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A REFLECTIVE PROCESS MEMORY IN DECISION MAKING

by
C. D. Laing

**A thesis submitted to the University of Bristol in accordance with the
requirements of the degree of Doctor of Philosophy in the Faculty of
Engineering.**

Department of Civil Engineering

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ABSTRACT

The overall objective is to provide a theoretical basis for a case-based learning model of the technical and business processes in an organisation. As a result of this work, it will be possible to design a prototype system for capturing case histories in a corporate memory to support organisational decision making. The specific objectives are to present a model of knowledge as a set of interacting processes with emergent properties and to describe how a grounded theory methodology provides the basis for an appropriate and formal explanation of the interactions and meanings of these interacting processes.

The representational relevance of the form and vocabulary of the Process Model explanation as defined by a *grounded* methodology is demonstrated. This includes a description of how a Process Model explanation can be used to represent emergent properties in a machine-based system. A formal method that discriminates between stored Process Model explanations using a measure of connectivity is presented. Finally, the way in which a Reflective Process Memory may aid corporate decision making is discussed.

To gauge the dependability of competing decision paths, a decision maker needs to have experiences of decision expectations. Expectation failures are used to discriminate between competing decision paths. An explanation serves as a reminder that indicates how and why the expectation failed and what was done to resolve that failure. It is hypothesised that these contextual explanations should consist of interacting processes. The relevance of selected failed explanations relies on appropriate indices of features that are related to those expectation failures and grounded in experiences of those failures. It is suggested that notions of dependability and justification are used within a reflective activity to re-evaluate the relevance of the actual versus the predicted expectation failures of previous decisions.

If case-based systems are to help human decision makers question the effectiveness of the proposed solution, then these systems must include a representational structure that can capture, identify and then recognise those emergent properties in other case-histories. The representational appropriateness of this model depends upon the model being able to express not only the emergent properties of the external object, but also the interacting processes that connect those emergent properties. A grounded theory analysis is used to define those aspects of a situation that are responsible for causing a particular problem. The results are expressed as

a Process Model. Aspects that are considered responsible for causing a problem are categorised as being predictive of a problem. The recognition of predictives in a new decision path will help in the selection of case histories. The uncertainty of the selection process is represented by a discrimination measure that selects and ranks case histories on the basis of the connectivity of these predictives.

In conclusion, the Process Model explanations that are selected could, (i) provide the user with relevant reflections and actions on how, when, where and why a problem has previously occurred; (ii) point out to the user which aspects are responsible for the problem and; (iii) suggest to the user relevant questions that were needed to be asked (but were not), during the initial decision path. Thus, dependable evidence of failure surrounding similar situations could be added (by the user) to judgements about the present situation (through an audit) and future projections (from judgements about future opportunities). The diagnostic use of those Process Model explanations leading to the anticipation of potential problems in future engineering projects would be especially valuable to the user. It is anticipated that the next stage of the work is the building and testing of a prototype corporate memory of case histories to aid decision making.

DEDICATION

to Karla and Sally

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DECLARATION

The work on which this thesis is based was carried out between November 1995 and November 1998 under the supervision of Dr D. I. Blockley of the Department of Civil Engineering.

It is entirely due to the author except where otherwise acknowledged in the text and has not previously been submitted for a degree or diploma of this or any other University or examining body.

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NOTATION

c	connectivity
$card$	cardinality
d	discrimination
PMX	process model explanation
R	relationship
RPM	reflective process memory
\neg	negation
\cap	intersection
\cup	union

INTRODUCTION:

CASE FOR SUPPORT

OBJECTIVES OF THESIS

The objectives of this thesis are;

- to present a model of knowledge as a set of *interacting processes* with *emergent properties*;
- to describe how a *grounded theory* methodology provides the basis for an appropriate and formal explanation of the interactions and meanings of these interacting processes in context;
- to demonstrate the representational relevance of the *form* and *vocabulary* of the Process Model explanation as defined by the grounded methodology;
- to describe how a Process Model explanation can be used to represent these emergent properties in a machine-based system;
- to present a formal method that *discriminates* between stored Process Model explanations as defined by a measure of *connectivity* between *predictive-processes*;
- to present a critical analysis of the way in which a Reflective Process Memory may aid corporate decision making.

THE NATURE OF THE PROBLEM

1. WATSON [1997] has argued that the commercial success of some case-based problem-solving systems is based in part on their successful implementation in shallow problem-solving exercises using simple case representations. These representations “*will usually be flat file structures based on relational data-base technology*” [WATSON, 1997]. The knowledge structure of a flat file format forms part of a consensus concerning, (i) a measure of *usefulness*; (ii) defined by a degree of similarity as a function of a *nearest-neighbour* or *induction* metric and; (iii) governed by the shared data attributes of the flat file format [HAMMOND, 1989;

KOLODNER & MARK, 1992; HENNESSY & HINKLE, 1992; PEARCE ET AL, 1992; WATSON & MARRIR; 1994; WATSON, 1997]. In this respect, the use of case-based reasoning (CBR) in such shallow domains represents a “*high, hard ground*” in which “*manageable problems lend themselves to solution*” [SCHON, 1987].

2. BARR & MAGALDI [1996] have suggested that the traditional business environment is being replaced by a state that can be “*characterised by instability, rapid technological advances and uncertainty*”. In this “*swampy lowland*” [SCHON, 1987] of uncertainty, problem solving or decision making is composed of knowledge that is of a more imprecise, fuzzy and ambiguous nature. Therefore just as individuals within this domain provide complex and highly contextual explanations when deriving solutions [DUNCAN, 1987], then case histories should be “*enhanced by supplementing them with descriptions of the informal rationale by which the final decision was made*” [BARR & MAGALDI, 1996]. They suggest that this requires “*a fundamentally new knowledge management technology infrastructure not currently met by conventional data-focused systems*”.

3. Consider a geophysicist assessing the geology of competing field developments. In such an uncertain environment a geophysicist needs to have experiences of differing expectations of reservoir complexity. To discriminate between these competing expectations, then the geophysicist also needs experiences of the many failures of those expectations. An explanation serves as a reminder that indicates how and why the expectation failed and what the individual did to resolve that failure. It is hypothesised that these *rich* contextual explanations may consist of interactive processes with emergent properties. Some of these emergent properties of the problem-solution environment may represent the reasons behind that failure. These interactive processes and emergent properties have not previously been thought significant. Expressed in case-based terms, this requires an appropriate representational format (storing and indexing) and the means of identifying those explanations that are relevant to the particular problem under consideration.

4. The relevance of selected failed explanations relies on appropriate indices for those emergent properties. They have to be related to those expectation failures and grounded in experiences of those failures. The explanation of expectation failures is connected with the notion of justification. That is, the ability to defend a decision. It is suggested that this forms part of a reflective activity. In which the actualities of the expectation failures of previous decisions are compared with the predicted expectation failures of future decision. It is hypothesised that the prognostic use of previous qualitative event sequences could lead to the *anticipation* of potential problems in future projects. This would be especially useful if this prognoses could identify *relevant questions that should have been asked at the time*

but were not.

5. If case-based systems are to help human decision makers question the effectiveness of the proposed solution, then these systems must include a representational structure that can capture, identify and then recognise those emergent properties in other case-histories. In addressing these issues the author has , (i) considered the identification of information uncertainty as it impinges upon the way management decisions are made and how appropriate actions are identified, planned and executed; (ii) proposed a formal methodology to capture, identify and recognise the emergent properties of previous decisions and; (iii) considered the representational appropriateness of this formal methodology.

FOCUS AND STRUCTURE OF THESIS

The layout of the thesis is as follows;

- In Chapter 1 current theories of expert reasoning and decision making are reviewed. Explanations of rule and model based reasoning and their accounts of expert performance during problem-solving tasks in an uncertain world are examined. This review leads to the conclusion that the way in which expert's categorise objects will critically influence how expert's reason about them.
- In Chapter 2 the linguistic aspects in the categorisation of objects are discussed. It is suggested that when an expert uses a concept description to reason about an external object, he is testing a hypothesis about the meaning and the dependence of that concept on the content and context of the object situation. This testing is a function of the expert using past knowledge in deciding if he/she has or has not seen this concept description before. It is hypothesised that decision making is a type of reflective-explanation.
- In Chapter 3 the reflective-explanation model of decision making is presented. It is hypothesised that individuals use their experiential memory to identify pivotal events (or emergent properties) of the problem. The chapter concludes with a discussion on the representational structure that a reflective-explanation may need and how the reflective-explanation must include a vocabulary for describing those experiences.
- In Chapter 4 a formal representation of reflective-explanation called a Process Model explanation is presented. It is argued that a grounded theory methodology provides a formal explanation of the interactions and meanings of emergent properties as they relate to the content and context in which they occur. This analysis will result in the generation of an array of concepts, categories and their processes and process-interactions that provide the building blocks of the Process Model explanation.

- In Chapter 5 the representational appropriateness of the form and vocabulary of the Process Model explanation as defined by a grounded methodology is demonstrated. It is suggested that a grounded Process Model explanation can represent experiences in a machine-based Reflective Process Memory. The Reflective Process Memory could create an index of Process Model predictives that are associated with previous failure conditions. By recognising those predictives, the Reflective Process Memory will be able to *anticipate* similar failure-conditions in other Process Model explanations of decision problems.
- In Chapter 6 a formal methodology that discriminates between stored Process Model explanations is presented. This discrimination may be defined by a measure of *connectivity* that exists between predictive processes and process-interactions. A comparison algorithm that selects Process Model explanations as defined by their relevance to the problem is introduced.
- In Chapter 7 a series of case studies of a frequent petroleum engineering problem [*implementing time-depth conversion*] are presented. The case studies represent open world decision problems in the field of reservoir evaluation. These case studies are used to demonstrate the complete methodology from knowledge acquisition to the selection of the most-relevant Process Model explanation of the decision problem.
- In Chapter 8 the conclusions of the thesis are presented. These conclusions lead to a critique of the thesis and number of alterations to the existing work are presented. The possible use of a Reflective Process Memory in capturing corporate experiences and how this may aid organisational decision making is discussed.

1. THE REPRESENTATION OF KNOWLEDGE

1.1 OBJECTIVES

- To review critically some current theories of human reasoning.
- To explore the nature of the *internal* models representation of the *external* object.

1.2 INTRODUCTION

1. RUMELHART & NORMAN [1985] have stated that, “*most of the representational systems that have been developed and evaluated to date fall into the category of propositional representations*”. Further, “*these representational systems all share the characteristic that knowledge is represented as a collection of symbols*” consisting “*of formal statements that reflect the represented world*” [RUMELHART & NORMAN, 1985]. These propositional representations may be divided into separate and possibly two distinct categories. These categories may be classified as *mental logic* (or rule-based) theories [RIPS, 1983] and *mental model* (or knowledge-based) theories [JOHNSON-LAIRD, 1983].

2. Mental logic theories of human reasoning state [RIPS, 1983] that individuals continuously develop and refine a mental logic representation of the problem. It is assumed that inferences are drawn from conditional statements. For example, *if p then q*. RIPS [1983] suggested that the reasoning mechanism applies this mental logic to an abstract form of the problem. This abstraction is defined by an encoding device, which has extracted this abstraction from a given information set. Some followers [BRAINE & O'BRIEN, 1991; OSHERSON, 1975; RIPS, 1983] of the mental logic argument have suggested that human subjects use a *natural logic*. It is assumed that this mental logic forms a direct, but abstract correspondence to the *external* object. Furthermore, this natural logic consists of a set of general inference rules. Only a small number of rules are necessary, since they could be applied iteratively and in combinations thereof. For example, consider the following;

If there is an A, then there is a B.

There is an A.

Therefore, there is a B.

3. The *testability* of this argument relies on the application of an *appropriate* rule. In this example, such a rule could be defined by the {implication} connection. If we let p represent *there is an A* and q represent *there is a B*. Then following, *if p then q*, the conclusion; *therefore, there is a B* is readily asserted. This relatively simple example adequately demonstrates the deductive methodology of rule-based theories. If inference rules have an abstract form, then some mechanism must encode the domain specific problem into an abstract format. This mechanism must then decode the generated abstract solution. However, what are the operational requirements of this encoding and decoding mechanism? Consider the notion of *appropriateness*. How does the reasoning mechanism generate the *most-appropriate* inferences from this abstract representation? In the example above, the most-appropriate inference was the {implication} connection. How did the reasoning mechanism know this? How does the reasoning mechanism know that the {implication} connection is more-appropriate than a {conjunction} connection? RIPS [1983] suggested that a combination of forward and backward reasoning operations can be applied, until each assertion has been proved true or false. However, in an open world full of incomplete and inconsistent information, what do the terms true and false (as defined by RIPS) mean? As Evans [1989] points out “*the results of the many hundreds of such experiments that have been reported in the psychological literature indicate that subjects’ responses very frequently deviate from the logically prescribed answers*”.

4. In an attempt to overcome these difficulties, JOHNSON-LAIRD [1983] has proposed an alternative theory. He suggested that human reasoning is not based on mental logic, but upon the manipulation of *mental models* [JOHNSON-LAIRD, 1983; JOHNSON-LAIRD & BYRNE, 1991; JOHNSON-LAIRD, SCHAEKEN & BYRNE, 1992]. The generation of these models are defined by *tokens* and tokens represent *all* possible states of the problem. These tokens (although not explicitly stated) are probably abstract representations of the problem. In this way the mental model represents an abstract plan of the problem. Therefore, when the human subject reasons, the individual constructs a mental model that represents the various ways in which the premise of an argument could be true or false. Problems are solved by reading a *semantically informative* [JOHNSON-LAIRD & BYRNE, 1991] statement, that is developed during the manipulation phase of the model’s construction. Some followers [JOHNSON-LAIRD, SCHAEKEN & BYRNE, 1992] of this hypothesis assume that this semantic information (which has not been explicitly stated during the construction phase) is derived from information that is *implied* by the premise. If a

conclusion is derived from information implied by a premise, how is this different from mental logic theories? How does the semantically informative statement know that the {implication} connection is more-appropriate than a {conjunction} connection? How does this statement deal with incomplete and inconsistent information?

5. JOHNSON-LAIRD [1983] suggests that in any inference task the human subject will attempt to formulate other models as a search for counter examples. These other models will be consistent with the given premises. JOHNSON-LAIRD & BYRNE [1991] believe that human subjects having formed a provisional conclusion will actively search for other models, that while compatible with the given premises, can be used to invalidate the inference. If no counter examples are found, then the inference is deemed appropriate. However, it is worth noting here, that the constraints of the working memory may restrict the number of models available for comparison.

6. Consider the following example;

*If C is greater than B and A is less than B.
Then C is greater than A.*

7. In the mental logic approach a rule may be defined by the assertion, $(p \cap q) \rightarrow r$. Therefore, if we let p represent the statement *C is greater then B* and q represents the statement *A is less than B*, then the application of this rule to the premise *C is greater than B and A is less than B* implies r which represents the conclusion *C is greater than A*. See truth table below.

p	q	$p \cap q$	r	$p \cap q \rightarrow r$
T	T	T	T	T

8. However, in the mental model approach it is assumed that human subjects will attempt to construct a *complete* representation of the *external* world problem. This representation will integrate (or combine) the two separate premises. Therefore, the first premise would allow the human subject to form a model as shown by the representation $c > b$ in which c (representing C) holds a relationship with b (representing B). The second premise will extend the model

$$c > b > a$$

9. When the human subject interrogates the model, $c > a$ (representing C is greater than A) may easily be derived. However, as EVANS points out; “*the basic problem is that the theories are formulated in very general terms which are necessarily augmented by many ad-hoc assumptions when applying the theory to model in any given context*” [EVANS, 1991]. He then goes on to state that “*it seems very likely that models based on either set of principles will be able to be constructed to fit any given set of data*” [EVANS, 1991].

10. ROBERTS, has argued that “*if a theory of reasoning is being proposed that is intended to describe the processes used by all people for all reasoning tasks, then what is the status of this theory if it is subsequently found that not all people are using the same processes?*” [ROBERTS, 1993]. For example, research by GALOTTI ET AL (1986) indicates that when human subjects use mental models in problem solving tasks, they may also discover logic rules. If mental models can be used to identify logic rules, then human reasoning must depend upon mental models and rule-based reasoning is a function of the underlying mental model reasoning mechanism. However, research undertaken by SHAVER ET AL [1974] appears to demonstrate the complete opposite. According to SHAVER ET AL [1974], mental model reasoning is a function of the underlying rule-based reasoning mechanism. Reasoning by rules and reasoning by models, offer incomplete and incompatible explanations of human reasoning.

11. A considerable amount of attention has been directed towards deciding whether the fundamental reasoning mechanism is based upon mental logic or mental models. Unfortunately, the existence of differences presents problems when judging the universality of one theory over an other. If individual differences exist, then reasoning theories cannot be universal. A universal reasoning theory will always be weakened by its persistent failure to account for the irregular performance of human subjects. Notions of *personalised representations* [BANNISTER & FRANSELLA, 1971] and *reasoning strategies* [ROBERTS, 1993] may account for the differences shown by individuals and may be viewed as a mechanism by which individuals solve reasoning tasks.

12. DUNCAN, (1987); RASMUSSEN, (1987); REASON, (1987) suggest that humans have developed reasoning strategies that attempt to match current problems with previous solutions. These stored solutions may be viewed as a set of personalised representations. The appropriateness of those representations are dependent upon the *point-of-view* of the individual and the *role-requirements* of the *problem-solution* environment. In this context, a problem-solution environment consists of the problem inputs and the solution outputs with the transformation in-between. This

represents a holistic view of the problem-solution domain. For example, this view may be a closed world, deterministic problem-solution domain, in which the appropriateness of the solution outputs can be defined by comparison with the problem inputs. It could also be an open world, non deterministic problem-solution domain, in which case a comparison may not be possible. In each case, the role-requirements will differ. In a closed deterministic problem-solution domain, the role-requirements may be defined by the need for a correct solution and the means for checking on the correctness of that solution. However, in an open problem-solution domain, the role-requirements may be defined by the degree of acceptable uncertainty in the solution outputs.

13. These role-requirements may help the individual in deciding *have they* or *have they not* [REASON, 1987] come across this particular problem before. For example, conclusions could be compared with previous conclusions derived from similar inferences. This would help the human subject when choosing if a conclusion is believable, or unbelievable. If from a [PETROLEUM ENGINEERING] point-of-view, the individual recognizes particular role-requirements of problem-solution environment, then this may aid the individual in determine if they have a pre-formed corrective solution available. However, it is worth noting, that although problems may be the same, individuals rarely are. Consequently, individuals may have differing points-of-view, they may recognize differing role-requirements of the problem-solution environment and therefore the re-called solution may also differ. For example, a [PETROLEUM ENGINEERING] solution will be defined by a [PETROLEUM ENGINEERING] point-of-view. An [RESERVOIR ENGINEERING] solution will be defined by a [RESERVOIR ENGINEERING] point-of-view. Consequently, the [PETROLEUM ENGINEERING] solution may not be the same as the [RESERVOIR ENGINEERING] solution.

14. These personalised representations could act as an operational definition of the task under consideration. For example as ROUSE & MORRIS state (when talking about mental models) such representations must include “*knowledge about the system to be controlled, knowledge about the properties of disturbances likely to act on the system, and knowledge about the criteria, strategies, and so forth associated with the control task*” [ROUSE & MORRIS, 1986]. Individuals will “*use their knowledge of the language and their general knowledge to understand the premises; they construct an internal model of the state of affairs that the premises describe*” [JOHNSON-LAIRD & BYRNE, 1991]. When “*interacting with the environment, with others and with the artefacts of technology, people form internal, mental models of themselves and of the things with which they are interacting*” [NORMAN, 1983] and that, “*these models provide a predictive and explanatory power for understanding the interaction*” [NORMAN, 1983]. This construction will have to be consistent with

the individuals understanding of the role-requirements of problem-solution environment, in which personalised representations are used for explaining observed events, predicting future events and determining appropriate actions to alter those events. However, while this hypothesis presents a reasonable understanding of the human reasoning processes, how do human subjects develop and modify their strategies? What factors constrain the development and modification?

15. BRECHTEL [1990] has argued that solving problems and the way in which the problem solving task is performed, appear to be dependent upon the nature of the problem and the way in which the individual understands the problem. He states that the “*perspective which characterises people and the information they have about their environment plays a critical role for those developing any internal processing*”. Hence, the selection of an appropriate strategy may be constrained by the task that the human subject needs to perform. So how do individuals select the most appropriate reasoning strategy? It has been previously suggested by REASON [1987], that individuals confront a task by deciding have they, or have they not come across this particular problem before. If a particular problem is recognized, then the individual will determine if they have a pre-formed problem-solution pattern available. However, there may not be an available match or the match may be only partial. In this situation the individual (in an attempt to generate a solution), may modify an internal representation of the problem. This modification may reflect a more abstract representation of the problem-solution environment. DUNCAN [1987] believes that this decision to generate a more abstract form of the problem-solution pattern depends upon a complex interaction between uncertainty and stress. For example, the failure of successive attempts at a problem solution, will increase the stress levels and hence this interaction. This in turn, will trigger the focus of the problem-solution response to become more abstract. Consequently, the generation of an appropriate strategy may be constrained by the problem-solution environment, the role-requirements of that environment and the point-of-view of the individual. Such a strategy represents the individuals understanding of the problem-solution environment.

1.3 UNDERSTANDING THE PROBLEM-SOLUTION ENVIRONMENT

16. Understanding may be described as a highly developed repertory of pattern-oriented representations [REASON, 1987] of the problem-solution environment. Experts (when reasoning at the knowledge-based level), have been shown to develop conceptually abstract models of the task that confronts them [RASMUSSEN, 1987]. These representations allow experts to encode new information

quickly and completely. For example, research [DREYFUS & DREYFUS, 1986] has demonstrated that expert chess players were able to recall clusters of information, that represented entire attack or defence configurations. BRECHTEL [1990] has argued that *“if Dreyfus and Dreyfus are right, pattern recognition may figure in even what seemed to be exemplars of high-level reasoning tasks”*. Consequently, reasoning, problem-solving and decision-making, may be dependent upon the individual discriminating between a selection of retrieved conceptual patterns and recognizing *“a situation as being like certain previous ones and responding to it in similar ways”* [BRECHTEL, 1990]. However, this discrimination and recognition process may place a heavy burden upon the capacity of the working memory. It is possible therefore, that tasks may be *pattern-limited*, that is, tasks may have a limited range of available patterns, or (given the limitations of the working memory), a limited range of feasible patterns.

17. Research by BREHMER [1986] & TVERSKY & KAHNEMAN [1986] into decision-making demonstrates that irrespective of how individuals cope with familiar problems, tasks or situations, performance will begin to deteriorate once the repertoires of patterns and models are exhausted by the demands of problem. One explanation of this stems from *“that of generalisation from experience”* [EVANS, 1989]. For example, EVANS [1989] suggests that *“a young child whose experience has been largely confined to cats might well over-generalise and classify the first dog it sees as a cat”*. Hence *“this false deduction implies possession of an incorrect rule which is consequently revised”* [EVANS, 1989]. TVERSKY & KAHNEMAN [1986] have suggested that individuals rely on heuristics or *rules of thumb* because of the limited cognitive processing capacity of human subjects. As TVERSKY & KAHNEMAN state, *“these heuristics are highly economical and usually effective, but they lead to systematic and predictable errors”* TVERSKY & KAHNEMAN [1986]. Further, *“a better understanding of these heuristics and of the biases to which they can lead could improve judgements and decisions in situations of uncertainty”* [TVERSKY & KAHNEMAN, 1986]. This argument is continued by BREHMER [1986], who suggested that the reason why individuals have difficulty with uncertainty is, *“that they lack the necessary basic schemata to help them understand and use the information provided by their experience”*. He goes on to state that *“if we do not learn from experience, this is largely because experience often gives us very little information to learn from”* [BREHMER, 1986].

18. For example, when solving well-structured exercises, the expertise consists in *identifying* the correct procedure to obtain a solution and then applying it. The procedure may be learned by experience or instruction. The procedure is known to provide a correct solution and provides the means of checking on the *correctness* of

the solution. However, when problems are solved or decisions are made under uncertainty, the correct procedure remains unknown and unclear. There is no definitive way of evaluating the effectiveness of the modified model on the outcome of the task. Therefore, the degree of model manipulation remains unknown and unclear. Consequently, the amount of manipulation may be too little or too much, resulting in under or over estimations of the problem solution. CAMERER & JOHNSON, [1991], indicated that expert decision making under uncertainty may be influenced by their attention to different variables within the model. While REASON has suggested that, *“accuracy of reasoning performance is a consequence of whether the problem solver’s attention is directed to the logically important rather than to the psychologically salient aspects of the problem”* [REASON, 1987].

19. Given that some domain specific information may be uncertain, then how can individuals use that information to represent the properties of the problem-solution environment. If the degree of representation becomes more abstract, at what basic abstract level will the human subject acquire the most relevant information? How is this level designated? When BRECHTEL [1990], argues that how we categorize objects (or items), will critically influence how we reason about them, it will also influence how we develop and modify our conceptual patterns. Hence, any generated explanations (and therefore solutions) can be dependent upon the nature of the task representation.

1.4 THE NATURE OF THE TASK REPRESENTATION

20. As RUMELHART & NORMAN [1985] state *“the problem of representation is one of determining a mapping between the concepts and relations of the represented world and the concepts and relations of the representing world”*. They have suggested that this problem has resolved itself into a debate *“over the distinctions between representational formats: propositional versus analogical, continuous versus discrete, and declarative versus procedural”*. The nature of the declarative and procedural representations will be discussed in more detail in Chapter 4, but in essence this controversy *“really reflect differences in the accessibility of the information to the interpretative structures”* [RUMELHART & NORMAN, 1985]. Some of the issues of the propositional versus analogical controversy have been discussed above. In this respect a distinction can be drawn between *“formal statements that reflect the represented world, either in the form of networks, schema-based structures, or logical formulae”*, and those representation formats that attempt *“a direct mapping between the characteristic of the represented world of primary importance and the represented world”* [RUMELHART & NORMAN, 1985]. However this distinction may be meaningless since the very nature of a representational format

is “*to capture the essence of the represented world*” and is therefore analogous of that world [RUMELHART & NORMAN, 1985]. The following will concentrate on the discrete versus continuous controversy.

21. THE SHORTER OXFORD ENGLISH DICTIONARY defines representation as, “*the action of presenting to the mind or imagination; an idea thus presented; a clearly conceived idea or concept*”. PALMER states that a “*representation is something that stands for something else*” [PALMER, 1978]. In this context, a representation may be viewed as an implied *agreement*, or *understanding* between an object and a related but separate object that represents it. These have previously been termed *represented* and *representing* worlds. However, in this thesis, they shall be referred to as the *external* problem-solution environment and the *internal* conceptual pattern respectively. In which the conceptual pattern reflects (or symbolizes) some aspect of the problem-solution environment. PALMER suggests that, “*the nature of representation is that there exists a correspondence (mapping) from objects in the represented world to objects in the representing world, such that at least some relations in the represented world are structurally preserved in the representing world*” [PALMER, 1978].

22. For example, let a relationship R_E , symbolize an information set of a problem-solution environment.

$R_E = \{ x_E, y_E \}$ In which x_E and y_E are *external* information.

23. The representational mapping would therefore require a corresponding relationship R_I . Where R_I symbolizes the information set of the conceptual pattern. Furthermore, there must also exist a corresponding agreement between R_E and R_I , such that R_I may represent R_E .

$R_I = \{ x_I, y_I \}$ In which x_I and y_I are *internal* information.

24. Therefore, “*world X, is a representation of another world, Y, if at least some of the relations for objects of X are preserved by relations for corresponding objects of Y*” [PALMER, 1978]. However, while in this example the internal conceptual pattern conforms to the external object, there may be times in which representations can differ. One way to account for human inconsistencies and the consequences of such inconsistencies (the generation of errors), is that the information remains the same, but the representations differ. Therefore, conceptual patterns may differ in the representations that they represent. This may be defined as the difference between *specified* and *realized* representations. If a problem-solution environment *specifies*

particular information, then the conceptual pattern could either *realize* different relationships of the problem-solution environment, or *realize* the same relationships in different ways. Therefore, if each representation *realizes* different relationships of the same *specified* information, then each conceptual pattern would not be able to provide the same answer to the same question. PALMER [1978] suggested that one way to account for the differences between specified and realized representations will rely on the notion of qualitative differences. Some aspects of the problem-solution environment may be symbolically different in each representation. However, these representational differences may also be a result of a conceptual pattern only storing some of the problem-solution information. For example, let some problem-solution environment be specified as, [PALMER, 1978]

$$R_E = \{ x_E, y_E \} \text{ \{relative mass of object, relative gravity \} .}$$

25. During the representational transformation phase, two conceptual patterns are *realized*. Which are,

$$R_I^1 = \{ x_I \} \text{ \{relative mass of object \} and}$$

$$R_I^2 = \{ y_I \} \text{ \{relative gravity \} .}$$

26. Consequently, the differences in these representations, would make it impossible to answer (*is it heavier than*) questions much less (*how heavy is it*) questions about particular objects.

27. Representations may not have similar values of categorization. For example, in one, *mass* may be categorized into a *big* and *small* value hierarchy. In another internal representation, *mass* could be categorized into an infinite number of values. These representations are non-equivalent. Similar questions will provide different answers. For example, *objects* classified as having either a *big weight*, or *small weight*, when using the two-valued representation, will be classified as having different *weight* categories when using the infinite value representation. (Unless, the two *objects* are identical.)

28. Representations may not have similar types of categorization and may not contain information sets that correspond to the same information sets in the problem-solution environment. For example, road maps may have different types of categorization representing the same road type or city size [PALMER, 1978]. In one map, the cities may be represented by dots of differing sizes. In this map the larger the city the larger the dot. However in another map, the city size is symbolized by

different colours. Unless a key indicates a size-to-colour relationship, then all the information that this map can provide is when city sizes are similar and when they are different. Without the key the two maps are not equivalent. For the representations to be compatible, then the number of representational levels and the categorization of these levels must be similar.

29. Representations may not be numerical. For example, representations could be classed as concepts, theories and knowledge. While numerical representations maybe able to confer meaning to similar concepts, how will non-numeric representations perform the same task? Human subjects must be able to identify the mutual and reciprocal relationships of non-numerical transformations and thereby assign a meaning value to these concepts, theories and knowledge. Note, it cannot be assumed that similar concepts will result in similar representations. In Chapter 2, the manner of this categorization, the way in which individuals assign meaning and the implications this may have on the representation of knowledge will be discussed. For the moment, it is accepted that representational methods may differ and it is assumed that any reflections of the problem-solution environment that they represent will remain the same. Consider the following conditional example [PALMER, 1978].

CONDITION 1: ASYMMETRY.

If object x is larger than object y, then y cannot be larger than x. Therefore in this representation, the IS LARGER than relationship may be logically defined as ASYMMETRIC, that is the relationship only holds for one way.

CONDITION 2. TRANSITIVITY.

If object x is larger than object y, and y is larger than z, then x is larger than z. In this representation, the IS LARGER than relationship may be logically defined as TRANSITIVE. Such that if the relationship holds between the first element and the second element, and between the second element and the third element, it also holds between the first and third elements.

30. PALMER [1978] has suggested that these asymmetric and transitivity relationships are constraints of the internal model. For example, if the {is larger than} relationship is represented by two relationships, then both relationships will need to be asymmetric and transitive. The {is larger than} relationship may be replaced by a {is longer than} relationship. If the internal model's information set represents a {is longer than} relationship for object [x] and object [y], then [y] cannot be longer than [x]. Let the information set now represent a {is longer than} relationship for objects [x] [y] and [z]. If [x] {is longer than} [y] and [y] {is longer than} [z], then the internal model must also represent the conclusion that [x] {is

longer than} [z]. Therefore, this new *{is longer than}* relationship could also be considered to be both asymmetric (CONDITION 1) and transitive (CONDITION 2). This method of knowledge storage (or intrinsic representation) allows the stored information set to be categorized as belonging to the essential nature of the concept being represented.

31. PALMER [1978] has extended this hypothesis by suggesting that in a different model a *{is connected to}* relationship now represents the *{is larger than}* relationship. Consequently, [x] *{is connected to}* [y] will now allow [y] to be or not to be *connected to* [x]. Previously, the *{is larger than}* relationship is deterministic and [x] *{is larger than}* [y], could be measured, evaluated and analysed. However, as PALMER [1978] argues, just because [x] *{is connected to}* [y], does not mean that [y] *{is connected to}* [x]. Similarly, if [x] *{is connected to}* [y] and [y] *{is connected to}* [z] then [x] might or might not be *connected to* [z]. This connectivity “*is not necessarily either asymmetric or transitive, although it is possible for it to be either or both*” [PALMER, 1978]. Further, he suggests that “*asymmetry and transitive can be literally imposed on it by requiring that it preserves the structure of its represented relation*”. To ensure that both asymmetry and transitivity are imposed, then any representation must reflect the total *knowledge structure* of the problem-solution environment. According to PALMER [1978] the internal representation “*cannot be dissociated from the operators that define the information it contains*”, and “*once the information content has been discovered, it must be related back to the world it represents*”. In this respect “*the most important point of a representation is that it allows us to reach conclusions about the thing being represented by looking only at the representing world*” [RUMELHART & NORMAN, 1985]. From this it could be surmised that the representation can only be considered complete, if and only if, the constraints of the conceptual pattern are a reflection of similar constraints of the problem-solution environment. For example, if there exists a relationship [x] *{is connected to}* [y] and this relationship is constrained by the relationship [y] *{is connected by}* [x], then the conceptual pattern must also reflect these constraints. Consequently, the conceptual pattern can easily answer any *connected-to* and *connected-by* questions. How will these constraints be imposed? To address this issue, in the next section consideration will given to the nature of the relationship between the external world and the internal model.

1.4.1. THE EXTERNAL OBJECT & THE INTERNAL MODEL

32. A theory is essentially an abstract description of principles offered to explain a phenomenon. A model is a concrete embodiment of a theory. The relationship a model holds with the theory must satisfy specific assumptions of that

theory. In this respect, the internal model is a representation of the external object and the cognitive model is in turn a representation of that internal model. Thus the cognitive model is a representation of a representation of the external object. Both the internal model and the cognitive model are representations of the same external object. As RUMELHART & NORMAN [1985] state “*in studying representational systems, it is important to realise that there are several different pairs of representing and represented worlds, and that our theories of representation are in actuality representations of a representation: that is representations of the mental activity that in turn is a representation of the environment*”. Therefore, what sort of equivalence can be achieved between the internal model and the hypothetical cognitive model of that model? This equivalence must be at a level of abstraction that is appropriate and this appropriateness must be of such a level, so that the cognitive theory can simultaneously describe both the internal and cognitive models.

33. It is suggested that the development of appropriate theory of representation will have to address the nature of the correspondence between the *object meaning* of the external object, the *represented meaning* of the internal model and the *represented meaning* of the cognitive model. Where does this correspondence exist? Does it exist in language or does it exist in human thought? Furthermore, how does this correspondence *become known*? How do individuals come to know the correspondence shared by all [MOTORCYCLES]? For example, to grasp a concept such as [MOTORCYCLE], is it necessary to have some knowledge about individual [MOTORCYCLES]? Is it necessary to understand the concept [MOTORCYCLES] to recognize that individual [MOTORCYCLES] all share something? This has been previously defined as the *learning paradox*. Note, this paradox is not new, in its earliest form it was considered by PLATO in his dialogue *The Meno* [DAY, 1993]. For PLATO [DAY, 1993], the *learning paradox* arises from the situation, in which to learn something *new*, a human subject must already know something *old*. However, how is this something *old* related to the something *new*. For example, let something *old* be [x] and something *new* be [y]. If [x] and [y] are identical, then an individual knows what they need to know about [x] to understand [y], since [x] and [y] are identical. If [x] and [y] are different, then an individual does not know what they need to know about [x] to understand [y], since they do not know what [y] is. PLATO [DAY, 1993] gets around this paradox by simply suggesting that human subjects are able to grasp the structure of more complex objects than they presently know, since they have buried within their minds remembrances of past lives that have not been washed down, what PLATO terms the *river of forgetfulness*. It would appear that individuals are able to grasp these complex structures because we begin to remember our past lives. This theory of recovery has been embraced (in a modified form) by people such as CHOMSKY [1967, 1968] and FODOR [1981, 1990] when they talk about a *public* and *private* language and the *language of thought*

respectively. However, while they are able to explain the use of this *sub-language* by individuals, they have to yet adequately define where this *sub-language* comes from. FODOR [1981, 1990] looks upon this *sub-language* as an innate quality that we have and which is universal to all human subjects irrespective of creed, colour or religion. However, if individuals use their *private language of thought* to grasp the structure of more complex objects that they already know, then their *private language of thought* must be a conceptual *richer* language than their *public language of actions*. How might this be so? This may be a function of the social and cultural aspects of knowledge growth. In other words a social and cultural construct [BANNISTER & FARNSELLA, 1971] forms a link between the knowledge in the environment and the knowledge in the mind. Therefore, an attempt to solve this paradox may be made by considering the social and cultural mechanism of knowledge acquisition (or learning). This will be considered in more detail in Chapter 2.

34. In this respect, the hypothesized conceptual patterns may be said to form a connection between the knowledge of the problem-solution environment and the individual. This connection should reflect the (i) situation description (categorization process); (ii) situation format (classification process); (iii) situation function (operational process) and; (iv) situation status (condition process) of that environment. This connection should be consistent with individuals understanding of the premises, context and content and should reflect relevant and appropriate information about the problem-solution environment. This consistency may be viewed as a relationship between the knowledge in the environment and the knowledge in the individual. In this respect, knowledge as represented by a conceptual pattern involves a dynamic interaction between the memory and the problem to be solved. This is used by the individual to understand the context and content of the problem-solution environment and thus generate a descriptive, explanatory and predictive analysis of the problem-solution environment.

35. Aspects that are specific to the external concept [MOTORCYCLE] may be stored with the representation {*motorcycle*}. Aspects that are specific to the concept [TRIUMPH] may be stored with the representation {*triumph*}. The representation {*motorcycle*} will at some point overlap with the representation {*triumph*}. For the model to operate at these different levels, with higher order levels being dependent upon the lower order levels, then these conceptual patterns must carry relations that link one pattern to another. Thus reasoning about an object may be defined by the relations that may exist between two or more conceptual patterns. That is, if a pair of conceptual patterns can be considered to be a *particular object*, then reasoning can be considered to be a *process relation* of that pattern pair. This may be termed the “*associative nature of knowledge*” [RUMELHART & NORMAN, 1985].

Thus the conceptual knowledge may be reflected as associations that connect these hierarchical conceptual patterns.

36. However, for a conceptual pattern to provide a human subject with an understanding of the description, explanation and prediction status of the problem-solution environment, then a control and monitoring function must be able to understand and inferential manipulate these patterns. This function must be capable of, (i) examining these patterns; (ii) determining their dependencies and their meanings and then; (iii) executing specified actions. It is hypothesized that the control and monitoring function performs categorization and classification transformations. For example, assigning defined meaning-values and determining the range of situations for which a conceptual pattern provides a dependable explanation of the problem-solution environment. This will be discussed in more detail in Chapter 2. They will also perform operational and conditional transformations, for example, accessing them, comparing them and depending on the comparison, initiating actions. This has been termed reflection and will be discussed in more detail in Chapter 3. Note, it is possible to make a distinction between deductive and inductive representations of knowledge. However, Evans [1989] has concluded that *“inductions and deductions may alternate, as a provisional rule which has been induced is then applied deductively to a new example”*. In later chapters, particularly Chapter 4, the implications of inferring the specific from the general will be addressed.

1.5 CONCLUSIONS

- There appears to be evidence to suggest that reasoning by rules and reasoning by models offer incomplete and incompatible explanations of human problem solving.
- Solving problems and the way in which the problem solving task is performed, appear to be dependent upon the nature of the problem and the way in which the individual understands and represents that problem.
- Individuals seek out commonly occurring patterns. These are cued from the individual's memory as required and matched with the current problem. If there is an exact match then patterns of the previous experience are re-used. If an exact match is not possible then the pattern will undergo some modification.
- It is hypothesized that, (i) conceptual patterns are used by individuals to understand and thus generate an analysis of the problem-solution environment; (ii) they consist of descriptive, explanatory and predictive processes and; (ii) knowledge may be represented by a set of hierarchical conceptual patterns.

2. CATEGORIES AND CONCEPTUAL PATTERNS

2.1 OBJECTIVES

- To review the use of categories and concepts in human reasoning.
- To discuss the *linguistic* aspects in the construction of conceptual patterns.
- To explore the hypothesis that the use of conceptual patterns in human reasoning is part of a *reflective process loop*.

2.2 INTRODUCTION

1. In Chapter 1 it was hypothesized that knowledge may be represented by a set hierarchical conceptual patterns and that these patterns are used by individuals to understand and thus generate an analysis of the problem-solution environment. This understanding may be governed by the point-of-view of the individual and the role-requirements of the problem-solution environment. Since, a point-of-view is particular to each individual and the role-requirements of the problem-solution environment is dependent upon the problem-solution domain, then the represented characteristic knowledge of some external objects may not be universal.

