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The Uses of Qualitative Data in Multimethodology: Developing Causal Loop Diagrams During the Coding Process

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Abstract – In this research note we describe a method for exploring the creation of causal loop diagrams (CLDs) from the coding trees developed through a grounded theory approach and using computer aided qualitative data analysis software (CAQDAS). The theoretical background to the approach is multimethodology, in line with Minger's description of paradigm crossing and is appropriately situated within the Appreciate and Analyse phases of PSM intervention. The practical use of this method has been explored and three case studies are presented from the domains of organisational change and entrepreneurial studies. The value of this method is twofold; i) it has the potential to improve *dynamic sensibility* in the process of qualitative data analysis, and ii) it can provide a more rigorous approach to developing CLDs in the formation stage of system dynamics modelling. We propose that the further development of this method requires its implementation within CAQDAS packages so that CLD creation, as a precursor to full system dynamics modelling, is contemporaneous with coding and consistent with a bridging strategy of paradigm crossing.

Keywords— multimethodology; paradigm crossing; qualitative data analysis; causal loop diagrams (CLDs); computer aided qualitative data analysis software (CAQDAS); problem structuring methods (PSMs)

1. Introduction

Combining together different research methods has been the subject of much debate over the last decade, in that both the intention of the research and the research process are complex and multidimensional, requiring a range of different approaches. This paper makes two key contributions.

First we propose a further development of multimethodology approaches from different paradigms that are appropriate in complex settings. Multimethodology has been defined as "*combining… more than one methodology (in whole or part) within a particular intervention*" (Mingers & Gill, 1997). It refers to the whole area of utilizing a plurality of methodologies or techniques within the practice of "*taking action in problematic situations*"

(Mingers & Gill, 1997). In the cases described in this paper it is bridging between grounded theory and system dynamics through an adequately theorised integration of Causal Loop Diagram (CLD) development with the process of qualitative data analysis. The motivation behind grounded theory as described by (Glaser & Strauss, 1967) is "*the discovery of theory from data*". Such theories are not abstract or deductive; instead the intent behind them is to create "*theory suited to its supposed uses*". Since grounded theories are based on extensive interview data they are usually quite enduring and are well suited to the need to provide predictive and explanatory descriptions of behaviour or action and decision making (Glaser & Strauss, 1967; Strauss & Corbin, 1998).

Secondly, we propose a specific enhancement to Computer Aided Qualitative Data Analysis Software (CAQDAS) to support development of CLDs thus improving what we have called the *dynamic sensibility* of grounded theory, by which we mean the capability of theorising about dynamic behaviour (i.e. behaviour over time) through use of language capable of expressing and reasoning over concepts to do with positive and negative feedback loops.

In the next section we review the status of multimethodology and where the hybridisation of grounded theory and CLD formation is situated with respect to questions of paradigm commensurability. We then review the method of generating grounded theories and briefly outline the terminology of CLDs and their use, which leads to a simple classification structure which positions the hybridisation discussed in this paper. We then describe the practical process of developing CLDs based on the use of a matrix query in a CAQDAS package. Results that illustrate the method are presented in three case studies, two from organisational change and the third from entrepreneurial studies. We then provide a discussion on the practical value of this approach and a critique based on a review of multimethodology.

2. WHAT KIND OF MULTIMETHODOLOGY?

2.1. Review of multimethodology and paradigm commensurability

In recent years the preference for Systems/OR practice to be underpinned by a single methodology has been called into question – see for example (Mingers & White, 2010). The calls for more research on multimethodology are now filtering through into the literature (Mingers & Brocklesby, 1997; Mingers & Gill, 1997; Pollack, 2009; Taket & White, 1998). Such development is desirable to improve practice, in particular by focusing upon how multimethodology can deal more effectively with the richness of the real world and better assist handling complex problems through the various intervention stages. A central concern with multimethodology is the problem of incommensurability of methodologies. This concern is raised by a number of theorists, some of whom, on the one hand, argue that it is inappropriate to use methodologies from different epistemological traditions together, because there may not exist a fundamental framework to which all assumptions about knowledge can be reduced so that conflicts and inconsistencies can be resolved (Burrell & Morgan, 1979; Guba, 1990). Whereas, on the other hand, there is the more pluralist view that suggests different approaches deal with different issues and the combination of paradigms may enrich insights of interventions. However, the justification for combining different schemas for methods is difficult to elaborate. In this paper we focus on the latter view.

Modelling paradigms have been studied by several authors and there is now an established literature offering proposals for methodology classification and explicit paradigm differentiation e.g. (Georgiou, 2012; Harwood, 2011; Howick & Ackermann, 2011; Kotiadis & Mingers, 2006; Pollack, 2009; Zhu, 2011). Here, the most common proposals for classification and differentiation are hard/soft, normative/descriptive and bottom-up/top-down paradigms or approaches. There is no consensus on the paradigm or approach classification category for these since the analysis framework at times transcends the purely methodological views of the approaches (Georgiou, 2012; Harwood, 2011; Kotiadis & Mingers, 2006; Pollack, 2009; Zhu, 2011). However, for clarity in this paper it is the hard/soft characterisation of paradigm differentiation that concerns us. Taking the lead from Table 3-1 of (Checkland & Holwell, 2004) this characterisation aligns the functionalist and interpretivist sociological paradigms of (Burrell & Morgan, 1979) with the positivist and phenomenological philosophical paradigms underpinning business and management research. These two alignments are explained as the division between Hard and Soft OR practice as illustrated in Figure 1 of (Kotiadis & Mingers, 2006) and further described in (Brown, Cooper, & Pidd, 2006; Mingers & Rosenhead, 2004; Pidd, 2004). The discussion of multi-paradigm multi-methodology approach in literature has been mainly focused on a valid and relevant definition of the resulting analysis frameworks and the establishment of a formal context to structure the applications and therefore to build the foundations for guidelines for interventions (Kotiadis & Mingers, 2006; Zhu, 2011). The most relevant summary is the contribution by (Kotiadis & Mingers, 2006) in which they present an analysis of previous discussions on the topic and present a review of the philosophical and practical challenges.

