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Systemic Thinking and Complex Problem Solving
A theory building empirical study

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ABSTRACT

This study addresses the relationship between systemic thinking and complex problem solving. The efficacy of systemic thinking in complex problem solving has received scant attention to date in the literature. The research examines the effectiveness of the use of systemic thinking in the context of a simulation task. The Verbal Protocol Analysis methodology was used to gather and analyse data. As part of this approach, a coding scheme was developed to operationalise the systems thinking paradigm and hence enable systemic thinking to be quantified. Three research questions were specifically addressed. While the research questions guided the study, there were no clear expected outcomes due to the paucity of prior research in the area.

The findings of the study indicate that the notion that more systemic thinking leads to better task performance is a simplistic one and that in reality, the picture is more complex. While the degree of systemic thinking does matter, results suggest that in fact it is certain types of systemic thinking that are more relevant. The type of systemic thinking carried out is however not solely accountable for performance in complex problems. The subject's approach to the problem is also a highly pertinent factor in task performance. This study contributes to the field of research by providing insight to both the fields of systems thinking and complex problem solving. Specific contributions include the research approach and the approach to operationalising systems thinking. That is, the use of a simulation in combination with the Verbal Protocol Analysis method for the study of systems thinking, and the development of a coding scheme based on Richmond's (1997a) thinking skills.

Key words: Systems Thinking Theory, Complex Problem solving, Empirical Studies

INTRODUCTION

There is a widely held belief that systems thinking is an answer to the increasing complexity of the environments in which we live and function. However there is little empirical evidence to support the notion that systems thinking is indeed effectual in dealing with complexity. There is scant evidence in the literature to address this gap. Recently however, there have been calls for empirical research to focus on the issue. "Many claims have been made concerning the ability of systems thinking interventions to change the nature and quality of thought about complex systems, …[yet] important questions about the relationship between systems thinking and basic cognitive processes such as problem solving, decision-making, and updating mental models remain unanswered" (Doyle, 1997, p. 253).

This study attempts to address this gap in the literature. The research focuses on whether use of the systems thinking *paradigm* (thinking systemically) leads to better performance on a complex problem.

The approach adopted for the study is the use of a simulation with the Verbal Protocol Analysis methodology. To address the problem of measuring systemic thinking, a coding scheme was developed, based on the work of Richmond (1997a). This coding scheme served to operationalise the systems thinking paradigm and allowed its use to be quantified.

A research sample of ten students who had received systems thinking training were selected to participate in the study. They were required to work through a simulation, which also gathered data on their task performance. Subjects were instructed to take a "systemic approach" to the task and to verbalise their thoughts as they worked. These verbalisations generated the core data for analysis. Each participant's verbalisation generated a verbal protocol approximately 35 minutes in length and contained on average 358 statements. These statements were subsequently coded and analysed. The analysis revealed some insightful findings for both the fields of systems thinking and complex problems solving.

SYSTEMIC THINKING PARADIGM

In this study, we adopt systems thinking as a *paradigm*. This refers to systems thinking as a "world view' – seeing things holistically and interconnected. Therefore, here, by thinking systemically, we mean subscribing to the systems thinking *paradigm*. However, translating systems thinking principles into 'tangible' elements has remained a research challenge. As an attempt to define practical ways to understand systems thinking Richmond (1993) proposed a set of 'thinking skills'. Since his first article, Richmond (1997a) has added and further defined these thinking *skills*. To date, they still remain the main foray into an 'operational' guide to thinking systemically.

Richmond suggests that systemic thinking requires operating on at least seven thinking tracks simultaneously. The updated seven thinking skills are (1997a) as follow:

1. Dynamic thinking
2. System-as-cause thinking
3. Forest thinking
4. Operational thinking
5. Closed-loop thinking
6. Quantitative thinking
7. Scientific thinking

Richmond stipulates that the numbering and consequently the sequence of the seven thinking skills is important as this serves as a process for using systems thinking, with each thinking skill building on the previous. As skills 6 and 7 are primarily relevant to system dynamics modelling efforts, in this study, we focus on the first five skills. These are defined below (Richmond, 1997a).

Dynamic thinking is essentially a mental application of the behaviour over time graph. It allows a problem or issue to be framed in terms of a pattern of behaviour over time. It means, one needs to put a current situation in the context of time scale - "The trajectory should thus have a historical segment, a current state and one or more future paths" (Richmond, 1997b, p. 6).

System-as-Cause thinking expectedly builds on dynamic thinking. This thinking enables the determination of plausible explanations for the behaviour patterns identified with dynamic thinking. Richmond suggests that "relationships that are not under the control of decision makers within a system should be eliminated from consideration" (1997c, p. 6). Essentially, this perspective means viewing a system's behaviour as the result of the systems and as such under the control of decision makers.

Forest thinking is seeing the 'big picture'. "Forest thinking gives us the ability to rise above functional silos and view the system of relationships that link the component parts" (Richmond, 1997d, p. 6).

Operational thinking attempts to identify causality – determining how a behaviour is generated. Generally people have a tendency to think 'correlationally' or to think about influence. Operational thinking looks at the structure or 'physics' of relationships, at *how* one variable affects another not just that they affect each other. Operational thinking helps to recognise the notion of interdependence; that generally within a system, there is a web of relationships (Richmond, 1998a).

Closed-loop thinking helps to identify the principle of a closed-loop structure. It enables a person to see that causality does not run in just one direction, but rather that an 'effect' usually feeds back to influence one or more of the 'causes', and that the 'causes' themselves affect each other. It is important as part of closed-loop thinking not to prioritise 'causes' as being most or least important but rather to understand how dominance amongst them may shift over time (Richmond, 1997a).

SYSTEMS THINKING AND COMPLEXITY

Systems thinking is purported as being highly germane for dealing with complex systems and problems. There is a widely held view that systems thinking is superior to other approaches in dealing with complexity (Richmond, 1993). It is asserted that today systems thinking is needed more than ever as we are being overwhelmed by complexity (Senge, 1990). Checkland adds his words: It is "the use of a particular set of ideas, systems ideas, in trying to understand the world's complexity" (Checkland, 1981, p. 3).

As it is clear from these comments, systems thinking has increasingly been offeredas an answer to complexity, and with it the idea that our intuitive understanding in complex situations, does not lead to adequate actions (Schaffernicht, 1999). However, despite the accepted value of systems thinking for dealing with complex systems, most individuals have a great deal of difficulty thinking systemically. "We've grown up in a reality in which 'local' perspectives enabled us to do just fine, we have developed certain 'habits of thought' which make it difficult to learn in an interdependent reality" (Richmond, 1994a, p. 213).

Numerous studies reported in the literature illustrate non-systemic behaviour by individuals confronted with a complex problem. Explanations of participant behaviour "reflect an 'open-loop' conception of the origin of dynamics, as opposed to a mode of explanation in which change is seen as arising from the endogenous interactions of decision makers with their environment" (Sterman, 1989b, p. 336). In addition, it has been found that people are insensitive to feedback and underestimate time lags between action and response (Sterman, 1989b). This insensitivity to feedback "reflects a failure on the part of the decision maker to assess correctly the nature and significance of the causal structure of the system, particularly the linkage between their decision and the environment" (Sterman, 1989a, p. 324).