2. Before continuing, please note the following nomenclature. Concepts may be identified by square brackets and upper case font, e.g. [LITHOLOGY], whereas an external object may be represented by square brackets and an italic font, e.g. [*lithology*]. The conceptual pattern (or the individuals internal model of the external object) is represented by curly brackets and an italic font {*lithology*}.

3. Consider the concept [LITHOLOGY]. A conceptual pattern that an individual may have of that concept could be expressed as, {*the visible characteristics that impart individuality to the rock*}. Obviously, this pattern will depend upon the individual identifying and hence understanding the defining nature that constrains the concept [LITHOLOGY]. That is, the external object will have a range of these definitions that make up the totality of [*lithology*]. These definitions will be

manufactured with the intention of fulfilling the expected role-requirements of the external object [*lithology*]. Understanding these requirements relies on the human subject being able to generate (or have access to) related background information about which there is general agreement. Further, this understanding will be defined through the point-of-view of the individual, which in the main is defined by the experience, education and cultural aspirations of the individual. In Chapter 1, it was suggested that a conceptual pattern that an individual may have of the concept [LITHOLOGY] would reflect a series of processes that form a connection between the knowledge in the environment and the individual. Since the conceptual pattern represents the total understanding that an individual may have of the external object [*lithology*], then a conceptual pattern is the means by which external objects are categorized into a set of processes and relations that represent the concept [LITHOLOGY].

4. However, what are concepts? HAMPTON & DUBOIS [1993] use “*the word concept to refer to the idea or notion by which an intelligence is able to understand some aspect of the world*”. SMITH & MEDIN, suggest that concepts provide, “*a taxonomy of things in the world and to express relations between classes in that taxonomy*” [SMITH & MEDIN, 1981]. Is this taxonomy universal? Are concepts a singular and identical description of similar objects and is this description a representation of a defining knowledge common to those objects? If the understanding an individual has of an object is defined by the point-of-view of the individual, will a different point-of-view generate a different understanding? For example, will a *petroleum engineers* conceptual representation of the concept [LITHOLOGY] be the same as a *reservoir engineers* conceptual representation? Will these differences influence how individual’s develop and modify their conceptual patterns and will they also influence how individual’s use these conceptual patterns to reason about the external object?

5. The discussion in the following section will focus on the categorization and classification mechanisms and the results of research on the nature of concepts. In later sections, the linguistic aspects in the categorization of objects are discussed. It is suggested that when an expert uses a conceptual pattern to reason about an external object, they are testing an hypothesis about the meaning-values and the dependence-condition of that conceptual pattern on the content and context of the object situation. This testing is a function of the expert using past knowledge in deciding if he/she has or has not seen this object situation before. It is hypothesized that this decision making is a type of reflective-explanation.

2.3 THE PRINCIPLES OF CATEGORIZATION

6. RUMELHART & NORMAN [1985] have suggested that “*perhaps the simplest of the propositional systems is the assumption that concepts are properly represented as a set of semantic features*”. These features could be the essential elements of reasoning [SMITH & MEDIN, 1981]. For example, an individual may have no previous knowledge or experience of a new concept (apart that is, from its membership of a specific category). The individual may use this membership to infer that the new concept has the characteristics that are common to the category membership. This view of reasoning assumes that this membership may be defined by “*set relationships: two concepts can be disjoint (have no attributes in common); overlap (have some but not all attributes in common); be nested (all of the attributes of one concept are included in another); or be identical (be specified by exactly the same set of features)*” [RUMELHART & NORMAN, 1985]. These attributes can be used to classify the membership level of that object [SMITH & MEDIN, 1981]. Consequently they may be viewed as a description that the individual uses to identify the object as *belonging-to* or *not-belonging-to* a category membership. However, how do individuals classify and categorize these descriptions? How do individuals combine simple descriptions to form more complex descriptions?

7. HAMPTON & DUBOIS [1993], suggest that *categorization rules* are used to categorize external objects and that these categorization rules are influenced by *descriptive property information*. For example, the development of a conceptual pattern {*table*} would involve interrogating descriptions of external [*table*] objects and identifying those descriptives that define the external object. This operation would separate (or classify) the external objects into [*tables*] and [*non-tables*]. Therefore, some descriptive property information may be classified as physical (flat, square, stable), while others may be classified as functional (support’s weight). Others may involve complex combinations that are embedded in an implicit higher-level conceptual pattern held by the human subject, for example, {*Chippendale*}. HAMPTON & DUBOIS [1993] suggest that these descriptives may be looked upon as *properties*. For example, a property could be *is black & white*. This could be considered an *attribute property* termed *colour*, with a given *value property* of being *black & white*. Thus attribute properties may be looked upon as properties with a finite list of mutually exclusive value properties. Therefore, attribute properties allow these properties to develop into contrasting information sets, with the value properties providing a means by which attribute properties within a domain may differ. For example, consider the characteristic properties for the concept [CUP] [SMITH & MEDIN, 1981], such that,

[CUP] *specific object, concave, can hold liquids, has handle*

8. These characteristics would appear to offer a unitary description of the concept [CUP]. However, as noted by SMITH & MEDIN [1981] teacups used in Chinese restaurants do not normally have handles, yet they may still be classified as [cups]. Furthermore the remaining characteristics may also be true for [non-cups], for example, [bowl], [dish] or [vase]. This suggests that a human subject's understanding of the concept [CUP] may not only be reflected by *characteristic* properties. That is, there may be *non-characteristic* properties that define the concept [CUP]. Non-characteristic properties that are not common to all members of that category. Thus a [CUP] ISA [CUP], if a majority agree that the external object is a [cup] as defined by the conceptual pattern, {*a small open drinking vessel, that is usually bowl-shaped and has a handle on one side*}.

9. According to GARNER [1978] and TVERSKY [1977] a distinction could be made between *component* and *holistic* properties. A component property may be thought of as one that helps to provisionally describe a concept, while not usually constituting a complete description. For example, the component properties of concept [MOTORCYCLE] may be described as *two wheels, engine, characteristic shape*. Note, some of these component properties may refer to specific parts of the concept, for example, *two wheels*, while others may depict a totality of the entire concept, for example, *characteristic shape*. On the other hand a holistic property offers a complete description of the concept. The concept [MOTORCYCLE] may be a holistic pattern that represents a current production motorcycle, for example, *Triumph*. However, in the [MOTORCYCLE] example, what is the difference between the component property {*characteristic shape*} and the holistic property {*Triumph*}? It is suggested by SMITH & MEDIN [1981] that since the concept [MOTORCYCLE] will be made up of more than one component property, then each component is processed as an individual entity. They suggest that each of the component properties of a concept are individual and independent. This view is reflected in conventional similarity measures. In which each property is an independent and discrete data entity and the more of these independent and discrete data entities two concepts share the closer the similarity [TVERSKY, 1997]. This they argue contrasts with a holistic property, where the holistic property attempts to represent the totality of the object class. The holistic property is the complete unit. A unit that represents the totality of the object's knowledge.

10. However, how do individual's differentiate between similar, but differing external world objects? For example, a human subject may have a holistic representation {*Triumph*} for the object [motorcycle]. When confronted by an actual external world object of another motorcycle, for example [Ducati], how will the holistic representation help to distinguish between the two? How can the human

subject recognize that the object [*Ducati*] is not represented by the holistic pattern {*Triumph*} and consequently why [*Ducati*] IS-NOT-A {*Triumph*}?

11. SMITH & MEDIN [1981], have argued that when an object is represented by a holistic property, it is often intended as a *point-for-point* representation. For example, an individual's holistic representation {*Triumph*} is a *point-for-point* representation of a particular object [*motorcycle*]. Therefore, having used the *point-for-point* representation of {*Triumph*} to classify [*Ducati*] as the *external* object [*motorcycle*], then a *discrimination function* at the next level of classification will distinguish between [*Triumph*] and [*Ducati*]. This discrimination function could make use of a particular component property, for example, *characteristic shape* with which to identify the differences between [*Triumph*] and [*Ducati*].

12. Therefore, individual's have to choose the most *appropriate* way to categorize these components [TVERSKY, 1977]. For example, individual's could categorize them as *quantitative* components (or *dimensions*) and as *qualitative* components (or *features*). Dimensions are the state variables of the component properties. Whereas features are the characteristic attributes of the component properties. Consider the concept [MOTORCYCLE]. This concept could be represented by the dimensions of *cost*, *speed*, *make* or *model*. Therefore, the concept [SPORTS-MOTORCYCLE] would be at one end of a dimension *speed* while the concept [MOPED-MOTORCYCLE] would be at the other end of the dimension *speed*. Alternatively, each concept [MOTORCYCLE] could be represented by a set of features, such as *two-wheels*, *characteristic-shape*, etc. If two objects differ with respect to a particular dimension then one object must have more of that dimension. In the motorcycle example, the concept [SPORTS-MOTORCYCLE] will be faster than the concept [MOPED-MOTORCYCLE]. However, if two objects differ with respect to a feature, such that one object has IT, what ever IT is, while the other does not have IT, then the other may not be a motorcycle. For example, let the missing feature be *two-wheels*. If having *two-wheels* is a defining feature of a motorcycle, then an object that does not have this feature will not be a motorcycle.

13. ROSCH [1977] suggests that the fundamental *conceptualization* of external objects may be thought of as discrete *prototypes*. For example, some concepts when compared to a prototype, are judged to be better examples of a category than others. This is an important point, since the human conceptualization process will have to compare concepts with a prototype, to classify that concept as belonging-to, or not-belonging-to the category membership. ROSCH and her co-workers, suggest that some members of an information set are assumed to be critical characteristics (or weighting functions), of that set. Therefore, for a defined purpose, an object whose sets with more of the critical characteristics than others, will appear to be more

representative of that concept.

14. The Roschian view of the classification of external objects rests on the following assumptions, (i) external object characterizations do not occur independently (creatures with *feathers* are more likely to have *wings* than creatures with *fur*); (ii) there is one basic-level object at one level of abstraction (the human subject is able to obtain the majority of information with the least cognitive effort) and; (iii) even with the partial representation of external objects or when the characteristic attributes are continuous (and would normally produce categories that have a tendency to merge with other categories at similar abstraction levels), categories are still maintained as discrete information sets.

15. Note, these views of reasoning are concerned with defining characteristics of the external object. As stated above in order for defining properties to categorize the object, then those properties must be singularly necessary and jointly sufficient. Therefore, for a characteristic to be singularly necessary then every instant of that object will have that singular necessary characteristic. For a set of characteristics to be jointly sufficient, then every entity with that set must be an instance of that object.

16. For example, if a singularly necessary characteristic of the concept [MOTORCYCLE] is *two-wheels* then every instance of the concept [MOTORCYCLE] must have *two-wheels*. For a set of characteristics to be jointly sufficient, then every entity having that set must be an instance of the object. For example, if a set of jointly sufficient characteristics of the concept [MOTORCYCLE] includes *two-wheels* and *characteristic-shape*, then every entity with the set *two-wheels* and *characteristic-shape* must be an instance of the concept [MOTORCYCLE]. Consider the concept [TRIANGLE], this could be represented using the characteristics *closed-figure*, *three-sides*, *three-angles* & *the-sum-of-all-angles-is-180-degrees*, etc. Therefore, being a *closed-figure* is a singular necessary condition, since the object [*triangle*] must have this characteristic. The same is also true of the characteristic *three-sides*, *three-angles* and *the-sum-of-all-angles-is-180-degrees*. However, these four characteristics are also jointly sufficient. Since any entity defined as a *closed-figure*, *with-three-sides*, *with-three-angles*, *with-the-sum-of-all-angles-being-180-degrees* must, by those conditions be a [*triangle*]. Therefore such necessary and sufficient characteristics may be viewed as defining characteristics.

17. However, what is the defining characteristic of the object [*games*]. It cannot be a, *competition-between-teams*, or even a condition that there must be, *at-least-two-individuals-involved*, since [*solitaire*] is a [*game*] that has neither characteristic. Similarly, a [*game*] cannot be defined solely by the need to have a,

winner. For example, the [game] [ring-a-ring-a-rosy] has no such characteristic. Lets consider a more abstract characteristic, in which anything is a [game] if it provides, *amusement*. [Football] is clearly a [game] that provides, *amusement*, but for whom. Do professional footballers consider their Saturday outings, amusing and for that matter do the fans? Even if they do and, *amusement* is a singular necessary characteristic of [game], then [whistling] could also be considered a [game].

18. One solution to this problem is provided by KOESTLER [1976] and DIAS & BLOCKLEY [1995], namely the notion of *emergent properties*. In that the categorization of object is a function of its emergent properties. Consider the use of the concept [MOTORCYCLE] in the problem-solution environment, *is-x-a-motorcycle?* When an individual uses the concept [MOTORCYCLE], a set of emergent properties are implied or associated with the object [*motorcycle*]. Properties that emerges from the fact that bits of, *steel*, *plastic* and *rubber* have been assembled to form a *characteristic-shape*. They all co-operate when the ignition key is turned and the concept [MOTORCYCLE] has a *existence*. Thus the concept [MOTORCYCLE] becomes more than the sum of its parts. Some of these emergent properties will be culturally, contextual and content driven and so will emerge from the point-of-view of the individual. Some of them may emergent from an individuals understanding of the role-requirements of problem-solution environment. These emergent properties are used to classify the membership level of the new object. This implies, that if the emergent property of an object suggests that the object belongs to a particular concept category, then inferences may be deduced about the object. For example, let the concept [MOTORCYCLE] be represented by the conceptual pattern, {*a motorized two wheeled vehicle, used for carrying two people on the highway*}. Furthermore, let the individual recognize from the emergent properties of [MOTORCYCLE], that *x-ISA-motorcycle*. Having used the emergent properties to classify the membership level, then additional inferences can be made. For example, if [x] was seen in the UK, then [x] would need an [*mot*] and [*road tax*]. The level of *confidence* and *appropriateness* of these inferences will be a function of the human subject's understanding of the *content* and *context* of the problem-solution environment. For example, if the individual saw [x] on the [*motor-way*], then the *content* and *context* of the problem-solution environment would tend to reinforce the belief that *x-ISA-motorcycle*. However, if [x] was found in a [*Kellogg's Cornflake package*], then the *content* and *context* of the problem-solution environment would tend to suggest that *x-ISA-toy-motorcycle*. Therefore, it could be argued that categorization rules are constrained by the content and context of the problem-solution environment of an object and will generate a *belief* that two objects belong-to, or do-not-belong-to a category. This is done by comparing the emerging properties that are perceived by the individual, (i) as being shared by the two objects; (ii) given the point-of-view of the individual doing the classification and; (iii)

the understanding the individual will have of the role-requirements of the objects problem-solution environment. This would suggest that individual's engage in a *multi-level classification procedure* and implies that individual differences in the classification procedure will exist.

2.3.1 THE STRUCTURE OF A CONCEPT

19. Consider the concept [LITHOLOGY] definition of the object [*lithology*] as expressed by the following statement, "*visible characteristics that impart individuality to the rock*" [CHAMBERS SCIENCE AND TECHNOLOGY DICTIONARY, 1988]. This expression may be interpreted as follows, (i) *a rock's individuality that is imparted by its visible characteristics* and; (ii) *those visible characteristics that impart the rock's individuality*. Let the representation of a definition be dependent upon the representation of its parts. In the expression, *a rock's individuality that is imparted by its visible characteristics*, the explanation is a function of the relationship between *a rock's individuality* and *its visible characteristics*, which is only understood by semantic interpretation of *that is imparted by*. If however, the latter is replaced with *that is crushed by*, then the interpretation of the *whole* would change. This much is obvious. However, a deeper inspection, reveals that the semantic interpretation must be more abstract. For example, the interpretation of *that is imparted by*, underlies not only, *a rock's individuality that is imparted by its visible characteristics*, but also, *the visible characteristics that impart individuality to the rock* and *the visible characteristics that impart the rock's individuality*.

20. However, neither, *the visible characteristics that impart individuality to the rock*, nor *the visible characteristics that impart the rock's individuality* contains, *that is imparted by*, as a constituent part (or *surface structure*). Thus an abstract explanation, which underlies, (*the visible characteristics that impart individuality to the rock*) and (*the visible characteristics that impart the rock's individuality*), must have a direct correspondence (or connection), with an abstract explanation underlying, *a rock's individuality that is imparted by its visible characteristics*. This correspondence must exist despite the differences of the constituent parts. The interpretation of, *that is imparted by its visible characteristics*, is derived from *that is imparted by* and *its visible characteristics* and the interpretation of, *a rock's individuality that is imparted by its visible characteristics*, is determined from, *a rock's individuality* and *that is imparted by its visible characteristics*. For individuals to undertake such interpretations will require them to divide, *a rock's individuality that is imparted by its visible characteristics*, into separate constituents. This requires the human subject to firstly, represent the grammatical *relationships* and secondly, understand that, *its visible characteristics*, is a DIRECT-OBJECT [CHOMSKY, 1967] of, *that is imparted by* and that a SUBJECT-PREDICATE

[CHOMSKY, 1967] *relationship must exist between, a rock's individuality and, that is imparted by its visible characteristics.*

21. CHOMSKY, feels that these interpretative components are applied to determine, *"the semantic interpretation of a phrase X of the deep structure from the semantic interpretations of the immediate constituents of X, and the grammatical relation represented in this configuration of X, and its parts"* [CHOMSKY, 1967]. How might this be organized? CHOMSKY [1967] states *"of the many alternatives that might be suggested, the linguistic evidence now available seems to point consistently to the conclusion that the syntactic component consists of rules that generate deep structures combined with rules mapping these into associated surface structures"*. For example, the process could be composed of rules that firstly generate the constituent parts, then *map* these rules onto the associated abstract explanation. Conversely, rules that the generate abstract explanations may combine with an *associative surface structures* that map these rules onto the constituent parts. Or the process might operate via independent rules that are able to generate associative abstract explanations and constituent parts that have conditions of compatibility imposed them (or they express relations between them).

2.4 DISCUSSION

22. CHOMSKY [1967] has argued that a generative grammar may be said to generate a set of structural descriptions. Each of which incorporates a *deep* structure, a *surface* structure and a *methodology* that provides the human subject with a semantic and a syntactic interpretation of the concept. He suggests that syntactic attributes will give a formal characterization to the linguistic structure of a concept. He has argued, that the syntactic attributes are composed of, (i) a *phrase* structure that defines the underlying linguistic structure and; (ii) a *transformational* component, which converts these underlying structures into a surface structure. CHOMSKY [1967] assumes that individuals engage in a linguistic understanding process by recovering the underlying structures, when they reverse this transformation mechanism. However this assumption implies two conditions. Firstly, an individual *"must somehow mobilise rules of grammar that parse the sentences she hears into semantically significant parts of speech from which they are composed"* [LYCAN, 1990]. Secondly, where do these rules of generative grammar come from?

23. The notion that an individual uses rules of grammatical transformations to convert deep structures to surface structures lead CHOMSKY [1967] to an interesting

conclusion. Since these rules are able to define the specific properties of syntactic properties so precisely, then a basic-level structure may exist. Further, this basic structure may exist as a “*universal grammar*” [CHOMSKY, 1967]. LYCAN [1990] defines a universal grammar as “*a device that takes an infant’s environmental input and turns it into knowledge of a particular natural language such as English or Japanese*”. However, as LYCAN [1990] states, how can individuals “*develop, not just the same language or other, but everywhere much the same language so far as grammar is concerned*”. FODOR [1981, 1990] accounts for this, by postulating a *rich* internal structure. He concludes that when human subjects use (or learn) a language, they are testing (or confirming) a hypothesis about the *truth* (or meaning) conditions of that language. He suggests that such hypotheses take the general form, $P(y)$ is true, *iff* (if and only if) $G(x)$. Where P is a meaning-value of the language to be learnt and G is a meaning-value in the language of thought. FODOR [1981, 1990] has argued that to be able to form such hypothesis, let alone test them, will require the individual to already have the meaning of G . Hence, the language of thought must be at least as *conceptually rich* as any natural language. If language learning is hypothesis testing, then the hypothesis must be developed from a language that is already as rich as the language to be learnt.

24. Despite the commitment of both FODOR [1981, 1990] and CHOMSKY [1967] to the notion of *innateness* (that is, existing in or belonging to the individual), not all concepts need be innate. For example, it is dubious whether individuals have innate representations of the complex concepts [SEMI-SUBMERSIBLE DRILLING PLATFORMS] or [GENERICALLY MODIFIED ORGANISMS]. However, it does seem possible that these non-innate complex concepts could be composed of innate elementary meaning-values. Further, the notion of total innateness may be minimized, if it is assumed that only some concepts are innate and that innateness may be conferred on concepts by a degree of similarity to an exemplar (or prototype). For example, individuals may not have an innate representation for the concept [ROBIN], simply some mechanism for attaching an exemplar [BIRD] to the concept [ROBIN] and stipulating similarity rules for further use of the concept [ROBIN]. However, neither FODOR [1981, 1990] nor CHOMSKY [1967] give any attention to the interaction between language and its environment and the manner in which the environment attaches a meaning-value to a concept. Therefore, while certain aspects of a concepts construction may be explained in linguistic terms, other aspects, such as, (i) the combination of elementary meaning-values and; (ii) environmental influences can only be accounted for by the general and specific knowledge of the external world and the constraints and conditions this knowledge imposes on that construction. If representations are to provide meaning-values and dependency-conditions, then an account of how the meaning and dependency of the representations change must be forthcoming. CHOMSKY [1967] suggests that

concepts are constrained by the environmental input, without explaining how and FODOR [1981, 1990] relies on the individual intuitively grasping the representational semantics, without discussing where this intuition comes from.

25. In section 2.3, the notion that human subjects can abstract descriptions, such that individuals can judge category membership by the degree of similarity to an abstract *prototype* [ROSCH, 1977; 1978] was introduced. This description abstraction may have an average profile. Hence, individuals could judge membership and hence the meaning of an object, by judging the similarity of the object to an average profile. ROSCH [1978], suggested that judgements of human subjects concerning category membership appear to be *scalar*. Such that, a human subject will classify the object [a] as belonging to concept [B] to a *greater or lesser extent* [CLARK, 1993]. For example, human subjects will classify a *robin* as being a more dependable exemplar of *bird* than a *duck*. It would appear that such a theory represents a degree of reality that is at odds with the classical model of the psychological mechanisms that human subjects use to classify category membership. Especially if such models simply involve, “*testing for the presence of the defining features picked out by some set of necessary and sufficient conditions, for such features will either be present or absent, and hence there will be no metric by which to gauge goodness of example; the concept will either apply or fail*” [CLARK, 1993]. Consequently, the more representational and hence more dependable members are those that demonstrate more *defining features*. CLARK [1993], suggests that the representation becomes a *better* member of that category because of these increased defining features. Furthermore, SMITH & MEDIN [1981], suggest that categories may be represented by stored indications (or *exemplars*) of actual category members. They argue, that the existence of these exemplars, allows for a graduated membership to be explained by a *separation distance* from these exemplars. Note, this theory appears to have similarities with the prototype hypothesis proposed by ROSCH [1977, 1978]. Such that a concept’s defining characteristics can be developed into an abstraction of those characteristics, with an average profile, or *statistical central tendency* [CLARK, 1993]. Hence, an individual can subsequently judge the meaning and dependence of an object, by judging the similarity of the object to an average profile.

26. However, while such prototype theories are helpful in explaining how individuals understand and reason with simple concepts, they appear to be unable to explain how individuals understand and hence reason using complex conjunctions. To counter this problem, OSHERSON & SMITH [1981], suggested that the only means of describing prototypical combination (and thus determine the *truth* conditions of propositions) was ZADEH’S fuzzy logic [ZADEH, 1982, 1993]. This logic relies on the assumption that category membership may be defined by a degree

of *acceptability*. They suggested that fuzzy logic is able to provide rules, such that the negation, conjunction and disjunction functions can operate with the category membership propositions. These rules may be classified as operational functions that evaluate the truth value of the complex conjunctive, given the truth values of constituent components.

28. However, the fuzzy logic-prototype theory was shown to be invalid when HAMPTON [1987] demonstrated the difficulties fuzzy logic had in paralleling the ability of a human subject. While the conjunction of *motor* and *bike* to form *motorbike* was relatively easy, it was difficult to develop a single representation of *kindergarten*, *school* or *university* that captured their characteristic. Many proposals have tried to account for this discrepancy. For example, TAKAGI [1994] (extending ZADEH'S [1982] idea that an *appropriateness* rule within the fuzzy logic operators may be related to the domain of the concept), suggested that *conceptual fuzzy sets* may be able to use *context* sensitive knowledge. TAKAGI proposes that a conceptual fuzzy set may be realized as an associative memory, conforming to WITTGENSTEIN'S idea of concept *meaning*. Yet another approach has been proposed by YAGER [1995]. YAGER investigated the appropriateness of a general characterization function as a measure of ambiguity. (This appropriateness is with respect to the Dempster-Shafer theory of evidence). YAGER demonstrated that notions relating to uncertainty (taken from fuzzy logic), for example, measures of fuzziness, of specificity, of possibility (certainty interval), may satisfy this characterization function, thereby generating a degree of *conceptual fuzziness* that can operate within contextual constraints. All these proposals argue for a function operator (or a set of function operators), that predict the appropriateness of an attribute in a conjunction $[A] + [B]$. This appropriateness is dependent, (i) upon the appropriateness of the attributes within the constituent concepts $[A]$ and $[B]$ and; (ii) upon access to other extensional information. That is, information on the other objects within the conjunction.

29. HAMPTON [1987] has argued that since conventional extensional mathematical inferences rely on the abstraction of propositions whose existence is independent of the individual then "*fuzzy logic, which like classical logic, operates in extensional domain, does not address how the meanings of concepts modify each other when they combine*". He proposed a different approach to fuzzy set conjunction and suggested that the prediction of the conjunction is impossible without "*identifying the rules by which it inherits attributes from its constituent concepts*". He has suggested that the inheritance of these attributes forms part of a intension process during the conjunction. This will be a function of an interrogation process and "*that the intension of a conjunction is formed as the union of the constituent attribute sets*" [HAMPTON, 1987]. During this process only some

attributes for each constituent part will be appropriate for the conjunction. Hampton terms this a *composite prototype*. This composite prototype is governed by two constraints, “*one constraint is that attributes that are necessary for either constituent (i.e., common to all members) will also be necessary for the conjunction. The other, converse, constraint is that those attributes that are impossible for either constituent will similarly be impossible for the conjunction*” [HAMPTON, 1987]. Therefore, the conjunction will not carry every attribute of all the constituent parts. Thus an *exemplar’s typicality* during conjunction will outweigh its typicality for either constituent.

30. MURPHY [1988], takes an even more extreme view and argues that conjunction does not function as a simple linear rule (or relations). He argues that “*people do not have sets of pets and fish in their heads, and therefore they cannot perform set intersection. More likely, they have intensions in the form of mental representations or rules that allow them to pick out the exemplars of a concept. Thus, any extensional explanation must also supply an intensional explanation of some kind in order to be a psychological model*”. This conjunction requires the reference of external objects relations, so that the human subject is able to place the most appropriate attributes within the conjunction. This would help human subjects predict how the resulting combination would be influenced by the particular structure of the environment in which the conjunction takes place. Murphy, stresses that the conjunction formations are *non-compositional*, in that the conjunctions attributes will not just be those of the constituent parts. Thus the conjunction may be considered to be greater than the sum of their parts and part of properties that emerge from the individuals understanding of the problem-solution environment.

31. ALLWOOD, ANDERSSON & DAHL [1977] state that “*many of the types of reasoning we normally engage in cannot be captured in the simple type of predicate logic*” [ALLWOOD, ANDERSSON & DAHL, 1977]. They go on to argue that “*when we give an account of the meaning of a linguistic expression, it is not enough to relate it to an object or set of objects; we must also provide a sense or a concept for the expression*” [ALLWOOD, ANDERSSON & DAHL, 1977]. Since the subject matter of the expression will consist of personal constructions (or objects) and the existence of any personal construct will be defined both by (i) the individual that constructed it and; (ii) the environment in which it was constructed, then it cannot exist independently of that individual and the environment of the individual [BANNISTER & FARNSELLA, 1971]. As MURPHY [1988] states “*how do people combine concepts X and Y is not a well-specified question. It is only in the context of some task that it takes on a clear meaning*”. Therefore, assuming that the categorization serves the needs of the problem-solution environment, then it might be more appropriate to consider this

conjunction hierarchy being dependent upon that environment. For example, as the problem-solution environment becomes more knowledge-based, then the concept conjunction level becomes more *informationally dense*. In a manner similar to RASMUSSEN'S [1983] hierarchy of reasoning, then conjunction may also be defined as a hierarchical process. Thus, at the *skilled-based* level, the conjunction could be considered instinctive, organized and highly practised. The conjuncture pattern matching becomes mechanical, where regular exposure develops a reflex skill. At this level, conjunction may be part of some evolutionary defence mechanism, that would have been a necessary response during our past evolutionary periods. At the *rule-based* level, the conjunction of more complex or novel situations takes place. At this level, the individual will attempt to minimizing the reasoning process by *actively* searching the memory and utilizing a conceptual pattern that *fits* the of the observed situation. For example, if an individual already has a conjunctive pattern for the concept [MOTOR-CAR], then a conjunctive pattern for the concept [MOTOR-CYCLE] will follow. At the *knowledge-based* level, reasoning in unfamiliar situations would require the development of a new conceptual pattern. However, despite the implication of a *higher level* of thought, it is almost certain that an existing conjunctive conceptual pattern would be accessed and *modified* to suit the present situation.

32. This assumption is based on the premise that the categorization of a problem-solution environment is a function of its emergent properties. Some of these emergent properties will be culturally, contextual and content driven and so will emerge from an individuals point-of-view. Others may emerge from the individuals understanding of the role-requirements of the problem-solution environment. Those properties that emerge from an individuals point-of-view are *perceptual* (unique to human subject), whereas those that emerge from the individuals understanding of the role-requirements are *functional* (unique to object). These attributes form natural separations in the information sets. Therefore, conceptual patterns are derived from these separations. For example, let the concept [BEER] function at the *rule-based* level at which there are emergent properties common to all (or the majority) of members of that category. Then the category knowledge (at that abstraction level), may have a conceptual pattern of {*an alcoholic drink brewed from fermented malt flavoured with hops*}. Therefore at this level all *alcoholic drinks*, that have been *brewed from fermented malt* and *flavoured with hops*, may be categorized as [BEER]. At one level more abstract, that is the *knowledge-based* level, the concept could be become the conjunctive [ALCOHOLIC-BEVERAGE]. At this level, members share few emergent properties and those that are may be classified as functional. For example, the category knowledge may have the higher conceptual pattern of {*intoxicating drink containing alcohol, where alcohol is a colourless volatile flammable liquid that is the intoxicating agent in*

fermented and distilled drinks}. At one level less abstract, that is the *skill-based* level, the concept could be [GUINNESS]. The concept [GUINNESS] may contain many properties that overlap with other categories. For example, [GUINNESS] shares many properties with other kinds of [BEER], nonetheless it also contains properties specific to [GUINNESS]. At this level, the information sets may become more perceptual. The knowledge contained with the conceptual pattern has moved more towards the individual and is less concerned with the object. The knowledge is now governed more by the perceptual understanding the individual may have of [GUINNESS] and the value the individual places on that understanding. The knowledge becomes more subjective and less objective. For example, at the knowledge-based level the knowledge contained with the conceptual pattern *{intoxicating drink containing alcohol, where alcohol is a colourless volatile flammable liquid that is the intoxicating agent in fermented and distilled drinks}* is almost completely objective. This conceptual pattern represents a detailed explanation of the conjunctive [ALCOHOLIC-BEVERAGE] and could be used in some higher level reasoning about the effects of alcohol. Whereas, the information contained within the conceptual pattern representing the concept [GUINNESS] will be part of an individuals cultural and contextual understanding of that concept.

33. How will the individual assign meaning and dependence to the descriptive, explanatory and predictive processes within the conceptual pattern? A hypothesis is required that views meaning and dependence as a fundamental relationship that links the conceptual pattern to the external object (and vice versa). In Chapter 1, it was suggested that a control and monitoring function performs categorization, classification and operational, conditional transformations. For example, assigning defined meaning-values and determining the range of situations for which a conceptual pattern provides a dependable explanation of the problem-solution environment. It is hypothesized that when an individual determines the range of situations for which a conceptual pattern provides an dependable explanation of the external object, they are testing a hypothesis about the meaning of the conceptual pattern and the dependence of that conceptual pattern, when compared to the component processes of the external object. This testing is a function of the individual using previous experience in deciding if they have or have not seen this conceptual pattern-object relationship before. In Chapter 1, it was suggested that the development of this decision strategy is based on operational and conditional transformations that access and compare conceptual patterns of similar experiences. This decision and hence categorization could be modelled as a type of *reflective process loop*.

2.4.1 THE NATURE OF REFLECTION

34. Before discussing the rationale behind the use of a reflective process loop, it may be wise to explore the nature of reflection. BOUD, KEOGH & WALKER, have previously defined reflection as, “*an important human activity in which people recapture their experience, think about it, mull it over and evaluate it. It is this working with experience that is important in learning. The capacity to reflect is developed to different stages in different people and it may be this ability which characterise those who learn effectively from experience*” [BOUD, KEOGH & WALKER, 1985]. DEWEY adds, “*reflective thinking, in distinction from other operations to which we apply the name of thought, involves (1) a state of doubt, hesitation, perplexity, mental difficulty, in which thinking originates, and (2) an act of searching, hunting, inquiring, to find material that will resolve the doubt, settle and dispose of the perplexity*” [DEWEY, 1933]. SCHON [1983] defines reflection in terms of knowledge gained from the individual’s own experiences. He describes two forms of reflection. These are *reflection-on-action* and *reflection-in-action* respectively. SCHON [1983] argues that reflection-on-action is very similar to DEWEY’S [1933] ideas on reflection, where reflection-on-action can be seen as a systematic and deliberate thinking back over one’s actions. However, reflection-in-action could be understood by the terms, *thinking on your feet, keeping your wits about you and learning by doing*. This suggests that not only do individual’s think about *doing* but that individual’s can think about *doing something* while they are *doing it*. Consequently, reflection-in-action will also consist of redefining the problem situation.

35. DEWEY [1933] defined five *phases of reflection*. This, he argued, demonstrates that reflection is a purposeful and deliberate act of inquiry, through which a perceived problem is examined so that a thoughtful reasoned response might be tested. He has termed these phases as, *suggestions, problem, hypothesis, reasoning and testing*. These may not follow the same order or sequence, but DEWEY [1933] suggests that they will combine to form what he defines as a *reflective cycle*. It is important to note, that although the definition of reflection suggests that it is a type of *reasoning-after-the-event*, reflection could occur before, during and after an experience. DEWEY [1933] makes no reference to the influence of context in the problem recognition process. The context of the problem-solution may well influence the nature of the reflection itself. An experience from one context may influence thoughts and actions in another context. Context may well embrace domains, such as *content, knowledge, experience, time, action, feelings and self confidence*. All these will vary from situation to situation and individual to individual and will be very closely linked to their educational and cultural backgrounds and experiences.

36. Some results from the *testing* phase of the reflective cycle may ne satisfy the individual and consequently could lead to further reflection. In this respect, reflection may be defined as a *consequence loop*. The individual, (i) will develop a working hypothesis; (ii) they will make observations and; (iii) in consideration of those observations evaluate the hypothesis. As a consequence of that evaluation a conclusion will be generated. This conclusion is defined by its dependability. If the hypothesis is considered to be dependable, then it is accepted. If the hypothesis is non-dependable, then more information is acquired and the hypothesis is re-evaluated. This loop continues until the hypothesis is either accepted or rejected.

37. Dependability is a function of evidence. Therefore, when an individual enters the consequence loop with a proposed hypothesis, the individual looks for evidence to support that hypothesis. If the evidence can be found that supports the hypothesis, such that the belief in the conclusion that follows is greater then the non-belief, then the loop can be closed and the hypothesis can be accepted. However, not all evidence is equal. For example, some evidence may be, (i) more appropriate to the defined conclusion than others or; (ii) preferential selected to support a pre-defined conclusion. Some evidence may be uncertain. For example, this uncertainty may manifest itself in *doubts* over the *quality* of the supporting evidence. An individual categorizes an external object by referring to a process of gathering evidence and forming a belief about the object belonging-to or not-belonging-to a category. If the quality of evidence indicates that the individual has no sure knowledge on which to fall back on, then a degree of uncertainty will creep into the process. If there is some uncertainty between categories, then there will be a degree of hesitation in categorizing the object. How is this confusion resolved?

38. Contemporary theories of concepts and categorization, for example TVERSKY [1997]; HAMPTON [1987]; MURPHY [1985]; TAKAGI [1994] and YAGAR [1995] make little reference to the problems of uncertainty in the categorization processes. Any attempt by the individual to resolve that uncertainty, will involve an examination of other information. This information may be a previous experience. For example, observations may indicate that some aspects of the object are similar to a previously known object. An individual will scrutinize the information provided by the memory and look for evidential experiences that will support their chosen belief. In this way, the reflection links the past to the future. For example, when a medic makes a diagnoses, they will use the past to define the present. They will also make a prognoses of the possible outcome. They will make use of the past to anticipate the future. In this respect a medical diagnosis and treatment is a type of hypothesis testing, with the difference between the prognoses and the actual outcome of the treatment helping to modify the development of future hypotheses.

39. Testing is used to confirm (or refute) the inference, [A] ISA [B]. Testing is an opportunity to find out how well the individual has thought about the situation. This can be very helpful, since failing is instructive and is very important part of the learning process. As DEWEY states, *“it either brings to light a new problem or helps to define and clarify the problem on which he has been engaged. Nothing shows the trained thinker better than the use he makes of his errors and mistakes”* [DEWEY, 1933]. POPPER suggests that *“criticism of our conjectures is of decisive importance: by bringing out our mistakes it makes us understand the difficulties of the problem which we try to solve. This is how we become better acquainted with our problem, and able to propose more mature solutions: the very refutation of a theory—that is, of a tentative solution to our problem—is always a step forward that takes us nearer to the truth”* [POPPER, 1972]. Reflection may provide a means of learning from past mistakes in order to anticipate future problems.

40. In this manner, a reflection process loop using previous experiences will help an individual, (i) to hypothesis a possible solution; (ii) to test that hypothesis and from those tests to make a prognoses of the possible consequence and; (iii) hence anticipate the evidential course of a particular problem-solution environment. The outcome of which is used to modify future hypotheses. This is explored in more detail in Chapter 3, in which the notion of decision making as a reflective learning process is discussed.

2.5 CONCLUSIONS

- It is hypothesized that the categorization of an object is a function of its emergent properties. Some of these emergent properties will be culturally, contextual and content driven and so will emerge from an individuals point-of-view. Some of them may emerge from the individuals understanding of the role-requirements of the object.
- When an individual uses a conceptual pattern to reason about an external object, they are testing the hypotheses about the meaning-values and dependence-conditions associated with the object environment. This testing is a function of the individual using past knowledge in deciding if they have or have not seen this conceptual pattern before.
- It may be useful to model this decision making as a type of reflective process loop. This will be explored in Chapter 3.

3. DECISION MAKING AS A REFLECTIVE PROCESS

3.1 OBJECTIVES

- To explore the idea that reflection is a process of envisaging the possible consequences of pursuing various possible courses of action and evaluating the merits of the possible courses of action in terms of their possible consequences.
- To define a model of decision making as part of a reflective learning process, supported by a reflective loop [BLOCKLEY, 1992; DIAS & BLOCKLEY, 1995], between the information acquisition, the process model and the evaluation of the available courses of action.
- To discuss how this model is derived from a view of understanding as an explanation process.

3.2 INTRODUCTION

1. Many theories of human reasoning view decision making as a logical activity [NEWELL & SIMON, 1972; MCGREW & WILSON, 1982; CARLEY, 1982]. This implies that the building of a decision is looked upon as a purely abstract and rational process that ignores other aspects of human behaviour. It will be argued that individuals use their experiences to develop decision paths as part of a reflective process.

2. Before continuing this chapter, two important assumptions concerning decision making need to be discussed. The first assumption is concerned with the notions of decisions and how individuals choose between alternatives in a complex open world [NEWELL & SIMON, 1972]. They suggest that any proposed methodology depends upon individual choices being reduced to comprehensible models that identify and explain the world and the processes involved in making decisions about that world. For example, a decision to place a bet on the Grand National or vote for a particular political party or indeed undertake a Ph.D., are all judgements undertaken by an individual. Consequently, it is assumed that the individual has

an understanding, (i) of the external environment; (ii) of what they *want* from that environment and; (iii) of how they need to react with that environment to achieve that need.

3. The second assumption is concerned with the thoroughness of investigation and presupposes that individuals are able, (i) to thoroughly investigate a wide range of alternative scenarios and; (ii) to make choices between these scenarios on the basis of reasoned arguments as defined by supporting evidence [NEWELL & SIMON, 1972]. These assumptions have been defined by a procedural criterion [JANIS & MANN, 1977]. This criterion implies that the human subject is a conscious entity that actively, (i) conducts a search for alternative responses to a defined problem and ensures that the search process is based on the objectives to be satisfied and on the evidence that results from the response being able to satisfy those objectives; (ii) analysis this evidence dispassionately comparing the risks as supported by the negative evidence with the benefits as supported by the positive evidence; (iii) searches for new evidence that will contradict the accepted view and when evaluating the alternatives takes account of this new evidence, even when it does not support the response that is preferred; (iv) examines all the positive and negative evidence (even if some of that evidence is considered to be unacceptable), before making a decision and (v); makes detailed plans for the implementation of the chosen response and reacts to the development of unacceptable risks within the chosen response by defining and initiating a contingency response.