Our conception for multi-paradigm consideration and a multi-methodology approach is based on an open line of discussion on the different strengths and weaknesses of the different paradigms, which can ultimately be defined as a strategy to reach the closest approximation of real world problems, involving the complexity related to several different lines of analysis and their inherent emergent results. In our view, paradigms are by definition different "ways of seeing" by either contradiction or replacement, and so paradigm combination has to be mediated by a strategy. The combination itself is not an explicit formulation of paradigm underlying rationale, but rather a practical engagement for model implementation. This is close to the suggestion by Kotiadis and Mingers that the combination of methodologies coming from different paradigms emphasize problems at philosophical, cultural, cognitive, and practical levels (Kotiadis & Mingers, 2006). In particular, this corresponds to the paradigm crossing position, which we think is the most pertinent proposal to real practice in complex problems and which deals with a consideration of various paradigms (Kotiadis & Mingers, 2006). Two other positions, summarized by Kotiadis and Mingers, are the *integrationist* position that proposes the combination by ignoring the different underlying paradigms and therefore disregarding the paradigmatic assumption impacts on the analysis, and *incommensurability,* which takes a position that denies the real possibility of multi-paradigm coordination and therefore refuses to confront the various problems.

Multi-paradigm thinking (or paradigm crossing) needs to acknowledge the different assumptions, characteristics, and competing approaches in order to establish a coordination strategy. Proposals illustrating this idea, summarized by the authors (Kotiadis & Mingers, 2006), are the sequential and parallel strategies that propose the movement between paradigms as a sequence of methodologies and information chain, being a sequential, linear and unidirectional movement with parallel and unrestricted sequencing in which all paradigms can be applied on an equal basis and a more flexible information chain can be established.

We have witnessed recently a number of attempts to bring more qualitative (research) approaches to the field of OR (Hindle & Franco, 2009; Horlick-Jones & Rosenhead, 2007). For example Rosenhead and Horlick-Jones described the use of more ethnographic approaches with PSMs in a number of studies exploring risk (Horlick-Jones & Rosenhead, 2007). Their study addressed problems at a strategic level, which they claim is typically burdened by two interconnected difficulties: a plurality arising from the diversity of perceptions and commitments of actors involved in associated decision processes, and the existence of often irreducible uncertainties. They suggest that more ethnographic approaches should be combined with OR. This work recognises the need to contextualise the range of knowledge that is seen to constitute "*expertise*". By assessing a wider range of both expert and tacit knowledge, it is argued, contested values and sources of uncertainty, as well as the possible impacts on related policy areas, can be incorporated into the decision-making process. It is worthwhile clarifying that a PSM is a codified approach to intervention in a problem context and explicitly exists to enable action to resolve the problem – see (Ackermann, 2012) for a recent review and critique of PSMs. There is no need for any explicit qualitative data analysis in the use of a PSM. However, qualitative data analysis by itself might only address the Analyse phase of the 4 'A's of multimethodology (Mingers, 2001) and be used as a pure research method with no regard to action.

3. THE METHOD OF DEVELOPING GROUNDED THEORIES

3.1. Overview of qualitative data analysis approaches

We have witnessed that in OR and PSM interventions that there is an avalanche of qualitative data availability in actual fact. At the same time there is an industry of qualitative data analysis, for a review see (Binder & Edwards, 2010; di Gregorio, 2003; Fendt & Sachs, 2008; Glaser & Strauss, 1967; Hutchison, Johnston, & Breckon, 2010; MacMillan & Koenig, 2004; Partington, 2000; Pearse & Kanyangale, 2009; Strauss & Corbin, 1998). It has been argued that a postmodern interpretation of data *views the world as text* and thus subject to narrative analysis (White & Taket, 1994). Therefore, not all data need be collected by direct interview and most organisations have huge sources of textual data from meeting meetings up to sources extracted through processes of automatic data mining.

We make use of the fact that data is predominantly held and analysed by the application of Computer Aided Qualitative Data Analysis Software (CAQDAS) packages such as ATLAS.ti and NVivo. It should be noted that our approach to grounded theory has adopted a "*constructionist*" version of Glaser and Strauss early writings, stressing the need for creativity in the collection and handling of data (Glaser & Strauss, 1967). We describe this in detail below.

3.2. Developing grounded theories

Different interpretations of grounded theory have emerged between Glaser and Strauss over the years. In this paper we follow the approach associated with Strauss and articulated in various editions of (Strauss & Corbin, 1998). Strauss and Corbin offer a practice-based approach for conducting qualitative research and describe the notion of a *grounded theorist*; literally the creator of grounded theories. By grounded theory they mean theory "*derived* *from data, systematically gathered and analyzed through the research process"*. The grounded theory methodology they describe contains three major components:

1. Collection of data; for example interview transcripts and relevant expert documents
2. Procedures for interpreting and organising data; broken down into a) conceptualizing, reducing, elaborating and relating data; which are collectively referred to as *coding*, and b) analytical procedures, such as non statistical sampling, writing of memos, and diagramming.
3. Written and verbal reports, which elaborate theorising about "*what is going on*".

Strauss and Corbin describe theorizing as "*conceiving or intuiting ideas"* and their formulation into a "*logical, systematic, and explanatory scheme"*. Their approach is also intentionally iterative, in that hypotheses should be "*checked out against incoming data"*.

The techniques behind generating grounded theories, based on obtaining qualitative data through interviewing, coding, and theorizing, originated in sociology and focused on behaviours of the individual within some relevant social construct that would be the focus of a study. We note the similarity of data gathering in PSMs or Soft OR approaches (Horlick-Jones & Rosenhead, 2007). We also observe that there is a direct link between grounded theory and systems modelling. The processes of grounded theory therefore provide a means for *grounding* systems modelling, especially structural modelling approaches such as CLDs and system dynamics (Kopainsky & Luna-Reyes, 2008; Luna-Reyes & Andersen, 2003; Sterman, 2000; Yearworth, 2010).

As an alternative conceptualisation of this bridging strategy we can think of introducing the notion of *dynamic sensibility* to grounded theory allowing for reasoning about possible behaviour over time in the form of feedback models expressed as CLDs. Lane and Oliva's idea of bringing a specialised *coherence* to another method, in this case dynamic coherence to SSM (Lane & Oliva, 1998), can be generalised and is useful in multimethodology research. This is important and deserves wider recognition and discussion. We recognise that the property of dynamic coherence can only be achieved by recourse to full system dynamics modelling and simulation (Lane & Oliva, 1998). However, eliciting behavioural explanations for system behaviour over time requires reasoning about causal relationships between variables, which are the categories emerging from the process of qualitative data analysis, and the patterns of positive and negative feedback. These relationships can be captured as CLDs and thus we view CLD development as a precursor to full system dynamics model development in our schema. We believe this is consistent with widely known techniques of system dynamics model development such as described in (Sterman, 2000).

3.3. *What is the process of coding?*

Strauss and Corbin describe the nuances of conducting qualitative analysis and as a practical guide to follow in coding data especially on these points (Strauss & Corbin, 1998):

1. To develop *"In Vivo"* categories – where the name of the category is a word or words taken directly from the data (as in the example presented later).
2. During open coding, breaking data into parts that could be "*compared for similarities and differences"*, and then grouped together into "*more abstract concepts termed categories"*.
3. Axial coding, which relates categories to their sub categories, and in the process to "*Systematically develop and relate categories"*.

