Links Between Systems Thinking and Complex Problem Solving - Further Evidence

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ABSTRACT

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. Despite strong assertions, however, the relationship between systems thinking and complex problem solving has received slight attention in the literature. Using Richmond's (1997) seven-classification scheme as the theoretical base, this paper investigates the link between systems thinking and complex problem solving. The Verbal Protocol Analysis (VPA) methodology was used to gather and analyse the empirical data. The findings of the study indicate that while the degree of systems thinking does matter, in fact, it is certain *types* of systemic thinking that are more relevant to performance. Further, evidence shows that subject's approach to the problem is also a highly pertinent factor in task performance in that better performers displayed a distinctive pattern of thought that differed from that of the worse performers. Better performing subjects attempted to gain understanding of the system structure *before* they proceeded to develop strategies and take action. The findings also revealed a cyclical thought pattern that was consistently followed by better performing participants. This pattern, termed the CPA cycle, consists of three distinct phases of *conception*, *planning*, and *action*.

This research contributes to both fields of systems thinking and complex problem solving. Specific contributions include novel research methodology and in particular operationalization of systems thinking paradigm, as well as identification of disintegrated factors affecting complex problem solving.

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.

Despite some notable research work (see for example Booth Sweeney & Sterman 2000, Doyle 1997, Buchner 1995, Pennington, et al 1995, Brehmer 1992, Funke 1991, Sterman 1989a, 1989b) there is a curious gap in the literature on the relationship between systems thinking and complex problem solving. According to Doyle (1997) "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"

This paper seeks to investigate the link between systems thinking and complex problem solving. Richmond's (1997) seven-classification scheme is used as the theoretical basis for this research. The Verbal Protocol Analysis (VPA) methodology was used to gather and analyse the empirical data. As part of this approach, a coding scheme was developed to operationalize systems thinking. Three distinct but related research questions are addressed in this study.

The findings of the study refute the simplistic notion that systems thinking leads to better task performance. In reality the story is much more complex. While the degree of systems thinking does matter, the results suggest that in fact it is certain *types* of systems thinking that are more relevant to superior performance. The type of systems 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. Further analysis provides evidence that better performers displayed, in their problem-solving approach, a distinct pattern that differed from that of worse performers. Better performing subjects attempted to gain understanding of the system structure, develop strategies, make decisions and carefully assess the outcomes of their decisions, in order to determine the validity of their understanding of system structure.

This pattern, termed the CPA cycle, consists of three distinct phases: *conception* (C), *planning* (P) and *action* (A). The conception phase of the cycle is where a subject would try to gain understanding of the structure of a problem. This is where systemic thinking could be undertaken and would be of value. The planning phase is where the strategy is developed, ideally based upon the understanding of the system structure gained in the conception phase. The third and final phase is the action phase. Here, the strategy developed is implemented with specific decisions.

For the cycle to be most effective and value adding, it needs to be iterative. As one cycle is completed, the action phase should lead directly to the conception phase of a new cycle. This is necessary because due to their opaque nature, understanding of complex problems can often only be gained progressively. If the cycles are not iterative, then they can become largely ineffective in gaining understanding of problem structure.

Further analysis confirmed that the good performers in addition to the amount of high-level systems thinking were also following the CPA cycle. One of the key differences between good performers and poor performers was the number of completed cycles. This is illustrated by the number of decision periods containing all three phases of the CPA cycle. Another difference was that better performers completed far more continuous iterations of the cycle than did poor performers. In fact, poor performers often did not follow the cycle at all or would progress in a rather disjointed fashion.

This paper explains and contrasts CPA patterns for superior and poor performing subjects and discusses their theoretical and practical implications. This research contributes to both fields of systems thinking and complex problem solving. Specific contributions include novel research methodology and in particular operationalization of systems thinking paradigm as well as identification of disintegrated factors affecting complex problem solving.

SYSTEMS THINKING PARADIGM

Systemic thinking refers to cognitive processes. In this study, we adopt systems thinking as a *paradigm*. This refers to systems thinking as a “world view’ – seeing things holistically and interconnected. Hence, here, by thinking systemically we mean subscribing to the systems thinking *paradigm*.

However, translating systems thinking paradigm 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’ and later (1997a) added to and further defined these thinking *skills*. To date, these still remain the sole ‘operational’ guide to thinking systemically.

Richmond (1997a) suggests that systems thinking requires operating on at least seven thinking tracks simultaneously. His updated seven thinking skills are shown below. 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.

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

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. System-as-cause thinking "holds that relationships that are not under the control of decision makers within a system should be eliminated from consideration" (Richmond, 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 tries to identify causality – determining how 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 closed-loop structures. It maintains that causality does not run in just one direction but rather 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). In Checkland's 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). It is also argued that today systems thinking is needed more than ever as we are being overwhelmed by complexity (Senge, 1990).

As it is clear from these comments, systems thinking has increasingly been accepted as a response to complexity as our default 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 appear to 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 illustrate non-systemic behaviour by individuals confronted with complex problems. 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).

CALL FOR EMPIRICAL RESEARCH

Despite the wide acceptance that systems thinking is highly effective for dealing with complexity, there have been calls from within the field for empirical substantiation of this belief:

"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." (Doyle 1997, p. 253)

Huz, Anderson, Richardson and Boothroyd (1997, p. 150) have raised similar issues. 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). 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 recognise that a gap exists with regards to empirical research on the effectiveness of systems thinking.

In recognising this gap, two articles[1] were published in 1997 in the System Dynamics Review, addressing the question of effectiveness of systems thinking interventions. Huz et al. (1997) repeated 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. The report of their pilot study concludes:

1. The modelling team felt the intervention was very successful and that the group process went well and participants were pleased with the intervention.
2. 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.
3. Attention within the organisation was refocused away from client-level concerns towards system-level considerations.

In another 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

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

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.