4. These criterion suggests the individual, (i) is able to rank alternatives in the order of maximized usefulness; (ii) possesses all the relevant information concerning the decision problem; (iii) knows all the possible decision solutions from which they can choose; (iv) as well as knowing all the consequences of each decision solution. For example, consider an individual who is contemplating a period of study leading to a Ph.D. To begin with, this contemplation may require the individual to have some conceptual understanding of a Ph.D. and the value that they bestow upon it. The individual will need to develop some definition of how supervisors and universities should be judged. Having defined those attributes as significant, then the individual may have to order those attributes, such that the individual can order the available choices. Others may require the individual to have complex conceptual patterns supporting that simplified representation. For example, when a geophysicist constructs a velocity model of a particular reservoir there are assumptions in that model. Implicit in the assumptions of that model are the hidden complexities and uncertainties of homogeneity, fluid flow, permeability, porosity and the migration of sound waves.

5. In the following sections a review of contemporary decision models and

some ideas on a reflective model of human decision making will be presented. Perhaps at this stage, a few definitions concerning the attributes of a proposed model should be outlined. To begin with, can the model successfully demonstrate, (i) how the individual selects their preferences; (ii) how the individual chooses between those preferences and; (iii) hence how the individual builds a decision path. If the model can, then it will provide an explanation of what lies behind those preferences and how the decision path is built. For example, if a model can predicted that the reason why individuals undertake a Ph.D. was a function of the supervisor concerned and that the model successfully explained this function (later confirmed by empirical research), then it could be argued that the model was heuristically effective in that particular situation.

6. However, this does not presume that the model will be as equally effective in predicting and explaining why individuals undertake an undergraduate course. It must be made clear that the presented reflective model does not represent some *truth of correspondence*. The reflective model is an attempt at an *explanatory* and *prescriptive* representation of the decision building process. It will attempt to explain the *actuality* of the *how* and the *why* of a particular decision path. It will also attempt to predict the *potentiality* of the *how* and the *why* of a particular decision path. It is suggested that this *duality* of actuality and potentiality (as represented by the reflective processes of the model), should not be considered to be *true*, only more *appropriate* and more *dependable*.

3.3 WHAT IS A DECISION?

7. Decision making could be defined as a selection between alternatives. However this implies that decision making is a static activity. It could be better defined as a path through a state space (in which the selection of the final decision is the end state of a series of interdependent processes), governed by the problem-solution environment. For example, consider the following. Harriet Harman MP announced recently that as a package of measures to reduce the governments public sector borrowing it had been decided to restrict the financial subsidy given to single parent families. In this example, the problem-solution environment may be defined by the Labour Party's perception, (i) of how the electorate will react to Harriet Harman's announcement; (ii) of how the electorate understood the Labour Party's manifesto promises; (iii) of the consequences of a decision, especially a reflection and re-evaluation by the electorate of that previous understanding and; (iv) of how such a decision could inflict serve damage to the credibility to the present government, etc. In this example, the processes may be viewed as the various meetings, presentations and reports, etc., that make up that path. Recently, my

brother and his wife decided to have a baby. This decision could also be viewed as a path through a state space governed by the problem-solution environment. In this example, the problem-solution environment will be completely different and may include such states as, (i) are we both ready to start a family; (ii) is this the right environment to raise a child and; (iii) can we afford the necessary time and resources, etc. The processes could be defined as medical examinations, seeking advice, etc. However, in these differing contexts, what is understood by the notion of decision and decision making and are they the same?

8. MACKENZIE [1982] states that the major difficulty “*has been whether to accept the word ‘choice’ as synonym for ‘decision’*” [MACKENZIE, 1982]. MCGREW & WILSON suggest “*that the conception of decision which MacKenzie offers is one of a process: a cumulative sequence of stages of choice*” [MCGREW & WILSON, 1982]. This may be looked upon as *decision path*. A sequence of choice that defines a path leading from the *problem-space* [NEWELL & SIMON, 1972] to the *decision-space* [MCGREW & WILSON, 1982; CARLEY, 1982]. MCGREW & WILSON suggest that the notion of decision and deciding can be, “*simply reduced to the notion of a final definitive solution in a problem-solving process*” [MCGREW & WILSON, 1982]. However, is there another level to this decision making process? Is it possible as stated by MCGREW & WILSON [1982] and defined by [JANIS & MANN, 1977] that “*behind the decision is an element of procedure*”. Or do “*decisions arise from a complex process of interactions among actors*” [HALL, 1982]. Can these *actors* be defined as, (i) identify the current state(s) of the problem; (ii) define the desired end state(s); (iii) construct various paths for achieving those end state(s); (iv) examine those paths using some sort of selection procedure and; (v) finally end the process by defining a response. And are their interactions part of the decision process? Is this decision process universal? Do these assumptions imply that even when operating in an ill-conceived and badly-ordered external world of uncertainty, that all decision building processes consists of well-structured and well-ordered steps of certainty? These issues will be addressed by considering the development of a decision making model.

3.3.1. MODELS OF DECISION MAKING: A DISCUSSION

9. The development of a decision making model will be used to address the concerns set out above. To begin with, consider the notion of a problem-solution environment as a well-structured and well-ordered domain. If all the costs to be incurred and all the benefits that resulted from using any decision path were completely known, then decision making would be operating in a closed world environment. In a closed world the problem space, the decision path and the

decision space are related and the best decision can be calculated. Fortunately, the external world is not a closed system, but open and uncertain where information is incomplete and inconsistent. In this sort of environment it may not be possible to define a desired end state let alone the decision path necessary to reach it. The distinguishing characteristics of decision making in the external world may be classified as the uncertainty within that world and the constraints imposed by those uncertainties. For example, consider again the decision taking by Harriet Harman MP. How did the decision makers address the uncertainties imposed by such issues as, (i) single parent poverty; (ii) the effect this will have on the child's development and; (iii) the moral and ethic issues associated with the financial punishment of those, who are already at the bottom of the social pile.

10. In explaining the decision making process, all theories structure their explanation as a function of implicit models. These implicit models may be looked upon as assumptions about the behaviour of the individual. These assumptions will consequently constrain the nature of that explanation. MCGREW & WILSON [1982] have proposed three dominant perspectives on decision making (which they suggest have been derived from those assumptions) namely, *“the rational, organisational processes and political bargaining models”*, respectively. The organisational processes model is built around the notion that *“an organisation should not be considered as some sort of ‘super-individual’ behaving as a true individual but with greater information-handling and calculation capabilities”* [MCGREW & WILSON, 1982]. For example, *“an organisation does not have in practice, a single set of goals with an agreed order of preference amongst them, nor does it carry out a similar search process amongst its means, as an individual might”* [MCGREW & WILSON, 1982]. Consequently, an organisation may develop a decision path that was different from that of an individual, even if that individual had the similar objectives and constraints as the organisation. MCGREW & WILSON [1982], suggest that the *“organisational process model emphasises the centrality of routines and procedures in reducing the effects of uncertainty, and also emphasises the management of information to protect individual and departmental interests in the organisation”*. This has links with the political bargaining models, in which *“any collective decision is a process of bargaining, with its own (usually) implicit rules, in which outcomes are determined by the relative resources devoted by each participant to the achievement of some satisfactory solution”*. How is this process defined? MCGREW & WILSON [1982], suggest *“by a general process of bargaining and trade-offs between participants a final outcome is arrived at which has general support and in which the interests of all are seen to be accommodated”*. In this respect, the derived decision can be considered to be a rational agreement between *participants*, in which lesser interests are sacrificed to ensure the greater good is accrued to the decision maker(s).

11. The explanation of a decision path as defined by a rational process depends upon certain assumptions surrounding human behaviour and the ability of an individuals to analysis the problem-solution environment. Consequently, as [MCGREW & WILSON, 1982], state rationality implies that the decision path *“can be both explained and justified by relating it to the objectives of the decision maker.”* Given that a decision path must have a set of input states and desirable end state, then a rational individual when faced with a given problem-solution environment *“will attempt to rank his/her objectives or goals in some kind of relative order”* [MCGREW & WILSON, 1982]. This they suggest will leave the individual free to concentrate on examining all the alternative decision paths needed to achieve that end state. Consequently, the individual will then choose the decision path that either maximizes the values of the desired end state, or minimizes the ill-effects incurred if the desired end state is not reached. In process model terms an explanation of the decision path could be defined as, (i) a process model representation of the current state inputs; (ii) the desired end state; (iii) the sub-process hierarchy needed to reach that end state; (iv) the organisation of the decision path and; (v) the control and constraints that were imposed on the decision path.

12. The major problem with rationality stems from the variations in attributed definitions. For example, a rational individual may be defined as, *“endowed with reason, reasoning; sensible, sane, moderate, not foolish or absurd or extreme; of, based on, reasoning or reason, rejecting what is unreasonable or cannot be tested by reason in religion or custom”* [THE CONCISE OXFORD DICTIONARY OF CURRENT ENGLISH, 1964]. However, LEVINE *et al* [1975] state that some scholars believe rationality, *“means achievement of goals, some associate it with individuals maximising satisfaction, others conceive of it as a decision making process without regard to how successful a person is in achieving goals, and still others consider rationality to be broadly synonymous with intelligent and purposeful behaviour”*.

13. CARLEY [1982] suggest that a *distinction* can be drawn between the objectives and the decision path used to satisfy those objectives. This may be viewed as a *decision strategy*. A strategy, based on the perceived objectives of the individual can be used by the individual to, (i) analysing and evaluating the advantages and disadvantages of each alternative decision path and; (ii) in the selection of the optimum or most relevant solution to the decision problem. Consequently, such decisions can be *justified to others* [MCGREW & WILSON, 1982] and once this justification is accepted than an agreement may be reached. Especially, when in reaching that agreement, the individual can show evidence of *rejecting what is unreasonable or cannot be tested by reason in religion or custom*.

14. In this context the notion of justification and agreement may be viewed as a pre-requisite of the prescriptive nature of all models of human decision making. However, a clear distinction should be drawn between rational and irrational decisions. This distinction implies that a distinction can also be drawn between the degree of justification and agreement applied to such decisions. For example, irrational decisions could be defined as rational decision that have become *confused*. This confusion may be the difference between the intention of the individual and the decision path that is selected to achieve that intention. Decisions that have become confused do so because either the individual fails to define the objectives of the problem-solution environment or is unable to do so because of the uncertainty that surrounds that environment.

15. The *usefulness* of rational models have been defined by MCGREW & WILSON [1982] as “(a) *finding the conditions under which human agents can calculate the consequences of their decisions with a reasonable degree of certainty, and (b) defining the rules of calculation which will choose the best alternative from the means available.*” Note, since this depends upon the individual being able to anticipate the determinants of the consequences of their decisions, then the model must also act as a predictive mechanism. MCGREW & WILSON [1982] suggest that this “*strong meaning of ‘rational’ is a way of modelling the outcomes of consequences of decisions so that the decision-maker has one and only one way of arriving at a best decision - and what is best is itself defined by the model and the assumptions which it makes*”. ZEY [1992], has suggested that these theories of rationality view the notion of a *best decision* as utility maximising and that “*neoclassical theorists see utility as the basic unit of all human preferences and profit maximisation as the ultimate individual goal*”. She points out that this “*economic metaphor*” is used to “*explain not only economic behaviour but also the behaviour studied by nearly all social science disciplines, from political philosophy to psychology*” [ZEY, 1992].

16. In this context, the *economic metaphor*, may be defined as “*the price which will maximise the producer’s profits (his optimum solution) is the marginal cost of production*” [MCGREW & WILSON 1982]. This view of human decision making implies that if the individual did not calculate the price in this manner, then the individual will suffer. That is, the competitive nature of market forces will ensure that individuals who do follow this decision strategy will be more successful, than individuals who do not follow this decision strategy. As MCGREW & WILSON [1982], state, individuals “*who did not follow rational rules would leave the market*”. This notion of decision making suggests that individuals are not concerned with *how decisions are made*. If the how is defined by the rules that form part of the rational decision strategy that governs the market place, then individuals just follow the

rules.

17. ZEY [1992] points out that the social-economic-political theoretical implications of utility underlie all rational models of human decision making. She argues that utility is viewed as a measure that indicates the way in which the individual seeks to optimise their goals, satisfy their objectives and hence maximise their success. In this respect individuals, (i) will attempt to reduce costs and thereby maximise rewards; (ii) allocate their resources according to a defined utility function (in that individuals thereby allocate these resources in a rational and self interested manner) and; (iii) have a ranking of preferences. Rational models assume individuals are able to rank alternatives in the order of maximized utility. SIMON [1987], has suggested that the *"assumptions of utility maximisation"* does not *"provide a sufficient base for explaining"* the notion of profit maximisation is always being the ultimate individual objective. SIMON [1987] has argued that to preserve this notion of utility maximising requires a number of very dubious empirical assumptions. He suggests that, *"when verification is demanded, they tend to look for evidence that the theory makes correct predictions and resist advice that they should look instead directly at the decision mechanisms and processes"* [SIMON, 1987] and that, *"it fails to observe that most of its "action" - the force of its predictions - derives from the, usually untested, auxiliary assumptions that describe the environment in which decisions are made"* [SIMON, 1987]. Furthermore the neo-classical economic theorists will always reach a decision that is, *"objectively, or substantively best in terms of the given utility function"* [SIMON, 1987] and what these theories of rationality fail to address, is that any value of utility is *"subjectivity because it is defined as individual preferences and therefore varies from individual to individual"* [ZEY, 1992].

18. As ZEY [1992] points out, *"the rational choice models assume that individual choices are independent of one another. They fail to acknowledge that our utility may be a result not only of our own welfare but also of the welfare of those for whom we care"*. These theories argue that humans are only self-interested and have only self-interested preferences. However, they cannot account for the reasons why an individual *"might act against his or her self-interest and in the interest of another person"* [ZEY, 1992]. In this respect this action of non self-interest may be viewed as an emotional driven response and *"the emotion has some utility"* [ZEY, 1992]. It may have some utility attached to it, but how can it be measured? Emotions may have a benign or malignant effect upon the individual. Will a benign emotion have a greater utility value than a malignant emotion?. However, rational theories of decision making view these values as *"value-neutral"* [ZEY, 1992].

19. SIMON [1987] has suggested that we should stop debating over *"whether a*

theory of substantive rationality and the assumptions of utility maximisation provide a sufficient base for explaining and predicting economic behaviours. The evidence is overwhelming that they do not". This is highlighted by SAMUELSON [1982] who considered that the majority individuals instinctively recognize that "*in the real world, competition is nowhere near 'perfect'*" and that individuals do not always suffer, if they break the rules. As MCGREW & WILSON [1982] state, "*unlike the perfectly competitive market, decision makers operate under conditions where both information itself and the consequences of decisions are characterised by uncertainty to some degree or other*". If the problem-solution environment is placed within an open world of uncertainty, then any outcomes of the decision process will contain uncertainties. The rules of rational economics cannot function and a *certain* solution to an *uncertain* problem is not possible. Empirical research by NEWELL & SIMON [1972] & SIMON [1982] would appear to confirm that claim. Rational choice models may be limited by the complexities of the external world. SIMON [1982], defines these limitations as being the product of the incompleteness and the inadequacy of the individual's knowledge. Furthermore, there are he suggests conflicts and inconsistencies within the preferences and beliefs of the individual. In suggesting that uncertainty and complexity are two major limitations of rational choice theory SIMON [1982] is outlining the limits of human rationality. These limits of rationality will not only be constrained by the inconsistencies of the preference of the individual, but also by the conflicts of belief and values of the pluralistic society in which they live. As SIMON [1982], SMITH & MAY [1982], JABES [1982] and LINDBLOM [1982] point out, even before individuals reach the decision path, the observational and explanatory abilities of individuals, let alone the selection of relevant information may be flawed.

20. Assumptions that lie at the very heart of economic theories of human decision making appear to be insensitive to the cognitive limitations of human subjects [REASON, 1990]. SIMON [1982], has argued that individuals when making decisions will have a *bounded rationality*. Individuals may only compare and evaluate a small number of alternative decision paths and their objectives. SIMON, states that "*they use selective heuristics and means-end analysis to explore a small number of promising alternatives. They draw heavily upon past experience to detect the important features of the situation before them, features which are associated in memory with possibly relevant actions. They depend upon aspiration-like mechanisms to terminate search when a satisfactory alternative has been found*" [SIMON, 1982]. In some respects, these alternatives may be *edited* [MCGREW & WILSON, 1982] using a *strategic analysis* [LINDBLOM, 1982]. This may account for the way in which individuals deal with the open world environment. For example, cognitive and temporal limitations may force the individuals to "*stop the search when they find a satisfactory alternative*" [ZEY, 1992]. Having selected the most

satisfactory alternative, then the individual may preferentially seek information that proves rather than disproves, the selection. This has been termed a *confirmation bias* [REASON, 1987]. ZEY [1992] argues that since individuals selectively gather information and “*cannot obtain complete information even before making important decisions, all possible alternatives are not known, outcomes attached to each alternatives are not obvious*”. Consequently, individuals will not have the complete information set and therefore cannot fully predict the result of their decisions. These decisions would obviously be non-maximized and *sub-optimal*. Since it is now very difficult for the individual to place objective values “*on all the consequences of choices, so the subjective values (utilities) of the actors prevail*” [ZEY, 1992]. REASON [1987], has also argued that instead of considering all the alternatives, only those alternatives that have been recently used, will dominate, this he terms as *frequency gambling*. There will only be a small number of these, thereby limiting the number within which a satisfactory solution can be selected. Additional research by REASON [1987], suggests that the ability of an individual to make decisions may seriously decline in situations of high stress. REASON [1987], defines these problems with decision building as arising from stress escaping behaviour and that they fall into three categories, (i) a *simplification* bias, in which memory limits cause the simplest solution to be favoured; (ii) an *ignoring* bias, defined as *out of sight is out of mind*, the mind will not easily call up variables that have dropped out and; (iii) a *mind set* bias, where there is a focus on events that favour the working decision and a disregard of counter evidence.

21. Rational theories of human decision making are unable to provide an explanation of why these limits should occur. They concentrate instead on the definition and development of pure logical as the fundamental understudying behind the human decision making process. As NORMAN states, “*while there has been considerable process in some areas of cognitive science, overall the understanding of the individual has still not advanced much beyond pure intellect and reason*” [NORMAN, 1985]. Such theories still view decision making as some sort of logical dialogue between the problem space and the decision space, in which individuals perceive and think with a logical and abstract mind. Furthermore, this idea of abstract reasoning at a purely symbolic level is constrained by the notion of a universal mind language. Since, individuals are modelled as reasoning at an abstract level when deciding between competing solutions to everyday problems, then such abstract symbols must be shared between all individuals at a similar level of abstraction. CHOMSKY [1967, 1968] and FODOR [1990] suggest that such a level must be universal, however there is no evidence to support that suggestion.

22. But why should decision making be looked upon as a pure abstract activity divorced from experience and learning? This question is partly answered by the

way in which mathematics provides the models of human decision making. As mathematical models are defined by the logical and abstract qualities of mathematics, then mathematical models will continue to define a logical and abstract image of the individual. Thus, the individual when making decisions, will be continually defined as a computational general purpose problem solver separated from their experiences, their emotions and their ability to learn. There appears to have been too much emphasis on the formal properties of a human decision making and not enough consideration given to the informal properties such as experiential reasoning, reflective learning and process explanations. They appear to ignore any considerations of other aspects of human behaviour, especially the interaction with other people and the interaction of the individual with the environment. By not considering the influence of the individuals own experience on this decision building process, then these theories also ignore the cultural identity that each individual will bring to, (i) their understanding of the environment and; (ii) the methodology used to solve a problem and make a decision.

3.4 THE NATURE OF REFLECTION

23. BOUD, KEOGH & WALKER [1985] have suggested that the reflective processes may be composed of, *“returning to the experience, attending to feelings and re-evaluating the experience”* and that the nature of reflection is conditioned by the individuals memory of decision experiences. For example, the experience of an individual may include external world knowledge, behaviour, ideas, feelings and plans. This knowledge can be both objective (of the problem-solution domain) and subjective (of individuals understanding of the problem-solution environment). This knowledge may include possible outcomes, scenarios, actions and hazards associated with a particular decision path. In this, the reflection process functions as a conduit, through which a previous decision experience communicates with the selected decision path and vice versa. Consequently, the reflective process acts as a control and learning loop that monitors and evaluates the outcome of the selection process and communicates that analysis to the stored decision experiences.

24. BOUD, KEOGH & WALKER [1985] state that *“one of the most useful activities that can initiate a period of reflection is recollecting what has taken place and replaying the experience in the mind’s eye”*. Reviewing that experience, observing the salient aspects of that experience as they occurred, interrogating the experience to explain the how, what and why and analysing the response is considered by BOYD & FALES [1983] to be of fundamental importance in a decision building process. BOUD, KEOGH & WALKER [1985] suggest that this may help the individual to, (i) recognize details that were originally either ignored or if considered, then only

cursory and; (ii) reconsider and re-examine the feelings and responses that built the original decision. This review forms the foundation upon which any reflection undertaken by individual may be based and that *“this description provides the data for subsequent processing and can help to ensure that our reflection is on the basis of the actual events as we experienced them at the time, rather than in terms of what we wished had happened”* [BOUD, KEOGH & WALKER, 1985].

25. This review can be considered *“a more complete identification or clarification of the problem as it is experienced by the self”* [BOYD & FALES, 1983]. This clarification of the understanding by the individual of the events that make-up a particular decision, could include external events that were initially considered outside the sphere of interest. For example, the individual may wish to consider the wider context in which the event sequences were operating. The individual could include an awareness of new knowledge that may be now linked to the initial decision. This awareness could be combined *“with the ability to observe and take in from a variety of perspectives”* [BOYD & FALES, 1983]. For example, the response and behaviour of those other individuals that are effected by the decision, additional ideas, feelings and plans that are part of the reaction to the selected decision path and ultimately the outcome of that path. In this respect, the review may include some *“observations of judgements and interpretations”* [BOUD, KEOGH & WALKER, 1985] that occurred during the initial decision building experience. Consequently, this review may carry some *a priori* beliefs in the appropriateness of the decision path and these beliefs may act as pre-selectors and blind the individual to any further evaluation. As BOUD, KEOGH & WALKER, state, *“our perceptions of events are conditioned by past experiences which has shaped our response to the world around us”* [BOUD, KEOGH & WALKER, 1985]. For example, positive feelings about the benefits that may accrue from a selected decision may override the understanding the individual may have surrounding the hazardous consequences of such a decision. These feelings of positive self-confidence may allow the individual to develop and pursue a decision path that is excessively optimistic. This was demonstrated by empirical studies conducted by PASCOE & PIDGEON [1995], in which individuals classified as risk seeking consistently selected more risky decision strategies. These strategies, when successful achieved higher gains. However, the positive self-confidence of these individuals led them to overlook the more likely dire consequences, in favour of the less likely greater gains. It may be useful if the representative model of the reflective process is able to recognize the occurrence of these feelings and ideas, since these positive and negative feelings form an inherent part of the decision building process.

26. BOUD, KEOGH & WALKER [1985] suggested that emotions play an important part in the development of an intuitive appreciation of some hidden truth and

explanation of the salient events that make up decision path. They may help the individual to enter the next phase of the decision process in which the newly developed *insights* as well as the recalled experiences are involved in the re-evaluation stage of the reflection process. BOUD, KEOGH & WALKER [1985] stress that the emotions of an individual can be an important component process of decision making. BOYD & FALES [1983] argue that the insight is re-evaluated in terms of its emotional affect. That is, “*safest (emotionally) in terms of not brutally shattering the subjective certainty of its rightness*” [BOYD & FALES,1983]. However, REASON [1987] suggests that emotions can be substantial barriers to effective decision making. For example, individuals may be so constrained by the emotional background, that the individual becomes fixed to one perspective, or indeed fixed to a given interpretation of previous decision experiences. In some respects the individual becomes blinkered or develops tunnel vision, to such an extent that the individual discontinues the reflection phase. The tunnel vision focuses the individual and instills a belief in the individual that the understanding of the decision building experience is appropriate to the current situation. A belief that when looked upon in the cold light of hindsight may not be as appropriate as first thought.

27. BOUD, KEOGH & WALKER [1985] have distinguished four elements which in their view contribute to the re-evaluation phase of the reflection process. These, they have termed, “*association, that is relating of new data to that which is already known; integration, which is seeking relationships among the data; validation to determine the authenticity of the ideas and feelings which have resulted; and appropriation, that is, making knowledge one’s own*”. In the following paragraphs, the ideas surrounding these processes are briefly discussed.

28. The first phase deals with the connection of new knowledge to that which already forms part of previous decision experience. The connection of knowledge and the linking of related conceptual elements becomes the foundation of *associated knowledge* and a possible pre-requisite of the learning process. This phase of reflection is considered by BOUD, KEOGH & WALKER [1985], to be essential in developing a clearer understanding of the problem-solution environment. They suggest that this clearer understanding will help the individual to identify those elements of the initial knowledge that are *no longer consistent* with the requirements of the current problem-solution environment. Those elements that are no longer consistent while need to updated or modified. However, connections may be brought together arbitrarily. All these new connections will have to be examined. It is at the integration phase, that the active *discrimination* between these connections will occur. The integration process seeks to identify any relationships that may exist through these connections and then use those relations

to develop some conclusions. BOUD, KEOGH & WALKER have termed this the *synthesis* of the integration phase, in which “*we seek insight, which is the basis for further reflective activity*” [BOUD, KEOGH & WALKER, 1985]. BOYD & FALES [1983] state that this “*new insight or changed perspective is analysed in terms of its operational feasibility*” and “*attempts are made to “figure out” how it will work in practice*”.

29. The next phase is the validation process. This activity attempts to determine the authenticity of those changed perspectives. For example, the individual could check the validity of the derived *insights* against some degree of *reality test* [BOUD, KEOGH & WALKER, 1985], in which “*we are testing for internal consistency between our new appreciations and our existing knowledge and beliefs, for consistency between those and parallel data from others and trying out our new perceptions in new situations*” [BOUD, KEOGH & WALKER, 1985]. This reality test may be governed by two *certainty principles*, namely *coverage* and *coherence* [PENNINGTON & HASTIE, 1993]. PENNINGTON & HASTIE [1993] define coverage as referring “*to the extent to which the story accounts for the evidence*”. For example, the coverage of the derived insights could be defined by the manner in which the insight supports the necessary evidence for and the possible evidence against acceptance. A high coverage implies that the insight is a dependable explanation, whereas a low coverage would suggest a lower overall confidence in the derived insights and consequently in the confidence in the derived decision path. PENNINGTON & HASTIE [1993] state that coherence “*also enters into its acceptability and the level of confidence given that the story is accepted*” and is defined by three attributes; “*consistency, plausibility and completeness*”. In this context an insight may be considered to be, (i) consistent if the insight does not contain contradictory explanations; (ii) plausible if the insight corresponds to the decision makers understanding of the external world and therefore does not contradict that understanding and; (iii) complete if the insight is able to account for all the identified relations. Therefore, the coherence of the insight represents the consistency of the explanation both with itself and the external world. The individual is checking the consistency of these insights in which the individual is comparing the derivation of the insights with their existing knowledge and understanding of the decision problem-solution environment. BOUD, KEOGH & WALKER [1985] have suggested that, if any contradictions appear, then the individual will attempt a reappraisal and on the basis of this reappraisal either carry on down this decision path or go back. Note, just because a new insight is not consistent with conventional wisdom does not imply the automatic rejection of that insight. The decision that may be produced from this new insight could be the most effective solution to the decision problem-solution relation.

30. The final process deals with the consolidation of the knowledge into the decision building process. It is at this stage that notions of reflective learning become dominant. As BOYD & FALES [1983] state, *“as a result of the internalization and acceptance of the changed perspective, the individual is faced with the challenge of relating his or her changed self to the past self, to other areas of his or her present life, and to future behaviour”*. BOUD, KEOGH & WALKER [1985] suggest that *“some learning can become so related to the self that it enters into our sense of identity and can have a considerable importance and become a significant force in our lives”*. They go on to say that *“significant feelings can come to be attached to this type of learning and any learning experience which touches this area can give rise to strong emotions that may need to be taken into account in future reflection”* [BOUD, KEOGH & WALKER, 1985]. For example, during a decision building process, new connections may emerge between previously isolated states. Any future decision experiences that are similar to the above decision building process may, as part of the connection process, end up with similar emotions attached. In this respect, the above processes may be influenced by the intent of the decision maker. For example, individuals may not want to reflect upon their previous decisions at the same analytical level. There may be some decisions that the decision maker may wish to forget. The ability of a reflective model to explain the interaction between the previous decision experience and the current decision building activity is a function of the reflective model being able to account for the intentions and objectives of the decision maker. Unfortunately, during the decision building process, the intentions and objectives of the decision maker may not remain static. It is expected, that they will change. This then adds a temporal dimension to the decision building process and the problem of incorporating time into the reflective model of decision making.

3.5 A REFLECTIVE PROCESS MODEL

31. It is now possible to define a reflective process model of decision making. This model will emphasis the importance of experience and the role that reflection plays in the decision building process. The core of this model could be defined as process model explanations of the problem-solution environment used to guide the retrieval and selection process. This model is defined by an experiential explanation, reflective and predictive view of decision making, in which, (i) explanations of the current problem-solution environment are compared with explanations of similar experience and; (ii) a process of reflection uses previous experiences to transform the current state to a desired end state.

32. In the context of defining a model of reflective decision making, it is hypothesized that the mechanism of reflection as governed by, *“returning to the*

experience, attending to feelings and re-evaluating the experience” [BOUD, KEOGH & WALKER, 1985] consists of two component processes. These processes may be viewed as the selection and retrieval process and the reflective and predictive process. It is suggested that the process of accessing previous decision experiences consists of three component sub-processes, (i) recognizing that salient aspects of the current problem-solution environment are the same as those in a stored problem-solution environment; (ii) remembering where the stored problem-solution environment can be found in the decision memory and; (iii) reviewing those salient aspects. It is felt that the individual having selected and retrieved relevant experiences, the individual will then begin to evaluate those experiences. Evaluation (or in the light of additional information, re-evaluation), will involve the, (i) possible modification of the initial decision path; (ii) re-examination of that decision building process as compared to its performance and the decision makers intent (which may be different from the original intent of the initial decision path) and; (iii) integration of any new decision path into the decision makers conceptual pattern of the current problem-solution relation. Contrary to the discussion above, the notion of *attending to feelings* has not been ignored, merely integrated into the selection, retrieval and re-evaluation, prediction stages. Since these processes are conditioned by the individual and include the subjective and objective elements of the decision experience, then the feelings or point-of-view of the individual will not be a separate entity, but a connection that links one activity to the other.

33. Therefore, rather than just making decisions and then forgetting the results of those decisions, an individual will treat those results as opportunities to learn more about their domain and the problems that arise in it. Consequently, the nature of reflection in the Reflective Process model views decision building as an activity that tests an individuals understanding of the external world. Decision building forms a reflective loop, in which the failures of past decisions lead the individual to learn more about what caused them. Consequently, the individual develops a better understanding of how to avoid them.

3.5.1. DEFINING THE PREMISE OF THE REFLECTIVE PROCESS MODEL

34. The proposed reflection-explanation model is assumed to follow three component processes. Firstly, there is the construction process that accounts for the transference of information from the explanation of the problem-solution environment to the reflection-explanation model. Secondly, a decision building process that accounts for the classification of this reflection-explanation model into a best-fitting category. It is suggested that this decision building process is a function of a problem identification stage, a selection stage and a modification stage.

For example, the most-relevant decision path is selected and then modified to suit the current situation. It must be remembered, that the term most-relevant (as used above), does not refer to most-relevant as defined by the requirements of the situation, but the most-relevant as defined by the individuals understanding of the situation. In the majority of cases the most-relevant as defined by the situation and the most-relevant as defined by the individual will be similar, however in some cases they will not. Lastly, a reflection process that monitors, (i) the transference of information between the problem-solution explanation and the reflection-explanation model; (ii) the interaction of the construction and decision building processes and; (iii) the performance of the selected decision path, when operating in the external world. This model can be summarized as follows.

- The decision process cannot retrieve and access a relevant decision experience unless it understands the current problem-solution environment. This understanding may be defined as a reflective-explanation of that environment. The process of defining a reflective-explanation of the problem-solution environment is composed of two processes. These are (i) problem identification and; (ii) selection. During the construction of this explanation salient events of the explanation are compared to aspects that have been shown to contribute to the failure of previous decision paths. In this respect the decision memory is organized as a predictive function using an index of negative aspects and negative interactions that have been shown in previous decision paths to develop into failure conditions. The decision memory will use this index to interrogate the explanation of the problem-solution environment and identify those aspects that have (in previous decision paths) a proneness to failure. Those aspects having a proneness to failure attached are classified as predictive and used by the decision process to select a relevant decision experience. This index may be looked upon as dynamic and constantly evolving memory.
- It is unlikely that a previous decision experience will be exactly similar to the current problem-solution environment. Therefore, it will be necessary to modify the previous decision path to fit the current decision problem. Modification is part of the reflection stage and is connected to the processes of (i) re-evaluation and acceptance and; (ii) integration and monitoring. Modification, attempts to compensate for those aspects of the current problem-solution environment that are different from the selected decision experience. At this point, the decision process can either accept the modified decision path and let the decision memory proceed to integration and monitoring phase or the decision process could send the modified decision path back to the problem identification phase to be re-examined.

- At the integration and monitoring phase the decision memory integrates the decision path into the decision memory by comparing the anticipated outcome of the modified decision path with the predicted requirements of the problem-solution environment. This may be looked upon as the learning phase of the decision process and can be seen to occur as a natural consequence of decision making. For example, during modification the accessed experience a new decision path is derived. When this new path is executed its performance is monitored. If the performance monitoring indicates that the new path is a success, then the new decision path is remembered. The decision path is part of the current experience and stored within the decision memory.
- However, if during the performance monitoring of the new decision path problems are found to exist, then those problems may be added to the index of those aspects that have a proneness to failure. A warning could be attached to those aspects, so that when they are identified in another decision path, the decision memory could be reminded that its understanding of the problem-solution environment (associated with that decision path) and hence the explanation derived from that understanding is inaccurate. If an attempt is made to repair those problems then the new explanation (derived from that repair) could be considered to be a modification of the knowledge found in the initial decision experience. Note, an explanation provides a means of defining the *usefulness* of a decision experience and since the explanation of the initial decision experience has been modified, then the *usefulness* of that decision experience has also been modified.

3.6 MAKING DECISIONS FROM EXPERIENCE

35. It is hypothesized that the proposed model will provide, (i) a means of organizing and retrieving experiences; (ii) a set of primary and secondary processes used in making decisions from these experiences and; (iii) a way of integrating learning with the decision process. This section will consider these claims carefully, looking at the ways in which retrieved events are used for decision making.

36. One of the underlying premises of the reflective memory is that experiences, are necessary in understanding and making decisions. It is accepted that these experiences are not the only form of information within a reflective memory. However, it is assumed that experience and the act of reflecting upon that experience are the generator of responses to a particular decision problem. Each experience is indexed by the interacting processes and emergent properties that make up the experience. Experiences stored in the reflective memory will include

the interacting processes that were defined at the time of storage and additional emergent properties that were derived during the elicitation of that experience. Any of those interacting processes and emergent properties are available for use as an index. Some of these interacting processes and emergent properties may have failure conditions attached. Failure conditions are used by the individual to identify particular problems with a retrieved experience.

37. Accessing previous experiences and the act of reflecting on these experiences are the primary processes in any reflective decision building activity. These processes are composed of secondary processes. It is hypothesized that the primary process of accessing consists of the secondary processes, problem identification and experiential selection and that modification, re-evaluation and acceptance, integration and monitoring are secondary processes of the primary process of reflection. The ability of the individual to access and then reflect upon those experiences, is defined by the ability of the individual to understand the current problem-solution environment. Individuals will only be reminded of previous situation, when they begin to understand the current situation. A complete understanding may be defined as being able to, (i) explain the current situation; (ii) identify the problems; (iii) select a relevant experience; (iv) modify the conceptual pattern that represents that experience; (v) re-evaluating that modification; (vi) use the modified conceptual pattern to make predictions; (vii) monitor the performance of those predictions (as compared to the role-requirements of the problem-solution environment) and; (viii) then integrating that modified conceptual pattern into the memory. These component sub-processes have similarities with SCHANK'S [1985] notions of *memory organisation packets*.

38. Since a reflective memory will change with each new experience, then reflection implies an evolution. This may help to explain why given two decision problems of a similar nature the individual may not select the same decision path twice. Experience may have taught the individual to act differently. The accumulation of experiences also implies an evolution that is both dynamic (time variant) and idiosyncratic (culturally variant). This may explain the influences of time and cultural identity on the ability of individuals to make decisions. Something that the rationale models of human decision making have not been able to do. This evolution may be defined as, (i) acquire new experiences; (ii) re-index those experiences; (iii) create new explanations from those experiences; (iv) discard inappropriate explanations; (v) use those explanations to modify those experiences; (vi) monitor those modifications and (vii) acquire new experiences from those modifications. This may be thought of as a reflective learning loop. As part of a reflective learning loop new experiences are acquired from new decisions. If new experiences are understood by an explanation, then those new explanations (when

contrasted and compared to previous explanations), can be indexed in the reflective memory by violations (as defined by that contrast and compare exercise). For example, when an explanation of a previous decision experience is accessed and re-evaluated it may be found to be inappropriate to the current problem-solution environment. The relevance of that recalled experience is re-analysed and re-indexed as defined by the individuals new understanding of it. (Note, this may also occur if the previous experience has been modified or if a previous decision experience is re-used.)

39. SCHANK [1985], has argued that when several similar experiences are met during the accessing stage, then individuals will extract commonalties from these similar experiences and thereby construct generalized memory packets (MOP's). It is accepted, that generalized experiences may exist, but it is suggested that specific experiences will also exist. For example, the structure of the decision path (whether buying a book or buying a motorcycle), could appear to be *instinctive, organised and highly practised* [RASMUSSEN, 1983]. Consequently, regular exposure develops a reflex skill. However, at another level, the structure may be a function of failure or success. With success being defined by the usefulness of using a decision path to buy a book, when buying a motorcycle. In this situation, an explanation is used by the individual to search their memory; select a previous decision experience and then modify it to fit the observed problem-solution environment. The individual begins the construction of the new decision path by accessing a previous decision path. However, if the individual is unsure of the current decision problem domain, then accessing a previous experience may not be particularly helpful in predicting potential problems. In this situation the modification of experiences may be guided by previous modifications under similar problem-solution domains. If the modified decision path begins to fall short of the predicted requirements of the problem-solution environment, then the chosen modification strategy may be refined. As a result (and in a manner similar to the memory organisation packets of SCHANK [1985]), the individual may develop a set of modification strategies linked to a particular group of decision problems. A product of this construction is the derivation of explanations. The derivation of these explanations may help the individual to uncover misconceptions and misunderstandings, that may exist in their view of the problem and the external environment in which it operates.

40. The ability of the model to explain the interaction between the previous decision experience and the current decisions building activity is a function of the ability of the model to account for the intentions and objectives of the decision maker and problem-solution environment. This forms part of the construction of an explanation and will discussed in Chapter 4.

3.7 CONCLUSION

- A reflection-explanation model of decision making has been presented. This model may be defined as, (i) accessing previous decision experiences; (ii) explaining those experiences; (iii) re-evaluating those experiences; (iv) envisaging the possible consequences of pursuing various courses of action; (v) evaluating the merits of those various courses of action and then; (vi) monitoring the performance of the selected decision.
- Reflection could be considered to be part of a learning loop, in which the individual uses their experiential memory to identify pivotal events of the problem-solution environment.
- These events could be used to select a set of alternative decision paths (as defined by the experiential memory of the individual), from which a response will be chosen. Note, these alternative decision paths may simply be the re-use of stored memories, or they may involve the modification of those stored memories.
- After selecting a decision path, the individual will then monitor that decision and compare the potentiality of the chosen decision with the actuality of that decision in the external world. This will contribute to the confidence that is assigned to the appropriateness of the selected decision.
- However, a knowledge structure for acquiring and modelling those experiences as well as a vocabulary for describing those experiences is required. This will be discussed in Chapter 4 and Chapter 5.
- These hypotheses are not yet in a testable form. A system will be presented in Chapter 6 and Chapter 7 that has been designed to be testable. However, the dependability of these ideas will not be known empirically until that work is completed.

4. MODELLING REFLECTIVE DECISION MAKING

4.1 OBJECTIVES

- To explore the concept of a process model as a formal representation of the understanding by the individual of an external object.
- To explain how a *grounded theory* methodology can be used to *tease out* that understanding.
- To discuss how such a methodology can help build Process Model explanations of previous experiences.

4.2 INTRODUCTION

1. In Chapter 3 the notion of reflecting upon previous experiences in decision making was introduced and a model of reflective decision making based on a reflective learning loop was proposed. In this Chapter a knowledge structure for acquiring and modelling those experiences is introduced. The need for a vocabulary that is able to describe those structures will also be considered. It is proposed, that such a vocabulary could be based on a process model algorithm [BLOCKLEY, 1997].