The process of coding is a primary activity in qualitative data analysis and the steps described here lead towards the notion of developing and relating categories, which we later develop as we begin to consider the question of the *causal* relationship between categories.

3.4. *Tool support for the grounded theorist – using CAQDAS*

NVivo v8 from QSR International Pty Ltd was chosen as the Computer Aided Qualitative Data Analysis Software (CAQDAS) package to describe the method in the necessary practical detail for it to be followed and also to support the analysis and coding of the data in the case study presented in §6.3. NVivo supports two types of coding nodes, free and tree nodes. Free nodes are used during the early *open coding* stage to develop categories without initial thought to their relationships. However, during the process of coding it usually becomes possible to begin to link categories together i.e. categories and sub-categories and relationships such as influences start to become evident. The process of organising the free nodes into a hierarchical structure, or tree nodes in NVivo, corresponds to the process of *axial coding* (Strauss and Corbin 1998, pp. 123 – 142). However, the relationships between categories captured during axial coding are not necessarily causal. In the normal scheme of grounded theory, the relationships built up during the axial coding process are an essential element of theorising, however in this paper we discuss the development of a heuristic process built around using the matrix query capability built-in to NVivo, and described fully in the next section, which we have developed to help elicit possible causal relationships with a view to producing CLDs.

4. DEVELOPMENT OF CAUSAL LOOP DIAGRAMS WITHIN CAQDAS

4.1. Properties of binary matrices and their use to store CLDs

The properties of binary matrices and their use in systems modelling was first noted by (Warfield, 1973). A binary matrix as the name implies is a matrix that contains elements that are either 1 or 0. If we focus on the relationship between two elements in a system, S_i and S_j, then we can set the i,j^{th} and j,i^{th} elements of a binary matrix to 1 if a relationship exists between these elements, or 0 if not. The matrix can thus be used to describe the *structure* of the relationships between a set of system elements. Since the relationship could be in either direction the binary matrices for systems modelling are always square.

An example useful to describe concepts is shown in Figure 1. We have shown the interpretation of the binary matrix as a directed graph, or *digraph*, where the elements in the matrix are read lexicographically "from row element to column element" to indicate the direction of the relationship. In order to show how matrices can represent CLDs, part b) of the figure introduces a further simplification in that loops (relationships from/to the same vertex) have been removed, since these would have no meaning in a CLD. The cycle A→B, B→A has also been removed by choosing to keep only the A→B relation since this particular type of cycle would also have no meaning as a CLD. However, The cycle C→E→D→C... is precisely the sort of structure of mutual causality, *feedback*, we want to describe in CLDs. The digraph matrix is also called an *adjacency* matrix.

Figure 1 about here

Given that there is nothing special in the order of the labelling of rows and columns Warfield describes how it may be possible for a binary matrix to be *partitioned* into *submatrices* through a process of *permutation* of rows. These submatrices are called *constituents* of the system and the process of partitioning in this way provides a means of decomposing the structure of a system into *subsystems*. This process can identify two possible classes of systems – ones consisting of independent subsystems, and those with hierarchies. All these properties of binary matrices described by Warfield are of potential use in further development of the method we describe.

4.2. Creating a matrix representation from coding in CAQDAS

Whilst the process of axial coding leads to a structural relationship between categories that can be viewed as a hierarchy there is an orthogonal set of information available arising from the way in which CAQDAS stores the linking between codes and text in its database and this provides a method towards the generation of CLDs.

The fundamental idea on which our method is based can be stated in the following axiom: *A possible causal relationship exists between two categories (codes) if the two categories code data within the same scope of the source.*

This is of course in *addition* to relationships already decided by the grounded theorist in axial coding (organisation of tree nodes in NVivo). The axiom does not define the nature of the relationship; this has to be determined, or decided, by the grounded theorist examining the evidence (data). The scope needs to be defined meaningfully and here we describe some heuristics. Setting scope at the level of the *source* document will lead to every category being related to every other category and not useful, the essence of the method is after all to attempt to discover relationships, which describe *system* structure. We argue later that in practice the meaningful level of scope to produce useful structure is the paragraph. A useful consequence of this axiom is that categories from different parts of the axial coding tree can be linked by the text itself – and it is in the investigation of these serendipitous relationships that possible causal structure can be investigated. This structure is unlikely to found by just relying on the process of axial coding alone.

Some quantitative assessment of the significance of the relationship between categories can determined by counting the number of times a pair of categories is linked. The more frequently a potential relationship appears in the matrix query result then the more evidence there is in the data that the two categories may be related.

By way of an example, a set of possible relationships, which might be causal, has been generated by a matrix query in NVivo over the three *In Vivo* concepts shown in the coding strip of Figure 3. The matrix query was set-up to count the number of coding references simultaneously coded by the row and column categories by using the “NEAR content” choice for “Search Criteria”, and the “Proximity Parameter” set to “In Custom Context” and specified to find matches in the “Surrounding paragraph”. What this means in practice is that every time the pair of categories <Category$_i$, Category$_j$> is used to code data within a single paragraph the number of coding references in matrix cell <i,j> is incremented by 1.

Figure 2 about here

Using the scope of the relationship as defined by occurrence in the same paragraph, shown as horizontal lines in the example text in Figure 2, we see that the concepts <management’s ability> and <next stage of money> are potentially related by the paragraph context, whereas the concept <best practices> is not – *by definition* – since it appears in the next paragraph. The use of the paragraph as a scoping device is a compromise and strongly dependent on the way in which the text has been written. A better choice would be to use a sentence but this is not possible in NVivo. The alternative, word count, could lead to generating possible relationships across both sentence and paragraph boundaries. This particular specification of the matrix query search criteria is also suitable for *In Vivo* categories. Where a category has been identified and coded to phrase then the "NEAR content" could have options set to "Overlapping" however since this would generate the same matrix as the "In Custom Context" option described above, its use is considered unnecessary; although the final choice of configuring the matrix query is likely to reflect the coding style of the grounded theorist.

In the example presented next a matrix query was created to generate a table of *all* the potential relationships between pairs of categories defined in the free nodes and tree nodes list from the NVivo project file used in the case study described in §6.3. The resultant matrix generated is shown in Figure 3 using a shading scheme on the cells to highlight the sparsity of the matrix. As expected the matrix is symmetric about the leading diagonal. Possible links, defined as having a non-zero number of coding references, are shaded black. Potentially more significant potential relationships, with 5 or more coding references, are shaded magenta. Absence of relationship is shown by blanks.