COMPLEX PROBLEM SOLVING

The origins of complex problem solving can be traced back to the early experimental work of the *Gestaltists* in Germany. "Through the sixties and early seventies, research on problem solving was typically conducted with relatively simple, laboratory tasks[1] that were novel to subjects (e.g. the 'x-ray' problem and the 'disk' problem, later known as '*Tower of Hanoi*')" (Frensch & Funke, 1995, p. 16). During this period, it was thought tenable to generalise from these simple problems to more complex problems. However, researchers became increasingly convinced that empirical findings and theoretical concepts derived from simple laboratory tasks could not be generalised to more complex, real-life problems (Frensch & Funke, 1995).

There are varying definitions of a complex problem within the field of complex problem solving. Two examples follow:

- *Complex problem solving is concerned with people's ability to handle tasks that are complex, dynamic (in the sense that they change both autonomously and as a consequence of the decision makers actions), and opaque (in the sense that the decision maker may not be able to directly see the task states or structur*e (Brehmer, 1992)

[1] See Newel and Simon (1972) their work is "perhaps the best known and most impressive of this line of research" (Frensch & Funke, 1995, p. 16).

- *Complex problem solving is the successful interaction with task environments that are dynamic (i.e. change as a function of the user's intervention and/or as a function of time) and in which some, if not all, of the environment's regularities can only be revealed by successful exploration and integration of the information gained in that proce*ss (Buchner, 1995).

Although these definitions appear different the underlying ideas are contiguous and can be summarised as follows: Complex problem solving occurs to overcome the barriers between a given state and a desired goal, where the system in which the goal must be achieved is complex, dynamically changing and intransparent (Frensch & Funke, 1995). Hence, a complex problem is a type of problem that results in a *complex, dynamically changing* and *intransparent* system.

APPROACHES TO COMPLEX PROBLEM SOLVING

Two formal and divergent approaches to complex problem solving have emerged, namely, the *individual differences approach* and the *formal task analyses approach*. The individual differences approach has two primary goals (Brehmer, 1992, p. 223):

1. *To find ways of predicting behaviour* in complex tasks, so that it would then be possible to select good decision makers, and to
2. *Identify the demands* made by these tasks by comparing the behaviour of the subjects who are successful in controlling them with that of those who are not so successful.

The principal method in this approach has been the use of microworlds or "complex computer simulated domains of reality " (Funke 1988, p. 278). This approach involves a group of subjects performing in the same microworld, and then being divided up into two extreme groups, one that succeeds and one that does not (Brehmer, 1992). "These groups are then compared with respect to their performance on some test, or with respect to their behaviour in the simulation, to find possible explanations for the differences in performance" (Brehmer, 1992, p. 222).

The formal task analyses approach on the other hand, tries to understand the disparity between subjects' satisfactory control performance and their inability to answer questions about the system they had learned to control (Buchner, 1995). That is performance improvements in the absence of explicit knowledge about the task (Frensch & Funke, 1995). This approach uses simple simulations that are mathematically well defined.

Although much research has been undertaken in the individual differences approach since 1975, there are only few theories informing what an individual should do or what qualities they should possess in order to excel at complex problem solving. What exists to date can at best be described as general observations. Certainly, the literature of complex problem solving has not revealed any further insights about the effectiveness of systemic thinking for complex problem solving.

CALL FOR EMPIRICAL RESEARCH

Despite the wide acceptance that systems thinking is highly effective for dealing with complexity, recently there have been calls from within the field for empirical substantiation of this assertion. Doyle (1997) states in the regard:

"Many claims have been made concerning the ability of systems thinking interventions to change the nature and quality of thought about complex systems. Yet, despite the increasing number of interventions being conducted in both educational and corporate settings, important questions about the relationship between systems thinking and

basic cognitive processes such as problem solving, decision-making, …remain unanswered." (p. 253)

Further, Cavaleri and Sterman observe "The relationship between the use of systems thinking and organisational performance remains the province of anecdote rather than rigorous follow up research" (1997, p. 171). Huz, Anderson, Richardson and Boothroyd (1997, p. 150) have raised similar issues. More recently, Delauzun and Mollona added their voice "There has been some concern about the scarcity of reported studies dealing with the actual contribution of system dynamics in enhancing effectiveness or productivity" (1999, p. 364). Clearly, there is an influential body of researchers, who have identified a gap with regards to empirical research on the effectiveness of systems thinking.

In recognising this gap, two articles[2] were published in 1997 in the System Dynamics Review, addressing the effectiveness of systems thinking interventions. Huz et al. (1997) report a group model building intervention at Services Integration Projects (SIPs) in four counties in the state of New York. Four control counties were also selected and all eight counties were observed via pre and post intervention measures. Huz et al. report only the findings of a pilot study but their key conclusions were:

- The modelling team felt the intervention was very successful and that the group process went well and participants were pleased with the intervention.
- Participants' perception of the intervention was that it was productive and worthwhile and that there were significant shifts in participants' goal structures and change strategies. There was also greater alignment of participant mental models and greater understanding of system structure and behaviour.
- Attention within the organisation was refocused away from client-level concerns towards system-level considerations.

In a different study, Cavaleri and Sterman (1997, p. 171) report on a "follow-up evaluation of a well known systems thinking intervention designed to improve quality and performance in the claims adjusting unit of a US insurance firm [Hanover Insurance]." They found that subjects reported a much greater awareness of their thinking and changes in their behaviour, which they attributed to the intervention. Subjects went on to say that their management style became more "systemic" and that this helped in the design of new policies.

Most of the studies thus far have focused on systems thinking interventions rather than the effectiveness of systems thinking skill (*paradigm*). Further, the study of complex problems has shed little light on the issue of what attributes or skills are best for dealing with such problems. There are few conclusive findings and no established theories. Some consistent characteristics have emerged, however, amongst good and poor performing participants that show interesting parallels to systemic and linear thinking respectively.

To summarise, there is a curious gap in both systems thinking and the complex problem solving fields. The gap concerns empirical studies on the value of subscribing to a systems thinking paradigm when faced with complex problems. The absence of theories within the complex problem solving literature and empirical work in the systems thinking literature, certainly do not bode wall (with) resolving the issue of the value of systems thinking in solving complex problems. This paper, part of a larger study, seeks to contribute to this question in an exploratory manner.