2. The ability of an individual to understand a previous decision problem will require the individual to compare and understand the differences between types of decision objectives, decision paths and decision outcomes. These may be classified as, (i) the different decision objectives; (ii) the different types of decision objectives; (iii) the relationship between the different objectives; (iv) the different decision paths used to satisfy these objectives and objective types and; (v) the interaction between these different decision paths and those objectives. The representation of the decision building process requires a methodology that can acquire that knowledge and the organizational structure to represent that knowledge.

3. In section 4.3, the notion that a vocabulary of processes (as defined by the descriptive, explanatory and predictive processes of the decision path) may act as a formal representation of that decision is introduced. In section 4.4, the elicitation of those descriptive, explanatory and predictive processes is addressed. It is suggested that a *grounded* methodology may be used to *tease out* those processes and a Process Model explanation may represent those processes. Consideration is given to the structure of the Process Model explanation as defined by a Process Model algorithm. This algorithm may be looked upon as a vocabulary for describing and storing experiences within a Process Model explanation. It is hypothesized that the Process Model explanation will allow the Reflective Process Memory (RPM) to infer implicit events on the basis of previously encountered structurally similar events.

4. The Process Model explanation (as defined by its grounding in data and using a Process Model algorithm) may be used to translate a *messy* external situation into a structured internal representation. The objective of such a methodology is the building of a machine-based Reflective Process Memory that can infer implicit events on the basis of previously encountered experiences. The notion of inferring events on the basis of previous particular experiences is known as induction. In section 4.5, the nature of induction and the implications of using an inductive methodology for the Reflective Process Memory are discussed.

4.3 THE NATURE OF PROCESS MODELLING.

5. In this section the notion of knowledge will be examined. This examination will consider how knowledge can be structured as a series of process descriptions and will explore the rationale and assumptions behind this description.

6. Knowledge and the psychology of knowing something has often been defined as the difference between the *declarative* and the *procedural* components of knowledge [RICH, 1991; RUMELHART & NORMAN, 1985]. Declarative knowledge is defined as *knowing-that* [WINOGRAD, 1975] and represents knowledge of some object, situation or concept. RUMELHART & NORMAN [1985] suggest that this declarative knowledge may help an individual describe the object, situation or concept. Declarative knowledge may be looked upon as descriptors of state variables, whereas procedural knowledge is defined by how individuals *apply* their declarative knowledge. Procedural knowledge may be classified as *knowing-how* [WINOGRAD, 1975] and represents the transformation activities of *knowing-that*.

7. RUMELHART & NORMAN [1985] have suggested that the difference between declarative and procedural components of knowledge may be nothing more than a

difference in *accessibility*. For example, in the case of declarative knowledge, the structure allows for the direct examination and manipulation of the knowledge, while in the case of procedural knowledge the structure does not. The procedural knowledge structure must be executed and it is only then, that the results of that execution can be examined. It is proposed, that the distinction between declarative and procedural components may be classified as a distinction between *explicit* (clear and unambiguous) knowledge structures and *implicit* (not directly stated) knowledge structures. Therefore, any distinction between, “*what is declarative and what is procedural information is context dependent*” [RUMELHART & NORMAN, 1985] and that “*any realistic information processing system has several levels of processing and interpretations, and what is procedural at one level of interpretations is most likely declarative at a different level.*” [RUMELHART & NORMAN, 1985]

8. This multi-layered or hierarchical view of knowledge suggests that any distinctions between declarative and procedural components of knowledge are meaningless. In the following discussion it is argued that this distinction has caused much confusion. It is asserted that knowledge can be represented in terms of active processes, of which data is one set of attributes.

4.3.1 THEORETICAL BASES FOR KNOWLEDGE

9. Knowledge and the problem of representing knowledge can be divided into two camps. These camps may be classified as *declarative* and *procedural* [RICH, 1991; RUMELHART & NORMAN, 1985]. This classification may be looked upon as a “*philosophical distinction between ‘knowing that’ and ‘knowing how’.*” [WINOGRAD, 1975]. *Knowing-that* knowledge may be looked upon as data or statement driven whereas *knowing-how* knowledge is represented as procedural or programme driven. For example, consider the concept [football]. A [football] can be completely characterized by a set of defined axioms. These axioms represent the *knowing-that* of the concept [football]. Now consider, the *knowing-how* for the concept [football]. This may be defined as the procedures for using those axioms. *Knowing-how* procedures are necessary for the successful understanding of the *knowing-that* of the concept [football]. Procedures are operational actions used to understand axioms. Therefore, the *knowing-how* procedures for the concept [kicking-a-football] are operational actions used by the individual to understand the *knowing-that* knowledge of the concept [kicking-a-football]. The *knowing-how* procedures for the concept [playing-football] are operational actions used by the individual to understand the *knowing-that* knowledge of the concept [playing-football]. In each statement the individuals understanding of the concept [football] will be different. This understanding depends upon the role-requirements that are assigned to the

concept [*football*] and the way in which the role-requirements interact with environment. In the first statement the role given to the concept [*football*] may be defined as [*being a football; a large round inflated ball*]. In the second statement the role given to the concept [*football*] may be defined as [*being a game; a contest played according to rules*].

10. Clearly, for an individual to distinguish between a [*football*] as [*being an inflated ball*] or [*being a competition*], then the concept [*football*] needs more than knowing-how and knowing-that. This requires the individual to know why such a role is needed. It is hypothesized that *knowing-why* is a process explanation of when it is appropriate for a concept [*football*] to be the process [*being an inflated ball*] and when it is appropriate for it to be the process [*being a competition*]. A process explanation views *knowing-why* knowledge as hierarchical knowledge. This explanation (governed by its assigned role), includes the *knowing-how* procedures that access, interpret and evaluate the *knowing-that* knowledge of the process [*football*].

11. The notion of *knowing-why* process explanations using encapsulated *knowing-how* procedures to operate on *knowing-that* data offers some advantages. For example, letting data be a description of the state of the process, allows the individual to access a process as data and compare it to the process requirements. Consider a process explanation of [*kicking-a-football*]. The individual could access the process as data and compare the data description of the process [*football*] with the role requirements of the process explanation [*kicking-a-football*] as defined by the individual. The data describes the state of a process and since this description can change through time, then data can be viewed as a process explanation. Therefore, having the data as a process explanation allows the individual to follow the process and predict the outcome of the process. The individual having assigned the role [*being an inflated ball*] to the sub-process [*football*] in the process [*kicking-a-football*] will check that the object called a [*football*] is [*an inflated ball*]. During the process [*kicking-a-football*] the data description of the acceleration and velocity of the process [*football*] will change. This change allows the individual to predict the trajectory of the process [*football*] and estimated where the process [*football*] will land.

4.3.2 RATIONALE FOR STUDYING PROCESS KNOWLEDGE

12. One of the basic premises of the theory of the Reflective Process Memory is that experiential knowledge is organized hierarchically as interconnected processes. This process knowledge could be arranged in a series of *process models* of connected

experiences. These *process model networks* describe what the decision builder knows and forms the underlying structure of the *reflective learning loop*. This structure may be composed of two stages, (i) the *reflective-explanation* stage (during the accessing and re-evaluation of the process knowledge of the decision builder) and; (ii) the *reflective-learning* stage (during the modification and comparison of that knowledge). A process model network describes process knowledge and as such provides the vocabulary behind the representational assumptions made about process knowledge. The following will examine the rationale behind process knowledge.

13. Firstly, it is asserted here as a basic hypothesis that processes underlie all knowledge. Meaning and hence understanding will not exist until a hierarchically process flow is established. For example, consider the process [*playing-football*]. It is the representation of this process by a knowing-why explanation that gives the concept [*playing-football*] its meaning. For example, at one level the sub-process [*football*] may have the role [*a large inflated ball*] in the process [*playing-football*]. At the next level the process [*football*] can be represented as a set of data states such as [*circumference*], [*diameter*] and [*weight*] in the process [*being-a-football*]. Note, that these state descriptions of a process attribute are not static. For example, the process [*diameter*] may change. However, while the process [*football*] can be represented as a state description, it is the knowing-why process explanation of when it is appropriate for the process [*football*] to be the process [*being-an-inflated-ball*] that gives the process [*football*] its meaning. A meaning that an individual will use to understanding how it relates to other processes ([*football-pitch*], [*football-players*]), that are connected, although not directly. Therefore, while each process may have a state description, it is the knowing-why description, that defines its interaction to other processes. An interaction governed by the role one process plays in another process.

14. Secondly, process knowledge is considered to be an essential part of the accessing and re-evaluation components of reflection. In Chapter 1, the idea of the individual understanding an experiential event depends upon the individual using conceptual patterns was introduced. These patterns represent the individuals understanding of a particular experience. This model, as described in Chapter 1 explains how understanding and hence meaning is developed from the process connectivity that make up these conceptual patterns. An experience represented as a conceptual process structure is more easily accessed and hence re-evaluated than lists alone. (Note, data which at best may be represented as structured list does not represent knowledge, it is the process explanation of the list that generates knowledge. For example, how the list was produced, how the list will be used, etc.) In the paragraph above, the notion of process connectivity being dependent upon

the role that one process plays in another was introduced. The greater the role then the closer these interactions. Consequently, having accessed the role that the process [*football*] plays in the process [*playing-football*], then the easier it is to access and re-evaluate other related process. A comprehensive process structure defined by those process connections will facilitate the accessibility and re-evaluation of stored experiences.

15. Lastly, individuals learn by assimilating experiences represented as conceptual process structures. In Chapter 3, the idea that individuals learn by, (i) accessing previous experiences; (ii) modifying those experiences to suit the current situation; (iii) re-evaluating those experiences; (iv) monitoring the modification and; (v) thereby comparing the potentiality of the predicted performance of the modified experience with the actuality of that modification was introduced. Learning is, in essence, the monitoring of new conceptual process structures built from old experiences. The development of a connectivity between previous experiences and new experiences will help the newer conceptual process structures to be integrated into the overall process knowledge structure. In this context learning may be viewed as the construction of new process knowledge, the development of new connections and the integration of this new knowledge within existing process knowledge.

4.3.3 ASSUMPTIONS & LIMITATIONS OF PROCESS KNOWLEDGE

16. RASMUSSEN [1983]; DREYFUS & DREYFUS [1986]; REASON [1990] have argued that human reasoning relies on the individual being able to recognize that one event has similarities with other previous events. Therefore, if those previous events had successful outcomes, then the individual will respond in a similar manner. DREYFUS & DREYFUS [1986] have suggested that this can be seen quite clearly in the difference between competent and expert chess players. They argue that this distinction between expertise and competence is dependent upon the ability of the individual to recognize how a current problem set resembles previous problem sets. The notions of identification and comparison represent a central premise of the approach undertaken in this study.

17. However, theories that attempt to model an account of this pattern matching methodology are constrained by data. In this respect, reasoning is modelled as a data driven rule-based methodology. This is because the majority of the reasoning models have been developed from work previously done in mathematical logic and logic is rule based. However logic rules have difficulty dealing with uncertainty. The representation of decision making in many rule-

based expert systems (for example, MYCIN [SHORTLIFFE, 1985]) either do so in a closed world (in which everything apart from the solution is known) or have *weightings* attached to certain attributes of the decision problem. As KRAUSE & CLARK state, “*uncertainty values are associated with the rules and combined using simple syntactic principles as the rules are fired.*” [KRAUSE & CLARK, 1993]. That is, “*the way in which the values are combined in a formula just depends on the structure of the formula and the uncertainty values of its subformula.*” [KRAUSE & CLARK, 1993]

18. It has been hypothesized that this activity could be better performed by a process driven reflectionist methodology. This methodology is not data driven and hence rule based. Rather it is process driven, in which data and rules are merely a series of separate processes within a whole set of processes, which in turn make-up the attributes of the object or event. A process driven reflectionist methodology is able to classify an input with a stored experience, without accessing a stipulated but separate rule. This is because, firstly data (or state descriptors) and rules (or process controls and constraints) are already included within the process structure. Secondly, evidence (as defined by state descriptors and process controls & constraints) can assign a degree of belief. Thereby indicating whether an object belongs, or does not belong to a category. These state descriptors and process controls & constraints are not static. Evidence as defined by those descriptors, controls and constraints will vary and so will the assigned degrees of belief.

19. Since a logic-like representation has difficulty in dealing with uncertainty, it is hypothesized that individuals represent and hence reason about uncertainty using a different methodology. It is argued that processes represent experiences and that these processes are indexed by the relations that connect those processes. This approach views the memory in dynamic terms, as a function of the content and context of the social, environmental and cultural interactions of the individual and the constraints of the problem-solution relation. This is at odds with the conventional data driven view of memory, in which data is a static ordering of information and meaning is a function of the logic rules operating on that data.

4.3.4 STRUCTURAL PROCESS KNOWLEDGE AS A BASIS FOR DECISION MEMORY

20. SCHANK [1985], argues that to account for the ability of human subjects to learn from experiences requires a defined memory vocabulary. He proposes that this vocabulary must exist as a *memory organization packet*. The *memory organization packet* provides the means by which the human subject is able to infer implicit events on the basis of previously encountered structural similar events. In

a machine environment, it is hypothesized that *structural process knowledge* as represented by a Process Model explanation (PMX), defined by a Process Model algorithm [BLOCKLEY, 1997] and *grounded* in the testimony of experts may act as a process vocabulary. This PMX describes and explains previously encountered events, which are stored within the Reflective Process Memory (RPM). The RPM processes a new PMX by taking *aspects* of the new PMX that relate to an old PMX. These *aspects* may be defined as static *attributes* or they may be defined as dynamic *connections*. It then interrogates those *aspects* with reference to a series of *indices*. These indices could have *conditions* attached and if recognized in the new PMX could be used to remind the RPM of any consequences that may arise from those conditions. This interrogation will enable the RPM to infer implicit events when reminded of those events by similar Process Model explanations. This structured process knowledge is a representation of the understanding of a process by an individual. It will include the current and desired states, initiating states, transforming states, scenario states and consequence states as well as the various roles and other attributes. The description will also include reference to any sub-processes on which the process depends.

21. The advantages of using a qualitative structural process knowledge with quantitative state transformations of the state variables are (i) individuals appear to reason in a qualitative process fashion and since the processes are patterns rather than data representations of previous decision paths then the matching should improve the assimilation of information; (ii) the process models of the decision path are to be built up from a deep knowledge of actions teased out using *grounded theory* [PIDGEON, TURNER & BLOCKLEY, 1991] and thus they contain the underlying physical and data sub-processes ready for presentation at a higher level; (iii) since the process representation is constructed from sub-processes, then changes are localized and modifications to previous decision paths that now appear inappropriate can be implemented more easily than a rule based system; (iv) since the decision path is represented as a pattern, the causes of changes or failures can be tracked and consequently the initiating event sequence that caused a particular failure can be identified and isolated; (v) the process models will work with sparse quantitative data.

22. To summarize, structured process knowledge is a theoretical construct used during the reflection phase of a decision building process. It is a useful metaphor for describing the means by which individuals construct and store knowledge. The following sections of this Chapter are divided into (i) the use of grounded theory to elicit structured process knowledge; (ii) the implications of using Process Model explanations to infer implicit events on the basis of previous experiences. It will be argued in the remainder of this Chapter and in Chapter 5, that the use of (i)

grounded theory in the elicitation of knowledge and (ii) the process algorithm to represent that knowledge as a reflectionists type Process Model explanation can describe the states of the decision problem. In this respect a process representation of case histories may be looked upon as an appropriate methodology for the investigation of decision failures. Consequently, the inferential outcome of such a methodology represents a plausible explanation of the current situation.

4.4 THE STRUCTURE OF THE PROCESS MODEL EXPLANATION

23. The structure of the RPM must provide an appropriate representation of the behaviour of a decision path. This appropriateness may be defined by a description of the decision processes and an explanation of how those processes interact. A situation analysis is a formal catalogue of process descriptions and process interactions. Meaning and hence understanding of a decision path may be defined by the situation analysis of the processes and interactions as they correspond to the content and context of the decision problem. PIDGEON, TURNER & BLOCKLEY [1991] have argued that this type of knowledge acquisition “*is similar to that of the social scientist analyzing qualitative data*”. This implies that a range of methods originally developed by social scientists for the analysis of unstructured and semi-structured qualitative material will be of assistance to the knowledge engineer. It is proposed that one such method, namely *grounded theory* [PIDGEON, TURNER & BLOCKLEY, 1991; STRAUSS & CORBIN, 1994; PIDGEON, 1996; PIDGEON & HENWOOD; 1996] is useful for tackling this problem directly. A close and systematic analysis will result in the generation of an array of concepts, categories, their interacting processes and emergent properties. These provide the building blocks of the RPM.

4.4.1 THE ELICITATION OF KNOWLEDGE

24. It has been proposed in previous sections of this chapter that process driven structural knowledge is a useful way to model the pattern recognition activities of human cognition. Therefore, a methodology is required for the elicitation of the knowledge of the individual and the representation of those underlying processes. JONASSEN, BEISSNER & YACCI state that, “*knowledge of interrelationships is most frequently and effectively elicited using word association or similarity rating tasks. The interrelatedness of the elicited knowledge is then evaluated using advanced statistical techniques, like principle components or cluster analysis or multidimensional scaling to discover the structural framework underlying the set of concepts*” [JONASSEN, BEISSNER & YACCI, 1993].

25. The rationale behind these techniques stem from theories of long term memory. For example, concepts that are connected within the long term memory may be defined by their semantic proximity. These theories assume that concepts have a degree of *stored closeness* dependent upon the strength of that relationship. Consequently, semantic proximity theories assume that concepts (stored as associations within the long term memory) are therefore recalled from the memory as associations. Once one concept is recalled then others closely follow. These techniques assume that the transformation of the concept data into semantic distances can be represented by a dimensional geometric space. Unfortunately, each data point that is generated by these techniques will often be static. Concepts can only be included in one category (or data point) and one category only. However, some concepts may be in several categories. For example, [football] can be both a [sport] and a [profession]. These techniques are limited to categorizing as defined by observable similarities. This is rather restrictive, in that a fuller, richer and complete understanding of the cognitive structure of the individual and the meaning that the individual assigns to a particular concept is missing.

26. Conventional knowledge elicitation techniques (that are anchored in data matching techniques and defined by a grid-like or dimensional metric) such as *word association*, *similarity ratings*, *card sorts* [JONASSEN, BEISSNER & YACCI, 1993] are constrained by the representational difficulties associated with dimensional indices. Other multidimensional scaling techniques requiring “*a matrix of distance estimates for all pairs of items in a set to be scaled*” [COOKE & McDONALD, 1987] and techniques such as *protocol analysis* [ERICSSON & SIMON, 1984], *repertory grids* [GAINES & SHAW, 1980; SHAW & GAINES, 1987], *psychological scaling techniques* [COOKE & McDONALD, 1987] will suffer from similar difficulties. These conventional methodologies rely on observed similarities between concepts being represented as a similarity metric between their respective points. Conventional knowledge elicitation techniques consider concepts to be individual and independent and do not consider the possibility of *contextual interactions* within concepts and between the concept and its social and cultural environment. These techniques can tell us nothing about the contextual interactions of the concept and hence nothing about which aspects of the concept that may be pivotal.

4.4.2 UNSTRUCTURED DATA: A GROUNDED APPROACH

27. Knowledge elicitation may be better described as an explanation. An assessment of meaning may be grounded in a theory which individuals construct to explain why [A] IS-A [B], why [A] IS-NOT-A [B], why [B]?, did [A] cause [B]? and what's

wrong with [C]?, etc. STRAUSS & CORBIN state that such a theory could be viewed as “*plausible relationships proposed among concepts and sets of concepts*” [STRAUSS & CORBIN, 1994]. They also suggest that a grounded methodology could be used to tease-out those *relationships*, along with *patterns of action and interaction* from unstructured data. PIDGEON [1996]; PIDGEON & HENWOOD [1996]; PIDGEON, TURNER & BLOCKLEY [1991] have argued that a grounded theory methodology can generate theoretical explanations that are *conceptually dense* and expressed in terms of emergent properties. These explanations may be viewed as definitions of content and contextual interactions.

28. However the use of a grounded methodology in the generation of these explanations relies on interviewing domain experts. Interview data (which is the primary means of acquiring information from a domain expert [PIDGEON, 1996]) is often classified as unstructured or retrospective data. PIDGEON, TURNER & BLOCKLEY state that dealing with such data “*raises significant methodological and theoretical issues associated with the need to analyse systematically such qualitative data*” [PIDGEON, TURNER & BLOCKLEY, 1991]. For example, unstructured data can be long and complex and, if completely unstructured it is only after the analysis of such data that the completeness of the information or lack of it, is ascertained. Such expert testimony will also consist of unspecified and unsubstantiated assumptions, background data and industry specific knowledge. In addition, individuals when accessing past experiences may (if the individual has completed a series of similar projects) access a similar experience and a confusion of experiences may result. ERICSSON & SIMON, [1993] suggest that accessed experiences will often contain *redundant* information and that this information is used by the individual to validate the accessed experience. Secondly, information acquired subsequently may be associated with information generated at the specific time of the experience. For example, individuals tend to *recall* information they cannot remember, but think they *must* have used [ERICSSON & SIMON, 1993]. In the following section, a discussion on the philosophical issues that underlie the use of a grounded theory methodology and the use of that methodology in knowledge elicitation will address those concerns. The practicalities of the methodology will be discussed in Chapter 5 and an example will attempt to demonstrate the methodology.

4.4.3. THE USE OF GROUNDED THEORY IN KNOWLEDGE ELICITATION

29. As STRAUSS & CORBIN state, “*grounded theory is a general methodology for developing theory that is grounded in data systematically gathered and analysed*” [STRAUSS & CORBIN, 1994]. This requires a rigorous examination and detailed

analysis of data from which *rich conceptual models* (that describe and are therefore *grounded* in that data) are developed. It is hoped that use of the term data in this context will not confuse. In previous sections it has been argued that data is merely one on many process attributes. In this context the term data may be looked upon as the textual representation of open world information. This data may be expressed as a set of symbols that are points in the state space of the process. PIDGEON, TURNER & BLOCKLEY [1991] suggest that “*having obtained interview data the knowledge engineer is then faced with the difficult task of analysing what is initially relatively unstructured and complex material.*” The use of grounded theory attempts to turn that unstructured data into a process map of the experts knowledge of a particular event, decision or domain. This analysis is not simply a passive one of transcription and description, but more active in which the individual who is conducting the exercise takes control. Therefore, the individual thereby creates a structure from no structure, identifying and keeping what is relevant and irrelevant, while at the same time representing the inherent complexities within the data. This requires the individual to be rigorous and systematic and to be able to generate a *criterion of relevance*. It could be said that all knowledge elicitation methodologies are systematic and rigorous. However, the advantage of grounded theory requires the individual not to be a passive spectator, but an active participant within the activity.

30. PIDGEON, TURNER & BLOCKLEY [1991] have suggested that the components of unstructured interview data have similarities with problems associated with the *qualitative nature* of data from the social sciences. They argue, that (i) since human *behaviour, understanding and expertise are context driven*, then aspects of acquiring domain knowledge will be context driven and hence domain specific; (ii) any model that attempts to capture the appropriate contextual complexity is dependent upon the appropriate identification of the event sequences that characterize the problem domain; (iii) expertise incorporates strong *tacit components*. In that experts have difficulty in describing their expertise in a way that is universally understood and “*terms, symbols and ideas are normally left unspecified*” in the belief that other experts have similar implicit assumptions and levels of understanding [PIDGEON, TURNER & BLOCKLEY, 1991]. Grounded theory attempts to overcome these difficulties by an emphasis on “*the creative and demanding task of deriving and checking out working hypotheses from the available data, rather than utilising the data to test hypotheses generated by a specific prior theory.*” [PIDGEON, TURNER & BLOCKLEY, 1991].

31. Thus a grounded analysis will help to highlight the underlying aspects of the decision and thereby generate a more appropriate representation of the decision path constructed by an expert. As mentioned by PIDGEON [1996]; PIDGEON &

HENWOOD [1996] and PIDGEON, TURNER & BLOCKLEY [1991], any theoretical descriptions of the decision path will “*emerge from and hence be firmly grounded in the available data*” [PIDGEON, TURNER & BLOCKLEY, 1991]. These emergent properties will form part of the developing theories (or explanations) and models that identify the event sequences of a particular solution, while also reflecting the rational behind the experts decision.

32. The successful use of grounded theory relies on the knowledge engineer acknowledging various steps that, “*guide the researcher along a path from unstructured materials, to the generation of descriptive codes, on to more developed conceptual understanding or links, and finally to wider theoretical interpretations*” [PIDGEON & HENWOOD, 1996]. Relevant expertise can only be acquired from domain experts. Consequently, the knowledge engineer will have to engage, “*them as active participants, rather than as mere subjects of the research*” [PIDGEON, TURNER & BLOCKLEY, 1991]. They go on to state, that the expert’s “*individual qualities and contributions therefore need to be acknowledged by the researcher, and taken into account in the analysis of the information collected and in the formulation of theoretical statements about behaviour*” [PIDGEON, TURNER & BLOCKLEY, 1991].

33. STRAUSS & CORBIN [1994] believe that this methodology could provide a *rich* set of process descriptives. They argue that grounded theory is concerned with, “*discovering process - not necessarily in the sense of stages or phases, but of reciprocal changes in patterns of action / interaction and in relationships with changes of conditions either internal or external to the process itself*” [STRAUSS & CORBIN, 1994]. The methodology concentrates on the systematic analysis of data and the development of an explanation. The theoretical conceptualization of that data represents the process patterns of the action and interaction of the problem-solution environment. But what does the explanation represent? PIDGEON states that the explanation consists of, “*local interactions and meanings as related to the social context in which they actually occur*” [PIDGEON, 1996]. PIDGEON, TURNER & BLOCKLEY argue that the explanation is composed of, “*theoretical accounts of a problem domain*” [PIDGEON, TURNER & BLOCKLEY, 1991]. While PIDGEON & HENWOOD state that the explanation will result in, “*the generation of an array of concepts, categories and theoretical observations, which provide the building blocks for subsequent theorising*” [PIDGEON & HENWOOD, 1996]. In this respect a process model explanation could be said to consist of contextual driven *interactions* and *meanings* and represents a *theoretical* description of the *problem domain*. This may viewed as conceptual knowledge of the external world, (i) that the individual uses to reason with and about that world and; (ii) the means by which the individual understands the external world and the way in which individuals assign a meaning to that world. Grounded theory is an attempt by social scientists to analysis

unstructured data and develop from that data an explanation that is conceptual rich enough to give meaning to that data.

34. These explanations (or as described by STRAUSS & CORBIN [1994] these *patterns of action and interaction*), are concerned with processes or more precisely the action and interaction of these processes. These processes could be *actors* [STRAUSS & CORBIN, 1994], or *players and roles* [BLOCKLEY, 1997]. The identification of these processes may be classified as a *conceptualization* of the actions and interactions of an event as constrained by the conditions that define that event [STRAUSS & CORBIN, 1994]. Furthermore, in a strictly limited sense, if the explanation is able to specify the conditions under which a particular event will occur then the theory could claim *predictability*. It may be looked upon as a causal theory of processes, which if matched to other causal theories may be able *anticipate* a similar outcome. For as STRAUSS & CORBIN state, “*if elsewhere approximately similar conditions obtain, then approximately similar consequences should occur*” [STRAUSS & CORBIN, 1994]. This may seem unnecessarily simplistic, but it must be remembered that if emergent concepts and categories *fit* the data, then the explanation may provide a recognizable causal description of the events. However, these descriptive events must be *teased* from the data and not imposed by the knowledge engineer conducting the elicitation exercise. If they are developed using a grounded methodology, then a generated causal explanation will represent “*systematic statements of plausible relationships*” [STRAUSS & CORBIN, 1994].

35. However, grounded theory can very easily become a type of *content analysis* and content analysis has very different objectives to that of the grounded theory analysis. Content analysis concentrates on, “*the criteria of reliability and validity and the counting of instances within a pre-defined set of mutually exclusive and jointly exhaustive categories*” [PIDGEON, 1996]. PIDGEON [1996]; PIDGEON & HENWOOD [1996] have defined two *fundamental analytical commitments*, namely *constant comparison* and *theoretical sampling* that “*clearly differentiate grounded theory from traditional content analysis*” [PIDGEON, 1996]. The constant comparison techniques may be looked upon as a *principal analytical task* [PIDGEON, 1996], in which the knowledge engineer is in a state of flux and is constantly comparing data elements. PIDGEON classifies these elements as “*basic data instances, cases emergent categories and theoretical propositions*” [PIDGEON, 1996]. It is the contention of this Chapter that such elements are processes. Consequently, any emergent event sequences and the theoretical propositions that connect them are simply a sequence of processes that make up the particular situation in question. PIDGEON [1996], views theoretical sampling as the *sampling of new cases* defined by the requirements and results of the proceeding analysis. He suggests that in some situations, “*negative case analysis, where the researcher explores cases that do not*

appear to fit an emerging conceptual system” may prove beneficial. Especially if *“it serves to challenge initial assumptions and categories”* [PIDGEON, 1996].

36. However, a grounded analysis using constant comparison and theoretical sampling is a, *“highly interactive and iterative process in which the traditional distinction between the data collection phase and the data analysis phase of a project often breaks down”* [PIDGEON, 1996]. Therefore, while a grounded theory approach may be a process of interpretation, it is also a process in which the knowledge engineer and the expert are connected. As PIDGEON, TURNER & BLOCKLEY [1991] state *“the naive empiricist notion that scientific enquiry is merely a matter of collecting and transcribing messages about the material world being studied has now almost receded from view. It is widely acknowledged that, in both natural and social science, the investigator and the investigated display an interdependence”*. In which the knowledge engineer attempts to develop appropriate models as a process of interpreting the problem-solution description as supplied by the expert. Interpretation is not only limited to a qualitative grounded theory analysis, however grounded theory highlights the role of the knowledge engineer as being central to the whole process. A role that is not simply one of passive process enquiry, but one in which their *“interpretation of the experts language”* is critical [PIDGEON, TURNER & BLOCKLEY, 1991]. A role in which their creative skills in labelling concepts, creating connections and organizing the data are actively involved in teasing-out the underlying theory or explanation. PIDGEON TURNER & BLOCKLEY have stated that such skills might include, *“intelligence, sensitivity to the sources as well as the context of the data, creativity, thoroughness, stamina and perhaps above all a tolerance of ambiguity and disorder during the early stages of the analysis”* [PIDGEON, TURNER & BLOCKLEY, 1991]. These skills do not come easily. The quality of the explanation is dependent upon the analysis having a measure of *faithfulness* to the problem-solution domain. Consequently, those skills must be developed, practised and refined. A *goodness of fit* between the model and the expert testimony is an essential property of the grounded theory methodology. If this goodness of fit is maintained then the model derived from the analysis will not only reflect this faithfulness, but will also highlight any ambiguities and inconsistencies that can creep into expert testimony.

37. While the methodology requires rigour, this rigour also provides a means of documenting the progress of the analysis. The accountability and *traceability* of concept generation, process generation, the generation of relations that connect them and indeed the generation of the process maps that represent them, readily exists by simply checking through the documentation. This has proved invaluable to the author and can be seen in Appendices A and B.

38. To conclude this section, in other knowledge elicitation exercises the results of the analysis are expressed in a dimensional similarity metric. However, a data analysis using grounded theory will result in expressions of emergent properties (complete with definitions of content and contextual interactions) connecting concepts with process flow-maps (graphical representations) of the events. It is hypothesized that when these are combined with a process algorithm they will form a process model explanation. This process explanation can be used for describing the processes and the interactions between those processes and hence explain the process knowledge that underlies the textual description of the object, event or situation. This process map may be a powerful methodology for representing, accessing, re-evaluating and monitoring specific events or a sequence of events (as defined by grounded theory) that contributed to a particular consequence. This methodology may form part of a Reflective Process Memory. It is hypothesized that the system may be able to recognize patterns of events based on the processes and process interactions that may exist between them. This could be represented in a structured process hierarchy.

4.5 INFERRING IMPLICIT EVENTS

39. In previous Chapters it has been argued that the ability of human subjects to represent and learn from experiences requires a defined memory structure. A RPM that explains those open world experiences will also require a defined memory structure. In section 4.3, it was hypothesized that this memory structure must exist as a PMX. In section 4.4, the notion that a model of the PMX may be defined by a grounded theory analysis of the object, event or decision path was considered. It was suggested that the idea of process models of theoretical explanations emerging from and hence grounded in data may prove advantageous. Such a model may be able to achieve inferential operations in which implicit events are defined on the basis of stored case-histories. In this respect, the PMX provides the means by which the RPM is able to infer implicit events on the basis of the relevance of previously encountered similar processes. A descriptive methodology will be presented in Chapter 5, in this section the underlying philosophical issues surrounding the structure of the PMX will be discussed.

40. POPPER [1972] has shown that the inference of implicit events and the development of generalized rules from observations to be *logically false*. Just because it *always has been* is no justification for assuming that it will *always be*. Experiential evidence may show that the hypothesis is correct, it will however, never prove that the hypothesis is *true*. In this section, the notion that a reflective process memory using experiential knowledge is not concerned with truth, but with

dependability [BLOCKLEY, 1980; COMERFORD & BLOCKLEY, 1993] will be addressed.

41. A central premise of this thesis, is that a reflective learning loop (as represented in a Reflective Process Memory) may infer implicit events on the basis of previously encountered experiences. If a new event has similarities to other well-known experiences, then *predictions* about the attributes of that event may be developed. If that experience is classified as a decision path, then the possible outcome or any problems associated with that decision path may be *anticipated*. The notion of inferring events on the basis of previous experiences is known as *induction*. Induction is an activity in which an extrapolation moves from the results of observations to universal statements or theories. (cf. Deduction in which an inference is made from the general to the particular by a series of logical steps. If each step is *true*, then any conclusions derived from those steps must also be *true*). HUME [1711-1776] first highlighted the central philosophical problem of inductive reasoning. MAGEE [1982] in his discussion on POPPER rather neatly states that “*from the fact that all past futures has resembled past pasts it does not follow that all future futures will resemble future pasts.*” POPPER [1972] circumvented some of the problems associated with induction, by suggesting that before recording any experimental observations, a pre-observational definition of appropriateness and relevance must be made. These observations must be governed by the requirements of the problem hypothesis. POPPER [1972] also argued that by beginning all inquiries with a hypothesis allows the individual to develop testable arguments from that hypothesis. These arguments which when tested will either confirm or refute that hypothesis. POPPER'S reasoning may be represented as follows, (i) *identify the problem*; (ii) *formulate a proposed solution as a new hypothesis*; (iii) *use this hypothesis to generate testable arguments*; (iv) *test these arguments*; (v) *use the results of these test to establish a preference between competing hypotheses*.

42. The RPM (in a manner, similar to the Popperian view) attempts to overcome problems associated with the inference of implicit events from similar experiences. The RPM, (i) uses the problem input to access a series of stored experiences; (ii) from these experiences a selection of possible solutions are chosen for evaluation by the RPM; (iii) the evaluation criterion (as defined by the user) attempts to discriminate between the chosen solutions; (iv) the results of this evaluation are used to order the preference of the accessed experiences; (v) if a solution is accepted by the user, then the decision path of the problem input is modified in an attempt to reproduce the successful consequences of the chosen solution, while reducing its failings; (vi) the chosen solution is used by the RPM to make additional predictions on the successful outcome of the modified problem input.

43. However, as stated above, just because it always has been gives no

indication that it always will be, then where is the justification in using theoretical explanations of past events to reason about future situations? POPPER [1972] has argued that the justification of generated explanations may be based on the testability of the explanation. The justification of an explanation is defined by the tests that are constructed to refute the explanation and the ability of the explanation to survive those tests. BLOCKLEY [1980] has extended this by arguing that a criterion for the justification of generated explanations in engineering practice should be based on their *dependability*. He has suggested that POPPER'S notion of testability may be looked upon as a necessary condition of dependability. However, testability can give no indication of the explanation being *true*. All that can be said about an explanation that is dependable is that it is not false. HUME [1711-1776] noted, that while the inference of a set of event sequences from a set of similar event sequences may be well-founded, this well-foundness can not be proved. They can never be proved logically true. This pre-occupation with truth and the notion of truth may be misleading. As POPPER states "*most formulae used in engineering...are known to be false, although they may be excellent approximations and easy to handle; and they are used with confidence by people who know them to be false*" [POPPER, 1972].

44. The foundations of modern science and engineering practice are not built on truth. They are built upon the generation of hypotheses, that have developed into plausible and dependable explanations. If truth was the pre-requisite of engineering practice, then the three central propositions of Newtonian mechanics would be invalid. The laws of Newtonian mechanics are not true, but dependable. Engineers can justify their use since they have proved to be a dependable explanation of the action and reaction of physical objects operating within a specific space-time. They have proved to be a dependable foundation upon which current human society can exist. If this current society was moving at nearly the speed of light, then this dependability breaks down and Newtonian mechanics would be inappropriate. Consequently, dependability is a function of the context of the problem-solution environment. And in the context of this problem-solution environment, the reflective learning from the grounded explanation of previous case-histories is an appropriate methodology for the investigation of decision failures.

45. However, whilst induction is an activity that moves from results of observations to the generation of rules, *reflective induction* is not concerned with the development of rules. Reflective induction uses previous experiences to aid the decision making capabilities of the user and not to remove the user from the decision loop. The re-occurrence of similar event sequences may help the user to recognize and hence label those event sequences as a new concept. The

representation of commonly occurring event sequences may be capable of stimulating the creativity of the user. The dependability of these commonly occurring event sequences may be defined by the tests that the user employs to demonstrate the justification in using that particular inferred explanation.

46. Another argument against the use of the RPM to translate a *messy* external object into a structured internal representation, is that the interpretation and incorporation of human behaviour into the process memory may present difficulties. As PLATT states, “*human centred process modelling is not only context sensitive, it is also subject to the interpretation of the observer creating the model*” [PLATT, 1995]. PIDGEON notes, “*this dilemma arises from a simultaneous commitment, on the one hand to realism and science (by claiming to reflect objectively the participants’ accounts and perspectives) and, on the other hand, to constructionism through a recognition of the multiple perspectives and subjectivities inherent both in a symbolic interactionist world view and in the engagement of the researcher in the interpretative work of generating new understandings and theory*” [PIDGEON, 1996]. However, this *tension* between the *objective* and *subjective* element of *human centred process models* represents both the strength and the weakness of generating a theory from available data. The notion of a grounded approach to theory generation is based upon three propositions, (i) *plausible relationships* operate within an open world; (ii) these relationships are reflected in unstructured interview data; (iii) and they can be teased out by using a grounded methodology [STRAUSS & CORBIN, 1994]. The criticism above presupposes that the generated theory and hence any experiences derived from that theory are somehow fixed and represent some static empiricism or truth. The notions of truth and dependability have been addressed above and so will not be repeated. However, in the process of teasing out this theory, the knowledge engineer will have to “*access their participants’ lived experiences*” [PIDGEON, 1996]. The accessing of previous experiences forms part of the very creative tension of qualitative interpretation. This cannot be called static, involving as it does the dynamic and flexible movement between the expert, their testimony and the knowledge engineer. The use of a grounded methodology involving a repeated interaction between the knowledge engineer and the expert introduces an element of agreement into the elicitation of expert testimony. Therefore, while the methodology is grounded in data it is also grounded in agreement. This agreement may be defined by evidential support developed from a dialogue of *conjecture* and *refutation* [POPPER, 1972] between the knowledge engineer and expert witness.

47. Another criticism, is the danger of inappropriate use. There is a danger that the grounded methodology could become a prescriptive technique, in which individuals look upon the methodology as *guaranteeing truth* [PIDGEON, 1996]. It is

suggested by PIDGEON [1996], that the results of this inappropriate use will soon become apparent. The guaranteeing of truth presupposes a concern with the issues of rule generation and inductive reasoning. These issues have been addressed above. The notion of theory generation must be defined by justifiably dependability and by the tension between the understanding of the expert, the interview data and the conceptualization developed by the knowledge engineer. It has been argued that these generated explanations will be dependent upon, (i) the tests that the user employs to demonstrate the justification in using that particular inferred explanation; (ii) the knowledge engineer having a *degree of subjectivity and objectivity* from which they develop their analyses.

48. To conclude; where is the justification in using a grounded methodology? It is argued that this is concerned with a criterion of dependability and not with guaranteeing truth. The value of a grounded methodology in knowledge elicitation will be in its ability to identify concepts and conceptual patterns from unstructured data. A dependability that is defined by the ability of the grounded theories to fit the data, while also being recognized, understood and hence agreed on by the participants of the process. This criterion of dependability is currently being used by the author in defining the appropriateness of the elicited case-histories of depth conversion projects in oil reservoir management.