Figure 3 about here

The digraph of potential relationships can be interactively explored by a grounded theorist to clarify questions of i) whether the relationship is plausibly causal, ii) its directionality, and iii) the link polarity. The benefit to this exploratory approach built within a CAQDAS package is that it enables a potentially large, but almost certainly very sparse, adjacency matrix to be created and explored quickly. It also allows for repeated refinement of the parameters of the matrix query to ensure suitable scoping of relationships between categories.

In principle the significant category links from the matrix query could have been fed automatically, via some file formatting process, into a systems modelling tool. However, whilst such an approach would be technically feasible to achieve, the results it would generate would be meaningless as a CLD; primarily because it would create bi-directional cycles between pairs of categories (because the matrix generated from the matrix query is symmetric), but also there would be obviously no selection on causality, or information about link polarity and delays. We argue that it makes more sense to explore these questions *close to the data* inside the CAQDAS software *during the process of coding*, rather than in a systems modelling tool at a later stage, and thus implement the *integrated strategy* of (Schultz & Hatch, 1996).

The number of relationships can be pruned using the following ordered process of steps for deciding inclusion, directionality, delay, and significance. For each non-zero element in the adjacency matrix the following steps are required:

1. Determine the significance of the relationship between categories. The method already provides some quantitative data to help the grounded theorist since a count of the number of coding references relating both categories is returned in the matrix query. Deciding on what constitutes a meaningful threshold is a heuristic that can be developed by the coder since the effect of altering the threshold alters the number of potential relationships to be investigated.
2. All the coded text corresponding to the significant correlations needs to be examined in NVivo (by double clicking on the cells in the matrix) and re-read to confirm the significance of the correlation and to understand the meaning and direction of any causality. Ideally this text needs to be extracted for presentation in the written report in which the model is embedded to provide the evidence to the reader that the model is *grounded* in data.
3. Elimination of auxiliary variables. Chains of category links can be shortened where the intermediate categories would lead to an overabundance of auxiliary variables in the models.

Software tools that implement the approaches of graph theory and network analysis functions exist that could be used to examine the structure of the adjacency map generated by the NVivo matrix query for potential loops of relationships (Eden, Ackermann, & Cropper, 1992). Whilst it is tempting to view this possible procedural step as bringing more automation to the method described in this paper it does so at considerable risk.

Not all of the relationships in the adjacency matrix are likely to be causal; Rabinovich and Kacen list all the possible relationships that *could* exist between categories (Rabinovich & Kacen, 2010). Deciding which *must* be an act performed by the grounded theorist; therefore the only *useful* automation to be associated with the method we describe would be purely in making the process of interactive exploration of possible causality between variables more efficient.

5. Case Studies

5.1. The Start and Fizzle of Organisational Change

This case study presents an analysis of two distinct projects emerging from the same group at MIT with Professor John Sterman providing the link between them.

The original work by Repenning and Sterman described combining an inductive methodological approach with system dynamics modelling where the outcome was intended to provide theories concerning the failure of process improvement projects in an organisation (Repenning & Sterman, 2002). In their analysis they describe the organisations they study falling into a "*capability trap*", a dynamic hypotheses arising from the inductively generated system dynamics models created from their qualitative data analysis. This trap is characterised by machine operators' working very hard to meet short-term shortfalls in throughput in production at the longer-term cost of the time available that could have been used to concentrate on improvement activities. The approach used by Repenning and Sterman can be classified as implementing a *sequential strategy* (Schultz & Hatch, 1996). Qualitative data collection and modelling were conceived as two distinct phases in the project, the former preceding the latter.

Building on this work at MIT a practice-based study described by Morrison provides an excellent example of combining an ethnographic approach with system dynamics modelling (Morrison, 2003). Morrison's process led him towards theorising explanations for the *"start and fizzle"* of an organisational change initiative. It was based on an extensive ethnographic study and inductive modelling of an automotive manufacturer in the USA attempting to implement lean manufacturing processes, the Toyota Production Systems (TPS). Morrison developed a grounded theory to explain this start and fizzle, but it is the essential dynamic nature of the behaviour, the co-evolving interaction of process and content that generate the patterns of organisational behaviour observed, that required system dynamics to develop the theory – this is dynamic coherence in Lane and Oliva's meaning. The method Morrison describes is clearly the *parallel strategy* of paradigm crossing in the taxonomy of (Schultz & Hatch, 1996). System dynamics modelling and qualitative data collection and analysis were taking place simultaneously. Morrison's work was exhaustive consisting of 100 days of fieldwork with 1200 pages of field notes and 200 hours of recorded interviews and illustrates the sheer quantity of qualitative data that can be generated. In Morrison's words:

> "*Data analysis included listening to the recorded interviews and reading the transcriptions, coupled with a review of field notes. I identified patterns of interest and recurring themes in the data, bounding the analysis with a focus on efforts to implement change in the first production cell. As is*

typical in developing grounded theory, I organized the data into categories, which I represented with variables and causal relationships between them (Glaser et al., 1967). I combined variables and causal relationships to begin identifying causal loops as a description of the feedback processes gradually emerging from this analysis. During the data analysis, I occasionally translated portions of the emerging feedback structure into formal mathematical models and simulated their behavior in order to gain a richer understanding of the relationship between the feedback structure and the dynamic behavior. The iteration between the grounded data, causal loop diagrams, and formal mathematical models led to additional insights and generated new questions that I could explore in the available data or pursue with my respondents."

The results of Morrison's work demonstrate that an elegant and succinct concept can be *both* grounded in qualitative data analysis and expressive of a dynamic hypothesis that was *only* revealed through the process of causal loop diagramming and system dynamics modelling and simulation.

5.2. Enabling Quality in Design

An approach inspired by (Morrison, 2003; Repenning & Sterman, 2002; Yearworth, 2010) was taken by (Dunford, Yearworth, York, & Godfrey, 2012; Dunford, Yearworth, York, Godfrey, & Parsley, 2012) in on-going work to better understand the development of systems practice within a global engineering firm. This work was motivated by the desire to reduce unprofitable re-work occurring in later stages of product development projects for customers. The phase of the work reported was focussed on an inductive modelling approach to expressing dynamic hypotheses about possible causes and intervention. Model development and expression of dynamic hypotheses followed a process of semi-structured interview and coding supported by the use of CAQDAS. The method used was clearly the *sequential strategy* (Schultz & Hatch, 1996). This was despite an attempt to achieve the *integrated strategy* proposed in the method described in this paper due to inadequate tool support at the time when a purely automated form of search for CLD fragments was performed (Dunford, 2011). It was this experience that primarily led the authors of this paper towards the conclusion that purely automated approaches were a diversion and that the heuristics-based interactive search for causal links within CAQDAS that we describe in §4.2 was a better way forward. The dynamic hypotheses emerging from this work suggest that paradoxically the early application of systems engineering tools are causing problems later in the project lifecycle suggesting interventions directed towards encouraging more flexibility at the design stage, hence "*enabling quality in design*" (Dunford, Yearworth, York, & Godfrey, 2012).