To summarise, most of the studies thus far have focused on systems thinking interventions rather than the effectiveness of systems thinking skill (*paradigm*). 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 systems and linear thinking respectively.

To conclude, 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. Thus, despite some rigorous research, the absence of theories on the nature of systems thinking and its causal relationship with complex problem solving persists in the literature. This paper, a part of a larger study, seeks to contribute towards addressing this gap.

RESEARCH MODEL

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

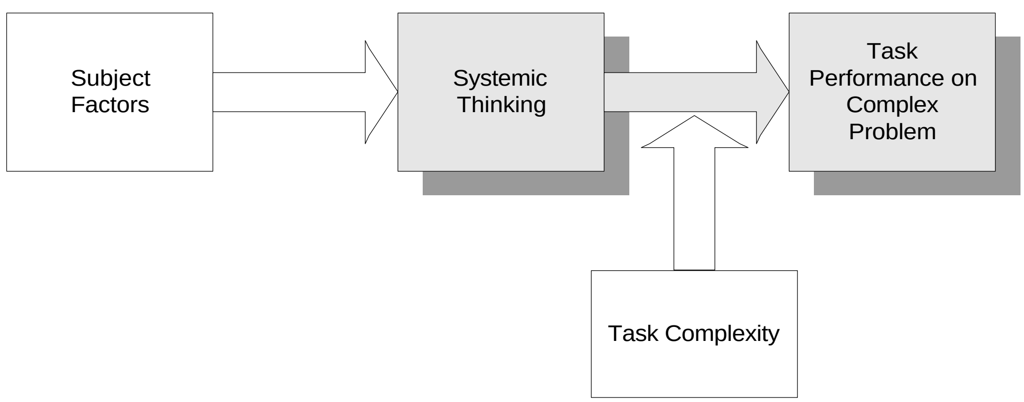

Figure 1 – Research Model

The shaded part of Figure 1 represents the scope of this study, the objective of which is to investigate empirically the postulate that systems thinking is effective for dealing with complexity. To put this study in the context of the research model (Figure 1), systems thinking falls within the area of 'subject factors' and more specifically within the topic of 'cognitive abilities', hence the arrow from subject factors to systems thinking. 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:

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

The first question addresses the main objective of this study. This may be stated as follows, that if a person is engaged in only a small amount of systems thinking and another a larger amount, it would be expected that the latter would perform better on the complex problem.

The second and third research questions can only be clearly explained in the context of their theoretical base, namely, Richmond's seven systems thinking skills. As stated earlier, no other theoretical guides to assist in the operationalization of systems thinking were found in the literature reviewed. Only the first five of the seven skills will be utilised in this study as the last two are primarily relevant to system dynamics modelling. Therefore, collectively, the first 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 disaggregating or 'splitting' of the systems thinking paradigm into five skills. As implied in research question two certain elements of systems thinking are perhaps more relevant and more effectual for performance on complex problems than others. The impetus for question three came not just from the 'splitting' of systems thinking, but also from 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. Hence, research question three postulates that a sequence or pattern of use may exist amongst the five skills, which would lead to better task performance. This may or may not be the same as that indicated by Richmond.

RESEARCH METHODOLOGY

The research method adopted in this study is Verbal Protocol Analysis. Protocol analysis 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 the availability of non-verbal indications. VPA is a well-established methodology for individual differences research. The individual differences approach typically involves subjects working through a microworld (ie, 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 systems thinking approach to the problem. Their performance will be ranked and based upon their use of systems thinking reasoning[2] it will be determined whether systems thinking has a relationship to performance on complex problems.

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[2] How this study will measure the amount of systems thinking done by a participant will be discussed later.

VERBAL PROTOCOL ANALYSIS

Protocol analysis 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 the more refined measure 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).

This study is interested in exploring individuals' thought processes in complex problem solving. A process tracing method is considered the most appropriate research method here because these methods allow research of the processes or "black box" which intervene between the independent variable 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). Alternative research methods such as surveys, case studies and interviews 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-output measures are sought.

This study is interested in what information is examined; the manipulations conducted on the input stimulus; and what evaluations or assessments are made by the problem solver. Todd and Benbasat (1987, p. 497) consider protocol analysis to be "the most powerful of all process tracing tools" adding, "verbal protocols provides the greatest data richness and information value per data point." 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. "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).

Verbal protocols can be divided into two categories - retrospective and concurrent. Getting a participant to recall his/her 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 thoroughly 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 period 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 had attended the courses from the same two instructors 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 'fully' subscribe to the systems thinking paradigm as a result of their training. It is expected that through their knowledge of the systems thinking paradigm (as a result of their training), they are capable of utilising it. Hence, subjects' knowledge of systems thinking was not assessed, since the objective of this study was not to investigate the effects of systems thinking training. Nevertheless, this selection of participants allowed us to control for systems thinking knowledge.

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

SIMULATION TASK

Participants were required to work on a simulation of a fictitious computer technology company called *Computech.*[3] In the simulation, *Computech* have 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 measure by gathering performance data. Microworlds are *complex* in the sense that they require subjects to consider many different elements - for instance many different and possibly conflicting goals. They are *dynamic* in some or all of following senses:

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

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

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).

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 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. Therefore, 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 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 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 had fragments of varying lengths in terms of the number of protocol lines contained in each. On average, fragments (statements)[4] 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.[5] The actual coding of a transcript involved assigning each of the fragments one of the nine category codes in the coding scheme[6].

The coding process itself, however, presented particular challenges as became apparent from the pilot analysis. The main challenge concerned the overlap amongst the five different systems thinking skills. As mentioned, the purpose of coding was to assign each fragment a single code from the coding scheme. However, due to the definitional overlap within systems

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[4] The terms 'statement' and 'fragment' will be used interchangeable to refer to a codable unit within a subject's verbal protocol.

[5] Details of coding process and results are available from the authors upon request.