4.6 CONCLUSIONS

- A conceptual pattern is a representation used by an individual to express their understanding on an external process. A Process Model explanation could be considered to be formal representation of that understanding.
- The representational appropriateness of such a model depends upon the model being able to express not only the processes of the external object, but also the process-interactions that connect those processes. The structure of the model must be able to provide an explanation of the object in terms of an explanation of those processes and process-interactions.
- It has been argued that a grounded methodology provides a formal explanation of the interactions and meanings as they relate to the content and context in which they occur. This analysis will result in the generation of an array of concepts, categories, their interacting processes and emergent properties. These interacting processes and emergent properties can be represented as Process Model explanations.
- The Process Model explanation is used to describe and explain an otherwise unstructured open world object in terms of a structured process representation. They represent the building blocks of the Reflective Process Memory and are used by the Reflective Process Memory to infer implicit events on the basis of previously encountered experiences. In this respect the Reflective Process Memory is not concerned with logical truth but with a dependability of representation, explanation and understanding.

5. FROM KNOWLEDGE ACQUISITION TO PROCESS MODEL EXPLANATION

5.1 OBJECTIVES

- To discuss the nature of the *form* and *vocabulary* of these Process Model explanation as defined through a *grounded* methodology.
- To discuss how *predictives* may be defined by a Process Model explanation of *how*, *when*, *where* and *why* a sequence of events occurred and who was responsible.
- To explore how the Reflective Process Memory to use this knowledge to *identify* problems in similar experiences.

5.2 INTRODUCTION

1. In Chapter 3 it was hypothesized that the building of a decision may be modelled as a reflective process. This hypothesis was characterized as follows, (i) the decision develops from dynamic reflective *interactions* with the physical and social world, external to the decision maker; (ii) decision building is a *pattern recognition and matching process*; (iii) the patterns are metaphors, analogies or images that the decision maker uses and updates from previous experiences; (iv) the decision building process forms part of a reflective learning loop, in which the individual constantly re-calls, re-evaluates and modifies that experience; (v) the decision building process will produce *emergent* properties at many levels of definition of modelling of the open world; (vi) the *effectiveness* of the outcome from a decision building process, depends on the *overall structure* of the interactions between the individual, the cultural identity and the problem-solution environment.

2. In Chapter 4 it was suggested that a machine-based Reflective Process Memory could make available to a decision maker a rich set of previous process attributes. These process attributes would be expressed as a Process Model

explanation. However, the representational appropriateness of such a model is dependent upon it being possible to express in the model not only the processes of the external object, but also the interactions that connect those processes. The structure of the model must be able to describe the object in terms of an explanation of those interactions.

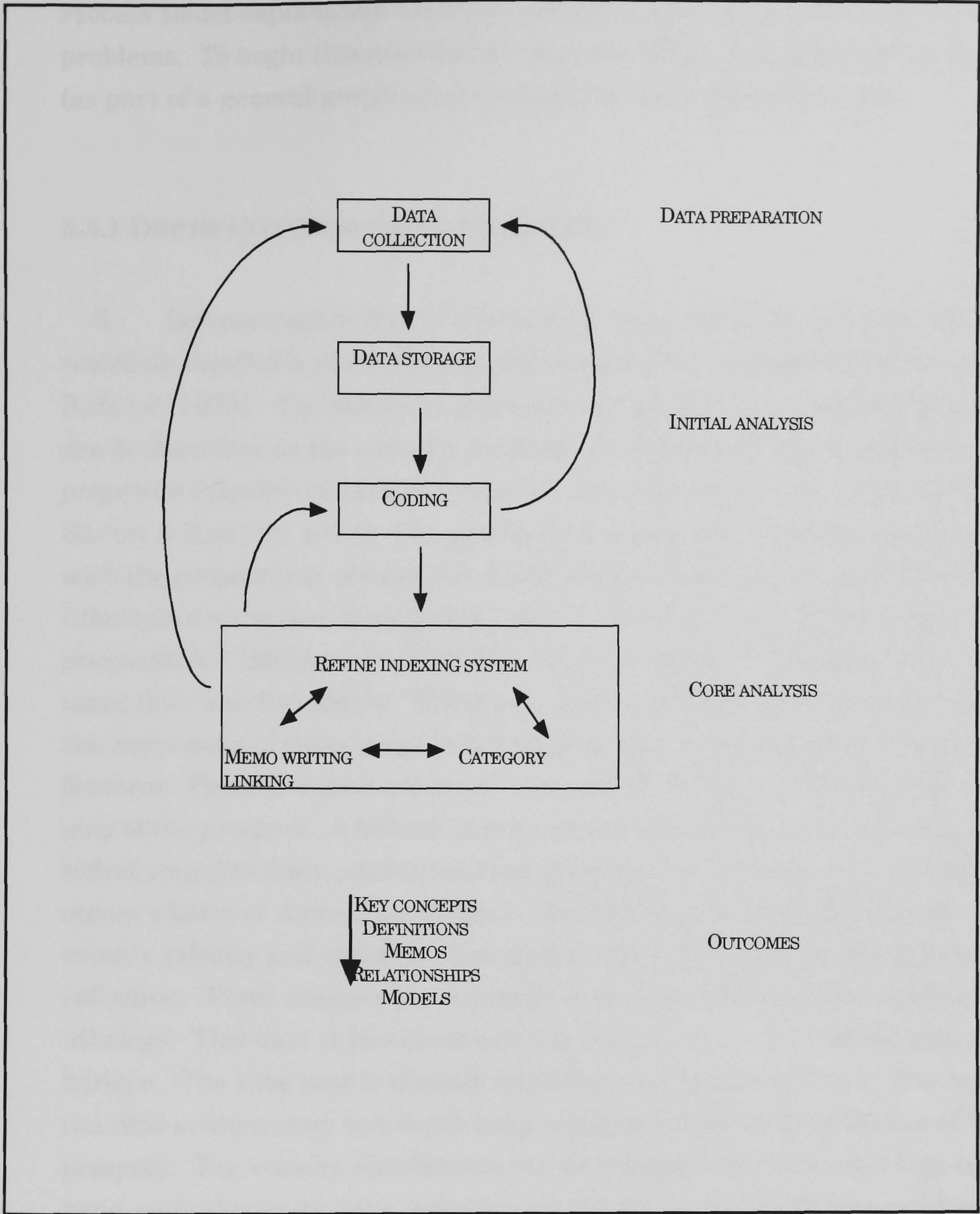
3. As discussed in Chapter 4 a grounded methodology provides a dependable explanation of the interactions and meanings as they relate to the content and context in which they occur. This analysis will result in the generation of an array of concepts, categories and their processes and emergent properties, which provide the building blocks of the reflective process memory. In the following sections an example of a grounded knowledge elicitation exercise and the representation of the emergent properties as a Process Model explanation will be presented. The example, will focus on the way in which the reflective model enables links to be made between technical factors and the economic, environmental, cultural and social considerations of the decision building process. The process interactions of previous decisions will be described through a Process Model algorithm [BLOCKLEY 1997]. This description, which is a representation of the understanding of a process by an individual, will include the current and desired states, initiating states, transforming states, scenario states and consequence states as well as the various roles and other attributes. The description will also include reference to any sub-processes on which the process depends.

5.3 DEPTH CONVERSION: A GROUNDED IMPLEMENTATION

4. In this section some of the practical aspects of grounded theory, particularly gathering, coding and the analysis of qualitative data associated with the depth conversion of seismic data in offshore oil exploration are discussed. The component processes of a grounded approach are shown in FIGURE 5.0 [PIDGEON & HENWOOD, 1996]. FIGURE 5.0 represents each process of the grounded approach as discrete steps. However, in practice it is an activity, in which the knowledge engineer constantly compares the difference between current and previous steps, checking the validity of the emerging interpretations. As PIDGEON, TURNER & BLOCKLEY note, *the knowledge engineer should be prepared to return to the expert sources frequently as analysis proceeds, in order to check initial interpretations and emerging propositions, to resolve ambiguities, and to gather new information in response to the analysis* [PIDGEON, TURNER & BLOCKLEY, 1991].

5. In the remainder of this Chapter and in the following Chapters 6 and 7, a depth conversion case study will be used to illustrate, (i) how the knowledge

FIGURE 5.0 GROUNDED THEORY APPROACH [PIDGEON & HENWOOD, 1996]



engineer generates a grounded explanation; (ii) how this forms part of a Process Model explanation of that domain expertise and; (iii) how the diagnostic use of that Process Model explanation could lead to the identification of potential decision problems. To begin this exercise, an overview of the core issues of depth conversion (as part of a general geophysical interpretation) is presented below.

5.3.1 DEPTH CONVERSION: AN OVERVIEW

6. Seismic exploration is a *“remote-sensing technique in which the aim is to record as detailed a picture as possible of subsurface geology”* [MCQUILLIN, BACON & BARCLAY 1979]. The results of this seismic exploration is a *“geological model which can be described as the sum of a finite series of layers of varying thickness, physical properties (density and seismic velocity) and structural attitude”* [MCQUILLIN, BACON & BARCLAY 1979]. The geophysical interpretation of this model is concerned with the preparation of reservoir depth contour maps of the *“geological structure, lithological variation, stratigraphy and, in oil exploration, hydrocarbon prospectivity”* [MCQUILLIN, BACON & BARCLAY 1979]. The preparation of these maps falls into two stages. These are, (i) the construction of velocity maps and; (ii) the conversion of those maps into depths to particular geological layers and features. Processed data received from seismic surveys is used to construct a time map of the prospect. A seismic survey uses the property of the subsurface geology to reflect sound to discriminate between geological structures. A sound reflection occurs wherever there is a change in acoustic impedance (defined as the product of seismic velocity and density). The greater the impedance the stronger the reflection. These changes are normally associated with changes in the geological lithology. This data is processed and the product is a time contour map to each horizon. The time map is directly related to the seismic sections. The conversion of the time contour map to a depth map requires a velocity distribution of the prospect. The velocity distribution can be defined from well sonic logs on the one hand and seismic stacking velocities on the other. Each will be considered in turn. Note, it is possible *“to estimate velocities by stacking the data assuming a constant velocity; strong events will tend to appear at those depths where the assumed velocity equals the true rms velocity, and by repeating the process for a suite of assumed velocities, a velocity profile can be prepared”* [MCQUILLIN, BACON & BARCLAY 1979]

7. Consider a prospect in which the seismic data is minimal or uncertain. Any velocities derived from that data will be undependable. To overcome these difficulties, it is normal to use the well velocity data. This information is provided by a sonic log and allows the geophysicist to deduce the average velocity in each formation through which the well passes. All that the geophysicist is required to do

is to contour this information for each formation. Unfortunately, unless the prospect has been extensively and uniformly drilled then the well velocities will have to be extrapolated into the deeper areas of the reservoir. (Note, this is unlikely, it is normal for the wells to be concentrated on the high areas within the reservoir trap.) The variation of velocity with depth of burial can be used to form a correlation between velocity and depth. In some prospects a good correlation between velocity and depth can be defined. However, the occurrence of an uplift seriously affects that correlation. An uplift may be defined as the process by which older, deeper and hence denser geological formations have been pushed towards the surface. The movement of geology from its initial depth (at time of burial), to a depth that is unrelated to time of burial will result in scatter on the velocity-depth graph. In practice such scatter is very common. However, if no other geophysical interpretation is available then the best estimate of the depth gradient versus velocity will be used to extrapolate away from the wells.

8. Fortunately, it is normal for stacking velocities to be available along the interpreted seismic lines. These are transformed into interval velocities for the various formations. An interval velocity may be defined as the seismic velocity through a particular formation layer. This velocity model is then *tied* to well velocity data as a means of instilling confidence in the interval velocities. Unfortunately, data uncertainties in the velocity model will mean that such ties are normally unsatisfactory. However, if the differences remain constant over depth then some form of correlation factor may be incorporated and thus increase the agreement between the two sets of velocities. These differences are a consequence of, “*the difference in geometry, namely, normal incidence for the check-shot and various angles of incidence for the CDP (Common Depth Point) gather.*” [MCQUILLIN, BACON & BARCLAY 1979] They go on to state that “*horizontal variations in interval velocity and also anisotropy will cause small differences between well and seismic velocity estimates.*” [MCQUILLIN, BACON & BARCLAY 1979]

9. Having constructed time maps to various horizons and velocity maps of interval velocities between those formations then the multiplication of one by the other will produce a depth map of each formation. Each depth to formation is added together which builds a depth *layer-cake* [MCQUILLIN, BACON & BARCLAY 1979] of the prospect. Even if a large area is to be mapped on several horizons, such a method is easily computable. However, the problem of consistency still remains. The chosen depth conversion method must ensure that the values at line-ties and well-ties is consistent throughout the procedure. This can be achieved by representing the velocity data as a set of values on a grid. The grid size being defined by the complexity of the formation. At a point at which the depth is required, a grid is generated and the average velocity can be derived from an

interpolation of neighbouring grid points. This velocity is then used in the depth calculation. This method has the additional advantage of being able to include well velocities at grid points, which if correlated correctly allow lines within the vicinity of wells to be tied in exactly.

5.3.2 THE GROUNDED APPROACH TO INTERVIEWING

10. A series of six structured and three unstructured interviews of approximately 45 minutes in duration were undertaken with petroleum geophysicists. The level of expertise varied. For example, one of the interviewees had very little experience having just joined the company direct from university. The other three interviewees had many thousands of man-hours of geophysical interpretation with over twenty five years of experience. These interviews were conducted over a period of four months. The purpose was the generation of a set of case studies of the process [*implementing time-depth conversion*]. These case studies represent a collection of theoretical explanations of the decision tasks that made up that process. The intention was, (i) to demonstrate the use of the grounded methodology in the elicitation of the process interactions and their emergent properties during the [*implementing time-depth conversion*] decision problem; (ii) to provide a grounded explanation of the interactions and meanings of the emergent properties as they related to the content and context of the process [*implementing time-depth conversion*]; (iii) to generate a collection of concepts and categories of these emergent properties that would ultimately be represented in the Process Model explanation of the decision problem.

11. During the knowledge elicitation exercise undertaken by the author, interviews were recorded and then later transcribed. These interviews concentrated on the human and organizational preconditions relating to failures (or near failures) of depth conversion projects in reservoir evaluation. Of the three collected case studies, two are retrospective case histories of depth conversion projects that have experienced decision problems and the third case study represents an on-going project. Each interview session was allocated a unique identifier. This included the date, reservoir identifier and source of information. TABLE 5.0 illustrates this process and represents an example taken from an interview with an geophysicist; G. For example, the case shown in TABLE 5.0 was given the name [TOM]. The other case studies were known as [DICK] and [HARRY]. TABLE 5.0 represents a section of an interview with senior geophysicists highlighting their failure to anticipate the effects of new software being unable to perform as required.

TABLE 5.0 EXAMPLE PARAGRAPHS FROM DEPTH CONVERSION INTERVIEWS

Interview with G, March 17 1998, Field [TOM]	
Para 31	One of the reasons that there was a time delay and a cost overrun, was that the project team were trying a new software package. This new software wasn't (which management didn't realise at the time) capable of doing everything the project team need. The team had to revert back to the original software package.
Para 32	We are co-developing new software package. This software is currently being pushed into market. The project team had pre-release version and decided to find out whether it could what was required by CASE TOM/J. Theoretically, it offered an easier path than some other methods, in that it integrated some of the techniques that currently require different software packages. However, it failed in several areas. There appears to be no pressure to use, but there was an interest and that interest stemmed from the fact that we have a financial stake in its development.

12. Previous studies [PIDGEON, TURNER & BLOCKLEY, 1991; PIDGEON & HENWOOD, 1996] indicated that the success of the grounded methodology will rely on the development of a *rich rapport* between the interviewer and the interviewee. This will lead to the generation of a *rich set of emergent concepts*. The experience of this author during the depth conversion exercise suggests that the interviewer should develop the interview along conversational lines and that the interviewer should follow an open-ended conversational style. It has been reported that a failure to establish any sort of rapport with the interviewee may result in *thin* data [PIDGEON, TURNER & BLOCKLEY, 1991]. They suggest that this will result in outcomes that “*are unlikely to reflect the substantive issues involved.*” FORSYTHE & BUCHANAN [1989] have highlighted a number of problems associated with the gathering of interview data of which “*dominating the interview*” and “*asking leading questions*” are the most frequent. PIDGEON & HENWOOD suggest that a commitment to the generation of rich stories relies on, “*grounded theorists who use interviews to view them as a directed conversation.*” [PIDGEON & HENWOOD, 1996]

13. The issues of *to-direct* or *not-to-direct* need to be considered. To address these concerns, it is suggested that questions of direction (such as *when*, *how* and *when not*) must run in parallel with questions associated with the explanations *fitting* the data, *bias* and *world-view*. A grounded knowledge elicitation exercise will involve some element of human judgement. Since, everyone will have a point of view, then the criticism of controlled direction or bias has to be addressed. What sets the grounded approach apart is the notion of agreement. At one level, this agreement may be between an individual expert and the knowledge engineer and is used to indicate the appropriateness of the grounded interpretation of a particular object or process. At another level, this agreement may be viewed as a shared or collective testing of the generated hypotheses. This agreement is part of a collective understanding of the scientific and technical rationale that lies behind the expertise of the expert. This highly tested agreement may act as a measure of dependability. For example, in the physical sciences, tests of dependability are defined by a set of rules that govern the way in which the physical world behaves and associated measures that represent that behaviour. However, in the social sciences tests of dependability are more difficult to define and hence the tendency for associated bias. The social world is more dynamic and more chaotic, hence the difficulty in obtaining total agreement. In this respect, a grounded approach tries to minimize the bias. It is a collective process, that generates concepts and concept definitions by agreement. This agreement can never be total and hence the generated concepts and concept definitions can never be true. But they can be dependable, a dependability that is governed by the degree of agreement that they excite. The modification of a well-known quotation; *direction tends to corrupt and absolute direction corrupts absolutely* [from “*power tends to corrupt and absolute power*

corrupts absolutely”, ACTON, First Baron 1834-1902] may help to guide the knowledge engineer in the elicitation task. The knowledge engineer must be vigilant to the dangers of heavy-handed direction, whether accidental or deliberate. The result of such inattention will be a reduction in theoretical explanations and an increase in the use of *leading* questions.

14. There will always be a tension between, on the one hand an explanation that requires direct questioning and on the other hand the dangers associated with the constraints imposed by such direct questions. Such a constraint may serve a specific purpose and hence be beneficial to the analysis. For example, while open-ended questions will allow the knowledge engineer to develop the general process explanation, direct questions can be used to elicit specific information concerning specific events and people. As CHARMAZ [1990] states, “*loaded questions may prove to be useful, when suitable and when raised in logical sequence.*” Unfortunately, such a constraint may also serve to bias the elicitation exercise and consequently the analysis of that elicitation exercise.

15. There is another element of human judgement associated with this activity. A *creative tension* between the *subjective creativity* of the author and the *objective creativity* required by the analysis. PIDGEON, TURNER & BLOCKLEY believe this creativity to be a necessary part of the analysis and state that, “*the facets of the evidence collected will vary with the aims of the system being built and with the nature of the testimony offered by the domain expert, as well as being responsive in some degree to the individual perceptions of the investigator.*” [PIDGEON, TURNER & BLOCKLEY, 1991] It is important to note here a distinction between a system and a system description or a meta-system language. The *testimony of the domain expert* represents their understanding of the problem domain. A grounded analysis of this *testimony* will represent the knowledge engineer’s explanation of the expert’s understanding of the problem domain. A grounded analysis represents a meta-explanation. It is a representation of an explanation of an explanation. As this representation moves away from the actuality of the domain, then this representation will become more abstract. In paragraph 13 above, the notion of bias was introduced as a measure of *controlled direction*. However, in this case bias is a function of the abstraction; in which *individual perceptions of the investigator* may begin to dominate the representation of an explanation of an explanation. The requirements of this abstraction may weaken the creative tension that exists between the subjective and the objective. If this occurs, then the subjective creativity of the investigator with all the associated bias begins to dominate.

5.3.3 THE GROUNDED APPROACH TO ANALYSIS

16. The analysis began by labelling the interview transcriptions. This represents the first permanent data record and is shown in TABLE 5.0. During the analysis the author found it necessary to construct a second record or index. This index allowed the author to sort and re-represent the data as the analysis progressed and developed. The analysis progressed with the author developing and labelling concepts that he considered to be relevant to the problem-solution environment. It begins by asking, “*what categories, concepts or labels do I need in order to account for the relevance of this section, paragraph or line?*” [PIDGEON, TURNER & BLOCKLEY, 1991; PIDGEON & HENWOOD, 1996].

17. This indexing and labelling of concepts is the initial stage of a creative categorizing and characterizing activity. The succeeding analysis is reliant on these beginnings. Consequently, a rigours and conscientious approach will help to ensure that the generated explanations represent a unambiguous understanding of the knowledge stored within the testimony of the expert. The author found that because the generated label must be a recognizable description of the concept, then sometimes the labels produced during this categorizing and characterizing activity appeared long-winded. However, irrespective of its length, if the goodness-of-fit of the label is deemed to be unsuitable, then the knowledge engineer must refine the label until they are satisfied with its definition of explanation. This is most important since the initial goodness-of-fit controls and governs the successful outcome of following operations. As discussed above, this activity requires a dynamic and creative tension “*between the data and the researcher’s developing conceptualizations.*” [PIDGEON & HENWOOD, 1996] This movement between data and knowledge engineer is a complex and difficult undertaking. Since this may result in the knowledge engineer developing a relationship between the expert, the text and himself, then subjective judgements may play a role in this labelling activity. Associated with these judgements is the distinct possibility that the point-of-view of the knowledge engineer may have an undue influence on this activity. As mentioned above, the knowledge engineer must be aware of this influence and act to reduce its effect.

18. To demonstrate this labelling activity, consider the data represented in TABLE 5.0. For example (as shown in TABLE 5.1), in paragraph 31, the author identified the following significant concept; (i) *Management unsure of new software capabilities*. This category is a reflection of a specific conceptual level and represents an initial analysis of the expert’s testimony. This initial analysis highlighted a poor management strategy that eventual lead to the delay of the project and serious financial overrun. The concepts identified in paragraph 32 were,

(i) *Selective attention to technical rationale hides potential problems*, (ii) *Financial interest* and (iii) *Problems associated with using untested software ignored*. The last two again highlight a serious shortcoming in management decision making while the first concept refers to a more theoretical viewpoint that had not been directly raised by the geophysicists. *Selective attention to technical rationale obscures potential problems* refers to a geophysicist having a narrow or displaced focus upon the supposed technical abilities of the new software package. Although it was admitted that it “*was unwise to give the client a depth map produced using almost untested software*”, that is exactly what the geophysicist did with the result that project suffered a time delay and a cost overrun.

19. The degree of abstraction surrounding these labels represents a vocabulary that reflects a measure of similarities, differences and connections that lie hidden within the interview data. What is required is a level of abstraction that results in the collection of features that point to significant concepts and their associations. The success of this operation depends upon choosing an appropriate level of abstraction for the concepts in question. For example, highly specific terms such as *Management unsure of new software capabilities* and *Problems associated with using untested software ignored* will fix the analysis to particular aspects of the case in question. However abstract terms such as *Selective attention to technical rationale hides potential problems* will allow the concept to be analysed at a higher level of generality. TABLE 5.2 illustrates a card for the concept *Selective attention to technical rationale hides potential problems* showing some of the entries that were made. This notion, of selective attention being given to technical rationale at the back of some management decisions is very interesting, especially as this almost lead to the project failure. This view emerged in a number of different forms, highlighted in TABLE 5.2. Following the advice in PIDGEON, TURNER & BLOCKLEY [1991] and PIDGEON & HENWOOD [1996] TABLE 5.2 illustrates the different types of information that may be needed when indexing and cross referencing. For example, as well as the card label, the concept's title and a brief synopsis of the incident, TABLE 5.2 also includes a note of possible connections with other emergent concepts and earlier concept labels.

20. In this example, *Selective attention to technical rationale hides potential problems* has been connected to **CARD 24-FOCUS UPON EVIDENCE OF CASE SUCCESS**. This is suggested by evidence of a narrow focus upon defining evidence of case success, in which the implications of such a concentrated view are not considered. Another potential connection, **CARD 20-IDENTIFYING CRITICAL PROCESS CONSTRAINTS** highlights the situation in which a potential hazard was anticipated but no preventative actions were initiated. PIDGEON, TURNER & BLOCKLEY [1991] and PIDGEON & HENWOOD [1996] state that “*such links will be*

TABLE 5.1 SIGNIFICANT CONCEPTS IDENTIFIED

Para 31	<i>Management unsure of new software capabilities</i>
Para 32	<i>Selective attention to technical rationale hides potential problems</i> <i>Financial interest</i> <i>Problems associated with using untested software ignored</i>

TABLE 5.2 EXAMPLE OF CARD-28 [*selective attention to technical rationale*]

CARD 28	SELECTIVE ATTENTION TO TECHNICAL RATIONALE HIDES POTENTIAL PROBLEMS
Para 20	harmonised information manipulation may reduce data processing problems
Para 32	management considered new software to be an advancement on previous packages, since it integrated techniques that required different packages and reduce data manipulation
Para 38	project called for geo-statistical technique of Kriging at specific locations and the new software was expected to perform this operation
Para 48	although software failed which resulted in delays and cost overruns it is still considered to be a technical advance on other methods
Links with	CARD 17-UNCERTAINTY IN SEISMIC VELOCITY ESTIMATION CARD 20-IDENTIFYING CRITICAL PROCESS CONSTRAINTS CARD 22-TECHNICAL ASPECTS CONSTRAIN PROJECT COMPLETION CARD 23-PROBLEMS WITH ENSURING QUALITY CONTROL CARD 24-FOCUS UPON EVIDENCE OF CASE SUCCESS CARD 26-SATISFYING CLIENT OR OWN TECHNICAL EXPERTISE
(1)	Data manipulation seen as problem
(2)	Technical expectation hides potential problems
Notes	Kriging, name (after D. G. Krige) for a suite of interpolation techniques that uses regionalised variable theory to incorporate information about the stochastic aspects of depth variation when estimating interpolation weights. [BURROUGH & MCDONNELL, 1998]

tentative” especially at the beginning of the analysis. However, during the later stages of the analysis particularly when “*it becomes necessary to specify relationships among significant concepts*” [PIDGEON & HENWOOD, 1996], then such links offer an additional information.

21. The usefulness of the grounded approach depends upon the way in which concepts are refined, extended and related to each other as additional data is explored. Techniques such as *memo writing* and *category splitting, writing definitions* and *category integration* (see FIGURE 5.1) can be used to refine the initial analysis and improve the goodness-of-fit between concept categories and situation events. These techniques also ensure that category definitions are rigorously developed as the analysis progresses. For example, during the initial exercise, some of the chosen labels were not adequate representations of the events that they attempted to describe. As noted by PIDGEON, TURNER & BLOCKLEY [1991] “*this is often resolved by either redefining the concept to a more general or a more specific label, or, where two separate categories are suggested by the incidents on a single card, by converting one card into two, each with its own separate label*”. During the depth conversion exercise both methods were repeated a number of times during the analysis. This highlights the importance of flexibility. The knowledge engineer must be able to develop an open and relaxed attitude to the analysis. Consider the example card shown in TABLE 5.2 the first event *harmonized information manipulation may reduce data processing problems* had suggested the label *Data manipulation seen as problem*. As further events were added, then it appeared that a more general label was needed and *Technical expectation hides potential problems* was considered by the author to be more appropriate. However, this was finally re-worked into the present label *Selective attention to technical rationale hides potential problems*.

22. As the analysis progressed the index of certain categories became full or *saturated* [GLASER & STRAUSS, 1968], in which the collection and analysis of additional data were unable to add to the information already stored. At this stage the author (as recommended by PIDGEON, TURNER & BLOCKLEY [1991]) began to summarize the information. This begins by writing an explanation of the meaning assigned to each label. This explanation must explicitly state which implicit qualities make up this label and category classification. PIDGEON, TURNER & BLOCKLEY [1991], consider this to be a “*demanding task*”. However, it is “*crucial to the analysis*” and “*often develops a deeper and more precise understanding of the nature of the phenomena being examined*” [PIDGEON, TURNER & BLOCKLEY, 1991].

23. This conceptual definition may be extended by the knowledge engineer into the writing of memos. For example, PIDGEON, TURNER & BLOCKLEY [1991] stress,

“the process of producing definitions should run in parallel to, and often directly stimulates the writing of theoretical memos”. Memos are used to *“capture and externalise the thoughts of the analyst generated by close contact with the data whilst coding and producing definitions”* [PIDGEON, TURNER & BLOCKLEY, 1991]. This activity forms the foundation of the grounded methodology. The knowledge engineer should record any thoughts ideas, etc, on *“generalisations (particularly general categories and patterns describing the data), new cases, new categories, links between categories, or links with existing models”* [PIDGEON, TURNER & BLOCKLEY, 1991]. Note, these are just suggestions and the knowledge engineer should not be limited by them. For example, the author used the memos as an opportunity to develop questions for the domain expert. The questioning of the domain expert about these emerging processes helped the author to develop explanations of those processes and define the interactions that existed between them. It also helped the author to develop the necessary *emergent-questions* about the how, when, where and why of those processes. This became especially important during the analysis of those case studies that suffered from *failure-conditions* when the processes represented *hazardous-event-sequences*. In this respect the memo effectively becomes a *failure-explanation*. This will be demonstrated below.

24. TABLE 5.3 illustrates a provisional definition produced by the author for the concept *Selective attention to technical rationale hides potential problems*, from which a memo, shown in TABLE 5.4 was produced. A closer examination of **CARD 28-SELECTIVE ATTENTION TO TECHNICAL RATIONALE HIDES POTENTIAL PROBLEMS** (shown in TABLE 5.2) demonstrated that some of the recorded events may be re-categorized. This is shown in TABLE 5.5.

25. TABLE 5.5 identifies several important features. Firstly, the re-categorization attempts to refine the distinction between the recorded events with events now identified as *Stress escaping behaviour* and *Narrow point of view* respectively. The categories are now separated and the interactions between each concept as well as possible suggestions to overcome these problems are noted. These interactions and suggestions will provide the initial process structure that represents the authors understanding in a graphical format (this will be discussed in some length in the following section). Secondly, the memo in TABLE 5.5 refers to previous literature in an attempt to relate the emerging processes *“to existing models and theories”* [PIDGEON, TURNER & BLOCKLEY, 1991]. Thirdly, the memo identifies those questions that on reflection should have been asked at the time, but were not.

26. The objective of this analysis is the integration of the emerging processes by the creation of interactions that connect these processes. The definitions of these

TABLE 5.3 PROVISIONAL DEFINITION OF [*selective attention to technical rationale*]

CARD 28-SELECTIVE ATTENTION TO TECHNICAL RATIONALE HIDES POTENTIAL PROBLEMS

The quest for sophisticated technical solutions in the optimisation of processing seismic information has in this example hindered the process and indeed may increase the uncertainty within the process. The selective attention given to the theoretical aspects of data processing may generate hidden hazardous event sequences or negative process interactions that may have dire consequences on the outcome of the depth conversion project. The desire to integrate some of the techniques that currently require different software packages while understandable has on the development path become a focused and unquestioning objective. The needs of the software user and the abilities of the developed software have become separated. Whether this stems from the software developers changing the comparison methodology used in the data processing without informing the users, or from senior management being unclear as to the requirements of the user remain unclear and ill-defined. However, what is clear is that the users in their need for technical superiority in a competitive market accepted the anticipated technical advantages of the developed software without question. This technical confidence manifested itself, in that no attempt was made to run the new software in parallel with the old software. The consequences of such an action resulted in cost and time overruns and the possibility of a serious hazard of process failure occurring. However, it was still felt that the newer software offered potential benefits and that it was a technical advance on previous methods.

See also:

CARD 17-UNCERTAINTY IN SEISMIC VELOCITY ESTIMATION

CARD 20-IDENTIFYING CRITICAL PROCESS CONSTRAINTS

CARD 22-TECHNICAL ASPECTS CONSTRAIN PROJECT COMPLETION

CARD 23-PROBLEMS WITH ENSURING QUALITY CONTROL

CARD 24-FOCUS UPON EVIDENCE OF CASE SUCCESS

CARD 26-SATISFYING CLIENT OR OWN TECHNICAL EXPERTISE

TABLE 5.4 CARD-28 NOTES

<div>CARD 28</div> <div>A high technical rationale and quality software have been shown to be critical in successful project completion. However, a naive acceptance of unproved technical benefits of untested software can be catastrophic. A convergent or selective attention can blind the user and the unforeseen results of this blindness can result in hidden problems being generated later.</div> <div>EMERGENT-QUESTIONS</div> <div>Have you identified all the critical process constraints?, Are you allowing technical aspects to constrain the project completion?, Are there any problems with the quality control of the project?, Are you focusing too closely on evidence of case success?, Are you satisfying the client or your own technical expertise?, Are you sure that software is being used in an appropriate manner?, Is the data model inappropriate for software requirements?</div>
--

TABLE 5.5 MEMO ASSOCIATED WITH CARD-28

CARD 28

There are a number of different meanings associated with *Selective attention to technical rationale hides potential problems*. Firstly, it is often assumed that error recognition and recovery are built into any good decision process. However REASON [1990] has suggested that that is incorrect. He argues that in any stressful situations, many primeval instincts and physiological reactions come into play. For example such instincts and reactions could include (i) *encystment*, a stress escaping activity where the mind concentrates on one detail to the exclusion of others; (ii) *a reduction in self reflection*, coherent plans are reduced and a search for other decision paths is not undertaken, this results in a stereotypical response or default; (iii) *fortification* of an existing decision path occurs and the *softening* of objectives takes place. These instincts and reactions are evident within the incidents on CARD 28. For example, clearly a reduced number of possible decision paths were considered. Which combined with stressful situation in which the project team found themselves may have lead *mastery at any price*. This in turn may have lead to the ignoring of incorrect or incomplete knowledge, resulting in the encystment of the decision path. Secondly, the label *Selective attention to technical rationale hides potential problems* raises the notion of *convergent* and *divergent* [BLOCKLEY & ROBERTSON, 1983] decision makers. It is suggested that convergent thinkers are wary of uncertainty and develop one *correct* or relatively well determined solution to a problem. Whereas, divergent thinkers are more willing to accept uncertainty in conclusions and decisions. Consequently divergent decision makers normally avoid thinking with rigid categories. Since “*engineers have to deal both with precise detailed logical argument (e.g. structural analysis) and with problem formulation using vague data (e.g. conceptual design)*” [BLOCKLEY & ROBERTSON, 1983], then a mixture of both convergent and divergent thinking abilities is required. However, BLOCKLEY & ROBERTSON [1983], state that “*the majority of engineers are probably convergers because the universities tend to select on the basis of performance in science and mathematical*”. They stress that this has significant implications for engineers when confronted with problems that have high levels of associated uncertainty. In such a situation having developed a convergent and well-determined solution, the engineer may be unable to consider alternative solutions to the problem.

The above suggests that the concept *Selective attention to technical rationale hides potential problems* may now be divided into two separate and distinct labels;

- (i) *Stress escaping behaviour (encystment)*
- (ii) *Narrow point of view (convergence)*

Some reflections on the notion of a selective attention to technical rationale hides potential problems;

- (i) *Are you allowing technical aspects to constrain the project completion?*
- (ii) *Are you focusing too closely on evidence of case success?*

connections are a significant function of these emerging processes and hence are necessary for the coherence of the resultant process explanation. The result of such an analysis as been previously defined as a set of *core primitives* [PIDGEON, TURNER & BLOCKLEY, 1991]. These primitives, or sub-processes may be represented graphically, thereby illustrating how the sub-processes are connected. The grounded methodology provides a documented record of this analysis and thereby allows others to *trace the derivation* of the emergent processes and their connections. This also acts as a quality audit, in which others are provided with the justification of the knowledge engineer that lies behind the way in which they formed the Process Model explanation. This is a significant and necessary resource for future knowledge engineers. For example, in the depth conversion exercise, the domain experts were asked to comment upon the interpretation of the author. In the majority of cases the interpretation was deemed appropriate and only in a few process definitions and interactions was the emphasis felt to be inappropriate. In cases in which the interpretation was considered inappropriate, the concepts were re-defined. The author therefore feels, that the generated Process Model explanations represent a very close goodness-of-fit and that consequently the process explanation is a very good description of the actuality of the domain expert's experience.

27. In the example of the depth conversion, the analysis of the interview undertaken by the author identified the necessary process definitions and their interactions. This is the form of a rich explanation. The graphical representation of this form as a Process Model explanation may be looked upon as the vocabulary of that rich explanation. In the follow sections the subsequent steps from the grounded analysis to the representation of the Process Model explanation will be discussed. The form of the process events and their interactions will be expressed as a vocabulary. This vocabulary defined by a Process Model algorithm will represent a Process Model explanation of the decision path taken to resolve a particular problem.

5.4 THE REPRESENTATION OF EMERGENT PROCESSES

28. In this section, the vocabulary used to represent the emergent processes and process interactions (generated from a grounded analysis) will be presented. The vocabulary is expressed as a series of sub-processes, modelled using a hierarchical Process Model algorithm [BLOCKLEY, 1997].

29. BALL, FOLEY & DAVIS [1996] have suggested that the representational appropriateness of a generated explanation may be defined by the ability of the

hierarchical process model in providing an “*account of the relationships between different levels and an account of how observed hierarchies come to be formed: what generates the levels, what separates them and what links them.*” One of the outcomes of a grounded analysis is the identification of a sequence of events that make up a particular process. Some events contribute to the failure of the process, while others contribute to the success of the process. These processes are “*transformed by executing a series of events which contribute towards the state of some super-process*” [BALL, FOLEY & DAVIS 1996]. BALL, FOLEY & DAVIS [1996] have identified various component processes that are a necessary part of the PROCESS: [*defining structure of the reservoir*]. These component processes include [*implementing time-depth conversion*], [*designing well program*] and [*analysing fluid samples*] and are represented in FIGURE 5.1. These PROCESS definitions were presented at the first Juniper programme workshop, April 1996 in Bristol [JUNIPER DOCUMENT NO 5-MR9501/05]. The ideas behind the process model for the determination of top structure and oil water contact were discussed. It was felt by the domain experts who attended the Workshop that the process model represented a dependable explanation of [*defining structure of the reservoir*]. BALL, FOLEY & DAVIS [1996] state that “*process descriptions are hierarchical and therefore contain sub-processes.*” For example, they identified a number of component processes of the [*defining structure of the reservoir*]. One of these sub-processes was [*implementing time-depth conversion*]. See FIGURE 5.1. This event operates as a SUB-PROCESS within the overall PROCESS: [*defining structure of the reservoir*]. However, at another level of the process model hierarchy, this event can also operate as a PROCESS: [*implementing time-depth conversion*]. Therefore, the PROCESS: [*implementing time-depth conversion*] will also be composed of component processes. See FIGURE 5.2. FIGURE 5.2 includes [*establishing velocity model of the earth*] and [*combining velocity model, seismic time surfaces and well data*].