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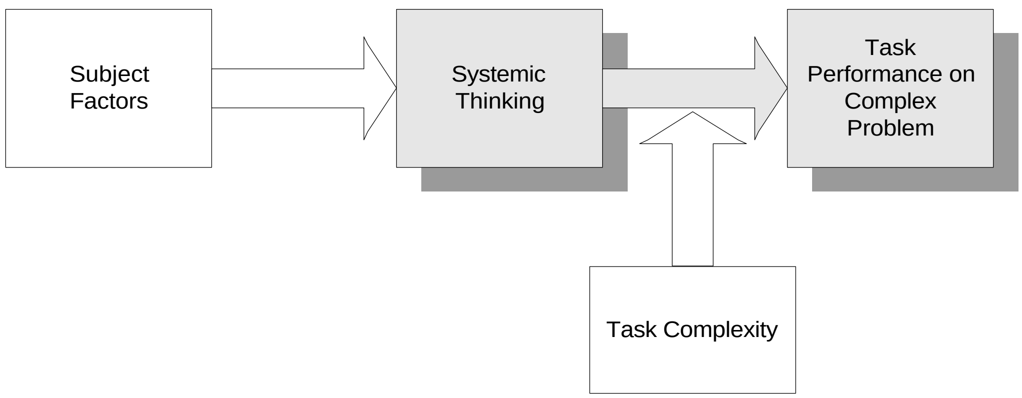
[2] Huz, et al., (1997) and Cavaleri and Sterman, (1997).

RESEARCH MODEL

The research model, derived from the conceptual model of the *individual differences approach* (Funke,1991) is pictured in Figure 1.

Figure 1 – Research Model



The shaded part of Figure 1 – Research Model represents the scope of this study, the objective of which is to investigate empirically the postulate that systemic thinking is effective for dealing with complexity.

To put this study in the context of the research model (Figure 1), systemic thinking falls within the area of 'subject factors' and more specifically within the topic of 'cognitive abilities', hence the arrow from subject factors to systemic thinking. Since this study is interested in the effectiveness of systemic thinking in dealing with complexity, outcome will be measured by performance on a complex problem. Performance is the most commonly used dependent variable in individual difference approach to the complex problem solving. The inclusion of task complexity in the research model is for contextual reasons as the level of complexity is an important factor, which could conceivably be varied, but this aspect lies beyond the scope of this study.

From the research model and the literature reviewed, three research questions are derived. They are:

1. *Does (more) systemic thinking lead to better performance in complex problem solving?*
2. *Do certain aspects of systemic thinking have a greater impact on performance in complex problem solving?*
3. *Do certain sequences or patterns of systemic thinking skills lead to better performance in complex problem solving?*

The first question addresses the main objective of this study – whether systems thinking is indeed more effective for dealing with complexity. This may be stated as follows that the degree or 'amount' of systemic thinking will influence performance on the complex problem.

The second and third research questions can only be clearly explained if their theoretical base is first elucidated. Richmond's (1997a) seven systems thinking skills will be used in this study as the basis for operationalising systems thinking. As stated earlier to our best knowledge, no other theoretical guides for the operationalisation of systems thinking is found in the literature reviewed.

As stated earlier the last two of the seven thinking skills are primarily relevant to system dynamics modelling efforts. Thus, only the first five of Richmond's (1997a) seven 'systems thinking skills' will be employed in this study. Collectively, these five thinking skills represent what it means to subscribe to a systems thinking paradigm.

Hence, the second and third research questions are developed based on 'splitting' of the systems thinking paradigm into five skills. As implied in research question two certain elements of systemic thinking are perhaps more relevant and more effectual for performance on complex problems than others. Research question three proposes that a sequence or pattern of use may exist amongst the five skills, which would lead to better task performance. The impetus for this question is also due to Richmond (1997a), who stipulated that there is a 'natural sequence' to the skills which is necessary for their use and consequently for better performance in complex problems. This may or may not give rise to Richmond's notion of sequence of skills.

RESEARCH METHOD

The research method adopted in this study is Verbal Protocol Analysis (VPA). Protocol analysis technique has a long history in the field of psychology (Ericsson & Simon, 1993). A *protocol* is an audio record of the thought processes of the decision maker. Video recordings can also be used to garner greater insight through observation of non-verbal indicatiors.
VAP is a well-established methodology for individual differences research. The individual differences approach typically involves subjects working through a microworld (a complex problem). Good performers are then separated from bad performers in order to analyse what factors contribute to each group's performance. The microworld computer program typically gathers the performance data and other data such as behavioural information is gathered through observation and sometimes through verbal protocols.

Since this study is adopting a method closely based on the individual differences approach, a microworld will be utilised. Hence, while the microworld will collect performance data, subjects will not be grouped into good and bad performers for analysis. Instead, subjects with systems thinking training will be used and instructed to take a systemic thinking approach to the problem. Their performance will then be ranked based upon their use of systemic thinking,[3] it will then be determined whether systems thinking exhibits any relationship to performance on complex problems.

VERBAL PROTOCOL ANALYSIS

Protocol analysis, also called verbal protocols, is an "approach that provides access to what information is examined, the manipulations conducted on the input stimulus and, additionally, what evaluations or assessments are made by the problem solver" (Todd & Benbasat, 1987, p.496). Verbal protocol analysis fits within a larger group of research methods known as process tracing methods. Process tracing methods allow for (more refined) measurement of what occurs between the introduction of a stimulus and the measurement of outcome, something that traditional input-output measures have difficulty doing (Todd & Benbasat, 1987).

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[3] The measurement of the 'amount' of systemic thinking done by a participant will be discussed later.

This study is interested in exploring individuals' thought processes during complex problem solving. A process tracing method is considered a most appropriate research method here because these methods allow research of the processes or inside the "black box" which intervene between the independent variables and the dependent outcome, rather than contextual factors such as characteristics of the task, availability of decision aids, etc. "With process models, the algorithm or strategies that people use in arriving at a decision are the main focus of inquiry" (Ford, Schmitt, Schechtman, Hults, & Doherty, 1989, p. 75). More common research methods such as surveys, case studies, interviews etc. are unable to reveal the intervening steps that occur between the introduction of informational inputs and the decisions outcomes. These methods are best suited when solely input and output measures are sought.

This study is concerned with what information is examined; the manipulations conducted on the input stimulus; and what evaluations or assessments are made by the problem solver. Of the process tracing methods, the concurrent "think aloud" verbal protocol method was selected because it is considered to be the most powerful process tracing method to use in less structured contexts, ie. for complex problems. "Protocol analysis has been used extensively as an effective method for in-depth examination of cognitive behaviours" (Schenk, Vitalari, & Davis, 1998, p. 32) and offers the greatest data richness of all the process tracing methods. Further, "there are a variety of psychological techniques that could be applied in replications of seminal experiments on dynamic decision making. One of the most promising techniques is the use of 'think aloud' protocols" (Doyle, 1997, p.260). Todd and Benbasat (1987, p. 497) consider protocol analysis to be "the most powerful of all process tracing tools" adding that "verbal protocols provides the greatest data richness and information value per data point."

Verbal protocols can be divided into two categories - retrospective and concurrent. Getting a participant to recall his/her thought processes after having performed a task generates retrospective protocols. Concurrent protocols are generated by getting participants to verbalise their thoughts while doing a specific task. This is done by instructing them to "think aloud." With this instruction subjects verbalise new thoughts and generate intermediate products as these enter attention. For example, a subject given the task of mentally multiplying 24 by 36 while thinking aloud might verbalise: "36 times 24," "4 times 6," "24," "4," "carry the 2," "12," "14," "144," and so on.