5.3. *Theorising in Entrepreneurialism Research*

This longer case study is based on previous research conducted by one of the authors and illustrates the steps towards theorising about dynamic behaviour in a complex system based on a qualitative data analysis and also presents raw data to describe the method. Morrison and Dunford et al made similar steps and Morrison's dissertation presents the most in-depth description of implementation for reference purposes, albeit without the aid of the partial automation in CAQDAS (Morrison, 2003).

The research question driving this work was based on the observation that the equity-funded entrepreneurial start-up *system* represents a practical solution to the problem of assessing technology development risk and deciding where to allocate capital. Translating this into a meaningful research question for an organisation led to – "*what can managers in the R&D laboratory of a multinational technology firm with a similar risk appetite learn from this other system that can be translated into a decision-making strategy for resource allocation within the organisation?*" Armed with an explicit systems-based view the author decided to go and ask entrepreneurs and VCs how they operated and to seek some way to integrate the data collected into a view of the system that could be used to learn. The research method of grounded theory followed naturally, and the use of a system dynamics modelling approach was used later in the process in order to deal with the problem of reasoning about the behaviour of the system over time. The method used in this work conformed to the *sequential strategy* of (Schultz & Hatch, 1996).

For the purposes of defining a usable scope for analysis the target system was chosen as the VC/start-up system in around the Bristol, UK, area. The VC/start-up system can be viewed as a complex self-organising and self-adapting system that has emerged to solve the problem of efficient conversion of financial investments in new ideas into new business ventures that achieve significant returns to the stakeholders of that investment, and the need of the wider economy for growth. The research question embodied in this case study was the problem of developing an understanding of this particular VC/start-up system such that it could be expressed as a *normative* social theory that can make testable predictions about the factors that impact the creation of new business ventures and therefore be of value to learning about the resource allocation problem in corporate R&D. Given that time was a significant dimension that determined the boundary of the system being analysed it was reasonable to think in terms of developing dynamic hypotheses *grounded* in qualitative data analysis.

The reinforcing feedback loop R0 shown in Figure 4 is characterised as the "*Spotting Opportunities, Testing and Validation (SOTV)*" loop, the aggregate of the reinforcing feedback loops R1-R4 as the "*Realistic Equity Position (REP)*" loop, and R5 as the "*Scale Up and Exit*" loop (Yearworth, 2010).

Figure 4 about here

Reference modes of behaviour were expressed in a single summarising schematic around the notion of bridging two *gaps*. The first is the gap in the market, which the entrepreneur senses and seeks to fill with an offering, probably arising from some new invention or technical/process improvement (Gap 1). The second is the funding gap, which has to be crossed and represents the ability of an entrepreneur to take the idea through an investment process to actually build an operation capable of delivering the offering (Gap 2). Thus gaps in the market are filled with suitable ideas and investors arrive at a decision on suitability by a complex process of sense making. The possible behaviour of an individual firm has been summarised in Figure 5.

The two main loops SOTV and REP are represented on the Evidence/Testing axis and the time axis is self-evident. Time is spent by the Proto-Company in the SOTV loop until Gap 1 is crossed. At which point the entrepreneur is seeking funding and engaged in negotiation with potential investors in a process of sense making leading to potential crossing of Gap 2. Proceeding through stages of funding the firm crosses Gap 2 each time a new deal is struck (e.g. Seed → Series A, Series A → Series B). Failure at any point generates balancing feedback for the system, although clearly for the individual firm this is likely to mean irretrievable failure of the venture. The REP/equity funded quadrant also corresponds to the SUE loop in operation. The firm will also be constantly testing the market, as its offering develops, represented by the loops back into SOTV and in effect crossing Gap 1 again. However, there may be firms where this is not necessary, as indicated by the dotted trajectory. The final crossing of Gap 2 represents achieving a successful exit and the generation of reinforcing feedback in the system, the release of capital to fund more ventures.

To answer the research question a similar approach has been applied to theorising about the behaviour of a corporate R&D project using the causal loop model. In Figure 6 a possible trajectory of a corporate R&D project has been shown. The need to demonstrate that a market exists and has been tested through a prototype that has proven to meet customers' requirements is not necessarily required of the research project before the intellectual property is transferred to the business unit (technology transfers) i.e. it is possible for Gap 2 to be crossed without having first crossed Gap 1. In fact, Gap 1 may not be crossed until quite close to final exit or failure of the idea. Figure 6 therefore suggests normative theory about the behaviour of the corporate R&D system as follows: technology transfer success rates in corporate R&D would improve if each project had to traverse the SOTV loop, in effect forcing the project to demonstrate crossing Gap 1 *before* it was possible to attempt to cross Gap 2. This then was the basis of the suggested intervention, in which the review and resource allocation process within the organisation should be modified accordingly.

Figure 5 & Figure 6 about here

6. Discussion

6.1. On the method

During the process of coding in grounded theory, categories are developed independently at first and only later, during axial, or second-order coding, related in some way (Rabinovich & Kacen, 2010). The identification of relationships between categories is central to the development of theory (Rabinovich & Kacen, 2010), and the primary focus in this work is theory that encompasses reasoning about dynamic behaviour, as a consequence of patterns of mutual causality and feedback, which would not otherwise be possible to express without the formalism of causal loop diagramming. Therefore, whilst relationships may be one or more of conditions (causal, circumstantial, contextual, or other), actions/interactions and consequences (Rabinovich & Kacen, 2010), it is the causal that is of interest as the primary building block of a causal loop diagram. The Relationships between Categories (RBC) Model as enlarged and elaborated by (Rabinovich & Kacen, 2010) goes beyond simple bilateral relationships, however this is not necessary for causal loop development.

The interpretation that a relationship between categories is causal is apparently controversial in qualitative research (Rabinovich & Kacen, 2010). However, the question of causality is legitimate (Maxwell, 2004) and for process of developing causal loop diagrams clearly of absolute primacy. The strength of the case for establishing causality rests on evidence in the data for the existence of a relationship between the categories in the first place. The co-coding, as revealed by the matrix query, at least establishes some basis for a possible relationship between categories. In our method we then appeal to an interactive process with the coder being questioned as to which possible causal relationship it is that links categories, should evidence for causality exist in the data.