30. The notion of event sequences represented by a Process Model algorithm formed part of the work on the *Event Sequence Diagram* undertaken by STONE [1989]. In his work on learning from structural failures, he uses the term event sequence diagram “*to emphasise the concept of a sequence of discrete events related temporally (i.e. in time order) and occurring in a distinct sequence*” [STONE, 1989]. Similarly a hierarchical Process Model explanation also represents “*a sequence of discrete*” temporal events that a grounded analysis has shown to “*occur in a distinct sequence.*” That is, the grounded analysis provided the means by which the hierarchical Process Model explanation is able to translate a textual account of an incident into a graphical representation. This graphical representation clarifies the component processes that occur during the completion of the process. The hierarchical Process Model explanation may be viewed as a process graph. In which the nodes represent the information of the discrete sub-processes that make up the

FIGURE 5.1 PROCESS: [DEFINING STRUCTURE OF RESERVOIR] [BALL, FOLEY & DAVIS, 1996]

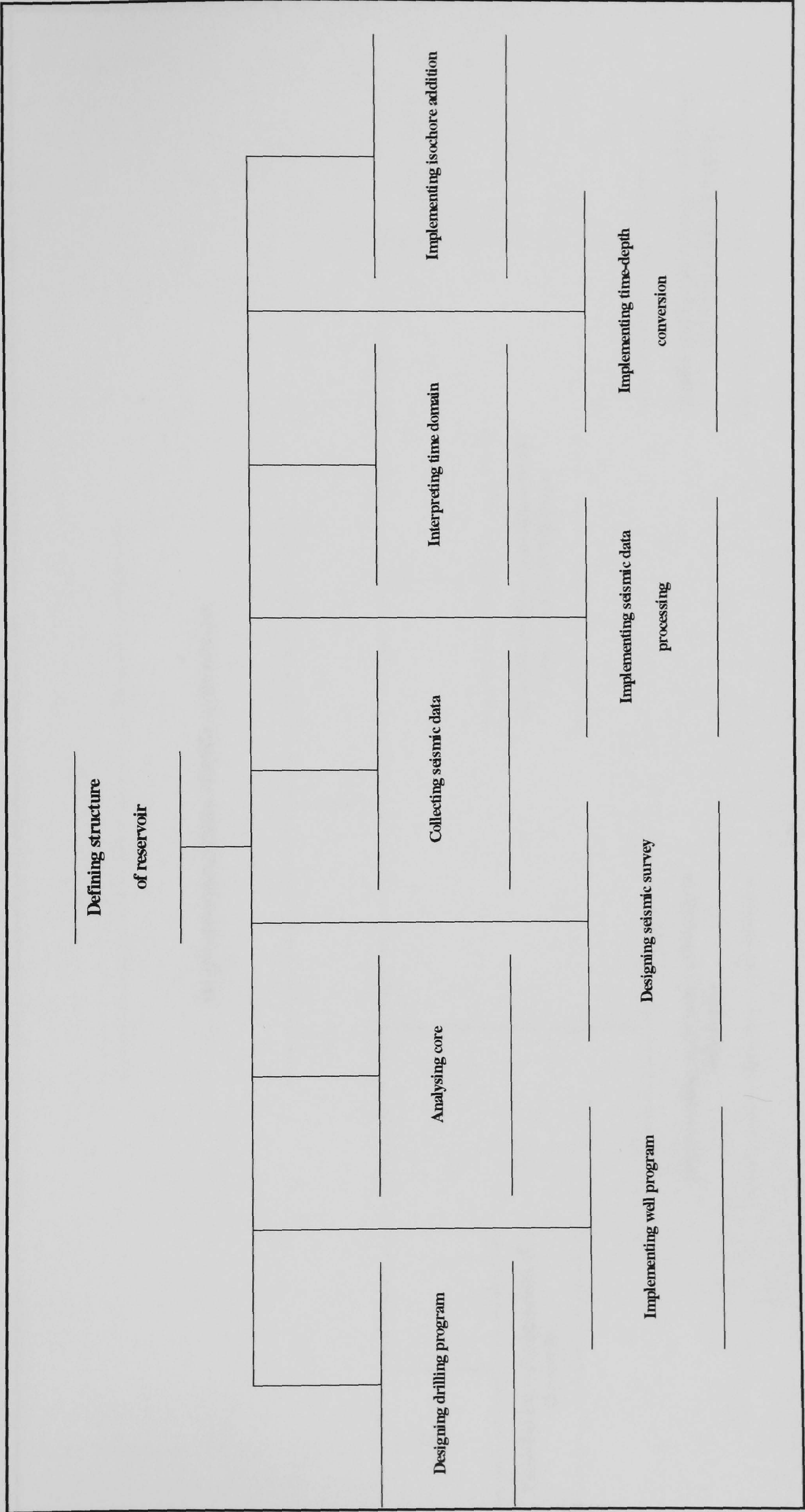
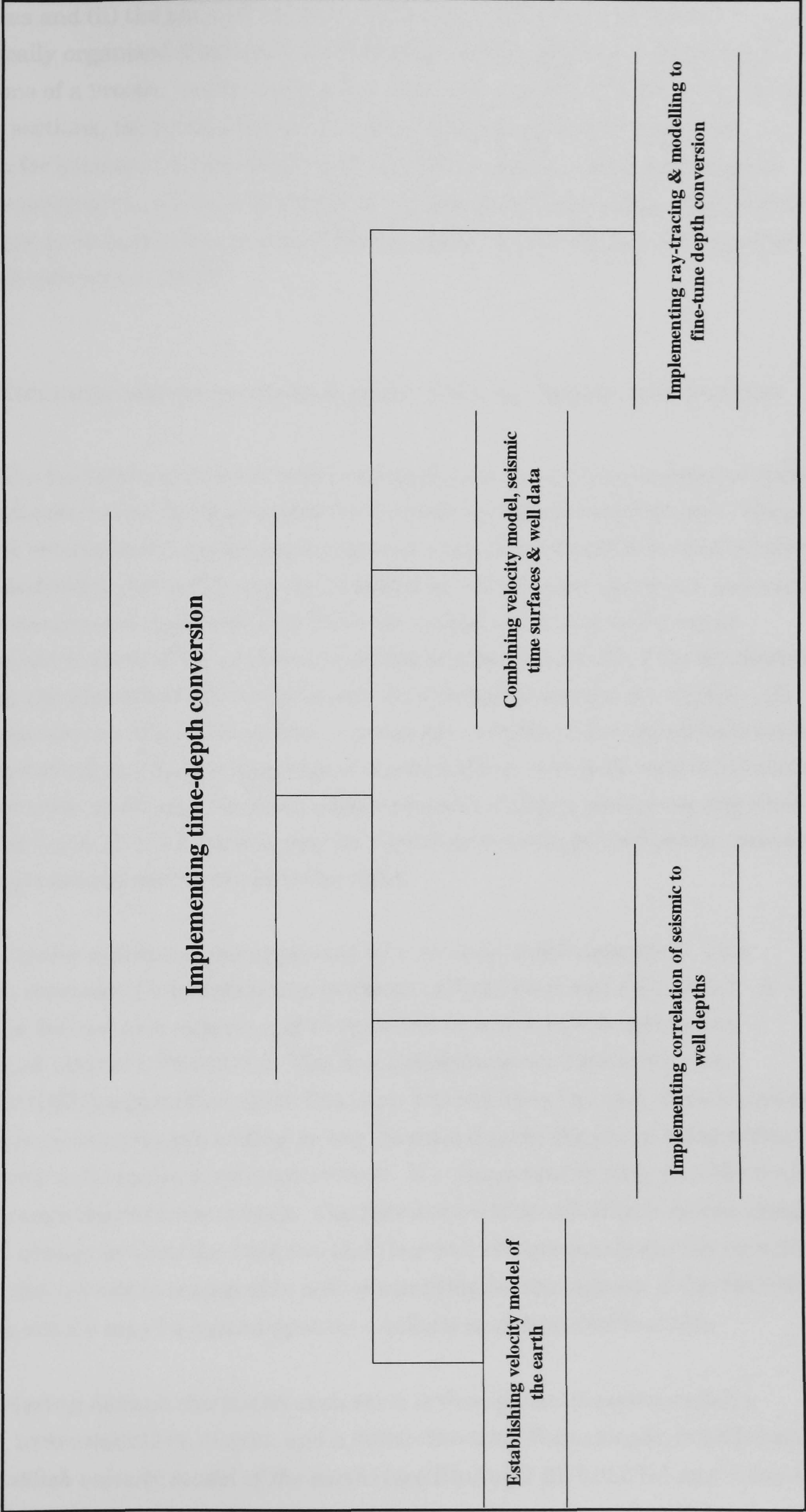


FIGURE 5.2 IMPLEMENTING TIME-DEPTH CONVERSION [BALL, FOLEY & DAVIS, 1996]



overall process and the edges between the nodes represent, (i) the temporal connections and (ii) the manner of their interaction. The ideas behind a hierarchically organised diagnostic representation of the processes and process interactions of a Process Model explanation will be discussed in Section 5.6. In the following sections, the basic premise of a Process Model explanation and the algorithm for process building will be introduced. This discussion will conclude with a demonstration of how a hierarchical Process Model explanation can be used to represent a complex chain of events surrounding the [PROCESS: *implementing time-depth conversion: Tom*].

5.4.1 THE PREPARATION OF HIERARCHICAL PROCESS MODEL EXPLANATION

31. The hierarchical Process Model explanation of the [PROCESS: *implementing time-depth conversion: Tom*] prepared for this section has certain features. These are, (i) the Process Model explanation represents a process description and consists of nodes and edges; (ii) nodes may be classified as either super-processes, processes or sub-processes and each node may have associated attributes; (iii) process attributes are organised by a Process Model algorithm; (iv) not all of the attributes defined by the algorithm will be necessary for a complete process description; (v) process attributes are generated from a grounded analysis of the expert testimony; (vi) process attributes form a language of commonalties; (vii) each node is connected to another node by an edge; (viii) an edge represents either a positive or negative interaction (note, this interaction may be viewed as a message that passes between nodes); (ix) time is positive towards the right.

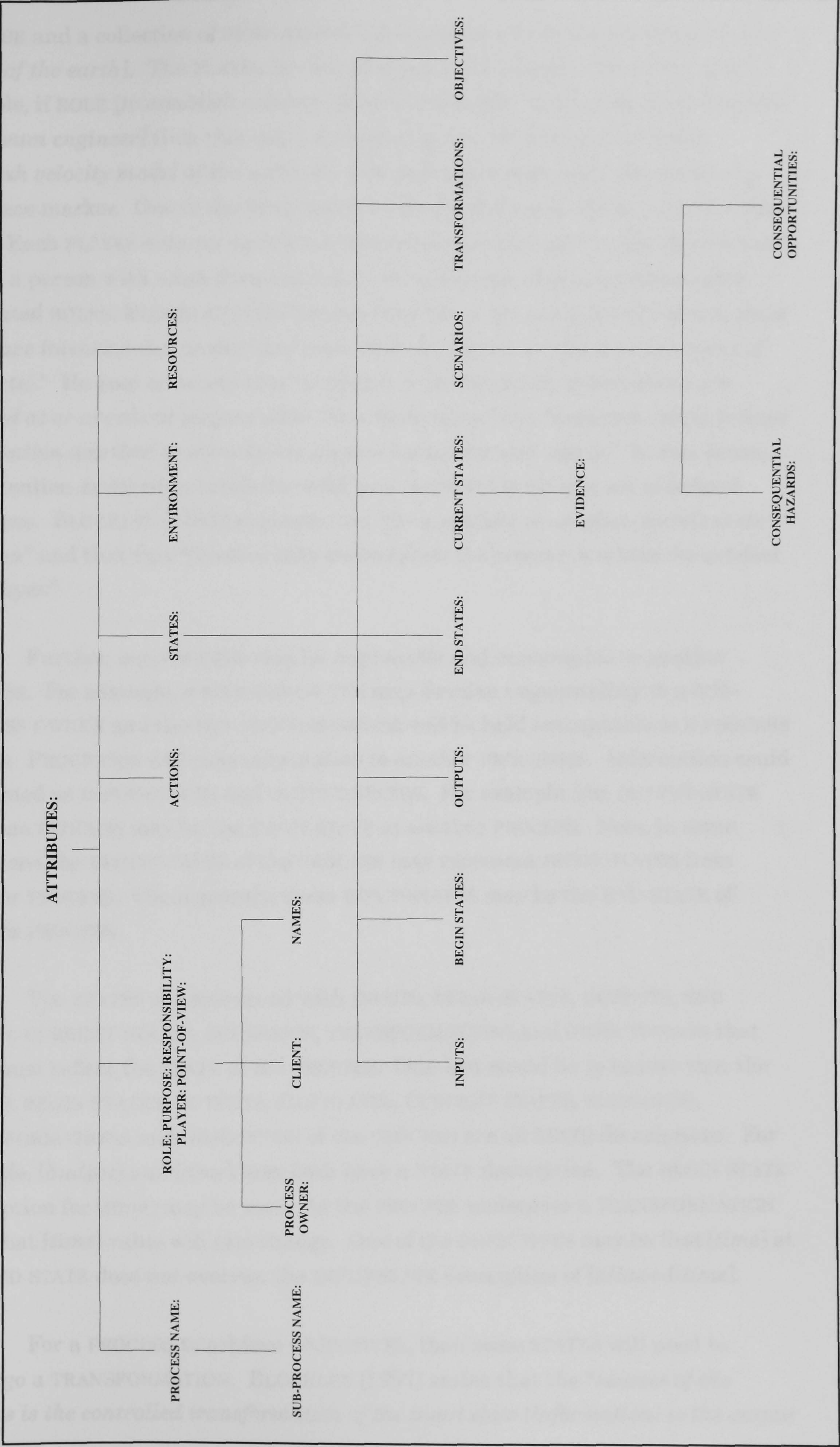
32. Process attributes are organised by a Process Model algorithm. This algorithm represents a template and is shown in TABLE 5.6 and FIGURE 5.3. A PROCESS is defined as a collection of ATTRIBUTES in which INPUT-STATES are transformed into OUTPUT-STATES. The first attribute is the PROCESS NAME. BLOCKLEY [1997] argues that since this is an activity, then “*always name a process using the present participle ending in ‘ing’ because it gives the feel of being active.*” This activity will require a PROCESS OWNER. It is important to note that the major ROLE is always the PROCESS OWNER. The PROCESS OWNER will always do two things. They will always initiate the PROCESS and they will always terminate the PROCESS. The PROCESS OWNER is responsible and accountable for the success of the PROCESS. Therefore a ROLE may be looked upon as a collection of RESPONSIBILITIES.

33. Having defined the ROLES each ROLE is then given (if appropriate), a PURPOSE, RESPONSIBILITY, PLAYER and a POINT-OF-VIEW. For example, ROLE [A] could be [*to establish velocity model of the earth*] (see FIGURE 5.2). ROLE [A] may have a

TABLE 5.6 PROCESS MODEL ALGORITHM [BLOCKLEY, 1997]

1. Name the PROCESS
2. Name the ROLES. Define the overall PURPOSE (Vision) and define each role as a set of RESPONSIBILITIES; include the PROCESS OWNER role. For a product or artefact the role is its FUNCTION.
3. Identify the PLAYER (Actor) for each role. Remember a player takes an active part in the process and can be a person with more than one role or an object with attributed roles (usually by the designer or user of the object).
4. Identify the CLIENT and the STAKEHOLDERS.
5. Be clear about the POINT OF VIEW of each player, stakeholder and client.
6. Identify the BEGINNING and END of the process.
7. Identify what is to be part of the model of the process and what is to be in the ENVIRONMENT (meta-system).
8. Identify the CURRENT STATE description.
9. Identify the OBJECTIVES which are to reach a DESIRED STATE description.
10. Identify SUCCESS as reaching objectives and avoiding failure.
11. Identify the INPUTS expected and the OUTPUTS required, the CONTROLS and CONSTRAINTS.
12. Identify the MODEL that TRANSFORMS the current state to the desired state (i.e. to obtain success and avoid failure).
13. Identify the various SCENARIOS that result from the model of those transformations and PREDICT the CONSEQUENCES.
14. Identify the HAZARDS, consider the RISKS and the ROBUSTNESS (vulnerability) of the processes.
15. Associate measures of EVIDENCE with 14.
16. Identify RESOURCES required for the process.
17. Identify the roles to be DELEGATED as SUB-PROCESSES in 2.
18. Identify the transformations to be DETAILED as sub-processes in 12 and develop the next layer in process HIERARCHY.

FIGURE 5.3 PROCESS MODEL ALGORITHM



PURPOSE and a collection of RESPONSIBILITIES associated with [*to establish velocity model of the earth*]. The PLAYER is the individual that occupies that ROLE. For example, if ROLE [*to establish velocity model of the earth*] is occupied by the PLAYER [*petroleum engineer*] then this may be represented as ATTRIBUTES: [ROLE: *to establish velocity model of the earth*, PLAYER: *petroleum engineer*]. This acts as a two-place marker. One is the ROLE and the other is the name of the PLAYER of that ROLE. Each PLAYER *acts out* each ROLE and takes an active part in the PROCESS and can be a person with more than one ROLE. A PLAYER can also be an object with attributed ROLES. BLOCKLEY [1997] states that “*there are two types of players, those that have intention (i.e. people) and those that do not (i.e. artefacts and systems of artefacts).*” He goes on to say that “*intention is the feature by which states are directed at or are about players other than themselves.*” and “*designed artefacts have an intention ascribed to them by the players (designers and users).*” In this sense, the intention ascribed to artefacts could be a *restricted* ROLE or a set of defined functions. BLOCKLEY [1997] suggests that “*for a product or artefact the role is its function*” and that this “*functionality derives from the process in which the artefact is a player.*”

34. Further, one PROCESS may be *responsible* and *accountable* to another PROCESS. For example, a PROCESS OWNER may devolve responsibility to a SUB-PROCESS OWNER and the SUB-PROCESS OWNER will be held accountable to a PROCESS OWNER. PROCESSES will pass information to another PROCESSES. Information could be defined as INPUT-STATES and OUTPUT-STATES. For example, the OUTPUT-STATE from one PROCESS may be the INPUT-STATE at another PROCESS. Note, in some situations the BEGIN STATES of the PROCESS may represent INPUT-STATES from another PROCESS. Consequently, these INPUT-STATES may be the END STATE of another PROCESS.

35. The STATES are concerned with INPUTS, BEGIN STATES, OUTPUTS, END STATES, CURRENT STATES, SCENARIOS, TRANSFORMATIONS and OBJECTIVES in that they must reflect the STATE of the PROCESS. One test would be to ensure that the INPUTS, BEGIN STATES, OUTPUTS, END STATES, CURRENT STATES, SCENARIOS, TRANSFORMATIONS and OBJECTIVES of the PROCESS are all STATE descriptions. For example, [*budget*] and [*time*] may both have a STATE description. The BEGIN STATE description for [*time*] may be zero. As the PROCESS undergoes a TRANSFORMATION then that [*time*] value will also change. One of the OBJECTIVES may be that [*time*] at the END STATE does not overrun the INPUT-STATE description of [*allowed-time*].

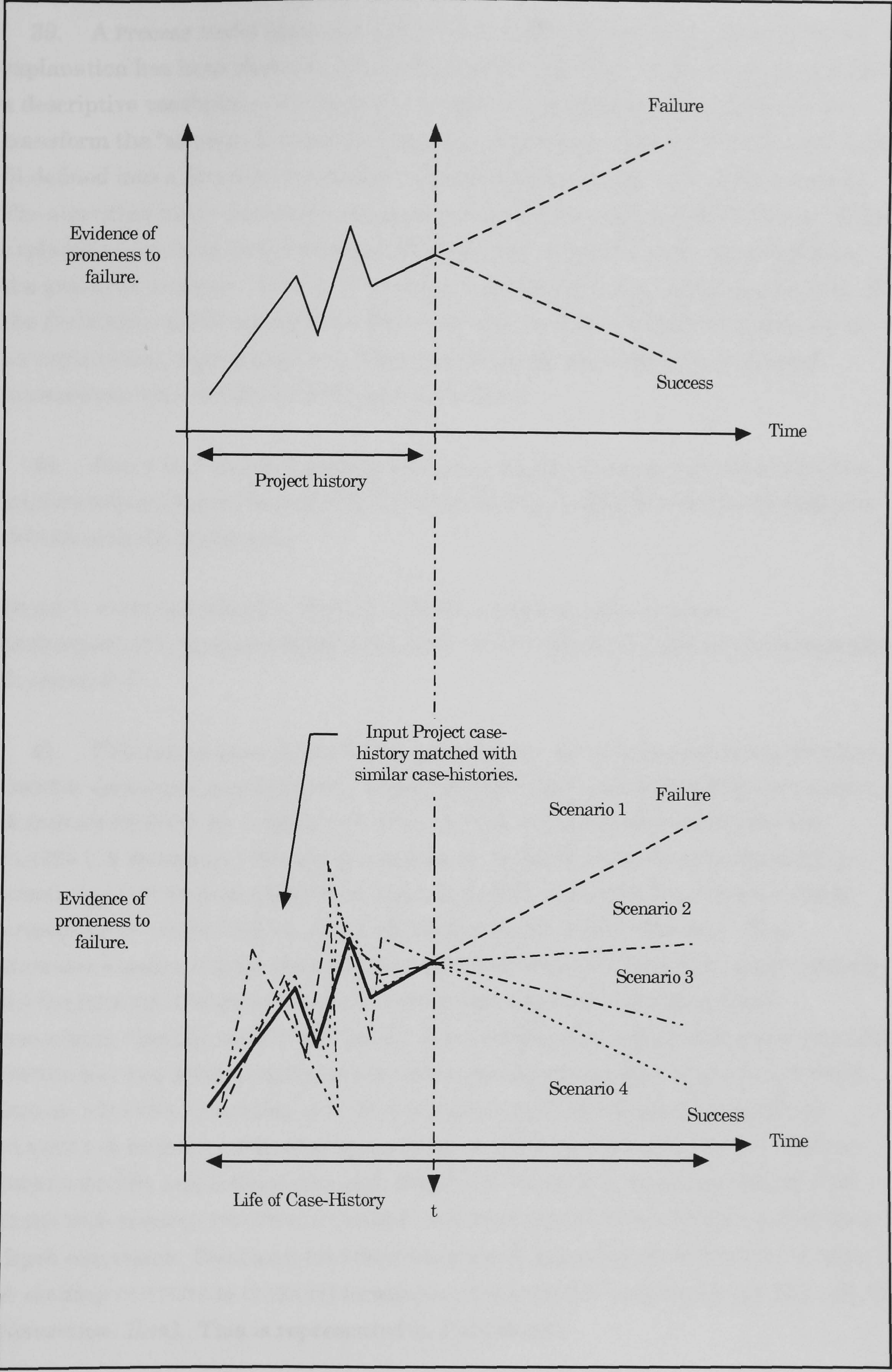
36. For a PROCESS to achieve OBJECTIVES, then some STATES will need to undergo a TRANSFORMATION. BLOCKLEY [1997] states that the “*success of the process is the controlled transformation of the input state (information) to the output*

state (information) or required objectives.” At any point in time during the PROCESS a model of the transformation may be used to generate a set of alternative SCENARIOS for the future. See FIGURE 5.4. RISKS are the probability that a given SCENARIO will result in a given type of negative or harmful CONSEQUENCE. However, while some SCENARIOS may normally be considered to be RISKS leading to negative CONSEQUENCES some may be SCENARIOS leading to positive CONSEQUENCES. Positive CONSEQUENCES may be viewed as OPPORTUNITIES, whereas negative CONSEQUENCES may be viewed as FAILURES. Thus a distinction can be made between negative SCENARIOS and positive SCENARIOS and HAZARDS that are pre-conditions to a FAILURE.

37. A PROCESS may have a sequence of events leading to a negative SCENARIO. In classical probability, a risk analysis will attempt to fit a probability on each event and thereby generating a total probability of a negative SCENARIO occurring. Therefore, RISKS can be defined as a product of the probability of occurrence and the consequence of that occurrence in a stated context. It may also be looked upon as identifying those events and predicting the negative CONSEQUENCES of those events. Consider the representation of the case history in FIGURE 5.4. Figure 5.4 represents a capacity of the project to fail. Through-out the history of this project, this capacity has grown and diminished until the project reached the present (*t*). This past capacity may be viewed as EVIDENCE of *prone-ness-to-failure* and the future capacity may be defined as a predictions of HAZARDS and OPPORTUNITIES. Since the future remains unsure, then the potential OPPORTUNITIES or HAZARDS of the project are uncertain. In FIGURE 5.4 the project is matched against a memory of previous case-histories. This matching may generate one potential future or many potential futures. Associated with each of those potential futures are evidential measures of the prone-ness-to-failure (or HAZARD content) that each previous case history suffered. The success or failure (or somewhere in-between) of those futures are dependent upon the SUGGESTIONS of the management teams and the actions that resulted from those SUGGESTIONS. The outcome that results from using those potential futures may rely on initiating similar actions.

38. Evidential measures of negative and positive CONSEQUENCES can be used to define the ROBUSTNESS of a project. ROBUSTNESS is concerned with the vulnerability of the system. ROBUSTNESS is concerned with the ability of a system to deal with damage. If the system fails in a manner disproportionate to the damage causing it, then it is vulnerable and not robust. It will have a low ROBUSTNESS measure.

FIGURE 5.4 CAPACITY OF FAILURE



5.5 BUILDING A HIERARCHICAL PROCESS MODEL EXPLANATION

39. A Process Model algorithm [BLOCKLEY, 1997] for defining a Process Model explanation has been shown in TABLE 5.6 and FIGURE 5.3. This algorithm provides a descriptive vocabulary of a project organisation or experience. It attempts to transform the “swampy lowland” of “messy, confusing problems” [SCHON, 1987] and ill-defined into a formalised internal representation suitable for machine storage. The algorithm helps the knowledge engineer to build a representative Process Model explanation by describing the processes and process-interactions generated from the grounded analysis. TABLE 5.7 shows a completed Process Model explanation of the [PROCESS: *implementing time-depth conversion: Tom*]. FIGURE 5.5 shows such an explanation, represented as a hierarchical model of processes and process interactions with ROLES, PLAYERS and SCENARIOS.

40. Row 1 in TABLE 5.7 assigns a name to the PROCESS, in this case [PROCESS: *implementing time-depth conversion: Tom*]. Row 2 associates a ROLE and PROCESS OWNER with the statement,

[ROLE 1: <*role definition1*>, PROCESS OWNER: <*process owners name*>, RESPONSIBILITY: <*responsibility definition*>, SUB-PROCESS 1: <*name1*>, SUB-PROCESS 2: <*name2*>]

41. This can be seen in the following, [ROLE 1: <*to oversee* PROCESS>, PROCESS OWNER: <*principal geophysicist*>, RESPONSIBILITY: <*to receive* INPUTS *from* CLIENTS & *initiate* PROCESS *by sending* INPUTS *to* PLAYER 1>; <*to receive* OUTPUTS *from* PLAYER 1 & *terminate* PROCESS *by sending* OUTPUTS *to* CLIENTS>, SUB-PROCESS 1: <*receiving* INPUTS *from* CLIENTS & *sending* INPUTS *to* PLAYER 1>, SUB-PROCESS 9: <*receiving* OUTPUTS *from* PLAYER 1 & *sending* OUTPUTS *to* CLIENTS>]. This statement makes it clear that, (i) the PROCESS OWNER is a [*principal geophysicist*]; (ii) the PROCESS OWNER manages the [PROCESS: *implementing time-depth conversion: Tom*] by ROLE 1; (iii) ROLE 1 is [*to oversee* PROCESS]; (iv) that the PROCESS OWNER has two RESPONSIBILITIES; (v) these are [*to receive* INPUTS *from* CLIENTS & *initiate* PROCESS *by sending* INPUTS *to* PLAYER 1] and [*to receive* OUTPUTS *from* PLAYER 1 & *terminate* PROCESS *by sending* OUTPUTS *to* CLIENTS]; (vi) the PROCESS OWNER BEGINS and ENDS a PROCESS, then [SUB-PROCESS 1: *receiving* INPUTS *from* CLIENTS & *sending* INPUTS *to* PLAYER 1] initiates the [PROCESS: *implementing time-depth conversion: Tom*] and; (vii) [SUB-PROCESS 9: *receiving* OUTPUTS *from* PLAYER 1 & *sending* OUTPUTS *to* CLIENTS] terminates the [PROCESS: *implementing time-depth conversion: Tom*]. This is represented in FIGURE 5.6.

42. Row 3 associates a ROLE and PLAYER with the statement,

TABLE 5.7 PROCESS: [implementing time-depth conversion: TOM].

1.	[PROCESS: <i>implementing time-depth conversion: Tom</i>]
2.	[ROLE 1: <to oversee PROCESS>, PROCESS OWNER: <principal geophysicist>, RESPONSIBILITY: <to receive INPUTS from CLIENTS & initiate PROCESS by sending INPUTS to PLAYER 1>; <to receive OUTPUTS from PLAYER 1 & terminate PROCESS by sending OUTPUTS to CLIENTS>, SUB-PROCESS 1: <receiving INPUTS from CLIENTS & sending INPUTS to PLAYER 1>, SUB-PROCESS 9: <receiving OUTPUTS from PLAYER 1 & sending OUTPUTS to CLIENTS>]
3.	<p>[ROLE 2: <to receive INPUTS & send OUTPUTS>, PLAYER 1: <senior geophysicist>, SUB-PROCESS 2: <receiving INPUTS from PROCESS OWNER>, SUB-PROCESS 8: <sending OUTPUTS to PROCESS OWNER>]</p> <p>[ROLE 3: <to load seismic data>, PLAYER 2: <geophysicist>, SUB-PROCESS 3: <loading seismic data>]</p> <p>[ROLE 4: <to establish geo-statistical model from stacking & interval velocities>, PLAYER 2: <geophysicist>, SUB-PROCESS 4: <establishing interval velocities from seismic stacking velocities>]</p> <p>[ROLE 4: <to establish geo-statistical model from stacking & interval velocities>, PLAYER 2: <geophysicist>, SUB-PROCESS 5: <establishing geo-statistical model for interval velocities>]</p> <p>[ROLE 5: <to define correlation between predicted seismic velocities & well velocities>, PLAYER 2: <geophysicist>, SUB-PROCESS 6: <using geo-statistical model to predict velocity at well location>]</p> <p>[ROLE 6: <to combine seismic interval velocity & well data>, PLAYER 2: <geophysicist>, SUB-PROCESS 7: <establishing velocity model>]</p> <p>[ROLE 7: <to define depth map of top reservoir>, PLAYER 2: <geophysicist>, SUB-PROCESS 8: <combining velocity model & time interpretation>]</p> <p>[ROLE 8: <to define reservoir volumetrics>, PLAYER 2: <senior geophysicist>, SUB-PROCESS 9: <producing depth map & volumetric calculations>]</p>
4.	<p>[CLIENTS: <senior management>]</p> <p>[STAKE-HOLDERS: <field owners>]</p>
5.	[POINT OF VIEW: <proneness to failure>]
6.	<p>[BEGIN STATE 1: <budget is known>]</p> <p>[BEGIN STATE 2: <completion date is known>]</p> <p>[BEGIN STATE 3: <time interpretations are known>]</p> <p>[BEGIN STATE 4: <well data is known>]</p> <p>[END STATE 1: <PROCESS will undergo TRANSFORMATIONS>]</p> <p>[END STATE 3: <PROCESS will meet all OBJECTIVES>]</p>
7.	<p>[INPUTS: <time interpretations are known, well data is known>]</p> <p>[OUTPUTS: <as defined by OBJECTIVES>]</p> <p>[CONTROLS: <as defined by TRANSFORMATIONS>]</p> <p>[CONSTRAINTS: <budget is known, completion date is known>]</p>
8.	[ENVIRONMENT: <CLIENTS, STAKE-HOLDERS>]

9.	[CURRENT STATES: <CLIENTS have OBJECTIVES>, OBJECTIVE 1: <generate best estimate of depth to reservoir>, OBJECTIVE 2: <ensure depth values are appropriate for defining structure of reservoir>, OBJECTIVE 3: <quantify uncertainty of depth map>]
10.	[SUCCESS: <of CURRENT STATES is given by EVIDENCE>, EVIDENCE: <as defined by NECESSARY EVIDENCE & POSSIBLE EVIDENCE>]
11.	[TRANSFORMATION: <BEGIN STATES to END STATES>, SUB-PROCESS 3: <loading seismic data>, SUB-PROCESS 4: <establishing interval velocities from seismic stacking velocities>, SUB-PROCESS 5: <establishing geo-statistical model for interval velocity>, SUB-PROCESS 6: <using geo-statistical model to predict velocity at well location>, SUB-PROCESS 7: <establishing velocity model>, SUB-PROCESS 8: <combining velocity model & time interpretations>, SUB-PROCESS 9: <producing depth map & volumetric calculations>]
12.	[SCENARIO 1: <software unable to perform specific geo-statistical computations>, SUB-PROCESS 6: <using geo-statistical model to predict velocity at well location>, SUB-PROCESS 7: <establishing velocity model>, CONSEQUENTIAL OUTCOME 1: <project suffered time delay and cost overruns>, HAZARD 1: <selective attention to technical rationale hides potential problems>]
13.	[NECESSARY EVIDENCE: [] [POSSIBLE EVIDENCE: []
14.	[PROCESS: <implementing time-depth conversion: Tom>, SUB-PROCESS 3: <loading seismic data>, SUB-PROCESS 4: <establishing interval velocities from seismic stacking velocities>, SUB-PROCESS 5: <establishing geo-statistical model for interval velocity>, SUB-PROCESS 6: <using geo-statistical model to predict velocity at well location>, SUB-PROCESS 7: <establishing velocity model>, SUB-PROCESS 8: <combining velocity model & time interpretations>, SUB-PROCESS 9: <producing depth map & volumetric calculations>]
15.	<p>[EVIDENCE: <there is no indication that consequences of SCENARIO seriously damages PROCESS>, CONSEQUENTIAL OUTCOME 1: <project suffered time delay & cost overruns>, HAZARD 1: <selective attention to technical rationale hides potential problems>, REFLECTION 1: <a concentration on the technical benefits of software may compromise project>]</p> <p>[REFLECTION 1: <a concentration on the technical benefits of software may compromise project>, SUGGESTION 1: <are the software requirements compatible with project requirements?>, SUGGESTION 2: <are you considering a 'contrast and compare exercise' between original & new software?>]</p> <p>[SUGGESTION 1: <are the software requirements compatible with project requirements?>, NEW OUTCOME 1: <a closer understanding between software and project requirements may result in fewer problems>]</p> <p>[SUGGESTION 2: <are you considering a 'contrast and compare exercise' between original & new software?>, NEW OUTCOME 2: <project team may have greater confidence in ability of software>]</p>

FIGURE 5.5 PROCESS: [implementing time-depth conversion : TOM]

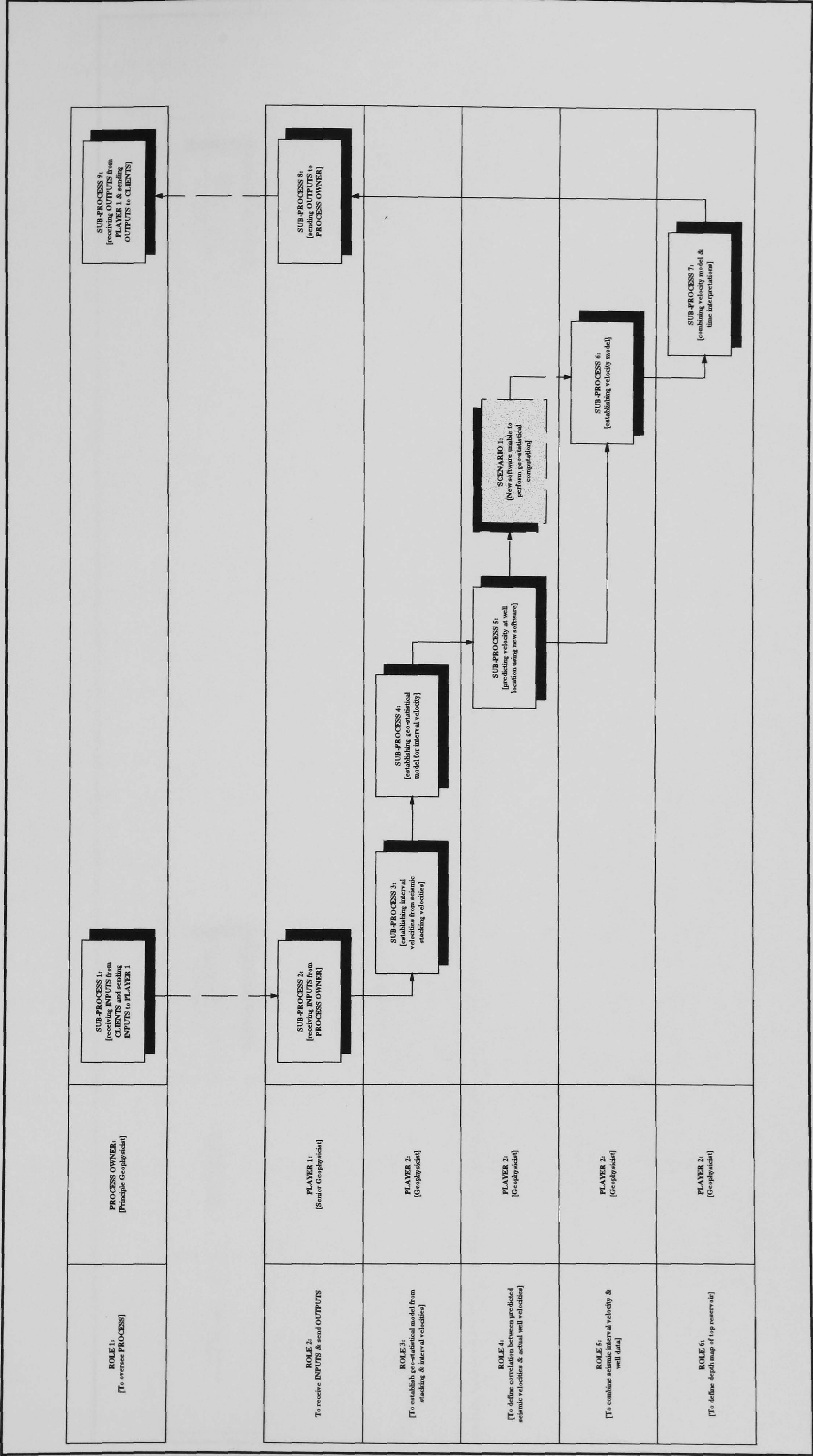
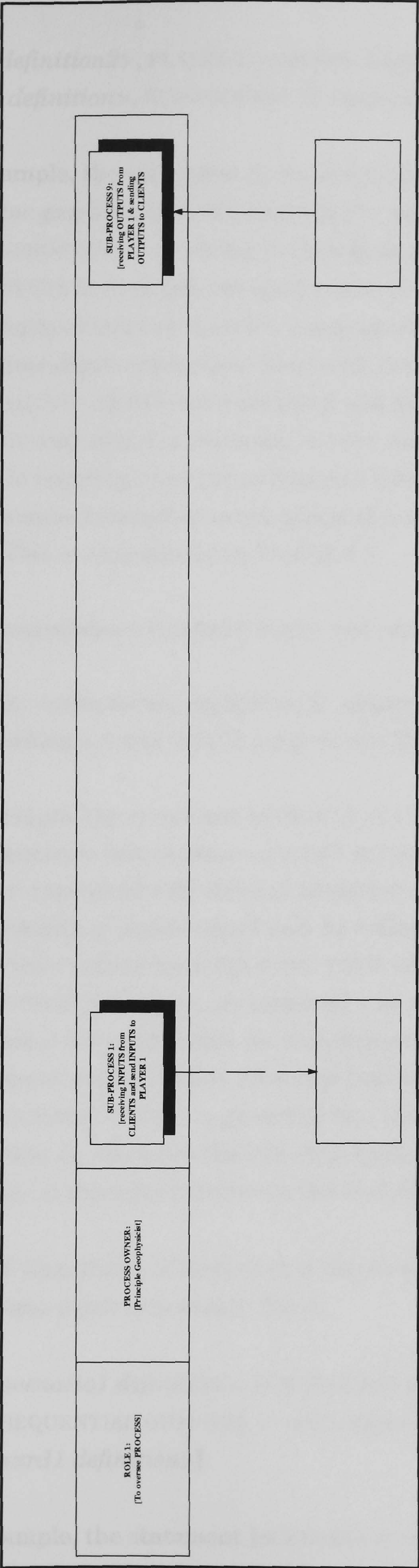


FIGURE 5.6 ROLE 1 of PROCESS: [TOM]



[ROLE 2: <role definition2>, PLAYER 1: <players name1>, RESPONSIBILITY: <responsibility definition>, SUB-PROCESS 1: <name1>, SUB-PROCESS 2: <name2>]

43. For example, the statement [ROLE 2: <to receive INPUTS & send OUTPUTS>, PLAYER 1: <senior geophysicist>, RESPONSIBILITY: *receiving* INPUTS and sending OUTPUTS>, SUB-PROCESS 1: <receiving INPUTS from PROCESS OWNER>, SUB-PROCESS 7: <sending OUTPUTS to PROCESS OWNER>] can be broken down as follows, (i) PLAYER 1 is a [senior geophysicist]; (ii) PLAYER 1 is responsible for the [PROCESS: *implementing time-depth conversion: Tom*] with ROLE 2; (iii) ROLE 2 is [to receive INPUTS & send OUTPUTS]; (vi) SUB-PROCESS 2 and SUB-PROCESS 8 are assigned to PLAYER 1; (v) SUB-PROCESS 2 is [receiving INPUTS from PROCESS OWNER] and; (vi) SUB-PROCESS 8 is [sending OUTPUTS to PROCESS OWNER]. In this manner the basic outline of the process description is transformed into a Process Model explanation of the situation. This is represented in FIGURE 5.7.

44. Row 9 associates a CURRENT STATE and OBJECTIVES with the statement, [CURRENT STATE: <definition>, OBJECTIVE 1: <objective1 definition>, OBJECTIVE 2: <objective2 definition>, OBJECTIVE 3: <objective3 definition>]

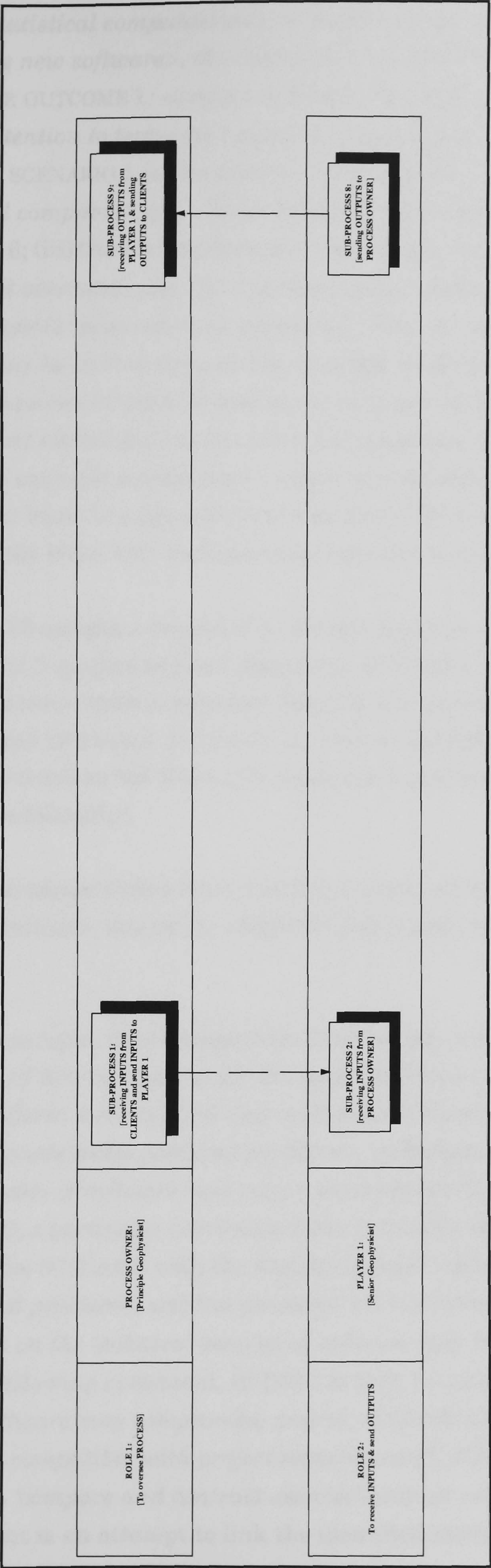
45. For example, the statement [CURRENT STATE: <CLIENTS have OBJECTIVES>, OBJECTIVE 1: <generate best estimate of depth to reservoir>, OBJECTIVE 2: <ensure depth values are appropriate for defining structure of reservoir>, OBJECTIVE 3: <quantify uncertainty of depth map>] may be defined as follows, (i) a CURRENT STATE is where the CLIENTS have the OBJECTIVES of the PROCESS; (ii) the PROCESS has three OBJECTIVES; (iii) these are [generate best estimate of depth to reservoir, ensure depth values are appropriate for defining structure of reservoir, quantify uncertainty of depth map]. Section 10 states that the SUCCESS of a PROCESS as defined by the CURRENT STATES is governed by NECESSARY EVIDENCE and POSSIBLE EVIDENCE. Section 11 identifies the SUB-PROCESSES needed for the TRANSFORMATION of the BEGIN STATES to the END STATES.