In summary, when elicited with care and interpreted with full understanding of the circumstances under which they were obtained, verbal reports are a valuable and reliable source of information about cognitive processes (Ericsson & Simon, 1993).

PARTICIPANTS AND SAMPLE SIZE

Participants for the study were ten business school graduate students undertaking courses in operations management. The ages of the participants ranged from 21 to 25. Participation in the research was voluntary and involved a maximum of two hours. All the participants had some form of systems thinking training. Of the ten participants, four had completed two courses in systems thinking, five were in the process of completing the second course and one was enrolled only in the second course. All participants received instruction from the same two lecturers in order to maintain consistency in their systems thinking training.

It should be noted here that it is not the assertion of the researchers that any of the selected subjects, as a result of their training, will subscribe to the systemetic thinking paradigm. It is, however, expected that through their knowledge of the systems thinking (as a result of their training), the subjects are capable of utilising it. Since the objective of this study was not to investigate the effects of systems thinking training, subjects' knowledge of systems thinking was not assessed.

The methodology is recognised for being labour intensive and thus, the majority of studies have utilised small samples sizes, thus the sample size of ten is within the norms of study methodology. Due to the high density of data that is found in a single verbalisation, samples are typically between two and twenty (Todd & Benbasat, 1987).

SIMULATION TASK

Participants were required to work on a simulation of a fictitious computer technology company called *Computech.*[4] In the simulation, *Computech* has been in business for two years, having just completed their first full year of product sales. The simulation task required the participant to act as the CEO for five years made up of 20 quarters starting from quarter 0 through to 19. The participant (CEO) could manipulate five levers – total sales force headcount, average sales compensation, marketing spending, average price per unit, and capacity order. There was no time limit set on the task but participants typically took around 30-35 minutes to complete the task.

Performance in the simulation was assessed by three objective measures – revenue, profit (as a percentage of revenue) and market share. Participants had to make a decision each quarter using as many, as few, or none of the five levers at their disposal. All three objectives had specified targets. For example, revenue was to reach $40 million from the starting level of $4 million by the end of the simulation.

Task Complexity

Simulations (microworlds) are perhaps the most widely used tools for representing complex problems (see Brehmer, 1992; Buchner, 1995; Dörner, 1980; Funke, 1988; Sterman, 1989b). Simulations are particularly advantageous tools as in addition to being the study task, they also serve as a measurement tool by gathering performance data. Microworlds are *complex* in the sense that they require subjects to consider many different elements – such as different and possibly conflicting goals. They are *dynamic* in some or all of following senses:

1. They Require a series of decisions;
2. Decisions are not independent; as resources are committed in one time point, they are unavailable later on, and current decisions are similarly constrained by earlier decisions; even though it is also possible to correct errors in earlier decisions;
3. The state of the problem changes as a function of the decision maker's actions.

And lastly, they are *opaque* in that they do not reveal all their characteristics automatically to the subject, thus requiring him/her to form and test hypotheses about their state and characteristics (Brehmer, 1992).

TASK CHARACTERISTICS

As described earlier, participants in the simulation had five levers at their disposal (total sales force headcount, average sales compensation, marketing spending, average price per unit and capacity order). However the task system itself contains a total of 13 variables. Figure 2 shows the task system structure represented by a causal loop diagram. As can be seen, the system comprises three key loops: a reinforcing loop and two balancing loops. Thus, there is constant adjustment modulating above and below a desired state.

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[4] The *Computech* simulation is part of a CD-ROM called *Next Step*, a product of *High Performance Systems, Inc.*

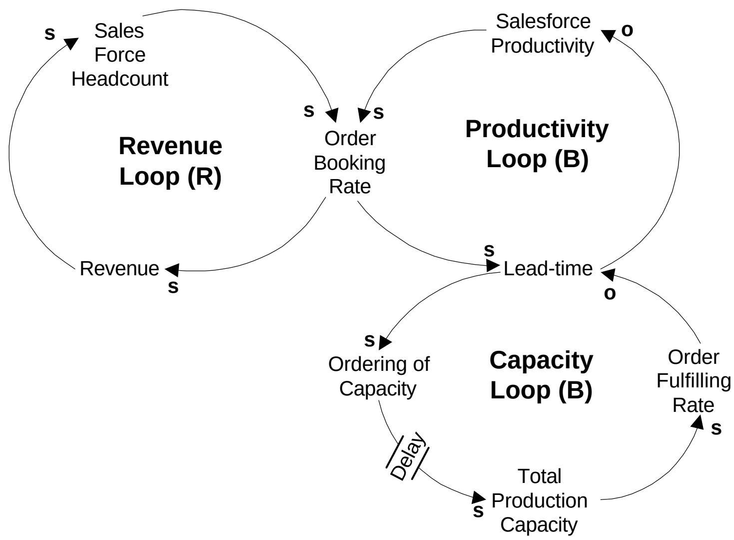

Figure 2 – Representation of Task Structure as a Causal Loop Diagram

In order to perform well in the simulation, a participant needs to begin by increasing sales force in an effort to increase sales and therefore revenue. Capacity must be ordered at the same time in an effort to increase the amount of total production capacity so that the increased sales can be handled. If the sales increase without a subsequent increase in total production capacity, leadtime will begin to rise dampening sales, in an effort to bring the system into a natural equilibrium. The key element in the simulation is to balance the production capacity with the sales, while simultaneously increasing both and using leadtime as a gauge to indicate when sales and capacity are out of sync. This strategy enables all three goals to be met. As sales increase, this leads to increased market share, revenue and profit. No information was given to participants about the 'structure' of the system, that is how variables were connected or interacted with each other.

DATA COLLECTION PROCEDURE

Data was gathered during the study while participants undertook the task. Participants were asked to verbalise their thinking as they worked on the task and the verbalisations were recorded using audiotape.

A data collection protocol was created prior to the commencement of any data collection. The objective of the data collection protocol was to maintain consistency in what was said and done and when, during data collection. [This was particularly important for parts of the session such as the practice verbalisation exercises and the systems thinking presentation.] Everything that would be said and done, and the sequence in which it would happen was "scripted" in the data collection protocol.

The first activity was to practise verbalising or "thinking aloud". Thinking aloud is a very important aspect of verbal protocols. A total of four practice verbalisation exercises had been compiled for participants. These practice exercises were developed by Ericsson and Simon (1993) to ensure that subjects learn to think aloud as distinguished from explaining. This is important so that the activity of verbalising does not interfere with the ongoing problem solving process.

CODING SCHEME

Coding scheme is a fundamental part of the protocol analysis methodology. It is important to ensure that the findings of the study are not data-driven. As such, the coding scheme was developed *a priori*. This also makes sure that "strict independence is maintained between hypothesis formation and data analysis" (Todd & Benbasat, 1987, p. 499).

As mentioned earlier, the basis for this study's coding scheme is Richmond's (1997a) 'thinking skills'. While Richmond (1993 and 1997a) developed the thinking skills from a system dynamics modelling point of view, they nevertheless represent a way to operationalise the concept of the systems thinking paradigm.