Since feedback cycles of causal links are by definition chains of mutual causality it is not possible to store such digraphs in hierarchical structures, they require matrices. Since axial coding, with associated CAQDAS support, leads the grounded theorist to use hierarchical constructs, both conceptually and in the software, the relationships thus captured and expressed are more likely to be classifications and influences, not causation; there is thus a tendency towards *arborisation* and away from *reticulation* using the language of Koestler. Tree structures (hierarchies) are intuitively easier to engage with and manipulate by a computer user compared to networks, which require matrices. File system hierarchies are good example of this intuitive simplicity. The axial coding process in CAQDAS goes hand in hand with hierarchical thinking about structure.

Whilst we have shown how a matrix can represent a digraph there is not a way in current CAQDAS software for a user to interact between a graphical representation of the matrix and the data, although it is possible to navigate between elements of the matrix and the data. However, this is clumsy and potentially extremely time consuming, ideally a systems modelling front-end is required to view the matrix whilst preserving the link to the data and coding structures in the CAQDAS database. For example, clicking on a candidate causal link between two categories presented graphically would immediately retrieve all the data that is simultaneously coded by the two categories. Only in this interactive way will the grounded theorist be able to adequately explore the evidence for the existence of a causal relationship.

The results presented in this paper have been limited by current technical capabilities of existing software tools. Whilst the interactive process of identifying causal relationships are close to the models that have been published elsewhere (Yearworth, 2010), and provide hints or pointers to possible loops, they appear to be fragments of model that are indicative of structure, but are not complete models. This suggests that the heuristic-based interactive process we describe should be implemented *within the CAQDAS software itself*. At the time of coding it would be possible to generate fragments of CLDs dynamically, the grounded theorist could then be queried about possible causality, and the modelling proceeds hand-in-hand with the normal process of coding. In the same way that "*memo-ing*" (Strauss & Corbin, 1998) at the time as coding is seen as best practice, we suggest that creation of CLDs too would become a natural process and best practice.

The method has some similarities with Interpretive Structural Modelling (ISM), the subject of Chapter 4 of (Sage, 1977). Sage's account emphasises the use of ISM as a means of eliciting systems *structure* by generating well-articulated models of systems as a digraph and this is where its similarity to our approach is apparent, together with its shared grounding in Warfield's work on binary matrices. It has yet to be brought into any discussion of its paradigm but its roots in mathematics must surely place it firmly within hard systems. As far as we are aware it has not been noticed as a PSM by the Soft OR community and ideally ISM needs to be critically reviewed, both with respect to its positioning within multimethodology but also for its potential use as an enhancement to the group model building approaches from the system dynamics community (Andersen, Vennix, Richardson, & Rouwette, 2007; Rouwette, Korzilius, Vennix, & Jacobs, 2011; Vennix, 1996; Vennix, Andersen, Richardson, & Rohrbaugh, 1992).

6.2. Multimethodology critique of method

Our critique is anchored by the positioning of the method described within the paradigm crossing strand of multimethodology and focuses on the strategies proposed by (Schultz & Hatch, 1996). It is broadened by reference to similar methods used by (Burchill & Fine, 1997; Dunford, Yearworth, York, & Godfrey, 2012; Morrison, 2003; Repenning & Sterman, 2002) and exhortations from the system dynamics community for integration with qualitative data collection and analysis (Kopainsky & Luna-Reyes, 2008; Luna-Reyes & Andersen, 2003).

Complementary bridging and interplay strategies refer to paradigm acknowledgement of the implemented approaches (Schultz & Hatch, 1996). Because bridging conceives the boundaries between the underlying paradigms as transition zones, it is not possible to completely establish "*...where one paradigm leaves off and another begins*". The authors suggest that this strategy "*can move back and forth between paradigms allowing cross-fertilization while maintaining diversity...*" Thus, this insight that an enriched perspective may arise through crossing paradigms is taken as a strategy for mixing methodologies. This permits us to explore connections between subjective approaches and more quantitative or hard approaches, within a constructivist frame of reference (see for example (White, 2006)).

Another common feature of the published work described is that is closely aligned with the Appreciate and Analyse phases of PSM intervention (Mingers, 2001), although clearly situated within wider projects addressing intervention it seems there was a common desire to *ground* intended intervention in the most basic of ethnographer's questions – "*what is going on?*" – first. We can only speculate that the sparsity of examples of this approach is due to the time-consuming nature of qualitative data collection and analysis, which would be difficult to bear, especially financially, in a commercial engagement. The method we describe at least speeds up the process of developing models grounded in data by proposed enhancement of the capabilities of existing CAQDAS software.

There is also strong advocacy for this type of approach from Luna-Reyes (Kopainsky & Luna-Reyes, 2008; Luna-Reyes & Andersen, 2003) and more recently from (Kim &

Andersen, 2012). Based on an extensive analysis of modelling "processes" across the systems dynamics literature, (Luna-Reyes & Andersen, 2003) arrive the following question *"…it seems apparent that the question is not* if *to use qualitative data, but* when *and* how *to use them appropriately?*". In their analysis they clearly separate the process of qualitative data collection, or gathering, from the process of analysis and treat grounded theory as an analysis stage, not something that is concurrent with data collection as suggested by (Strauss & Corbin, 1998). They do however note the close matching between the linking of concepts in grounded theory and causal links in CLD. They too also comment on the costliness of qualitative data collection, but that when borne can improve the "*formality and rigour*" of modelling, which is perhaps a concern shared by social scientists when looking at model-based approaches. Where do the models come from? What data are they grounded in? What process led from the data to the model? Questions that we addressed in this paper in the method we described in §4. We also note that Luna-Reyes and Andersen see the integration of grounded theory and system dynamics modelling happening at the "*formulation*" stage of modelling and whilst not framed within a discourse about paradigm crossing their argument lends some support for the idea that modelling for the purpose of developing theories about dynamic behaviour should occur at the same time as the coding process used in grounded theory and therefore is aligned with the bridging strategy of (Schultz & Hatch, 1996).

Kopainsky and Luna-Reyes explicitly treat model building as theory building and thus argue strongly for approaches such as grounded theory constituting a toolset that helps build *"…relevant system dynamics models, grounded in data, and with higher potential to provide rigorous and relevant generic structures*" (Kopainsky & Luna-Reyes, 2008). Whilst we have not explicitly addressed rigour in this paper it is interesting that there is a perceived need for rigour coming from the system dynamics community and that qualitative data collection and analysis, and specifically grounded theory, meets this need.