46. Row 12 identifies a SCENARIO that can be assigned to the [PROCESS: *implementing time-depth conversion: Tom*],

[SCENARIO 1: <scenario1 definition>, SUB-PROCESS 5: <name5>, SUB-PROCESS 6: <name6>, CONSEQUENTIAL OUTCOME 1: <consequential outcome1 definition>, HAZARD 1: <hazard1 definition>]

47. For example, the statement [SCENARIO 1: <new software unable to perform

FIGURE 5.7 ROLE 2 of PROCESS: [TOM]



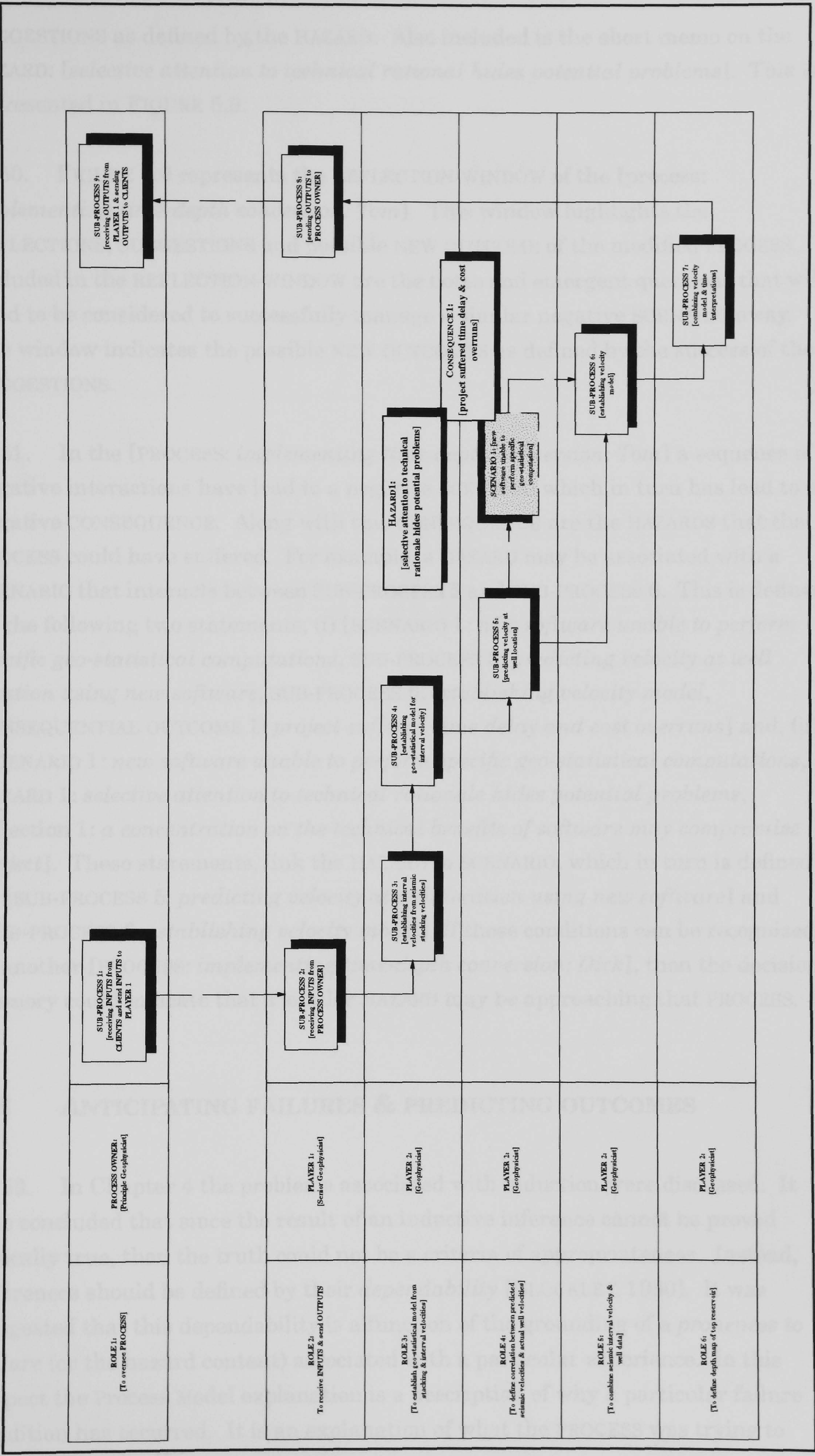
specific geo-statistical computations>, SUB-PROCESS 5: <*predicting velocity at well location using new software*>, SUB-PROCESS 6: <*establishing velocity model*>, CONSEQUENCE OUTCOME 1: <*project suffered time delay and cost overruns*>, HAZARD 1: *selective attention to technical rationale hides potential problems*] may be defined as follows, (i) SCENARIO 1 is classified as [*new software unable to perform specific geo-statistical computations*]; (ii) this SCENARIO acts between SUB-PROCESS 5 and SUB-PROCESS 6; (iii) the CONSEQUENCE of this SCENARIO is that [*project suffered time delay and cost overruns*] and; (iv) the identified HAZARD is [*selective attention to technical rationale hides potential problems*]. This is represented in the FIGURE 5.8. FIGURE 5.8 may be looked upon as the *actuality* window. The actuality window indicates a sequence of positive and negative interactions and their associated SUB-PROCESSES that contributed to the [PROCESS: *implementing time-depth conversion: Tom*]. In this example a sequence of negative interactions defines a negative SCENARIO that leads to a negative CONSEQUENCE. Behind this CONSEQUENCE is the HAZARD that the [PROCESS: *implementing time-depth conversion: Tom*] could suffer.

48. Row 13 assigns a degree of evidential measure to the affects of [CONSEQUENCE 1: *project suffered time delay and cost overrun*] on the [PROCESS: *implementing time-depth conversion: Tom*] by the statements, [NECESSARY EVIDENCE:] and [POSSIBLE EVIDENCE:]. This is highlighted again in Row 15, in which REFLECTIONS on the [PROCESS: *implementing time-depth conversion: Tom*] are defined by the following,

[EVIDENCE: <*evidence definition*>, CONSEQUENTIAL OUTCOME 1: <*consequential outcome1 definition*>, HAZARD 1: <*hazard1 definition*>, REFLECTION 1: <*reflection1 definition*>]

49. For example, the statement [EVIDENCE: <*there is no indication that consequences of SCENARIO seriously damages PROCESS*>, CONSEQUENTIAL OUTCOME 1: <*project suffered time delay & cost overruns*>, HAZARD 1: <*selective attention to technical rationale hides potential problems*>, reflection 1: <*a concentration on the technical benefits of software may compromise project*>], (i) associates a degree of EVIDENCE with a particular CONSEQUENTIAL OUTCOME; (ii) links the CONSEQUENTIAL OUTCOME of the SCENARIO with the HAZARD [*selective attention to technical rationale hides potential problems*] and the potential REFLECTION; (iii) this REFLECTION is [*a concentration on the technical benefits of software may compromise project*]. This leads to the following statement, (i) [REFLECTION 1: *a concentration on the technical benefits of software may compromise project*, SUGGESTION 1: *are the software requirements compatible with project requirements?*, SUGGESTION 2: *are you considering a 'compare and contrast exercise' between original & new software?*]. This statement is an attempt to link the identified REFLECTION with associated

FIGURE 5.8 ACTUALITY WINDOW OF [PROCESS: implementing time-depth conversion: Tom]



SUGGESTIONS as defined by the HAZARD. Also included is the short memo on the HAZARD: [*selective attention to technical rationale hides potential problems*]. This is represented in FIGURE 5.9.

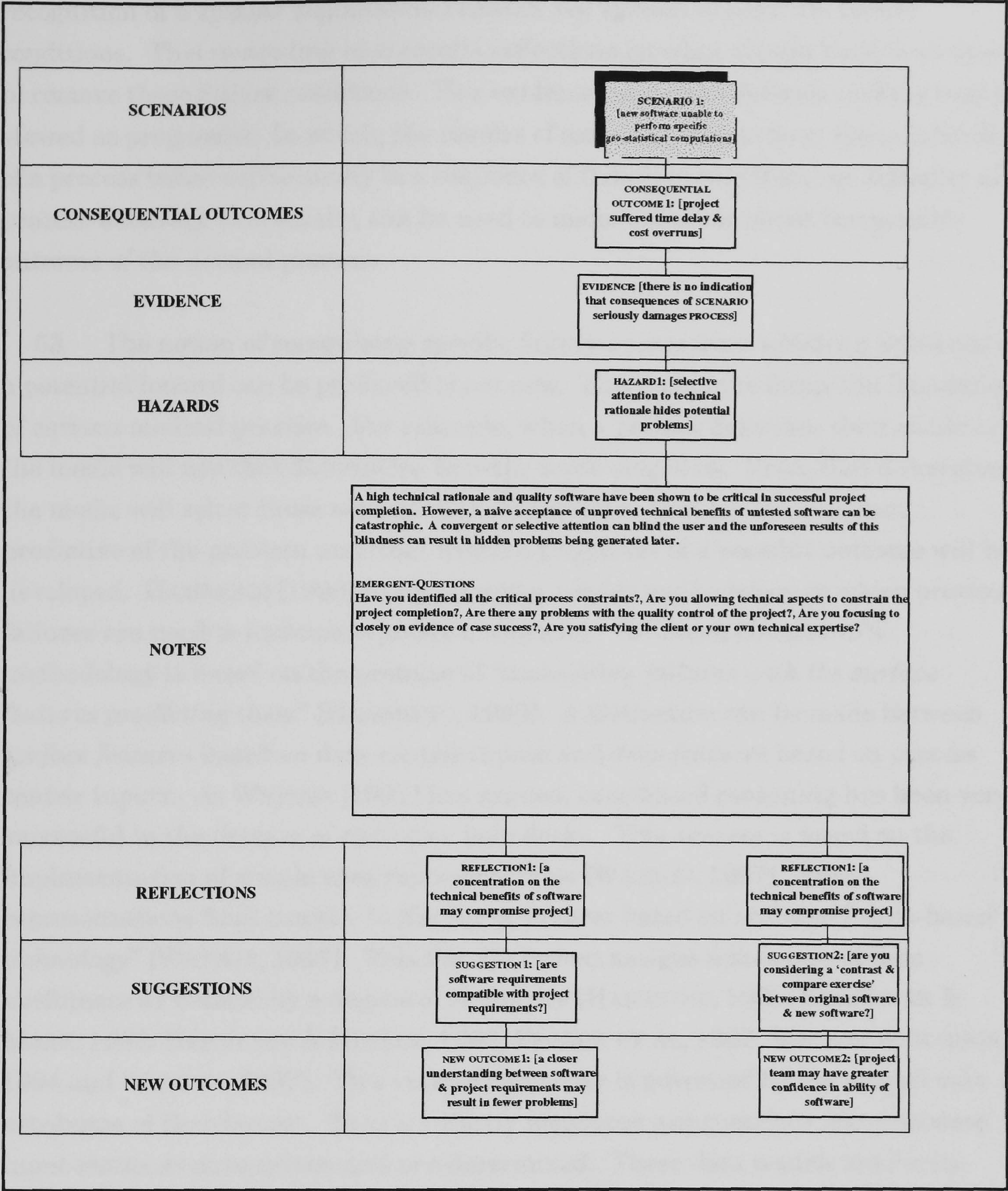
50. FIGURE 5.9 represents the REFLECTION-WINDOW of the [process: *implementing time-depth conversion: Tom*]. This window highlights the REFLECTIONS, SUGGESTIONS and possible NEW OUTCOME of the modified PROCESS. Included in the REFLECTION-WINDOW are the notes and emergent questions that will need to be considered to successfully manage a similar negative SCENARIO away. The window indicates the possible NEW OUTCOMES as defined by the success of the SUGGESTIONS.

51. In the [PROCESS: *implementing time-depth conversion: Tom*] a sequence of negative interactions have lead to a negative SCENARIO which in turn has lead to a negative CONSEQUENCE. Along with this CONSEQUENCE are the HAZARDS that the PROCESS could have suffered. For example, a HAZARD may be associated with a SCENARIO that interacts between SUB-PROCESS 5 and SUB-PROCESS 6. This is defined by the following two statements; (i) [SCENARIO 1: *new software unable to perform specific geo-statistical computations*, SUB-PROCESS 5: *predicting velocity at well location using new software*, SUB-PROCESS 6: *establishing velocity model*, CONSEQUENTIAL OUTCOME 1: *project suffered time delay and cost overruns*] and, (ii) [SCENARIO 1: *new software unable to perform specific geo-statistical computations*, HAZARD 1: *selective attention to technical rationale hides potential problems*, reflection 1: *a concentration on the technical benefits of software may compromise project*]. These statements, link the HAZARD to SCENARIO, which in turn is defined by [SUB-PROCESS 5: *predicting velocity at well location using new software*] and [SUB-PROCESS 6: *establishing velocity model*] If these conditions can be recognised in another [PROCESS: *implementing time-depth conversion: Dick*], then the decision memory could indicate that a similar HAZARD may be approaching that PROCESS.

5.6 ANTICIPATING FAILURES & PREDICTING OUTCOMES

52. In Chapter 4 the problems associated with induction were discussed. It was concluded that since the result of an inductive inference cannot be proved logically true, then the truth could not be a criteria of appropriateness. Instead, inferences should be defined by their *dependability* [BLOCKLEY, 1980]. It was suggested that this dependability is a function of the grounding of a *proneness to failure* (or the hazard content) associated with a particular experience. In this respect the Process Model explanation is a description of why a particular failure condition has occurred. It is an explanation of what the PROCESS was trying to

FIGURE 5.9 REFLECTION WINDOW OF PROCESS: [TOM]



accomplish at the point of failure. In the Reflective Process Memory this hazard capacity is stored within the Process Model explanation of the case structure. The recognition of a similar explanation reminds the system of previous failure conditions. This reminding also recalls reflections on what should have been done to remove those failure conditions. This explanation-driven decision making may be viewed as prognostic. In which, the results of matching events from the potentiality of a process behaving normally to a sequence of failure events from the actuality of a process behaving abnormally, can be used to make decisions about the possible outcome of the normal process.

53. The notion of recognising specific failure events from which an inference of a potential hazard can be produced is not new. This technique forms the foundation of current medical practice. For example, when a patient describes their condition, the medic will use that description to make some diagnosis. From that description the medic will select those aspects of the description that he/she considers predictive of the problem and from which a prognoses of a possible outcome will be developed. HAMMOND [1990] has proposed a similar methodology in which previous failures are used to anticipate possible solutions. However, HAMMOND'S methodology is based on the premise of "*associating failures with the surface features predicting them*" [HAMMOND, 1990]. A distinction can be made between *surface features* based on data centric inputs and *deep features* based on process centric inputs. As WATSON [1997] has argued, case-based reasoning has been very successful in the domain of customer help desks. This success is based on the implementation of simple case representations [WATSON, 1997]. These representations "*will usually be flat file structures based on relational data-based technology*" [WATSON, 1997]. This flat file format assigns a measure of case usefulness as defined by a degree of similarity [HAMMOND, 1989; KOLODNER & MARK, 1992; HENNESSY & HINKLE, 1992; PEARCE ET AL, 1992; WATSON & MARRIR, 1994 and WATSON, 1997]. This view of similarity is governed by the shared data attributes of that format. Thus similarity measures using surface features view input-states as data-driven and pre-determined. These data centric similarity measures can be seen as static inputs that sometimes generate *non-relevant* selections [DUTTA & BONISSONE, 1993]. This suggests that surface level features are only appropriate for the selection of simplistic, surface level representations. However, in the mess of uncertainty, problem solving or decisions making consists of knowledge that is of a more imprecise, fuzzy and ambiguous nature. In this respect uncertainty is not only a function of the uncertainty within the data, it is also a function of the uncertainty within the manner of its collection. Therefore, just as individuals within this domain construct complex and highly contextual explanations when deriving solutions [DUNCAN, 1987], then the case representations of that solution should be *enhanced* [BARR & MAGALDI, 1996]. BARR

& MAGALDI [1996] have suggested that this requires “*a fundamentally new knowledge management technology infrastructure not currently met by conventional data-focused systems*”.

54. A central premise of this thesis is that processes and process interactions are the media through which meaning and understanding are developed. These processes are active agents in constructing an experience of the past and present and may help in deciding about the future. It has been argued that a richer and hence deeper contextual explanation will be developed from interactive processes and emergent properties. Some of these emergent properties may represent the reasons behind a problem-solution failure and may be used in deriving explanations that are more relevant to the particular problem under consideration.

55. It is hypothesised, (i) that the *totality* of the process attributes are necessary for the overall success of the process; (ii) whereas it is the manner of the connection between these process attributes that may well contribute to the failure of the process. This approach views the assessment of relevance as a function of interacting processes. These connections may have emergent failure-conditions that could be used by the Reflective Process Memory to predict the possible failure of the process. These have previously been defined as *incubating hazards* [TURNER, 1978:1997] and *pathogens* [RASMUSSEN, 1983]. In this thesis they are defined as *negative-predictives*. These pivotal connections could be used by the Reflective Process Memory to recall an experience while not identical will have more relevance to the user. In this respect, the relevance of a solution may be defined by its ability in helping a decision maker to anticipate potential failures within the proposed decision path. Consequently, a similar-and-successful solution may be less useful to the decision maker, than a similar-but-failed solution. Especially, when a similar-but-failed solution can (i) explain *how* a similar solution suffered from that *failure-condition* and; (ii) provide reflections on the *why*, *where* and *when* aspects of that condition. This usefulness is a function of the *failure-explanation* and the *emergent-question* aspects of the similar-but-failed solution.

56. A measure of usefulness based on knowledge of previous failure behaviour relies on representing the failure behaviour using an explicit process explanation of that behaviour. Explaining the reasons behind a previous failure condition, allows the identification of similar observable failure conditions. The possible outcome of the identified failure condition and the results of that outcome can be used to modify the current decision strategy. A case that has failed or nearly failed will have negative SCENARIOS, negative CONSEQUENCES and HAZARDS and associated emergent questions attached to it. It will also include REFLECTIONS and SUGGESTIONS on, (i) why the case failed; (ii) which questions needed to be initially

asked; (iii) what modification are necessary to manage that failure condition and (iv) how the failure event is indexed by process attributes. In some respects this knowledge represents a SWOT (Strengths, Weakness, Opportunities and Threats) analysis of that particular case. The SCENARIOS, CONSEQUENCES, HAZARDS, REFLECTIONS and SUGGESTIONS represent the Strengths and Weakness of the case and the Threats that act upon the case. The use of this knowledge may be looked upon as an OPPORTUNITY.

57. At the diagnostic level, the Reflective Process Memory will use a Process Model explanation to explain, *how, when, where* and *why* the failure condition occurred. It will also use the Process Model explanation to explain *what* modifications were necessary to manage that failure condition and *which* questions should have been asked to minimise the occurrence of that failure condition. The Reflective Process Memory will make use of Process Model explanations it has for the problem to act as the reasons behind the *how, when, where* and *why* a failure has occurred. The Process Model explanation would described, (i) the STATES that defined the failure; (ii) the PROCESS OWNER, PLAYERS and ROLES that initiated the failure; (iii) the CONTROLS and CONSTRAINTS that allowed the failure to be initiated. In some respects this explanation may be looked upon as answers to specific questions. Questions of why a particular failure has occurred. The answering of these questions in future projects could act as an indication of the dependability of the proposed decision path. The diagnostic use of these Process Model explanations could lead to the *anticipation* of potential HAZARDS in future projects through the identification of relevant questions that perhaps should have been asked at the time but in fact were not.

58. At the prognostic level, these reasons may be marked as *negative-predictives*. Note, these negative-predictives could be composed of *predictive-processes* and *predictive-interactions*. Predictive-processes may be looked upon as specific predictives associated with a specific failure-condition, whereas predictive-interactions may be specific process-interactions that are associated with a specific hazardous-event-sequence. At this level the Reflective Process Memory could use the negative-predictives that result from a Process Model explanation to *predict* the NEW OUTCOME of a modified Process Model explanation. For example, if a SCENARIO is indexed by the negative-predictives that originally caused it, then when those negative-predictives are recognised in the current Process Model explanation the Reflective Process Memory can use those negative-predictives to identify that SCENARIO. Having identified the SCENARIO the Reflective Process Memory could inform the user of the problem that is associated with the current Process Model explanation. At this point the user could use the REFLECTIONS and SUGGESTIONS associated with the SCENARIO to re-define the Process Model explanation of the

current situation and thereby manage the failure condition away. Attached to the REFLECTIONS and SUGGESTIONS is a NEW OUTCOME. Since this NEW OUTCOME is the result of a previous Process Model explanation, then evidence of previous similar situations could be added to judgements about the present situation and future projections to form a measure of dependability associated with the NEW OUTCOME.

59. In some respects, the Reflective Process Memory parallels POPPER'S [1972] ideas on conjectures and the falsification of those conjectures. A current Process Model explanation may be viewed as a hypothesis surrounding a particular decision problem. The use of negative-predictives and emergent-questions in identifying problems within that hypothesis is an attempt to refute that hypothesis. This attempt at falsifying the hypothesis and the consequences of that falsification; namely the modification of that decision path may be used as a measure of justification and ultimately dependability in the NEW OUTCOME.

60. The whole approach is built around the idea of a dynamic constantly evolving reflective learning process. The nature of reflection in decision making considers decision building a process that tests and rationalises the decision makers understanding of the external world. Decision failures (or near misses) enable a Reflective Process Memory, through human reflection, to learn more about the causes of those failures (or near misses). Consequently, the Reflective Process Memory develops a better understanding of how to anticipate failures in the future. This model of decision building views learning as a reflective process that acts on the relationship between previous decisions, (i) an analysis of how those decisions actually performed and; (ii) the incorporation of new experiences into the decision memory. This approach attempts to *qualitatively* maximises the *usefulness* of the decision to the user, rather than *quantitatively* maximises the number of similar surface level input-states.

61. However, this requires the decision memory, (i) to structure the relationships between cases and parts of cases as processes and process interactions; (ii) to be able to represent those processes and process interactions of the decision problem; (iii) to index those negative-predictives; (vi) to identify the process knowledge of experiences that are indexed by these negative-predictives. The structure and representation of those cases as Process Model explanations have been discussed in this chapter. The indexing and identification of those Process Model explanations will be discussed in Chapter 6. Central to this discussion, is the idea that the Reflective Process Memory needs two kinds of knowledge. Firstly, an index of these negative-predictives and secondly, a process hierarchy that selectively discriminates between those negative-predictives. It is suggested that the Reflective Process Memory could use a discrimination function as defined by a

connectivity measure. This connectivity measure will use the negative-predictives to discriminate through the CASE-MEMORY and decide the overall order of the competing decision paths.

5.7 CONCLUSIONS

- The form and vocabulary of a case explanation have been outlined in this Chapter. The form (as defined through the grounded theory analysis), of the case explanation may be viewed as a Process Model and represented as a series of processes and process-interactions. The vocabulary of the Process Model explanation is defined by a Process Model algorithm.
- A grounded methodology generates a causal analysis of a problem and provides the means of defining those aspects of a situation that are responsible for causing a particular problem. These aspects may be categorised by a Reflective Process Memory as predictive of a problem. A Reflective Process Memory could create an index of predictives that are associated with previous failure conditions. The recognition of predictives in a Process Model explanation of a current decision problem may help a Reflective Process Memory to identify the occurrence of associated failure conditions.
- Process Model explanations that are recalled, (i) could provide the user with relevant reflections and actions on how, when, where and why a problem has previously occurred; (ii) could point out to the user which aspects are responsible for the problem; (iii) could suggest to the user relevant questions that were needed to be asked (but were not), during the initial decision building phase of the recalled process.
- The user could use those recalled Process Model explanation to modify the Process Model explanation of the current situation.

6. TOWARDS A CASE-BASED REFLECTIVE PROCESS MEMORY

6.1 OBJECTIVES

- To describe the methodology behind the concepts of discrimination and connectivity to be used in the retrieval of Process Model explanations.
- To present an example demonstrating the discrimination and connectivity methodology.
- To explore the idea of case *usefulness* as the relevance of the case history to the user.

6.2 INTRODUCTION

1. The reflective Process Memory (RPM) may be conceived as a formal language. Formalisation requires a definition of the form or arrangement. Form is a generic principle holding together the elements of the RPM. These elements consist of a vocabulary and a grammar. In Chapter 5, the vocabulary of the RPM was expressed as a Process Model explanations (PMX). In this Chapter the issue of the grammar or organisational structure of the RPM will be addressed. The organisational structure of the RPM is closely related to (i) the indexing of; (ii) the matching of and; (iii) the comparison and selection of relevant Process Model explanations.

2. In Chapter 4, the idea that Process Model explanations, defined as a series of emergent processes and process-interactions, generated from a grounded analysis was introduced. It was hypothesised that some of these processes and process interactions have a *benign* effect on the outcome of the decision path and some of these processes and process interactions have a *malign* effect on the outcome of the decision path. It is proposed that most-relevant may be defined by the usefulness

of the RPM in helping the decision-maker to recognise and understand how previous malignant process-interactions affected the outcome of similar decision problems.

3. In section 6.3, it is suggested that a RPM can use an index of those malignant processes and process-interactions to identify those attributes of the problem input that have a proneness to failure and hence retrieve from the CASE-MEMORY the most-relevant Process Model explanation. In section 6.4, a formal methodology that *discriminates* between stored Process Model explanations, as defined by a measure of *connectivity* that exists between those malignant attributes is introduced. In section 6.5 an example of the discrimination and connectivity methodology will be presented.

6.3 RETRIEVAL AS A FUNCTION OF DISCRIMINATION

4. The organisational structure of a Reflective Process Memory must ensure that relevant Process Model explanations are found and selected for a given problem. The efficient retrieval of relevant Process Model explanations is related to the indexing, matching and selection of those Process Model explanations. The retrieval mechanism is responsible for, (i) generating the necessary search details from the problem INPUT-STATES; (ii) searching the CASE-MEMORY for relevant patterns; (iii) ranking the returned Process Model explanations as being more or less relevant for the given problem.

6.3.1 INDEXING AS IDENTIFYING

5. An index may be viewed as a list or guide. In this respect, indices may be viewed as *pointers* that assist the RPM in comparing Process Model explanations and guide the RPM in choosing the most-relevant Process Model explanation. Consequently, the retrieval of relevant Process Model explanations are dependent upon the effectiveness of the chosen indices. It is hypothesised that for retrieval to result in the identification of relevant Process Model explanations and for selection to result in the identification of the most-relevant Process Model explanation, then the indices must represent the process-interactions and their emergent processes. In Chapter 5, the idea that a grounded methodology could provide the means for identifying those emergent processes and process-interactions was proposed. An example, demonstrating how the language of the process model explanation may be defined through this analysis was presented in Chapter 5.

6. It is assumed that the totality of these emergent processes and process-interactions represents the potential success of a decision path. However, some emergent processes and process-interactions are malign and can be associated with failure-conditions. These malignant processes and process-interactions represent the potential failures that lie in wait for the decision path. In Chapter 5, emergent processes and process-interactions associated with failure-conditions were defined as *negative-predictives* and were divided into *predictive-processes* and *predictive-interactions*. Since these negative-predictives are processes and process interactions that are associated with previous failure-conditions, then the RPM can use an index of those predictives to *discriminate* between the processes and process-interactions of a new Process Model explanation and identify those processes and process-interactions that have a proneness to failure. This discrimination can be defined as a measure of *connectivity* that exists between the negative-predictives. In section 6.3.2 the notion of discrimination as a function of connectivity is introduced.

6.3.2 FINDING AS MATCHING

7. The concept of pattern matching plays a fundamental role in knowledge and learning. Measures of similarity represent objects as points in some form of event space, in which the observed similarities between objects correspond to a similarity metric between their respective points. This event space is conventionally *static*. Conventional machine-based similarity measures are defined using a *nearest-neighbour* or *induction* metric as a function of the shared attributes of the flat file format [HAMMOND, 1989; KOLODNER & MARK, 1992; HENNESSY & HINKLE, 1992; PEARCE ET AL, 1992; WATSON & MARRIR, 1994; WATSON, 1997]. DUTTA & BONISSONE [1992] has argued that when, “*determining which case to retrieve from the case library, it is important to get not just the most similar case, but the most relevant case.*” In domains of uncertain knowledge, case usefulness may not be defined by measures of similarity, instead usefulness may be defined as being the *most-relevant* to the particular decision problem. But where is the difference between measures of similarity and measures of relevance? In addressing those concerns, it will be appropriate to first consider conventional approaches to similarity. Conventional data-centric approaches generate a *belief* that two concepts are similar, by comparing the properties that are commonly shared by the two concepts. In this respect, similarity measures as defined by a data centric view of knowledge are concerned with the content of the decision problem. Similarity is concerned with the assessment of shared data attributes. SMITH & MEDIN (1981),

suggest that each of the component properties of a concept are individual and independent. This view is reflected in conventional similarity measures. In which each property is an independent and discrete data entity and the more of these independent and discrete data entities two concepts share the closer the similarity.

8. Similarity as defined by a data centric approach may be viewed as an agreement. This stems from individuals, who over a long period of time test a statement about the defined meaning of a particular object. For example, one universal and defining agreement of the object [*planet earth*] is that it {*orbits the sun*}. However some agreements may not be universal accepted. For example, the property {*causes cancer*} is not universal accepted as being a defining property of [*smoking cigarettes*]. In Chapter 5, the discussion considered the agreement over what is the defined meaning of the object [*games*]? It was concluded that the agreement cannot be a {*competition between teams*}, or even a agreement that there must be {*at least two individuals involved*}, since [*solitaire*] is a [*game*] that has neither property. Similarly, a [*game*] cannot be defined solely by the need to have a {*winner*}. Since the child's [*game*] [*ring-a-ring-a-rosy*] has no such property. The discussion consider a more abstract property, in which anything is a [*game*] if it provides {*amusement*}. However, if {*amusement*} is a singularly necessary property of [*game*], then [*whistling*] could also be considered a [*game*]. In this respect the acceptance of a defined meaning can be seen as a flexible and a subjective agreement between individuals. An agreement defined by the point-of-view of the individuals concerned.

9. It has been previously argued that concepts are governed by a point-of-view, indexed by processes and process-interactions, defined by the role-requirements of the process explanation (applicable to the current situation) and distinguished by the *connectivity* of these processes and process interactions. These represent the contextual constraints of a concept. The usefulness of the concept definition is not a function of similarity as defined by properties of a concept, but by the nature of the processes and process interactions between two or more concepts. Therefore, if a concept pair is consider to be a set of processes, then the relevance of using one concept to identify another concept can be considered to be part of a consensus over the process connectivity of that concept pair.

10. Consider two process [*playing football*] and [*playing solitaire*]. Is [PROCESS: *playing football*] the same as [PROCESS: *playing solitaire*]? The individual could use the [POINT-OF-VIEW: *game*] to identify the indices of processes and process-interactions associated with [PROCESS: *playing football*] and the [PROCESS: *playing solitaire*]. The selection of these indices could be governed by the

ROLE requirements of the two process [*playing football*] and [*playing solitaire*]. For example, let the ROLE requirements for [PROCESS: *playing football*] and [PROCESS: *playing solitaire*] be [*an organised activity using rules*]. The RESPONSIBILITIES of the [PROCESS: *playing football*] could be [*to score goals using an inflated ball*] and the PLAYERS could be defined as [*competing teams*]. Therefore, the process explanation of [PROCESS: *playing football*] may be represented as follows; [ROLE: *an organised activity using rules*, RESPONSIBILITIES: *to score goals using an inflated ball*, PLAYERS: *competing teams*, POINT-OF-VIEW: *game*]. Whereas, the RESPONSIBILITIES of the [PROCESS: *playing solitaire*] could be [*to entertain in a pleasant manner using a deck of cards*] and the PLAYERS could be defined as [*a single individual*]. Therefore, the process explanation of [PROCESS: *playing solitaire*] may be represented as follows; [ROLE: *an organised activity using rules*, RESPONSIBILITIES: *to entertain in a pleasant manner using a deck of cards*, PLAYERS: *a single individual*, POINT-OF-VIEW: *game*].

11. Consider the question asked above, is [PROCESS: *playing football*] the same as [PROCESS: *playing solitaire*]? The individual could discriminate between the different processes and process-interactions as defined by their connectivity. For example, if [PROCESS: *playing football*] and [PROCESS: *playing solitaire*] are a concept pair as defined by the [POINT-OF-VIEW: *game*] and the concept pair can be considered to be a set of processes and process-interactions governed by the [ROLE: *an organised activity using rules*], then a distinction can be made by the connectivity of that concept pair. A discrimination measure as defined by the connectivity of the processes and process-interactions of the ROLE requirement [*an organised activity using rules*] will suggest that, (i) since [PROCESS: *playing football*] and [PROCESS: *playing solitaire*] are [*an organised activity using rules*], then [PROCESS: *playing football*] and [PROCESS: *playing solitaire*] ARE-A [*game*]; (ii) since [PROCESS: *playing football*] has the [RESPONSIBILITIES: *to score goals using an inflated ball*] using [PLAYERS: *competing teams*], then [PROCESS: *playing football*] and [PROCESS: *playing solitaire*] ARE-NOT-THE-SAME [*game*] and consequently; (iii) [PROCESS: *playing football*] IS-NOT [PROCESS: *playing solitaire*].

6.3.3 SELECTING AS RANKING

12. Various selection algorithms have been proposed. For example SMYTH & KEANE [1993], suggest that it may be *appropriate to select* cases by their ability to be *modified*, as opposed to their ability to match a set of current OBJECTIVES. However, recent studies [RIESBECK, 1996; MARK, SIMOUDS & HINKLE, 1996; HENNESSY & HINKLE, 1992] suggest that, (i) since case-modification techniques are rule-based, they are *brittle* and *quick to break*; (ii) it was unwise to restrict human involvement at the modification stage. It is proposed that selection may be defined by ranking the *usefulness* of Process Model explanations in helping the decision-maker reach a decision (or solve a problem).

13. Usefulness as defined by as THE CONCISE OXFORD DICTIONARY OF CURRENT ENGLISH [1964] is the ability to produce “*or able to produce good results*”. In this context and after constructing a Process Model explanation, (i) governed by a point-of-view; (ii) indexed by malignant processes and process-interactions; (iii) defined by the role-requirements of the process and; (iv) distinguished by the connectivity of these processes and process-interactions, then what is a good result. For example, a good result could be defined by the ability of the selected Process Model explanation to provide the user with explanations of *how* a Process Model explanation suffered from a failure condition and provide explanations, questions and suggestions on the *why*, *where* and *when* aspect of that failure condition. However, it is proposed that a good result will rely on the *relevance* of those explanations and the *relevance* of the supplied questions and suggestions. Two processes may have a superficial similarity. However, if the manner of the connectivity of the component sub-processes are dissimilar, then the explanations, questions and suggestions provided may have no relevance to the user. For example, the basic components of plastics are hydrogen and carbon, however variations of their connectivity produce differing physical properties. Consequently, expectations and explanations of these properties and questions and suggestions on their use will also differ.

14. The notion of which Process Model explanation is the *most-relevant* is dependent upon the overall process structure of the Process Model explanation as defined by the problem context. It is assumed, that the overall process structure, arrangement and interaction of the component processes and emergent properties are there to meet specific process objectives. A *selecting-as-ranking* procedure could use the totality of new case attributes as a means of selecting the *most-relevant* Process Model explanation. For example, (i) indices of malignant process interactions and their emergent properties help the RPM to identify those Process

Model explanations that are useful and hence relevant to the user; (ii) the RPM could then use the totality of new case to interrogate the already identified useful Process Model explanations and order the usefulness of those Process Model explanations into a ranking of the *most-relevant* Process Model explanations. A selecting-as-ranking algorithm is introduced in Chapter 7.

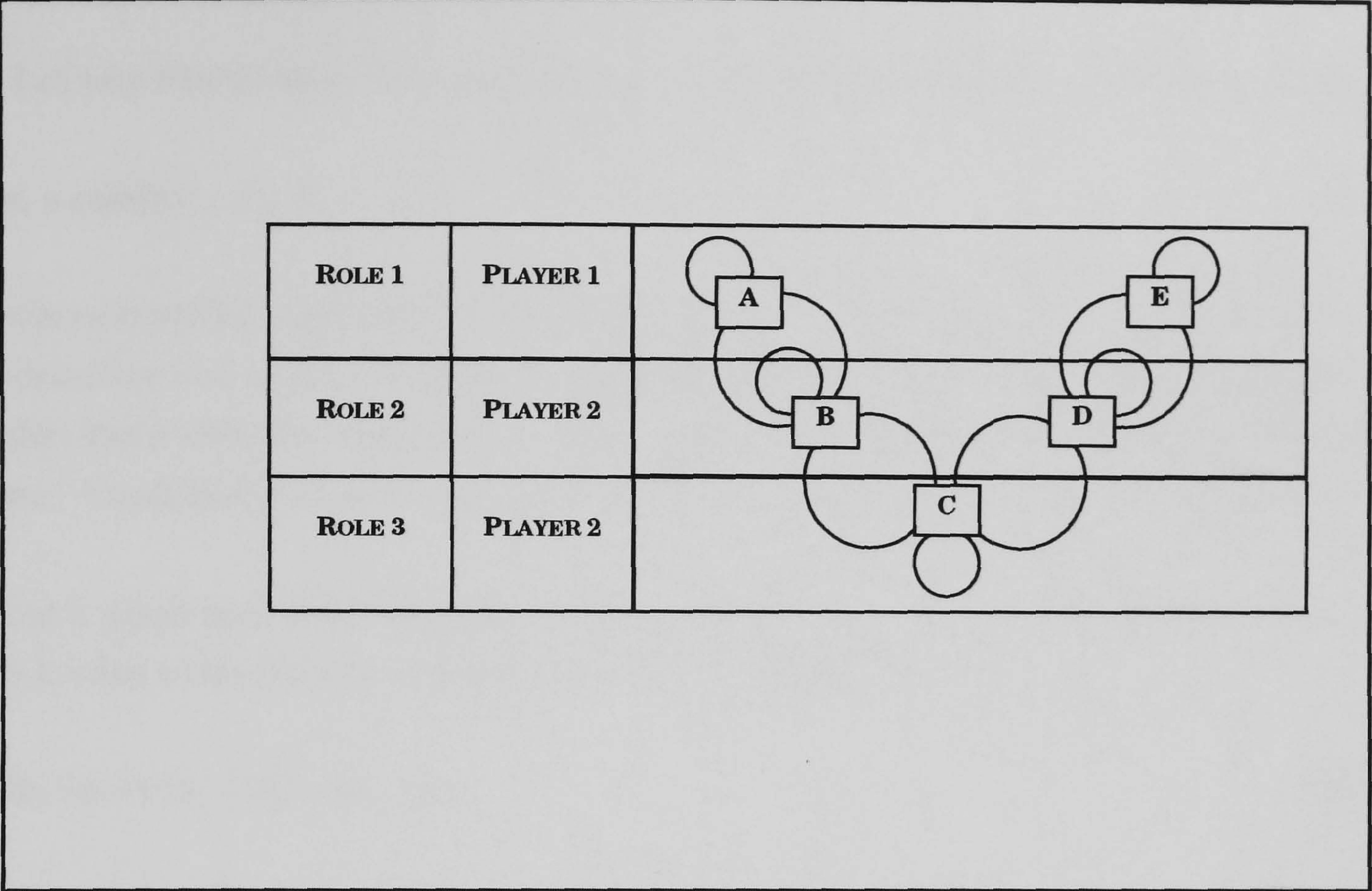
6.4 DISCRIMINATION AND INTERACTION

15. In this section a similarity measure based on discrimination and connectivity will be presented. Unlike approaches to similarity that generate a belief in similarity by comparing properties, this approach suggests that it might be more advantageous to define similarity by how much individuals make a distinction *between processes*. Below, the arguments, definitions and properties of the discrimination space and connectivity measures are discussed in detail. Some of the important properties of the discrimination and connectivity measures are introduced and the implications of this idea are highlighted with an example.