Initially, prior to the pilot test, the coding scheme contained seven categories - the first five systems thinking skills described above and two additional categories, *motor* and *other*. Due to the use of a computer simulation, the category motor was necessary in order to capture verbalisations of actions such as clicking the buttons or dragging levers. The other category was necessary for capturing any verbalisations that didn't appropriately fit into one of the other six categories or were just 'gibberish'.

The following example shows coding scheme for the dynamic thinking skill including a definition and some statements that were coded for this category.

> **Dynamic Thinking Coding Scheme**
> **Definition**: The ability to see and deduce behaviour *patterns* rather than focusing on, and seeking to predict, *events*. Enables the tracing of a trajectory of performance with a historical segment, a current state and one or more future paths.
> *Typical Statements*
> - profit's going down… (DM[5], line 23)
> - okay market share's climbing (IF, line 55)
> - the sales force has gone up (PL, line 69)
> - umm annual revenue's gone down (DC, line 5)

It should be noted that while the definitions provide a general guide to coding it would be a challenging task to discriminately code lines of verbalisation using these definitions. As such, following the pilot test, a set of 'rules of thumb' was developed to assist in the coding of the five thinking skills. These 'rules of thumb' provide a more practical and discriminatory guide for coding. They are based upon and derived from the definitions of the five systems thinking skills. The 'rules of thumb' for each thinking type are as follows:

> **Dynamic thinking.** Includes any statements about behaviour over time or trends. Statements of fact (or at least what the subject perceives as such) would not be included as these are static and do not indicate the perception of a trend. For example, a dynamic thinking statement would be: *"market share has dropped even further to 13% Jesus... " (IF, line 319)* as opposed to *"profit as a percent of revenue is 15%..." (IF, line 353).*
>
> **System-as-cause thinking.** Includes all statements made by subjects indicating a relationship between two or more variables. The important aspect here is that system-as-cause thinking simply reflects the perception that a relationship exists or may exist between two variables, but no knowledge about the nature of the relationship. For example, *"I'm going to add 10 capacity just because I think you need to be consistently ordering at a balanced level" (PL, line 587)* would be considered a system-as-cause statement rather than *"but our profit went down because I dropped the price" (PL, line 656)*. To put this distinction another way, system-as-cause statements reflect "what" relationships as opposed to "how" relationships. That is, which variable is affecting which other as opposed to how.
>
> **Operational thinking.** This includes what is essentially excluded by the system-as-cause category. That is to say, statements included in this category would be about *"how"* one variable affects

[5] In order to maintain participant anonymity in the study, each participant was allocated an alphabetical identifier.

another. This is as opposed to system-as-cause above, where statements would be just about stating that there appears to be some form of relationship between two variables.

Closed-loop thinking. Statements coded with this category were those reflecting an understanding of three way relationships. That is, a relationship where one variable affects another which in turn affects a third. These types of relationships were of a "how" nature, meaning that subject statements reflected an understanding of the nature of the relationship rather than just an awareness of their existence. An example of a closed-loop statement would be *"umm so revenue is affected by price and market share basically but what affects price, it's me..." (GJ, line 146).*

Forest thinking. Statements coded with this category were generally about relationships involving four or more variables or about seeing the "big picture". This can perhaps be best explained with examples: *"I have to increase booking rates and that can be done by marketing, by sales force and by sales compensations" (GJ, line 88)* or *"orders affects profit negatively and then marketing costs affects profit negatively and then salaries affect profit negatively and then revenue affects profit positively and profit affects back…" (GJ, line 80).*

CODING PROCESS

The end product of the data collection procedure was a verbal protocol for each participant. Once each participant's verbal protocol had been recorded (on audio tape), it then had to be prepared for coding after the tapes were transcribed. Following this, the transcripts were checked against the tapes and then parsed into quarters. As mentioned previously, the simulation ran for five years with each year divided into quarters hence resulting in a total of 20 quarters.

Within each quarter, the transcript was further parsed into "thought" fragments where each fragment represented a codable unit. Consequently, the quarters were of varying lengths in terms of the number of protocol lines contained in each. On average, fragments (statements)[6] contained ten words and the protocols averaged 358 statements each. Once the transcripts were parsed into "thought" fragments, they were in a form ready to be coded.[7] The actual coding of a transcript involved assigning each of the fragments one of the nine category codes in the coding scheme. Only seven of the ten verbal protocols generated were coded. Three were removed due to poor verbalisation and lack of speech clarity for transcription. To ensure objectivity and consistency throughout the coding process, an independent check was utilised.

The coding process itself, presented particular challenges as it became apparent from the pilot analysis. The main challenge concerned the overlap amongst the five different systemic thinking skills. As mentioned, the objective in coding is to assign each fragment a single code from the coding scheme. However, due to the definitional overlap within systemic categories, while some could be appropriately captured in a single fragment, other categories such as forest thinking could only be evidenced over a series of fragments. This presented a problem for analysis, as a codable fragment represented the unit for any comparative analysis. In other words, if one type of thinking skill could only be evidenced over a series of fragments and another in a single fragment, it would be very difficult if not impossible to undertake any comperison. Therefore, there would be no common medium of analysis such as a "thought" fragment.

[6] The terms 'statement' and 'fragment' will be used interchangeable to refer to a codable unit within a subject's verbal protocol.
[7] Details of coding process and results are available from the authors upon request.

A related problem was the need for multiple codes. This would arise as discussed above, if a thinking type could only be evidenced over several fragments. Since same fragments could also individually reflect other systemic thinking categories thus individual fragments would necessitate more than one category code. This was unacceptable for analysis purposes as it could result in more codes than statements, seriously undermining any analysis. At once, it would not be possible to differentiate one thinking skill from another, and furthermore no determination could be made about the individual or relative effects of thinking types.
To address this problem, a ranking system was developed for the five systemic thinking categories. The ranking system eliminated the need for multiple codes assigned to a fragment, thus removing the problem of more codes than statements.

This notion of a ranking system for the systemic thinking categories has a theoretical base. It is founded on the idea that the thinking types are *interdependent* (Richmond, 1997a). He maintains that when a systems thinking approach is applied to a problem, different thinking skills unfold in a particular sequence or order, implying that they are cumulative. These notions of 'cumulativeness' and interdependence underlie the ranking system in this study. The ranking system adopted for this study is, however, different from the one suggested by Richmond (1997a). In fact, as described above, Richmond's notion represents a sequence rather than a ranking. The ranking used in this study is shown below, with 1 being the lowest ranked thinking category and 5 being the highest.

Richmond's (1997a) Sequence

1. *Dynamic Thinking*
2. *System-as-cause Thinking*
3. *Forest Thinking*
4. *Operational Thinking*
5. *Closed Loop*

Study Ranking System

1. *Dynamic Thinking*
2. *System-as-cause Thinking*
3. *Operational Thinking*
4. *Closed-loop Thinking*
5. *Forest Thinking*

This difference in the two 'rankings' reflects the use of Richmond's thinking skills as a guide for operationalising the systems thinking paradigm rather than as a rigid 'way' of achieving this. In other words, this distinction between the two rankings results as a consequence of the way systems thinking has been operationalised for this study[8].