[6] 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.

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. To explain, if one type of thinking skill could only be evidenced over a series of fragments and another in one fragment, it would be very difficult if not impossible to undertake any analysis. There would be no common medium of comparison such as a "thought" fragment.

A related problem was the need for multiple codes. This would arise as discussed, if a thinking type could only be evidenced over several fragments. Those same fragments could also individually reflect other systems thinking categories suggesting that individual fragments would necessitate more than one category code. This was unacceptable for comparison purposes as this would result in more codes than statements, seriously undermining any analysis. It would not be possible to talk about one thinking skill relative to another and furthermore, no determination could be made about individual or relative effects of thinking types.

To address this problem, a ranking system was developed for the five systems thinking categories. The ranking system eliminated the need for a fragment to be given multiple codes thus removing the problem of more codes than statements.

The notion of a ranking system for the systems thinking categories has its theoretical base in Richmond's classification, which denotes interdependence amongst the classes. Richmond (1997a) also maintains that systems thinking elements unfold in sequence when one approaches a complex problem, implying that their effect is cumulative. These notions of interdependence and cumulativeness were relied upon to establish the ranking system in this study. The resulting ranking scheme is shown below, with 1 denoting the lowest ranked thinking category and 5 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*

As can be noted, the study ranking system is different from the scheme suggested by Richmond as his represents a sequence rather than a ranking. However this difference reflects the use of Richmond's thinking skills as a guide for operationalising the systems thinking paradigm rather than an established theory. In other words, this distinction between the two schemes is a result of the way systems thinking was operationalised[7] for this study.

As discussed earlier, the ranking scheme serves to overcome the problems of multiple codes, and that of capturing different types of systems thinking with single line fragments, by allowing a choice to be made if a statement is allocated more than one category code. The fundamental nature of the ranking is that evidence of a higher thinking type implies to a large extent that lower ranked thinking have also been undertaken. This means that if a fragment exhibits two types of thinking, it is coded with the higher ranked of the two thinking categories. For example, evidence of forest thinking would imply that some or all of the four lower ranked thinking categories have also taken place. Likewise, operational thinking would not be performed without a participant having done some dynamic thinking first.

The adoption of this ranking approach was an important and fully considered decision. This impacts on not only the coding decisions but also the subsequent analysis of the coded data.

SYSTEMS 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 not all protocols are of equal 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 resulting measure is called the *percent frequency measure of occurrence* (Schenk et al., 1998) and this 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 one 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.

[7] The reader is referred to the coding 'rules of thumb' for clarification of the operationalisation of systems thinking in this study.

TASK STRUCTURE UNDERSTANDING

In order to determine how well the participants understood the structure of the task and their relationships (system), an alternative performance measure was developed. This measure was developed to capture what the participant thought or *said* and correlating these to their performance. This measure was designed to complement and supplement the performance measures discussed earlier, which captured what participants *did*. This 'system understanding measure' was developed based on the relationships within the task system. Table 1 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

As can be seen, the measure contains four levels. The relationships contained in the system were grouped in terms of the structure and complexity of the relationship. This grouping is analogous to the different types of systems 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 understanding of the system. This distinction between what constitutes a level one as opposed to a level two relationship was made based upon the researcher's knowledge of the task structure and observation of subjects. 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, level four represents higher level relationships 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 also recognised that a participant who understood one level 4 relationship had greater understanding than one with understanding of three level one relationships. Again, this implies that in order to understand higher-level relationships, there needs to be some understanding of the lower level relationships.

The actual scores were tabulated by reading the protocols and giving the subject the allotted score, if 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

Overall, the results pertaining to the first research question do not support a simple relationship between the level of systems thinking and task performance. The results in the disaggregate analysis for this question did not find evidence of a relationship between systems thinking and task performance on a quarter level.

The second research question postulated that certain types of systems thinking play a more important role than others in affecting performance. In addition, Richmond categories suggest that they unfold in sequence when a systems thinking is applied to a problem, implying that they are cumulative.

In relation to these hypotheses, a notable trend has emerged from the analysis. As a single thinking type, better performers consistently undertake greater forest thinking. What is more interesting however is that participants who performed better utilised more of the three higher ranked thinking types cumulatively. The proportion of each participant's systems thinking that accounted for operational, closed-loop and forest thinking is: 45.33%, 33.96%, 28.26% and 16.5%, ranked by performance. Thus the analysis 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 systems thinking may be related to better task performance.

This confirms the notion 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 (Figure 2). In contrast, lower ranked thinking types (dynamic and system-as-cause) would be expected to be utilised in a largely procedural context. They would thus not deliver substantial aid in the understanding of the system structure, and consequently not significantly affect performance.

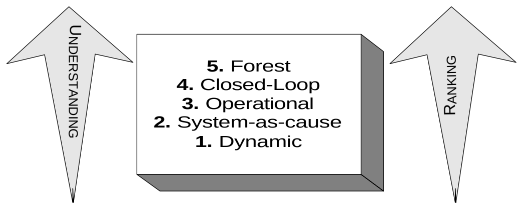


Figure 2 - Expected Effect of Types of Systems Thinking on Understanding of System Structure

These findings begin to explain how one participant, despite having the lowest overall amount of systems thinking (13%), ranked fifth in performance ahead of another participant with 30.29% systems thinking score. The former clearly dedicated a significant amount of his systems 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 systems thinking alone does not affect performance, but rather the degree of high-level (operational, closed-loop and forest) systems thinking does. Figure 3 schematically summarises the findings thus far.

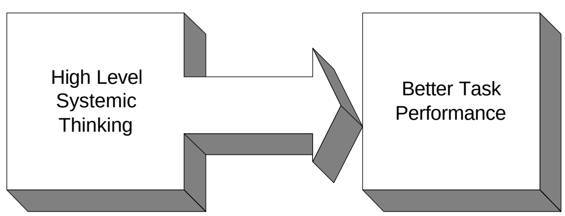


Figure 3 – Aggregate Level Findings for Research Question Two

The utility of systems thinking is further hypothesised to be through aiding the understanding of the structure of a complex, dynamic and opaque system. High-level systems 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 4.

