whether there is only one specific system dynamics paradigm or whether there are many paradigms to which system dynamics practices belong. What does matter however is that all system dynamics approaches contain some shared basic assumptions, and that different system dynamics approaches incorporate also different basic assumptions. These basic assumptions need to be revealed, especially when matching or mixing system dynamics with other methodologies, so as to use the particular forms of system dynamics what they could be used for, and match and mix them consistently. This means that critical reflection about the basic assumptions is needed every time system dynamics is applied. The paradigmatic framework developed in this paper could be used for that purpose. But other frameworks might be useful as well and are therefore more than welcome. The framework proposed here might also be extended with other paradigms –such as an interpretive paradigm which differs slightly from the constructivist paradigm discussed here. And new –at least to system dynamics– paradigmatic positions or marginal ones –such as the transformative-emancipatory-critical position– might also be further developed, demonstrated and used in practice.

Finally, it is interesting to point at an additional advantage of classifying system dynamics in the paradigmatic framework presented here, namely that the field of system dynamics –which looks even to many insiders as scattered and fuzzy– reappears as a clearly united field, which is

nevertheless characterised by different sets of basic assumptions or paradigms.

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