The ranking serves to overcome the problems of multiple codes, by allowing a choice to be made if a statement is allocated more than one category code and thus capturing different systemic thinking types with single line fragments. As described earlier, this is based on the properties of cumulativeness and interdependence on thinking skills which assumes a 'higher' ranked skill subsumes all lower ranked skills. As such, according to our ranking scheme, operational thinking would not be performed without a participant having done some dynamic thinking first; or that if a subject evidenced forest thinking, this would imply that he/she had

[8] Details of this work can be obtained from author on request.

done some or all of the four lower ranked thinking categories. Therefore, evidence of a higher thinking type implies, to a large extent, that the lower ranked thinking types have also been undertaken. Thus, when a fragment exhibits two types of thinking it is coded with the higher ranked of the two thinking categories.

The adoption of this ranking approach was an important and fully considered decision, as the coding scheme is a fundamental part of the protocol analysis approach. The decision to adopt the ranking scheme impacts on not only the coding but also the subsequent analysis of the coded data.

SYSTEMIC THINKING AND PERFORMANCE

Following the coding process, the codes generated from the subjects were converted to percentage frequencies for analysis. This procedure normalises the protocols and allows for comparison among subjects, as protocols are of unequal length and hence do not contain the same number of fragments. For example, if there were 56 fragments coded with dynamic thinking and a total of 380 fragments in a protocol, then a percentage frequency would be 56/380 = 14.74%. The use of percentage frequencies scales individual differences to a common denominator. The resulting measure is called the *percent frequency measure of occurrence* (Schenk et al., 1998) and it is used as the basis for the quantitative analysis. This measure gives an approximation of the “relative amount of time or energy devoted to an activity” (Pennington et al., 1995, p. 180) and is consistent with measures of time and effort used in prior studies (Irwin & Wasalathantry, 1999).
As stated earlier, participants were evaluated by their performance on three objective measures: revenue, profit and market share. Each “raw” performance score was translated into a score that reflected “closeness to goal”. For example if in quarter 1 a subject achieved market share of 20% this would be divided by the target of 25%, giving 20/25 = 0.8 or 80%. This process was also carried out for the other two performance measures. All three performance measures were considered when determining participant performance relative to each other.

TASK STRUCTURE UNDERSTANDING

In order to determine how well the participant understood the structure of the task system and the relationships within it, an alternative measure related to performance was also developed. This measure was developed to capture what the participant thought or said was important to achieving the system objectives and was designed to complement and supplement the performance measures above that captured what participants did.

The system understanding measure was developed, based on the relationships within the task system. Table 1 below, provides a detailed listing of the different relationships.

Level 1 (Basic 1-to-1 relationships - largely intuitive)
1. price increases, booking rate decreases
2. price increases, revenue increases
3. capacity order increases, expenses increase
4. marketing spending increases, booking rate increases
5. marketing spending increases, expenses increase
6. sales compensation increases, expenses increase
Potential Score /6 (1 point per relationship)
Level 2 (Complex 1-to-1 relationships)
1. sales force increases, sales compensation increases, expenses increase
2. order booking rate increases, revenue increases
3. sales force increases, booking rate increases
4. sales compensation increases, booking rate increases
Potential Score /8 (2 points per relationship)
Level 3 (Closed-loop)
1. capacity decreases, booking rate increases, lead time increases
2. revenue increases, expenses decrease, profit increases
3. sales force increases, booking rate increases, market share increases
4. price decreases, booking rate increases, market share increases
Potential Score /12 (3 points per relationship)
Level 4 (Big picture)
1. Understanding that lead-time is the balance between capacity and order booking rate
2. Understanding that price and sales people balance the order booking rate
Potential Score /8 (4 points per relationship)
Total Potential Score for Understanding /34

Table 1 – Definitions of Task Structure Understanding Measure

The relationships contained in the system were grouped in terms of the structure of the relationship. As can be seen, the measure contains four levels. This grouping is analogous to the different types of systemic thinking; hence the levels represent a similar type of ranking. Level one contains a list of the basic one-to-one relationships in the system. These relationships are considered to be largely intuitive, and it would not require much if any time exploring the task to determine them. Next are the level two relationships, which are also one-to-one relationships, but more complex – they are not intuitive and require investigation of the system. This distinction between what constitutes a level one as opposed to a level two relationship, was made based upon the researchers' knowledge of the task structure and observation of subjects.

The level three relationships are three way relationships with one factor impacting another, which in turn affects a third. These relationships are quite complex, and require at least some level one and/or level two understanding. Finally, the level four relationships are quite broad as they each encompass many variables. Understanding here requires comprehension at least to some extent, of the relationships in all of the three lower levels.

The actual measurement of understanding was done by means of scoring. Each relationship was allocated a potential score. As can be seen in Table 1 the relationships at the different levels have different potential scores. This was in recognition, as discussed above, of their ranking. This type of potential score assumes that a participant who understood one level 4 relationship had greater understanding than someone with understanding of three level one relationships. It acknowledges that in order to understand higher-level relationships, there is to some extent, an implied understanding of the lower level relationships.

The actual scores were tabulated by reading the protocols and assigning the subject the allotted score, provided that they showed evidence of the understanding of a given relationship. The participant then received a total for each level and an overall score out of 34.

ANALYSIS AND RESULTS

The results for the first research question do not support a simple relationship between the level of systemic thinking and task performance. The second research question postulates that certain types of systemic thinking play a more important role than others in affecting performance. Further, it is postulated that that systemic thinking skills are interdependent (Richmond, 1997a). In addition, Richmond suggests that when a systems thinking approach is applied to a problem, implying that they are cumulative, they unfold in sequence. The ranking that was developed for this study is repeated below; with 1 being the lowest ranked thinking category and 5 being the highest.

Study Ranking System

1. *Dynamic Thinking*
2. *Operational Thinking*
3. *System-as-cause Thinking*
4. *Closed-loop Thinking*
5. *Forest Thinking*

The ranking system reflects the expected relative contributions of the different thinking skills to task understanding. This is based on the definitions of the skills and their operationalisation for this study. Specifically, these expected contributions are that higher ranked thinking types (operational, closed-loop and forest) would contribute more to the understanding of a system and therefore play a greater role in performance (see Figure 3).

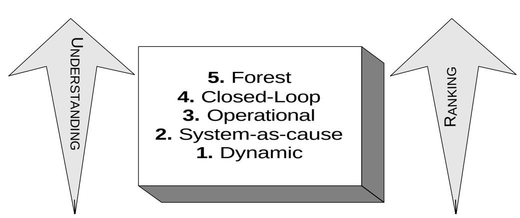

Figure 3 - Expected Effect of Types of Systemic Thinking on Understanding of System Structure

Alternatively, the lower ranked thinking types (dynamic and system-as-cause) would be expected to be utilised in a largely procedural context (as indicated by the 'rules of thumb'). They would thus not deliver substantial aid in the understanding of the system structure, and consequently not significantly affect performance.