However due to the opaque nature of complex problems, any understanding must be developed over time and thus it denotes a *gradual* and *cumulative* process. This understanding is then utilised to develop strategies that improve performance. This purports that the use of systems thinking would correlate directly with better understanding of system structure as Figure 4 suggests, rather than directly with task performance.

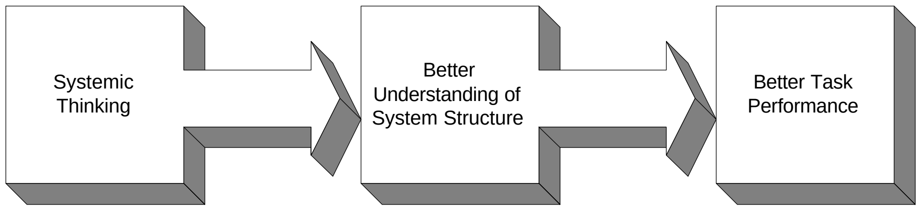


Figure 4 – Proposed Explanation for Disaggregate Level Findings

In summary, there is some evidence to support the idea that particular types of systems thinking have a greater impact on performance than others. The results indicate that the high-level thinking types, namely, 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 systems thinking skills by better performers. What is more interesting, as suggested by the disaggregated findings of research question two, is that systems thinking does not affect performance directly but rather affects *understanding* which can lead to better task performance. Therefore, systems thinking and task performance are unlikely to correlate directly at a disaggregate level.

The results thus far suggest that it is not simply the degree of systems thinking that affects performance, which was the initial premise of the study. Rather, it is the types of systems thinking that an individual engages in when encountering a complex problem and the amount of these types.

SYSTEMS THINKING TRANSITION PATTERNS

This section addresses the third research question. This question postulates whether patterns or sequences of systems thinking types have any bearing on performance. In order to investigate whether any recurrent patterns in the type of systems thinking carried out existed, transition graphs were constructed. Transition graphs illustrate shifts amongst different thought 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).

The premise being examined here is that better performing participants may display a different *pattern* of systems thinking throughout the simulation, or over a series of quarters than poor performing subjects. This attempts to explain performance not only in terms of quantity and type of systems thinking but in terms of how thinking patterns are linked together and when. Each transition graph illustrates *every* statement contained within a subject protocol. The y-axis shows the allocated values for systems thinking types while the x-axis contains a scale from 0 to 100% reflecting the volume of statements or fragments in the protocol. This is the same as the ranking scheme where 1 = dynamic, 2 = system-as-cause, 3 = operational, 4 = closed-loop and 5 = forest thinking (see Figure 5). As discussed previously, this ranking system reflects the value that each type is thought to contribute to the problem solving process.

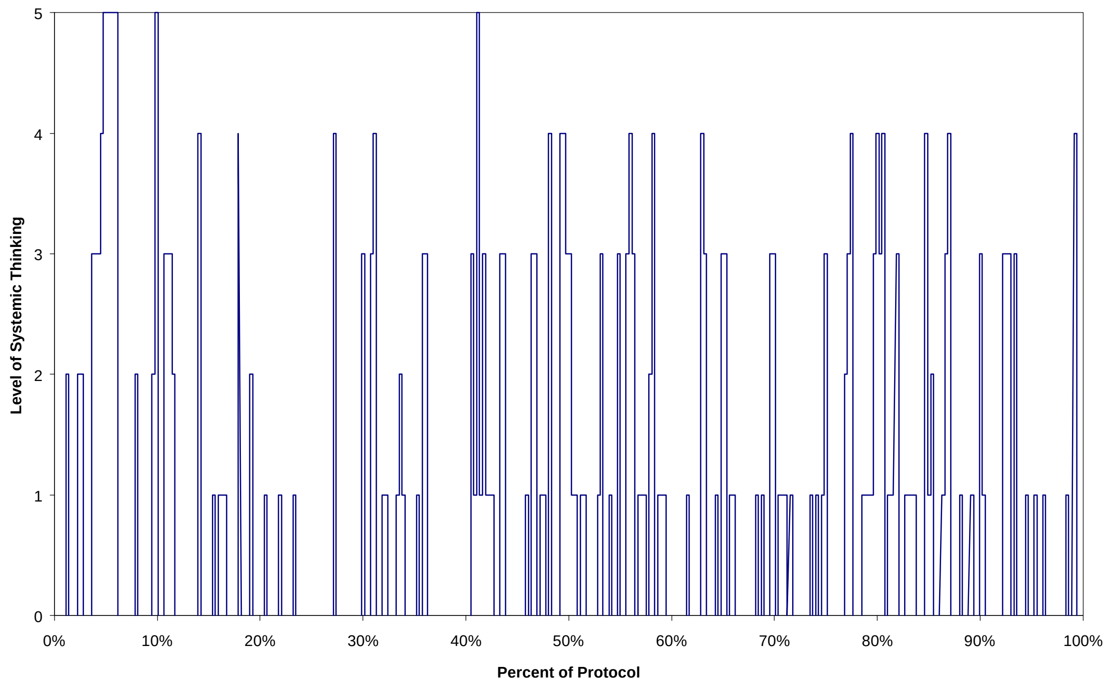


Figure 5 – Systems Thinking Transition Graph for Subject A

The transition graphs illustrate shifts amongst non-systems thinking and the five different systems thinking types during each protocol. 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-systems thinking categories e.g. reflection, motor etc., as these categories were allocated the value of zero.