Why then this narrow group in the system dynamics community as exemplars and advocates and why no further examples? Horlick-Jones and Rosenhead make a strong entreaty for the combination of ethnographic approaches with PSMs generally (Horlick-Jones & Rosenhead, 2007). We have rejected incommensurability as a barrier and have asserted that we are justifiably paradigm crossing. We have also argued that there is an appropriate bridging strategy in (Schultz & Hatch, 1996) that can be followed. Perhaps the inhibition is that ethnographic approaches are intensive in the use of researchers' time and require investigative skills to obtain the necessary data. Whilst this might be the case, we would argue to the contrary as follows. If we go back to the roots of OR in WWII and the work of

Blackett cited in (Horlick-Jones & Rosenhead, 2007) we can see that the authors cited have probably achieved what would have been described in the 1940s as "*vulgar competence*". Exactly what was required from OR researchers *then*, and we suggest that is exactly what is needed *today* as well. Perhaps another answer is an apparent disconnect between the Soft OR and system dynamics community? Whilst we have rejected incommensurability we are aware of criticisms of this stance in the OR/MS and systems thinking community e.g. (Jackson, 2003) as well as in the system dynamics world e.g. (Coyle, 2000). For example Jackson's trenchant rejection on qualitative uses of system dynamics modelling is set out by saying that it must stick to its "*functionalist aspirations*" else it becomes an "*under theorised soft systems approach*", a clear incommensurability position.

We have also argued that organisations are awash in qualitative data (an avalanche) and the methods described could work equally well with any sort of qualitative data, not just semi-structured interviews. We suggest that the limitation is in the tools of the trade. CAQDAS are ubiquitous but are not intrinsically suited to developing CLDs for the data structure reasons we have discussed. However, they could be made suitable with comparatively minor modification. We have demonstrated feasibility, but by the very lack of tool integration have not been able to do that in a fully "*bridged*" sense (Schultz & Hatch, 1996). Morrison did achieve this but by using a very laborious manual process (Morrison, 2003).

Tools alone are never usually the answer to a problem, but in the case where CAQDAS and CLD tools *are* widely used we make a plea for tight integration of CLD capability *into* CAQDAS, i.e. close to the data, to achieve the theoretically well-justified paradigm crossing technique we describe.

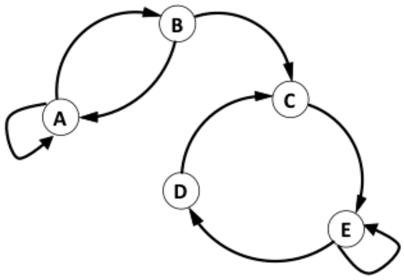
7. Conclusions

We have addressed a facet of the problem of paradigm incommensurability in multimethodology. It is assumed that methods are tied to paradigms, and that paradigms make incompatible assumptions. There are many arguments against this view and certainly in social research more generally pluralism is considered acceptable. In this paper we have presented a multimethodology that combines the qualitative data analysis process of coding using Computer Aided Qualitative Data Analysis Software (CAQDAS) with that of developing Causal Loop Diagrams (CLDs), which can be used in the formation stage of full system dynamics modelling. Our original motivation was based on the need to reason about dynamic behaviour during a process of qualitative data analysis. This need is seen to align well with a wider need to bring ethnographic approaches to PSMs and also the perceived need within the System Dynamics community to ground models in a formal qualitative data analysis stage to enhance formality and rigour. There is some evidence in the literature for successful use of the method we describe, although not positioned or justified theoretically within multimethodology. Our stance has been to reject both integrationist and incommensurability positions and have instead adopted paradigm crossing, and we have argued for using a parallel, bridging strategy for this to be well justified. Having presented three case studies in the domains of organisational change and entrepreneurialism that demonstrate implementations of the method we describe we conclude that for future practical implementation that fulfils this parallel bridging strategy requires the tight integration of matrix-querying of categories with CLD diagramming capabilities within the CAQDAS tool itself, so that questions of causality and application of practical heuristics can be carried out contemporaneously.

The practicality of multimethodology and PSMs means that we are working closely with stakeholders at all times and we have argued that it is in this process of engagement that we become awash with qualitative data. With appropriate tool support there is no reason why we cannot model *close to the data*.

We would expect that as more examples of appropriately theorised combinations of qualitative data analysis approaches with PSMs appear in the literature that support for paradigm crossing of this type would grow in the OR community. With CLD integration in CAQDAS we would expect more use of this method and by generalising our results to other forms of systems modelling, more could be done in CAQDAS to integrate qualitative data analysis approaches and PSMs. Suggestions for future work are to critically evaluate this conclusion in practical interventions, such as outlined in (Dunford, Yearworth, York, & Godfrey, 2012), using a pre-existing conceptual framework (White, 2009). It would also be appropriate to engage with the theoretical debate in the social sciences more generally about causality and to understand how this method sits with ideas of methodological individualism or localism and the centrality of mid-level theorising (Little, 2011).

	A	B	C	D	E
A	1	1	0	0	0
B	1	0	1	0	0
C	0	0	0	0	1
D	0	0	1	0	0
E	0	0	0	1	1



	A	B	C	D	E
A	0	1	0	0	0
B	0	0	1	0	0
C	0	0	0	0	1
D	0	0	1	0	0
E	0	0	0	1	0

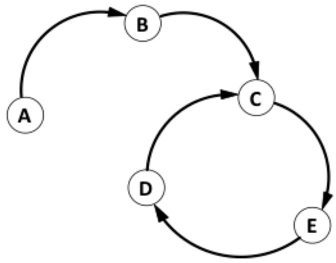


Figure 1. Binary matrix on the left describing the graph on the right. Note that the row and column labels are not part of the binary matrix but are shown for convenience.

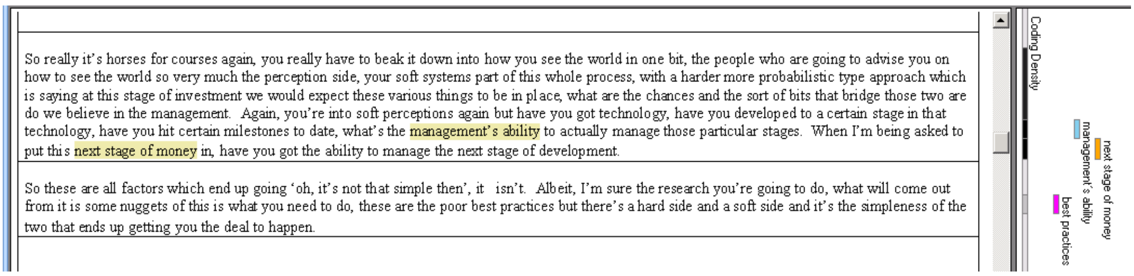


Figure 2. Example relationship highlighted by a matrix query over three 'In Vivo' concepts shown in the coding strip. The scope of the relationship is defined by occurrence in the same paragraph – shown as horizontal lines in the text. <management's ability> and <next stage of money> are potentially related, whereas the concept <best practices> is not – by definition.