Based on the research question, it was expected that good performers would have a prevalence of one or more of the systemic thinking types, indicating a relationship with their strong performance. A notable trend has emerged from this analysis. As a single thinking type, better performers consistently undertake more forest thinking. What is interesting however is that participants who performed better utilised more of the three higher ranked thinking types *cumulatively*. The proportion of best performers' systemic thinking that accounted for operational, closed-loop and forest thinking were: 45.33%, 33.96%, 28.26% and 16.5%, respectively. This indicates that better performers did more operational, closed loop and forest thinking and less dynamic and system-as-cause thinking than worse performers. The results suggest that particular types of systemic thinking may be more strongly related to better task performance.

The findings from this analysis (research question two) begin to explain how one participant, despite having the lowest overall amount of systemic thinking (13%), ranked fifth in performance ahead of another participant with 30.29% total systemic thinking score. The former clearly dedicates a significant amount of his systemic thinking to the higher level types (28.26%) as compared to the sixth ranked participant who only spent 16.5% of his time on these types. This finding is particularly significant, as it would suggest that the amount of systemic thinking alone does not affect performance, but rather that the degree of high-level (operational, closed-loop and forest) systemic thinking does. Figure 4 summarises the findings thus far.

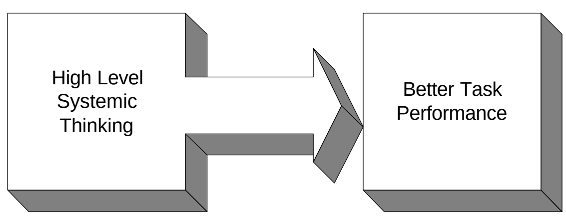

Figure 4 – Aggregate Level Findings for Research Question Two

The utility of systemic thinking is further hypothesised to be through aiding the understanding of the structure of a complex, dynamic and opaque system. That is, high-level systemic thinking types (operational, closed-loop and forest) are expected to facilitate this to a greater extent than the lower level types (dynamic and system-as-cause) as depicted in Figure 5.

However due to existence of hidden delays and the opaque nature of complex problems, any understanding must gradually be developed and thus this is a *gradual* and *cumulative* process. This understanding is then used as it is gained, to facilitate the development of strategies to achieve the problem objectives and therefore affect performance. This purports that the use of systemic thinking would correlate directly with better understanding of system structure as Figure 5 suggests, rather than directly with task performance.

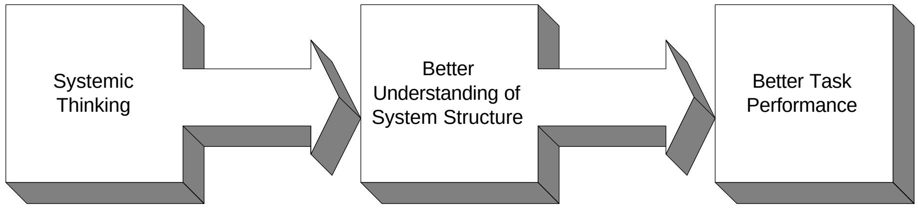

Figure 5 – Proposed Explanation for Disaggregate Level Findings

One or both of the reasons discussed above may be responsible for the lack of a direct relationship between high-level systemic thinking and performance at the disaggregate level. These confounding factors could also apply to the disaggregate analysis of research question one. The results (for the disaggregate analysis for research question one) did not find evidence of a relationship between systemic thinking and task performance on a quarter level. In summary, there is some evidence to support the idea that particular types of systemic thinking have a greater impact on performance than others. The results indicate that the high-level types of operational, closed-loop and forest thinking contribute more towards performance than dynamic and system-as-cause thinking. This is supported by the greater use of these systemic thinking skills by better performers. What is perhaps more interesting and suggested by the disaggregated findings of research question two, is that systemic thinking does not affect performance directly but rather affects *understanding* of systems structure which then leads to better task performance. Therefore, systemic thinking and task performance are unlikely to correlate directly at a disaggregated level.

When considered with research question one, the results thus far suggest that it is not simply the degree of systemic thinking that affects performance, which was the initial premise of the study. Rather, it is a far more complicated issue, namely, the types of systemic thinking an individual engages in when encountering a complex problem and the amount of these types.

SYSTEMIC THINKING TRANSITION PATTERNS

This section addresses the third research question. This research question investigate whether patterns or sequences in the systemic thinking types have any bearing on performance. This question follows on from research question two where the results of one participant can most appropriately be described as an 'outlier'.

The premise being examined here is that better performing participants may display a different pattern of systemic thinking throughout the simulation, or over a series of quarters than poor performing subjects. The study attempts to explain performance not only in terms of quantity and type of systemic thinking but in terms of how and when thinking patterns are linked together.

In order to investigate whether any recurrent patterns in the type of systemic thinking carried out by the participant existed, *systemic thinking transition graphs* were constructed. Transition graphs illustrate shifts amongst different processes during a protocol. They show *along a time line* the process description of what the subject was engaged in at various points in time. This allows the researcher to compare visually the protocols of the different participants and identify any consistent patterns evident. Transition graphs have been used by a number of researchers for similar analysis of protocols (see Irwin & Wasalathantry, 1999; Srinivasan & Irwin, 1999; Srinivasan & Te'eni, 1995).

Each transition graph illustrates *every* statement contained within a subject protocol. The y-axis represents the type of systemic thinking by ranking (see Figure 3). That is, 1 = dynamic, 2 = system-as-cause, 3 = operational, 4 = closed-loop and 5 = forest thinking. The x-axis contains a scale from 0 to 100% reflecting the volume of statements or fragments in the protocol. Statements in a protocol that were not coded with a systemic thinking category, are allocated a 0 and are indicated on the graphs by gaps in the transitions (see Figure 6). As discussed previously, this systemic ranking system reflects the relative value that each type is assumed to contribute to the problem solving process.