The results show 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. For example Subject A's graph (Figure 5) shows transitions throughout the protocol across all five levels. Poor performing participants, on the other hand, 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 subjects show many gaps indicating that no systems thinking took place during these segments of their protocols. These findings add further support for research question two. The transition graphs correlate well with the findings pertaining to the level and quantity of high-level systems thinking done by the various participants. Better performers illustrate greater time spent at higher levels of systems thinking on the transition graphs.

In summary, the results illustrate that better performers transitioned across all five systems thinking levels and did so repeatedly throughout the simulation. The results for another participant show an interesting contrast. 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 overall, as would have been expected given the high-level of his systems 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.

PROBLEM SOLVING APPROACH (PATTERN)

Thus far, the findings reveal the role of disaggregated systems thinking types and the distinctive patterns of thought processes by various research subjects where analyses have focused on the coded protocol statements. Next, we turn our attention to less fine-grained and more exploratory approach to studying the participants' behaviour. The focus also shifts here to looking beyond the systems thinking skills and towards other problem solving behaviour.

To this end, the transcripts were read again and quarter-by-quarter summaries were created. This removed much of the minor detail contained in the transcript, producing in essence an aggregate transcript containing the salient points of each protocol. These summary transcripts were then analysed qualitatively for evidence of any patterns, systems or otherwise. From this analysis it became evident that better performers displayed, in their problem-solving approach, a distinct pattern that differed from that of worse performers. In order to determine the validity of their understanding of system structure, superior performers attempted to gain understanding of the system structure, develop strategies, make decisions and carefully assess the outcomes of their decisions. We have termed this pattern the CPA cycle as is illustrated in Figure 6.

C = Conception
P = Planning
A = Action

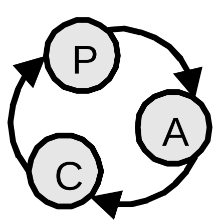


Figure 6 – CPA Cycle

The CPA cycle, which emerged from the analysis, has three distinct phases – the *conception* (C), the *planning* (P) and the *action* (A) phase. The conception phase of the cycle is where a subject would try to gain understanding of the structure of a problem. This is where systems thinking could be undertaken and would be of value. Examples of conception statements include:

> GJ: "okay great now first of all I'm going to try to see what and how affects each of the factors there"
> IF: "first we've got to figure out what's going into demand"
> PL: "yeah right the expenses are tracking up because I keep hiring more people

The next phase is the planning phase. This is where the strategy is developed, ideally based upon the understanding gained in the conception phase. Examples of planning statements include:

> PL: "first up sales people to get more sales we are going to increase sales people"
> DC: "we could probably look at reducing the price to get more customers…"
> IF: "and I actually want to pay these guys a little bit more to give them a bit more encouragement to do something"

As can be seen from the examples above, the planning statements are attempting to make decisions based upon understanding previously gained as distinct from the conception statements, which involve gaining or trying to gain understanding of the system structure.

The third and final phase is the action phase. Here, the strategy developed is implemented with specific decisions. In the context of the simulation task, this amounts to adjusting the decision levers and executing the model. Each quarter will therefore end with an action phase (including no new interventions). Examples of action statements include:

> DC: "I'll hire another person…"
> DM: "average sales compensation, increase it, by probably 20"
> AM: "spend say, spend say $30,000 on marketing"

The action phase should ideally lead to another iteration of the cycle by leading directly onto the conception phase of a new cycle (as shown in

Figure 6). The alternative to this is a 'break' between an action phase and a conception phase. A 'break' is possible in the cycle at any phase. A 'break' simply means that a new phase does not continue from the prior phase but instead performs its function independent of what occurred in the preceding phase.

When an action phase leads directly to a conception phase a closed loop is formed. The new conception phase will then begin by reviewing the outcomes (ie, feedback) of the decisions just made in the previous action phase. The purpose of the review is to evaluate understanding of the system structure that was developed in the last conception phase. The outcome of the conception phase, after each iteration, is a more detailed or clear picture of the structure and the nature of the problem. Examples of reviewing statements as part of the conception phase are:

GJ: "less price should have affected booking rates but hasn't, marketing should have affected it a little and then no"