Figure 3. Adjacency matrix generated from the matrix query in NVivo. Cells with 1≤References≤4 are shaded black; cells with references ≥5 are shaded magenta.

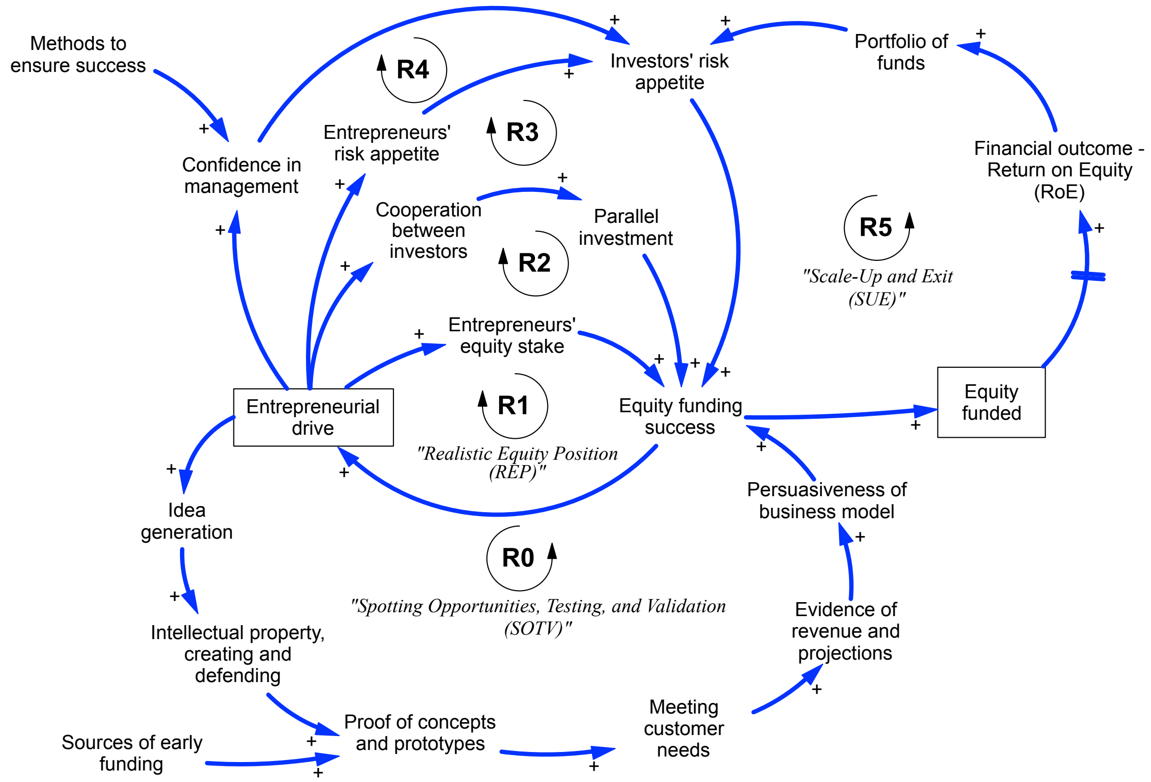


Figure 4. Refined CLD with pruned links and labelled feedback loops with stocks identified as a precursor to full development of a system dynamics model. Note that entrepreneurial drive is an example of a "soft stock" described by (Fowler, 2003).

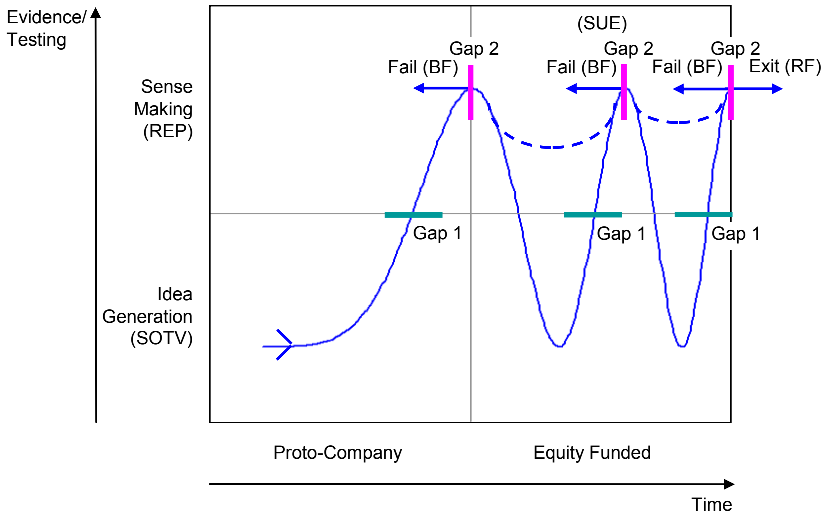


Figure 5. Small firm trajectory against Gap 1 and Gap 2

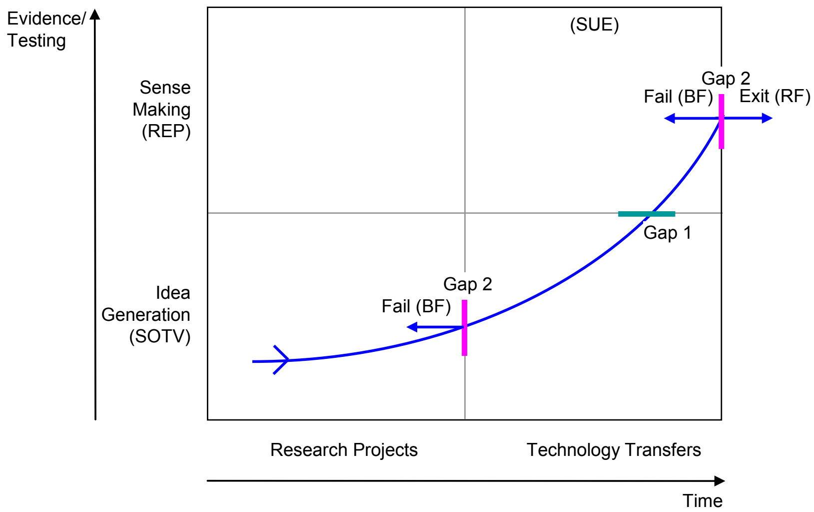


Figure 6. Corporate R&D project trajectory against Gap 1 and Gap 2

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