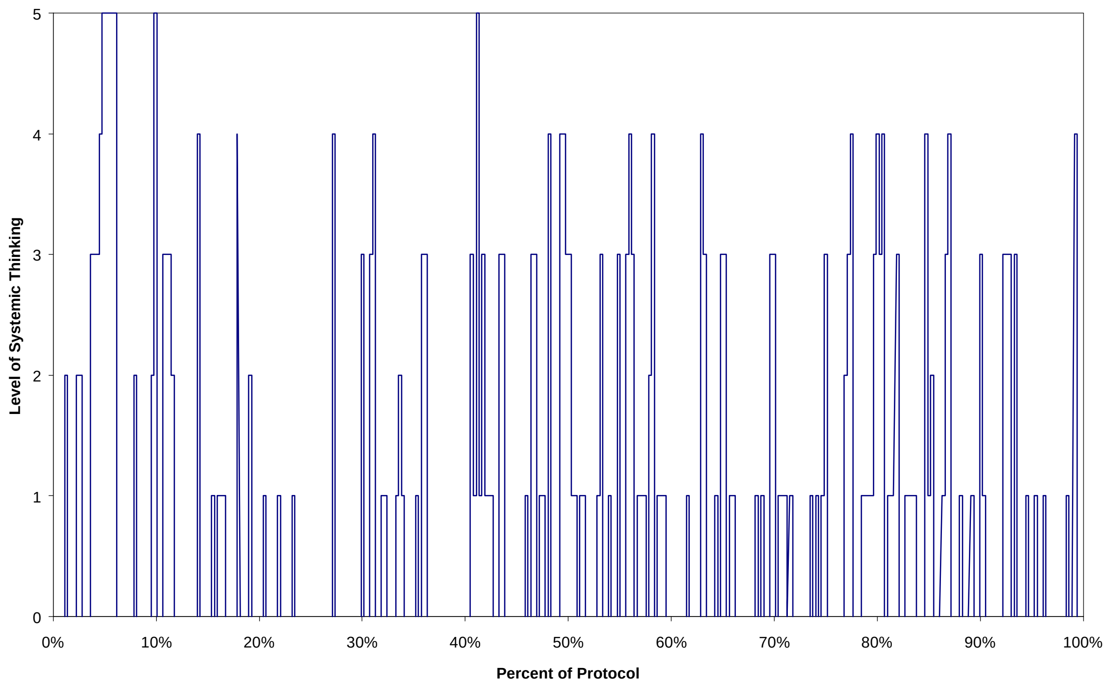

Figure 6 – Systemic Thinking Transition Graph for Subject A

The transition graphs illustrate shifts amongst non-systemic thinking (y=0) and the five different systemic thinking types during each protocol (1 = dynamic, 2 = system-as-cause, 3 = operational, 4 = closed-loop and 5 = forest). They show along a time line the type of thinking that each subject was engaged in at various points in time. Gaps in the graphs - when there are no bars - reflect one of the non-systemic thinking categories e.g. reflection, motor etc., as these categories were allocated the value of zero.

The transition graphs results show some consistent patterns overall. Better performing participants repeatedly transition across multiple levels, (including levels 3, 4 and 5 i.e. operational, closed-loop and forest thinking) throughout the protocol. Subject A's graph (Figure) for example shows transitions throughout the protocol across all five levels. Poor performing participants, in contrast, display sustained periods at low levels and little or no high-level thinking unlike their better performing counterparts. In addition, the transition graphs of poor performers show many gaps indicating that no systemic thinking took place during these segments of their protocols.

The transition graphs correlate well with the findings pertaining to the level and quantity of high-level systemic thinking done by the various participants. These findings add further support to the results for research question two. In other words, better performers illustrate greater time spent at higher levels of systemic thinking on the transition graphs.

In summary, the results suggest that better performers transitioned across all five systemic thinking levels and did so repeatedly throughout the simulation. The results for another participant deserves a mention. His transition graph (not shown here) shows a sustained period at high levels, but only during the early part of the protocol. This subject unlike the better performing participants fails, after about the first 38% of the protocol, to transition across the higher levels of thinking. These findings do go some distance towards explaining why this subject did not perform better, as would have been expected given the high-level of his systemic thinking. However, while poor transitioning may be a contributory factor in this subject's poor performance, it would appear not to be the only factor.

DISCUSSION

This study sought to investigate the postulate that systems thinking is effective in dealing with complexity. The findings reveal that in reality this is not as simple a notion as "the more systemic thinking, the better the task performance". Results indicate that although the amount of systemic thinking performed does matter, it is in fact the type of systemic thinking which is more important. Further the results indicate that participants who transitioned all five systemic thinking types and did this repeatedly throughout the simulation performed better.

Performance on a complex problem is a intricate and multi-dimensional process. Our analysis suggests that the scale of high-level systemic thinking, as well as consistent use of all types of systemic thinking throughout the problem solving exercise have an effect on task performance. What remains unanswered here, as was beyond the scope of this study, is to what extent each of these types (skills) individually contributes to task performance, which factor is most important and what combination(s) of the systems thinking skills is optimal for performance.

As touched on previously, characteristics that have consistently emerged, amongst good and poor performing participants, in complex problems solving studies, show strong parallels to aspects of the systems thinking *paradigm*. This lends support to the argument that thinking systemically is effective in dealing with complex problems. Individuals, who display the characteristics of systems thinking, even if they are oblivious to the fact, perform better on complex problem solving tasks.

The behaviour of subjects who perform well, reflects the attributes of systems thinking while the behaviour of subjects who tend to perform poorly, often reflects the direct opposite of systems thinking, that is to say linear or 'laundry list' thinking. For instance, Dörner (1980) found that subjects do not sufficiently consider processes in time. "When solving such complex tasks, most people are not interested in finding out the existent trends and developmental tendencies at first, but are interested instead in the 'status quo'" (p.91). This is atypical of static thinking, the polar opposite of dynamic thinking (Richmond, 1997b).

There are numerous examples that can be cited to further illustrate the significant parallels between aspects of the systems thinking paradigm and the findings of complex problem solving studies. These parallels add further support to the notion that systems thinking is effective in dealing with complexity. Whether the illustration is through superior participants showing attributes of systemic thinking or inferior participants showing attributes of linear thinking, the outcome is that systems thinking is evidenced as aiding performance in complex problems.

This study adds further support to Dörner, Reither, and Stäudel's (1983)[9] heuristic competence construct. The construct is described as "a general competence for coping with complex systems" (Brehmer, 1992, p. 223). Participants who display heuristic competence are described as those "who collect more information, who collect it more systematically, who construct adequate goals, who evaluate the effects of their decisions, and who generally behave in a systematic fashion" (Dörner et al., 1983)[9] in (Brehmer, 1992, p. 225). Schaub and Strohschneider (1989) who studied the construct, further described it as making fewer decisions, collecting more information before making decisions, and checking on results of decisions prior to making new ones. Brehmer (1992, p. 225) concluded that, "subjects who behave in a way that makes it more likely that they will acquire a good model of the task also learn to control the task better".

Heuristic competence is highly analogous with the notions of systemic thinking types and the *Conception-Planning-Action* (CPA) cycle that emerged in this study[10]. The CPA cycle was developed to gain understanding of the system structure, developing strategies, making decisions and carefully assessing the outcomes of those decisions in order to determine the validity of the understanding of system structure. Much of the description of heuristic competence provided above is congruent with the discussions of the CPA cycle as described by Dörner et al. "generally behaving in a *systematic* fashion" (1983)[9].

CONCLUSION

In summary, the complex problem solving literature has thus far formulated two constructs that are believed to affect performance on a complex problem – epistemic competence and heuristic competence. Of the two constructs, heuristic competence is thought to be of greater importance in its impact on performance. The construct of heuristic competence however, is still rather loosely defined. The findings of this study propose a more lucid definition for the construct. The results suggest systemic thinking, when used in concert with the CPA cycle, is analogous to the characteristics of heuristic competence. While providing a clear definition for the construct of heuristic competence, this similarity further supports the idea that systems thinking is indeed more effective for dealing with complexity.

In concluding, the contributions of this study are two-fold, as it contributes both to the field of systems thinking and to the field of complex problem solving. To begin with, this study has opened up the way for empirical research on the question of systems thinking's effectiveness in complex problems. The most significant aspects of this study, from a systems thinking perspective, are the research approach developed and the method utilised for operationalising the systems thinking paradigm.

[9] This article has only been published in German.
[10] The CPA study is reported in a sequel paper.

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