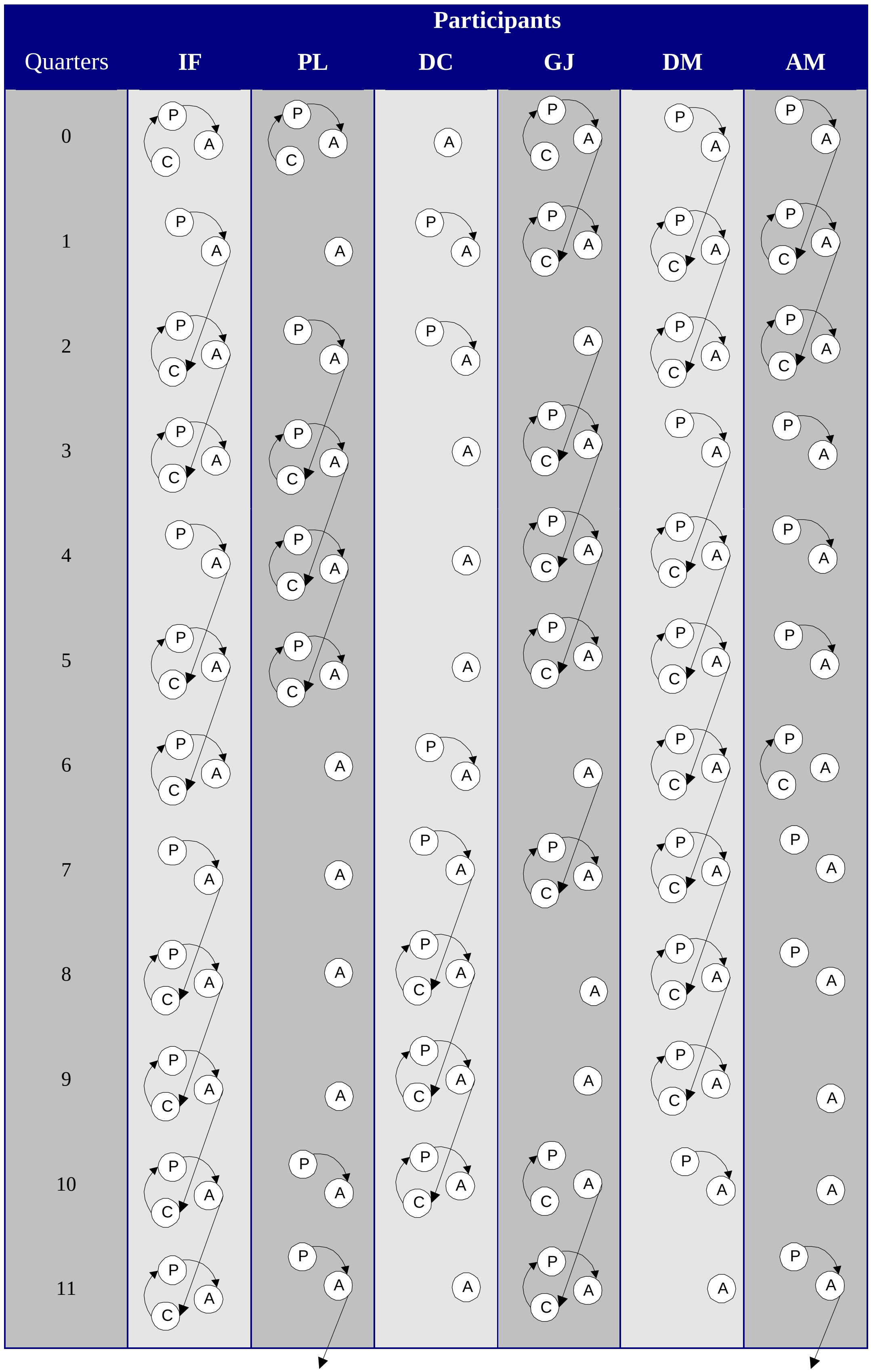
IF: "I increased sales compensation from 120 to 140 and I increased market spending as well, from zero to 100 and annual revenue per sales person went up from one million to 1.1"

PL: "my recent strategy has sent the revenue into a bigger nose dive in fact now I'm losing money and going backwards, ...the revenues, the problem seems to be the level of expense

The CPA cycle is thus pertinent to complex problem solving because the structure and behaviour of such problems are opaque. Hence it is necessary for a person to *incrementally* "build a picture" of the structure of the problem. This can be accomplished through an iterative process of conception, planning and action. For the cycle to be most effective and value adding, it needs to be iterative. As one cycle is completed, the action phase should lead directly to the conception phase of a new cycle. This is necessary because, as discussed earlier, understanding of complex problems can often only be gained progressively. If the cycles are not iterative, then they can become largely ineffectual in gaining understanding of problem structure.

Following the identification of the CPA cycle, the protocol summaries were analysed in a structured manner, to determine the extent to which participants followed the cycle. The results of this analysis are presented below in Table 2. The objectives of this analysis were twofold: (1) to see which stages of the cycle were evident in each quarter, and (2) to determine how many complete uninterrupted cycles each participant concluded.

As can be seen in Table 2, better performers, in addition to the amount of high-level systems thinking, were also following the CPA cycle more consistently. One of the key differences between good performers and poor performers was the number of completed cycles. This is illustrated by the number of quarters containing all three phases of the CPA cycle. The other difference was that good performers completed far more continuous iterations of the cycle than did the poor performers. In fact poor performers often did not follow the cycle at all or would progress in a rather disjointed fashion. The continuous cycles can be seen by the straight arrows that span across quarters. These show the action phase from one cycle linking to the conception phase of a new cycle which as described earlier, would be necessary to gain understanding of system structure.


Participants
Quarters
IF
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DC
GJ
DM
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0
1
2
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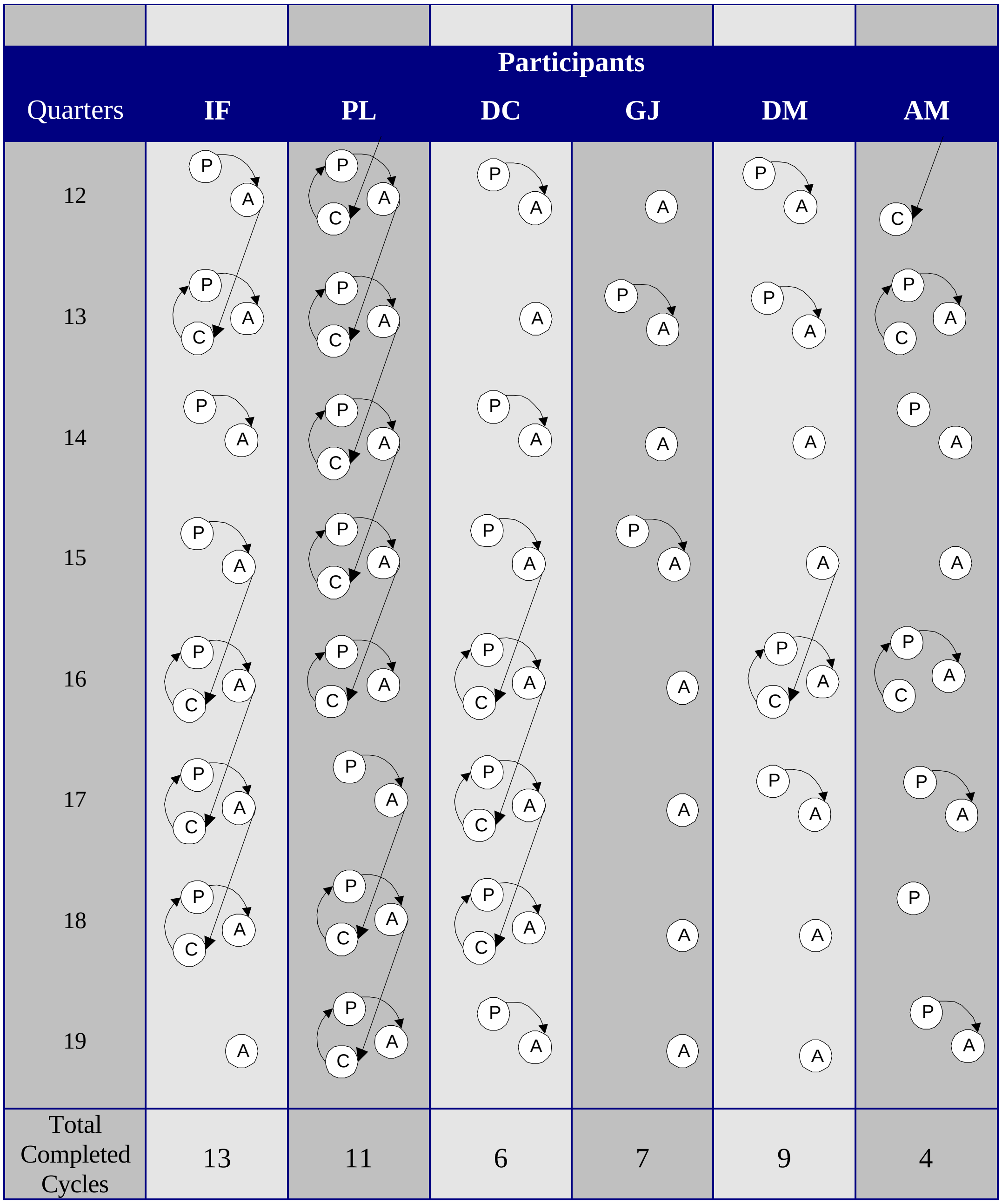

Table 2 – CPA Cycles through Subject Protocols

More importantly however, these results help explain the previous difficulty interpreting participant GJ's results. Completed and uninterrupted CPA cycles appear to be the deficient factor in his performance despite the good understanding demonstrated. From Table 2, it is clear that until approximately quarter 7, GJ has a chain of largely complete and uninterrupted CPA cycles, combined with large amounts of high-level systems thinking and sustained transitioning at high-levels. However, following this, he fails to go through complete cycles and as the task progresses, quarters become principally dominated with just the action phase, which illustrates that decisions are not being planned and understanding is not being developed. The *complete* verbalisations shown below, made by GJ from quarter 16 to 19 inclusive, illustrate his failure to use the CPA cycle as part of his problem solving.

> Q16: "it drops, why, why people why are you leaving... umm okay sales are high, people are high, prices low, market spending I won't do anything now and I will just try it once more"
> Q17: "still dropping"
> Q18: "still dropping"
> Q19: "it's dropping, I'll leave it the way it is because I screwed up badly, yeah"

For reasons that are beyond the scope of this study, GJ stopped both the conception and planning stages of the cycle as he progressed through the simulation task. Although this study is not able to conclusively determine why GJ began to utilise only the action phase, it nevertheless emerges as a significant contributing factor to his poor task performance.

SUMMARY

This paper began with a simplistic (in retrospect) research question that the more systems thinking a subject did, the better their task performance would be. While the amount of systems thinking explained the performance of some subjects (IF and PL), this premise was not consistent across the other participants. Most participants in fact had done similar amounts of systems thinking overall.

Research question two shed more light on the issue by showing that high-level systems thinking and particularly forest thinking seemed to be highly related to task performance. These findings were consistent across all participants except GJ. GJ had almost the same amount of systems thinking as the best performer IF, and considerably more forest thinking, yet ranked only fourth out of six in task performance. It was decided to further investigate research question two at the disaggregate level where the ensuing findings were inconsistent with those at the aggregate level. Two reasons were suggested for this inconsistency. Firstly, correlating systems thinking in a particular quarter to performance in that quarter was found to be flawed. Secondly it appeared that systems thinking and particularly high-level systems thinking is expected to aid understanding of the problem structure, which would *then* lead to better task performance. This would mean that the amount of systems thinking would not necessarily correlate directly with task performance, but rather with understanding of task structure.

In order to examine these postulates, the level of each participant's understanding of task structure was measured. As expected, participants who did more high-level systems thinking had better understanding of task structure. Subject GJ had the greatest comprehension of task structure, which was consistent with expectations. He had approximately the same amount of high-level systems thinking as the best performer IF and had considerably more forest thinking, the thinking type that was expected to be most effectual in garnering task structure awareness.

Since a clear explanation had still not emerged to explicate the study results, research question three focused on the possibility of good performing participants using patterns or sequences of systems thinking. In order to evaluate this, transition patterns for each participant were constructed and scrutinised. What was revealed was that good performing participants transitioned across all five systems thinking levels and did this throughout the entire simulation. In contrast, poor performing participants maintained sustained periods at the lower systems thinking levels and had many gaps in their transitions, indicating no systems thinking.

Nevertheless, all the investigations thus far still did not fully explain the research results, particularly the performance of subject GJ. Research question three was then considered with a slightly altered focus. This time the aim was to look for any general patterns or sequences of behaviour that might account for the findings rather than systemic patterns specifically. What emerged from this analysis was the conception, planning and action cycle, or CPA. The CPA cycle was another differentiator of good and bad performers. Good performers completed many more cycles than did poor performers. Additionally, good performers undertook chains of uninterrupted cycles enabling them to incrementally build their understanding of the task structure and thus perform better on the task. This analysis enabled the results to be fully explained.

Given all the preceding analyses, the performance of each participant can now be explained in terms of the amount of overall systems thinking, the amount of high-level systems thinking, the understanding of task structure, the transitions between types of systems thinking and the number of complete CPA cycles (3). This table presents a summary of each participant's performance in terms of these five factors, ranked in order from best to worst.

Task Performance (rank order)	Amount of Overall Systems Thinking	Systems Thinking devoted to High-Levels	Understanding of Task Structure (/34)	Transitions Between Levels of Systems Thinking	Completed CPA Cycles
IF	38.83%	45.33%	26	Consistent across all levels and throughout protocol	13
PL	31.43%	33.96%	21	Quite consistent across all levels and throughout protocol except for 1 sustained period at levels 1-2	11
DC	35.57%	20.29%	17	Frequent gaps and sustained periods at level 1 and 3	6
GJ	29.75%	44.44%	30	Across all 5 levels for first 40% of protocol after which largely confined to level 1	7
DM	13.03%	28.26%	14	Large gaps with transitions confined to levels 1-3	9
AM	30.29%	16.5%	11	Transitions primarily between level 1 and 2 and occasionally level 3, never level 5	4

Table 3 – Summary of Factors Affecting Performance

As stated above, each participant's performance can be explained as a combination of these factors. As can be seen in Table 3, all five factors are relevant to each participant's performance. When a participant carries out one factor poorly, this can be compensated by being superior on another or all other factors. For example, participant IF executed four of the five factors best and not surprisingly performed the best overall. Explaining the performance of one participant relative to another can serve to better clarify this five factor rationale. For example, subject PL performed better than DC despite having less overall systems thinking, because PL did more high level systems thinking, had better task understanding, better transitioning and completed more CPA cycles. This explanation is consistent amongst all six participants. Their performance relative to each other can be reliably explained by variances in the five factors.

EMERGENT MODEL

As a result of the foregoing analyses, a new model emerged (shown in 7). This model identifies all factors affecting the three research questions as being relevant to performance; they are: the amount of systems thinking, the type of systems thinking and the systems and non-systems problem solving patterns.

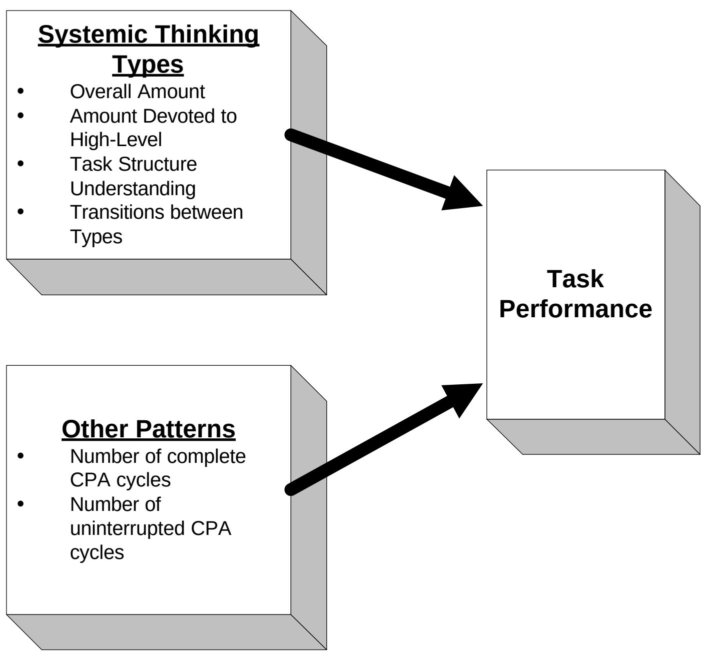

Figure 7 – Emergent Model

Based on the findings of the study, the factors represented in the emergent model have all been shown to impact on performance in a complex problem. This is further substantiated by results such as those of participant DM. He had the least amount of systems thinking overall but performed fifth out of six because he did more high-level systems thinking, had better task structure understanding and completed more CPA cycles than the worst performer AM.

Even though the importance of each of the factors has been identified, what is not clear and lies beyond the scope of this study, is to what extent each factor impacts on task performance. Also beyond the scope of this study is the combination of the factors necessary for superior task performance. There may be one or more advantageous combinations of these factors for optimal task performance.

DISCUSSION

This study sought to investigate the postulate that systems thinking is effective in dealing with complexity. The findings reveal that in reality it is not as simple a notion as "the more systems thinking done, the better the task performance". The study found that although the amount of systems thinking performed does matter, it is in fact the degree of higher-level systems thinking types (ie, operational, closed-loop and forest) that matter most. Further, the results indicate that participants who used all five systems thinking types and did this repeatedly throughout the simulation performed better.

This indicates that performance on a complex problem is a rich and multi-dimensional process. The scale of high-level systems thinking, and the consistent use of all levels of systems thinking throughout the problem solving exercise have an effect on task performance. What remains unanswered here, as is beyond the scope of this study, is to what extent each of these factors (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 performers in complex problems solving studies show strong parallels to aspects of the systems thinking *paradigm*. This lends support to the argument that thinking systemsally *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.

Examples of the parallels between systems thinking and complex problem solving can be found in the attributes of good and poor performing participants in studies undertaken in the individual differences approach. The behaviour of subjects who performed well, reflects the attributes of systems thinking while the behaviour of subjects who performed 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 such 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 systems 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)[8] 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)[8] 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 to the notions of systems thinking types and the *Conception-Planning-Action* (CPA) cycle that emerged in this study. 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)[8]. 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.

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 systems thinking, when used in concert with the CPA cycle, is analogous to the characteristics of heuristic competence. While providing a clear definition for the heuristic competence construct, this similarity further supports the notion that systems thinking is indeed more effective for dealing with complexity.

In concluding, the contributions of this study are two-fold, as it contributes to both fields of systems thinking and 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 to investigate this question and the method utilised for operationalising the systems thinking paradigm.

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[8] This article has only been published in German.

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