16. Discrimination and interaction are associated with the work undertaken by NORRIS, PILSWORTH & BALDWIN [1987] on medical diagnosis from patient records. They classified discrimination and connectivity as a pattern searching methodology and used a pattern search of data within a numerical tabular knowledge base. However, this approach focuses on finding patterns in the processes and process interactions of process knowledge.

17. The explanation of the methodology behind this type of analysis is based upon the process graphs first introduced in Chapter 5. Let the symmetrical graph FIGURE 6.0 represent a hierarchical process, composed of the sub-processes [A], [B], [C], [D] and [E]. FIGURE 6.0 has a defined terminology and is as follows, (i) the process model represents a process explanation and consists of nodes and edges; (ii) nodes may be classified as either super-processes, processes or sub-processes and each node may have associated attributes; (iii) process attributes are organised by a process model algorithm; (iv) not all of the attributes defined by the algorithm will be necessary for a complete process explanation; (v) process attributes are generated from a grounded analysis of the expert testimony; (vi) process attributes form a language of commonalties; (vii) each node is connected to another node by an edge and each node is connected to itself; (viii) an edge represents either a positive or negative symmetrical interaction; (ix) time is positive towards the right.

FIGURE 6.0 HIERARCHICAL PROCESS



18. It is hypothesised that an agreement between any two processes is a function of the *discrimination* between process attributes and the way in which those attributes are connected. Therefore,

- Let any **PROCESS** p , be a combination of attributes which can be expressed as,

$$p_x = \text{card}\{\alpha_x^1, \alpha_x^2, \alpha_x^3 \dots \alpha_x^n\} \quad (1)$$

where **card**{A} represents the cardinality of the set {A} and x is the **PROCESS** identifier and α_x are the **ROLES, PLAYERS, OBJECTIVES** or **SUB-PROCESSES** of that **PROCESS**. For example, α_x^1 may represent **ROLE**, α_x^2 may represent **PLAYER** etc. Cardinality may be viewed as a criteria for comparing the size of any set.

- Let a discrimination between any two processes p_x and p_y be expressed as $(p_x - p_y)$, where this may be represented as a set inequality,

$$(p_x - p_y) = (p_x \cup p_y) - (p_x \cap p_y) \quad (2)$$

- Let a measure of discrimination d_{xy} be defined as,

$$d_{xy}(p_x, p_y) = \frac{(p_x - p_y)}{(p_x \cup p_y)} \quad (3)$$

So that,

$$d_{xy}(p_x, p_y) = \frac{(p_x \cup p_y) - (p_x \cap p_y)}{(p_x \cup p_y)} \quad (4)$$

- Let conditions on the discrimination measure be defined as,

$$0 \leq d_{xy}(p_x, p_y) \leq 1 \quad (5)$$

$$d_{xy}(p_x, p_y) = 0 \quad \text{if } p_x = p_y \quad (6)$$

$$d_{xy}(p_x, p_y) = d_{yx}(p_y, p_x) \quad (7)$$

- Therefore $d_{xy}(p_x, p_y)$ may be expressed as,

$$d_{xy}(p_x, p_y) = \frac{(p_x \cup p_y)}{(p_x \cup p_y)} - \frac{(p_x \cap p_y)}{(p_x \cup p_y)} \quad (8)$$

$$d_{xy}(p_x, p_y) = 1 - \frac{(p_x \cap p_y)}{(p_x \cup p_y)} \quad (9)$$

- Let a measure of *connectivity* between any two processes p_x and p_y be defined by the inverse of the discrimination between p_x and p_y , Where the connectivity c_{xy} is expressed as follows,

$$c_{xy}(p_x, p_y) = \frac{(p_x \cap p_y)}{(p_x \cup p_y)} \quad (10)$$

Therefore,

$$c_{xy}(p_x, p_y) = 1 - d_{xy}(p_x, p_y) \quad (11)$$

- Let conditions on the connectivity measure be defined as,

$$0 \leq c_{xy}(p_x, p_y) \leq 1 \quad (12)$$

$$c_{xy}(p_x, p_y) = 1 \quad \text{if } d_{xy}(p_x, p_y) = 0 \quad (13)$$

$$c_{xy}(p_x, p_y) = c_{yx}(p_y, p_x) \quad (14)$$

- If we assume total dependency, then

$$p_{(x \cap y)} = \min[p_x, p_y] \quad (15)$$

$$p_{(x \cup y)} = \max[p_x, p_y] \quad (16)$$

- Therefore, the connectivity between p_x and p_y may be expressed as follows,

$$c_{xy}(p_x, p_y) = \frac{P_{(x \cap y)}}{P_{(x \cup y)}} \quad (17)$$

19. Equation (17) represents a measure of discrimination between process based on their connectivity. However, equation (17) also represents a condition of classical probability theory, namely that all probabilities on the sample space must sum to unity (only if $x \cup y$ represents the sample space). This condition defines the

sample space as a closed world model. Since only those attributes of the sample space are included in the model, then only combinations of those attributes are allowed. Closed world models may be defined as either, (i) Type I problems, in which all the consequences are known; (ii) Type II problems, in which all the consequences are identified, but only the probabilities of occurrence are known or; (iii) Type III problems, in which all the consequences are approximately identified, but only the probabilities of ill-defined occurrences are known.

20. In an ideal world, all information should remain consistent. Therefore, the information obtained during a grounded analysis and represented in a process model explanation should not be in conflict. However, this expectation as represented by the closed world models I, II and III and expressed in equation (17) is often at odds with open world realities. It cannot be assumed that an agreement on whether $[a]$ IS-A $[b]$ implies anything about whether $[a]$ IS-NOT-A $[b]$. To overcome these difficulties with inconsistent information requires an open world theory. DAVIS, BLOCKLEY, DROMGOOLE & FLETCHER [1996] state that “*an open world theory allows inconsistent information to be modelled and hence reasons for that inconsistency to be explored, understood and therefore, possibly, the structure of the model to be changed*”.

21. Since interval probability theory [CUI & BLOCKLEY, 1990] is an open world model, then it would seem appropriate to use interval probability theory for modelling the uncertainty in the discrimination process. Interval probability theory as developed by CUI & BLOCKLEY [1990] can be used for modelling decisions made up of sparse, incomplete and inconsistent information. An interval number may be used to represent a measure of discrimination between processes.

- Let P_{xy} be a measure of connectivity between **PROCESS** p_x and **PROCESS** p_y , where

$$P_{xy} = [c_n(x,y), c_p(x,y)] \quad (18)$$

22. $c_n(x,y)$ is a measure of support for the belief of the *necessary* connectivity between **PROCESS** p_x and **PROCESS** p_y and the opposite $-c_n(x,y)$ represents a measure of the *necessary* non-connectivity between **PROCESS** p_x and **PROCESS** p_y . However, as stated above, it cannot be assumed that evidence about a measure of connectivity between **PROCESS** p_x and **PROCESS** p_y implies anything about the non-connectivity between **PROCESS** p_x and **PROCESS** p_y . Consequently, a measure of the necessary non-connectivity is expressed by,

$$1 - c_p(x,y) = \neg c_n(x,y)$$
(19)

$$c_p(x,y) = 1 - \neg c_n(x,y)$$
(20)

23. Where $c_p(x,y)$ represents the measure of support for the belief of the *possible* connectivity between **PROCESS** p_x and **PROCESS** p_y . Following CUI & BLOCKLEY [1990] then the value $c_p(x,y) - c_n(x,y)$ represents the uncertainty associated with the measure of discrimination between **PROCESS** p_x and **PROCESS** p_y . This is shown below.

$c_n(x,y)$	$c_p(x,y) - c_n(x,y)$	$1 - c_p(x,y)$
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24. Please note, that the smaller the discrimination measure, then the greater the connection between **PROCESS** p_x and **PROCESS** p_y . Some examples may help to demonstrate the meaning of a necessary measure of connectivity and a possible measure of connectivity.

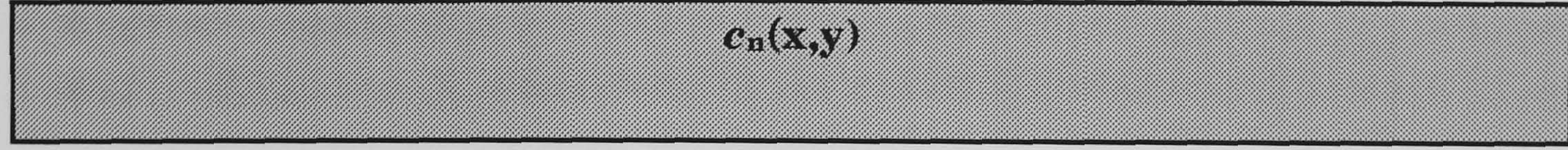
- $P_{xy} = [c_n(x,y), c_p(x,y)] = [0, 0]$ since both connectivity values are zero, then there is total discrimination between **PROCESS** p_x and **PROCESS** p_y and zero belief in the connectivity of **PROCESS** p_x and **PROCESS** p_y .

$$1 - c_p(x,y) = \neg c_n(x,y)$$

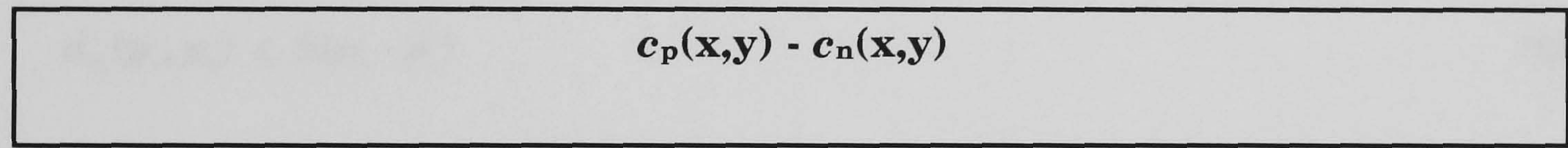
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- $P_{xy} = [c_n(x,y), c_p(x,y)] = [1, 1]$ since both connectivity values are unity, then there is zero discrimination between **PROCESS** p_x and **PROCESS** p_y and a total belief in the connectivity of **PROCESS** p_x and **PROCESS** p_y .



- $P_{xy} = [c_n(x,y), c_p(x,y)] = [0, 1]$ a necessary connectivity measure of zero and a possible connectivity measure of unity indicates total uncertainty. Therefore, while there is zero connectivity between **PROCESS** p_x and **PROCESS** p_y , there is also zero agreement.



6.4.1 PROPERTIES OF DISCRIMINATION AND INTERACTION

- Let $S(p_x)$ denote a relation between α_x^k and α_x^i . Where, $\{\alpha_x^k\}$ and $\{\alpha_x^i\}$ are attributes of the **PROCESS** p_x .

$$S(p_x) = S\{\alpha_x^1, \alpha_x^2, \dots, \alpha_x^n\} \quad (21)$$

- Let the process interactions be thought of as a set of intentional links that specify the relationships that exist between and within the attributes of a **PROCESS** p_x . For each relationship from $\{\text{attribute}\} \alpha_x^k$ to $\{\text{attribute}\} \alpha_x^i$ there exists a corresponding relationship from $\{\text{attribute}\} \alpha_x^k$ to $\{\text{attribute}\} \alpha_x^i$. That is, if $\{\text{attribute}\} \alpha_x^k$ *is-connected-to* α_x^i then $\{\text{attribute}\} \alpha_x^i$ *is-connected-by* α_x^k . See FIGURES 6.1(a), (b) & (c).

$$S(\alpha_x^k, \alpha_x^i) = 1 \quad \text{if } \{\text{attribute}\} \alpha_x^k \text{ *is-connected-to* } \alpha_x^i \quad (22)$$

$$S(\alpha_x^k, \alpha_x^i) = 0 \quad \text{if } \{\text{attribute}\} \alpha_x^k \text{ *is-not-connected-to* } \alpha_x^i \quad (23)$$

$$S(\alpha_x^k, \alpha_x^i) = 1 \quad \text{if } \{\text{attribute}\} \alpha_x^i \{\text{is-connected-by}\} \alpha_x^k \quad (24)$$

$$S(\alpha_x^k, \alpha_x^i) = 0 \quad \text{if } \{\text{attribute}\} \alpha_x^i \{\text{is-not-connected-by}\} \alpha_x^k \quad (25)$$

- Assuming total dependency, then

$$S_k(\mathbf{x} \cap \mathbf{y}) = \min[S_k(\mathbf{x}), S_k(\mathbf{y})] \quad (26)$$

$$S_k(\mathbf{x} \cup \mathbf{y}) = \max[S_k(\mathbf{x}), S_k(\mathbf{y})] \quad (27)$$

- A distinction between any two PROCESSES p_x and p_y has been expressed as the difference between p_x and p_y . Therefore, any increase in the relation $S(p_x - p_y)$ will increase the discrimination $d_{xy}(p_x, p_y)$ and any decrease in the relation $S(c_x - c_y)$, will decrease the discrimination $d_{xy}(p_x, p_y)$. From equation (3),

$$d_{xy}(p_x, p_y) = \frac{(p_x - p_y)}{(p_x \cup p_y)} \quad \text{therefore,}$$

$$d_{xy}(p_x, p_y) \leq S(p_x - p_y) \quad (28)$$

- Therefore, if a relationship exists between the discrimination d_{xy} and the connectivity c_{xy} , (such that the smaller the distinction between two PROCESSES p_x and p_y , then the greater the connectivity), and given that,

$$c_{xy}(p_x, p_y) = 1 - d_{xy}(p_x, p_y) \quad (29)$$

then,

$$c_{xy}(p_x, p_y) \geq S(p_x - p_y) \quad (30)$$

- For a given PROCESS p_x and a group of PROCESSES (p_y, p_z) having equivalent process attributes, then the discrimination d between p_x and any member of the group is equivalent to the connectivity c . Therefore, letting $S(p_y) = S(p_z)$ then,

$$d_{xy}(p_x, p_y) < d_{xz}(p_x, p_z) \equiv S(p_x \cup p_y) > S(p_x \cup p_z) \equiv c_{xy}(p_x, p_y) > c_{xz}(p_x, p_z) \quad (31)$$

- For a given PROCESS p_x and two reference PROCESSES p_y and p_z , when $S(p_x \cup p_y)$ and $S(p_x \cup p_z)$ are near enough to each other such that the corresponding connectivity's $c_{xy}(p_x, p_y)$ and $c_{xz}(p_x, p_z)$ are similar, then the larger connectivity will ensure a smaller discrimination. If,

$$S(\mathbf{p}_x \cup \mathbf{p}_z) > S(\mathbf{p}_x \cup \mathbf{p}_y) \quad (32)$$

then,

$$d_{xz}(\mathbf{p}_x, \mathbf{p}_z) < d_{xy}(\mathbf{p}_x, \mathbf{p}_y) \quad (33)$$

when

$$c_{xz}(\mathbf{p}_x, \mathbf{p}_z) > c_{xy}(\mathbf{p}_x, \mathbf{p}_y) \quad (34)$$

6.5 AN EXAMPLE

25. To illustrate the methodology, consider the examples represented in FIGURES 6.1 and FIGURES 6.2(a) and (b). FIGURE 6.1 represents a *new case* IC_1 and FIGURES 6.2(a) and (b) represent two *stored cases* SC_1 and SC_2 . The *new case* and the *stored cases* represent complete PROCESSES, composed from a set of SUB-PROCESSES. It is proposed that the connectivity measure defined from the totality of these SUB-PROCESSES and represented by the *{attribute} {is-connected-to}* connectivity matrix will discriminate between the *stored cases*. The *{attribute} {is-connected-to}* matrix as defined by equations (21), (22), (23) and (24) is represented in FIGURE 6.1 and FIGURES 6.2(a) and (b).

26. Cardinality measures of the connectivity of IC_1 and SC_1 , representing $\min(IC_1, SC_1)$ and $\max(IC_1, SC_1)$ are built from the connectivity matrix representing IC_1 and the connectivity matrix representing SC_1 using the matrix operator from equations (25) and (26). This can be seen in FIGURE 6.3 (a) which represents the connectivity-measure for $[IC_1 \cap SC_1]$ and $[IC_1 \cup SC_1]$ and takes into account the interactions or *connectivity* that may exist between the sub-processes.

27. The measure of connectivity as defined by the discrimination function [*attribute*: SUB-PROCESSES {A,B,C,D,F}, *is-connected-to*: SUB-PROCESSES {A,B,C,D,F}] returns the following,

$$c_n[IC_1, SC_1](\mathbf{p}_{IC_1}, \mathbf{p}_{SC_1}) = \frac{(\mathbf{IC}_1 \cap \mathbf{SC}_1)}{(\mathbf{IC}_1 \cup \mathbf{SC}_1)} = \frac{8}{18} = 0.44$$

FIGURE 6.2(a) STORED-CASE (IC₁)

FIGURE 6.1 NEW-CASE (IC₁)

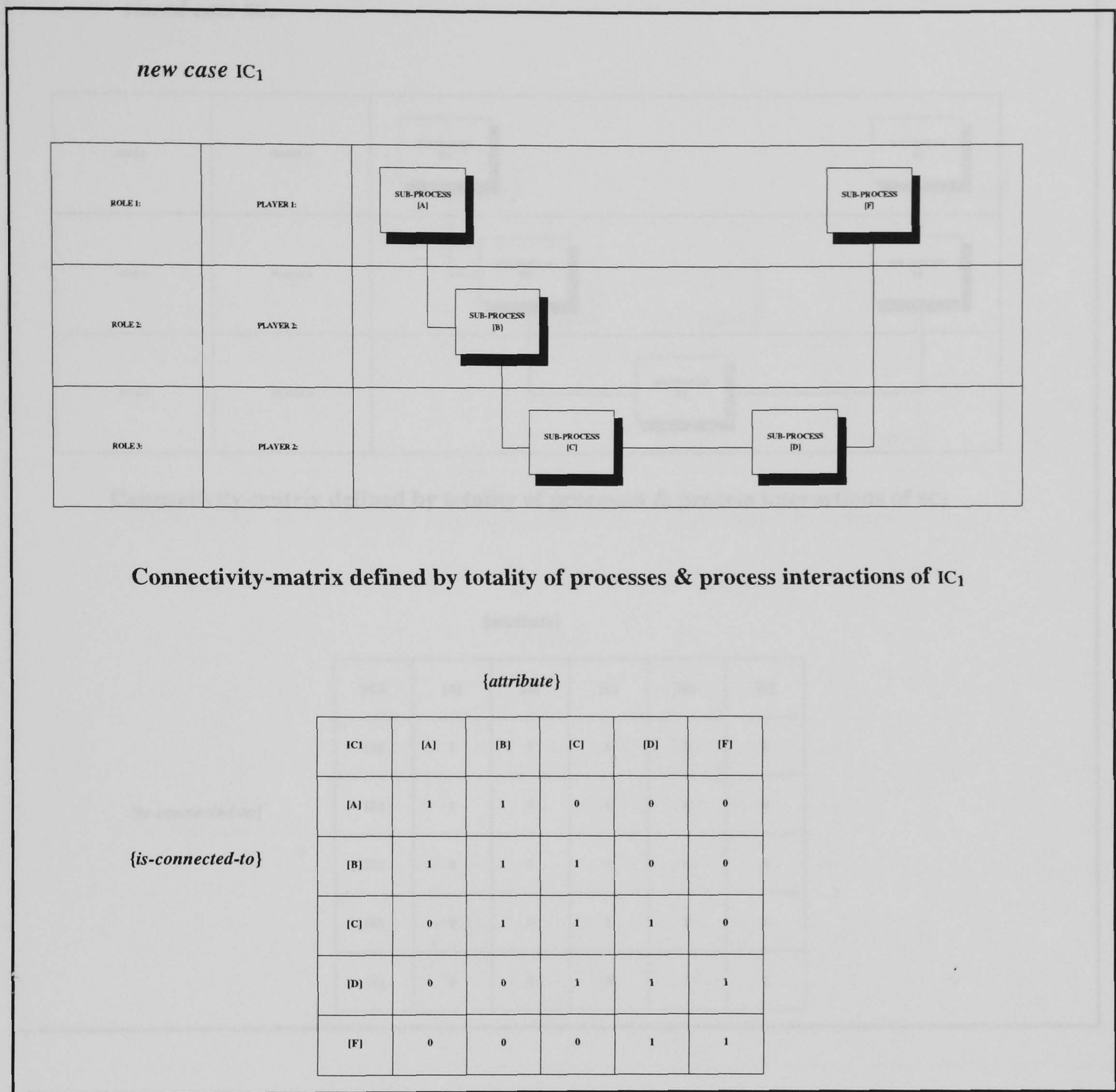


FIGURE 6.2(a) STORED-CASE (SC₁)

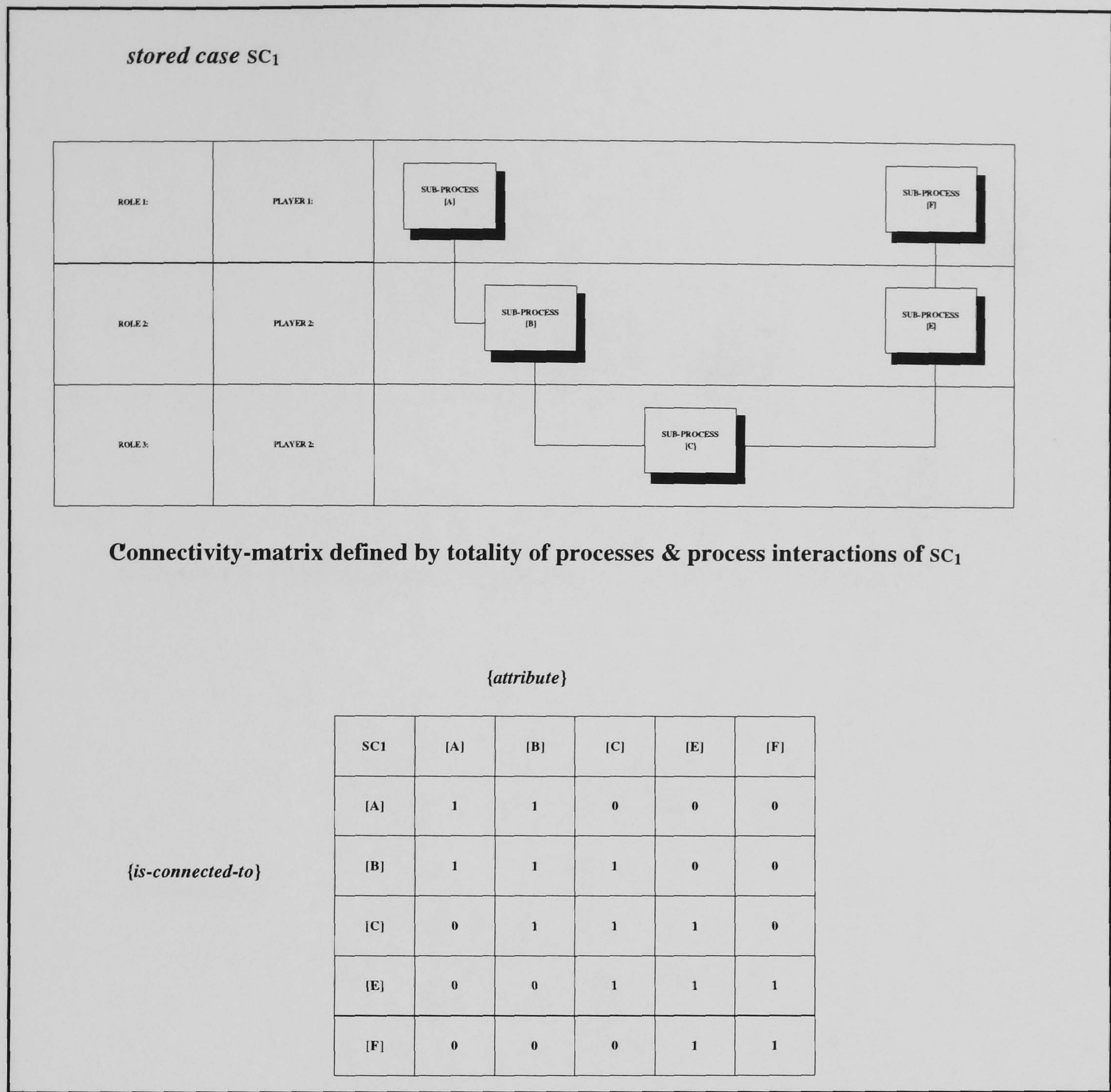
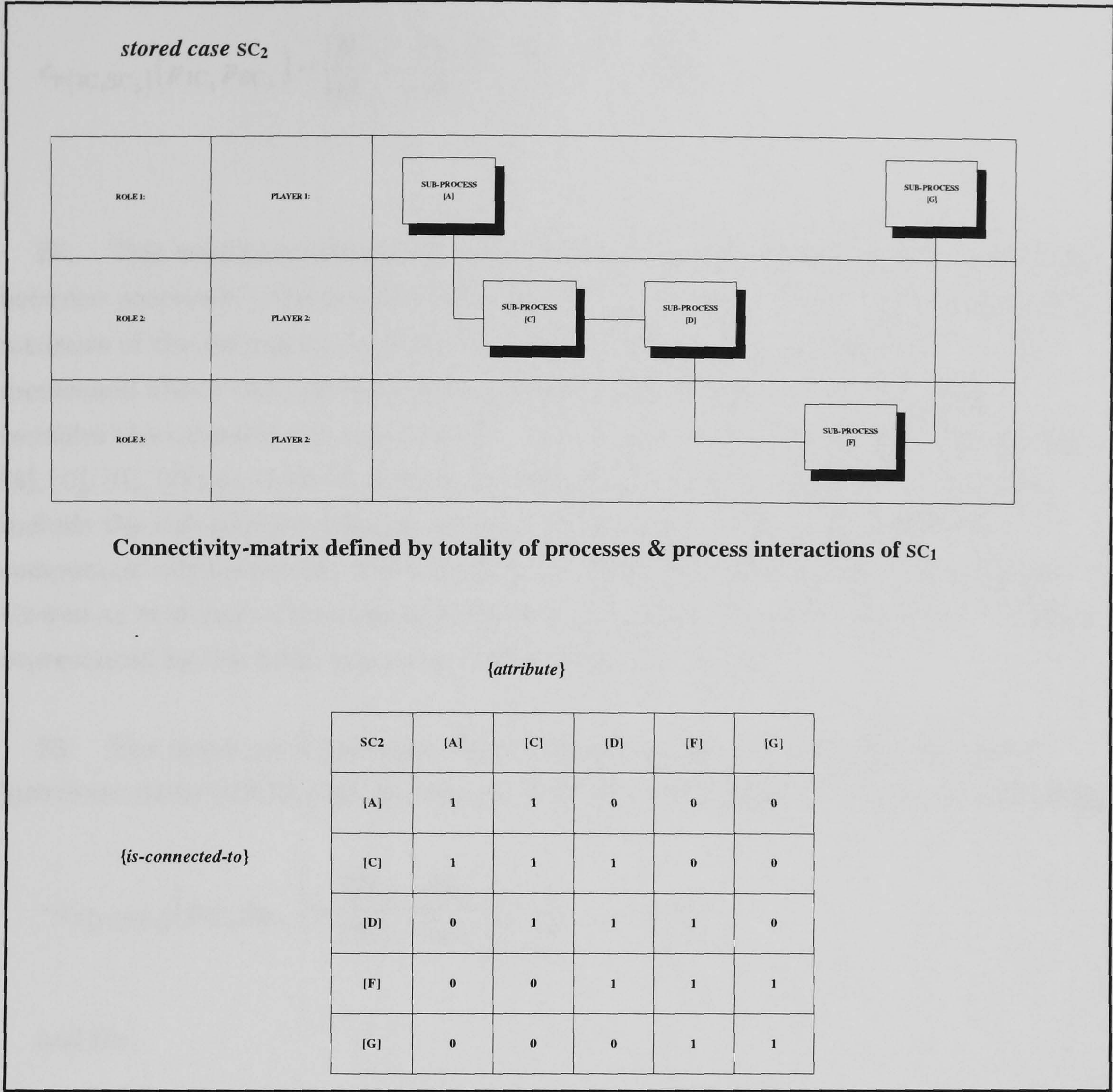


FIGURE 6.2(b) STORED-CASE (SC₂)



and for,

$$c_n[IC_1, SC_2](p_{IC_1} p_{SC_2}) = \frac{(IC_1 \cap SC_2)}{(IC_1 \cup SC_2)} = \frac{8}{16} = 0.50$$

28. This results represent the necessary support for a belief in the connectivity between process IC_1 and processes SC_1 and SC_2 . However, what is now required is a measure of the necessary support for a belief in the non-connectivity or $\neg c_n$. As mentioned above this not the inverse, but an actual measure. For example, consider the connectivity matrix of IC_1 . This is composed of five sub-processes [A], [B], [C], [D], [F] and their associated process-interactions. However, SC_1 does not include the sub-process [D] and its associated process-interactions within its component sub-processes. See FIGURES 6.1 and 6.2(a) respectively. This may be viewed as evidence of non-connectivity between process IC_1 and process SC_1 . This is represented by the **bold boxes** in FIGURES 6.3(a) & 6.3(b).

29. The measure of connectivity as defined by the discrimination function [*attribute*: SUB-PROCESS {D}, *is-connected-to*: SUB-PROCESS {D}] returns the following,

$$\neg c_n[IC_1, SC_1](p_{IC_1} p_{SC_1}) = \frac{(IC_1 \cap SC_1)}{(IC_1 \cup SC_1)} = \frac{5}{18} = 0.28$$

and for,

$$\neg c_n[IC_1, SC_2](p_{IC_1} p_{SC_2}) = \frac{(IC_1 \cap SC_2)}{(IC_1 \cup SC_2)} = \frac{5}{16} = 0.31$$

30. Therefore a measure of connectivity between IC_1 and SC_1, SC_2 may be represented by the interval,

$$P_{xy} = [c_n(x,y), c_p(x,y)] \tag{18}$$

FIGURE 6.3(a) CONNECTIVITY-MEASURE $[IC_1 \cap SC_1]$ & $[IC_1 \cup SC_1]$

(connected-to)

	(attribute)					
\min [IC1, SC1]	[A]	[B]	[C]	[D]	[E]	[F]
[A]	1	1	0	0	0	0
[B]	1	1	1	0	0	0
[C]	0	1	1	0	0	0
[D]	0	0	0	0	0	0
[E]	0	0	0	0	0	0
[F]	0	0	0	0	0	1

(connected-to)

	(attribute)					
\max [IC1, SC1]	[A]	[B]	[C]	[D]	[E]	[F]
[A]	1	1	0	0	0	0
[B]	1	1	1	0	0	0
[C]	0	1	1	1	1	0
[D]	0	0	1	1	0	1
[E]	0	0	1	0	1	1
[F]	0	0	0	1	1	1

FIGURE 6.3(b) CONNECTIVITY-MEASURE $[IC_1 \cap SC_2]$ & $[IC_1 \cup SC_2]$

(connected-to)

	(attribute)					
\min [IC1, SC2]	[A]	[B]	[C]	[D]	[F]	[G]
[A]	1	0	0	0	0	0
[B]	0	0	0	0	0	0
[C]	0	0	1	1	0	0
[D]	0	0	1	1	1	0
[F]	0	0	0	1	1	0
[G]	0	0	0	0	0	0

(connected-to)

	(attribute)					
\max [IC1, SC2]	[A]	[B]	[C]	[D]	[F]	[G]
[A]	1	1	0	0	0	0
[B]	1	1	1	0	0	0
[C]	0	1	1	1	0	0
[D]	0	0	1	1	1	0
[F]	0	0	0	1	1	1
[G]	0	0	0	0	1	1

where,

$$P_{[IC_1\ SC_1]} = [c_n(IC_1,SC_1), c_p(IC_1,SC_1)] = [0.44, 1-0.28] = [0.44, 0.72]$$

0.44 $c_n(x,y)$	0.28 $c_p(x,y) - c_n(x,y)$	0.28 $1-c_p(x,y) = \neg c_n(x,y)$
--------------------	-------------------------------	--------------------------------------

0

1

$$P_{[IC_1\ SC_2]} = [c_n(IC_1,SC_2), c_p(IC_1,SC_2)] = [0.50, 1-0.31] = [0.50, 0.69]$$

0.50 $c_n(x,y)$	0.19	0.31 $1-c_p(x,y) = \neg c_n(x,y)$
--------------------	------	--------------------------------------

0

1

31. It has been demonstrated that the measure of discrimination must lie between unity and zero, as represented by $0 < d_{xy}(p_x, p_y) > 1$. Since the measure of connectivity is represented by the inverse of the discrimination, then the greater the discrimination measure the smaller the degree of connectivity between processes. The measures of connectivity associated with the values of, $P_{(IC_1SC_1)} = [0.44, 0.72]$ and $P_{(IC_1SC_2)} = [0.50, 0.69]$ as shown above, illustrate various points. For example, (i) there is no complete match; (ii) both *stored case* SC_1 and *stored case* SC_2 are partially matched with *new case* IC_1 ; (iii) SC_2 may have a slight advantage, since the measure of connectivity is greater than that of SC_1 , while the level of associated uncertainty is lower and; (iv) while SC_1 has a lower measure of non-connectivity, it has a greater level of associated uncertainty.

32. In this Chapter, the discussion has focused on a demonstration of the discrimination and connectivity methodology. In the following Chapter, it is proposed that a discrimination function defined by the connectivity measure [*attributes*: negative-predictive-processes, *is-connected-to*: negative-predictive-processes] could be used to initiate a search routine defined by a proneness to failure. This follows the suggestion in section 6.3.1, in which predictive processes and the interaction of those processes could be used by the system to create an index of attributes associated with previous failure conditions. It was hypothesised that by recognising those predictives the system will be able to anticipate similar

problems in other cases. The use of indices defined by a proneness to failure would help the system to identify those cases that have failure conditions attached.

33. In Chapter 7, a series of case studies of a frequent petroleum engineering problem [*implementing time-depth conversion*] will be used to demonstrate how indices of NEGATIVE-PREDICTIVES could be used by a Reflective Process Memory to discriminate between Process Model explanations and identify those Process Model explanations that are useful to the user. A comparison algorithm that uses the indices of NEGATIVE-PREDICTIVES and the totality of the problem's component SUB-PROCESSES to compare the selection of useful Process model explanations and identify the most-relevant Process Model explanation will be introduced.

34. These case studies represent decision problems in the field of reservoir evaluation and examples of a grounded analysis (see Appendices A and B) of these case studies will demonstrate how the building of a Process Model explanation produces emergent processes and process-interactions. These case studies illustrate the effectiveness of reflective decision building (accessing, explaining decisions, modifying previous decisions, re-evaluating, integrating and monitoring the performance of a new decision path; as represented by a Reflective Process Memory), in creating an appropriate problem-solution environment between the user and the system.

6.6 CONCLUSIONS

- Emergent processes and their process interactions that have a malignant affect on the outcome of the decision path could be used by the Reflective Process Memory to identify those attributes of a new case that have a proneness to failure.
- The notion of a finding-as-discrimination was introduced and a formal methodology that discriminates between stored Process Model explanations, as defined by a measure of connectivity that exists between those malignant attributes was presented.
- The problems behind the condition of classical probability theory were discussed and the use of interval probability theory in modelling the uncertainty in the discrimination process was introduced.
- An example demonstrating how a measure of connectivity as defined by the discrimination function [*attribute*: SUB-PROCESSES, *is-connected-to*: SUB-PROCESS] could be used by the Reflective Process Memory to discriminate between Process Model explanations was presented.
- The idea that usefulness is a function of the ability of the Reflective Process Memory in helping a decision maker to recognise and understand how some malignant emergent process interactions may affect the outcome of similar decision problems was proposed.
- Usefulness was defined as a measure of the relevance of supplied explanations and the ability of the Reflective Process Memory in supplying relevant questions and suggestions.
- The notion of a selecting-as-ranking procedure was introduced and it was hypothesised that the totality of the new case attributes could be used to interrogate the retrieved Process Model explanations and generate a ranking of the most-relevant explanations.

7. USING FAILURE CONDITIONS TO COMPARE CASE HISTORIES

7.1 OBJECTIVES

- To introduce a comparison algorithm and to demonstrate how this algorithm uses the indices of NEGATIVE-PREDICTIVES and the totality of the problem's component SUB-PROCESSES to compare the selection of Relevant Process model explanations and identify the most-relevant Process Model explanation.
- To demonstrate the effectiveness of reflective decision building in creating an appropriate problem-solution environment between the user and the system.
- To demonstrate how the appropriateness of a problem-solution environment is governed by the notion of case relevance.

7.2 INTRODUCTION

1. In Chapter 6 a methodology was introduced to discriminate between a simplified Process Model explanation using a defined connectivity measure between processes and process-interactions. It was hypothesised that a methodology that actively discriminates in this way might be more beneficial than approaches to similarity which compares data properties. In this Chapter a comparison algorithm (using the connectivity that exists between processes and process interactions), is proposed. The algorithm uses an index of attributes associated with previous failure conditions to compare a *new case* with a CASE-MEMORY of *stored cases*. The algorithm is composed of five step-wise procedures, which are as follows, (i) problem identification; (ii) case selection; (iii) re-evaluation and acceptance; (iv) modification and; (v) integration and monitoring. The case selection stage is composed of two discrimination functions. These are, (i) a discrimination function defined by a connectivity measure [*attributes*: NEGATIVE-PREDICTIVE-PROCESSES, *is-*

connected-to: NEGATIVE-PREDICTIVE-PROCESSES] identifies those cases that have a proneness to failure and; (ii) a discrimination function defined by a connectivity measure of the totality of the component SUB-PROCESSES which selects relevant cases from those cases with a proneness to failure. This connectivity measure may be defined as [*attributes*: SUB-PROCESSES, *is-connected-to*: SUB-PROCESSES].

2. In this chapter, three case studies of a frequent petroleum engineering problem [*implementing time-depth conversion*] will be used to demonstrate the methodology behind this comparison algorithm. The PROCESS: [*implementing time-depth conversion*] has already been introduced in Chapter 5 and a description of the process will not be repeated here. However, in Appendices [A] and [B], examples of the knowledge elicitation exercise undertaken by the author are presented. These examples taken from interviews with an expert geophysicists will show, (i) how a grounded analysis of the data helped the knowledge engineer to identify the necessary process definitions, emergent processes and process-interactions and; (ii) how the focus of the knowledge elicitation exercise concentrated on the human and organisational preconditions relating to failures (or near failures). Regarding the three case studies, two are retrospective case histories of depth conversion projects that have experienced decision problems and the third case study represents an on-going project. The two retrospective case studies were assigned the identifiers [*implementing time-depth conversion*: TOM] and [*implementing time-depth conversion*: DICK], the on-going project was given the identifier [*implementing time-depth conversion*: HARRY]. Examples of the grounded analysis of the PROCESS: [*implementing time-depth conversion*] and the subsequent representation by a Process Model algorithm of the three case-studies can be found in Appendices A and B.

3. In section 7.3 an index of NEGATIVE-PREDICTIVES are used to rank the relevance of the two retrospective case studies and in section 7.4, the Process Model explanations are used to modify the Process Model explanation of the on-going project PROCESS: [*implementing time-depth conversion*: HARRY]. It will be shown how the usefulness of the recalled Process Model explanations is a function of, (i) relevant REFLECTIONS on how and why a problem occurred; (ii) SUGGESTIONS to return project to within acceptable limits; (iii) any EMERGENT-QUESTIONS that should have been asked (but were not) during the initial decision building phase of the project. Section 7.4 will conclude the chapter with a discussion on the proposed methodology.

7.3 PROBLEM IDENTIFICATION & CASE SELECTION

4. To demonstrate the methodology behind this comparison algorithm consider a *new-case* (IC_1) as represented in FIGURE 7.1(a). Let the *new-case* (IC_1) be a Process Model explanation of the decision problem [*implementing time-depth conversion: HARRY*]. To simplify the demonstration let the Process Model explanation be composed from a set of five SUB-PROCESSES. These are [A], [B], [C], [D] and [F]. It is assumed that the user wishes to compare the *new-case* (IC_1) with cases in the CASE-MEMORY and select the *most-relevant* case history. Let the CASE-MEMORY consists of only two cases; SC_1 [*implementing time-depth conversion: TOM*] and SC_2 [*implementing time-depth conversion: DICK*]. See FIGURES 7.1(b) and 7.1(c).

5. A new case may be looked upon as decision problem and is represented in the INPUT-MEMORY as a Process Model explanation. The comparison of a new case in the INPUT-MEMORY with cases in the CASE-MEMORY begins by the RPM using a PREDICTIVE-INDEX of *negative-predictives* to identify potential hazardous event sequences that may exist in the new case. See FIGURE 7.2.

7.3.1 PROBLEM IDENTIFICATION

Step 1: PROBLEM IDENTIFICATION

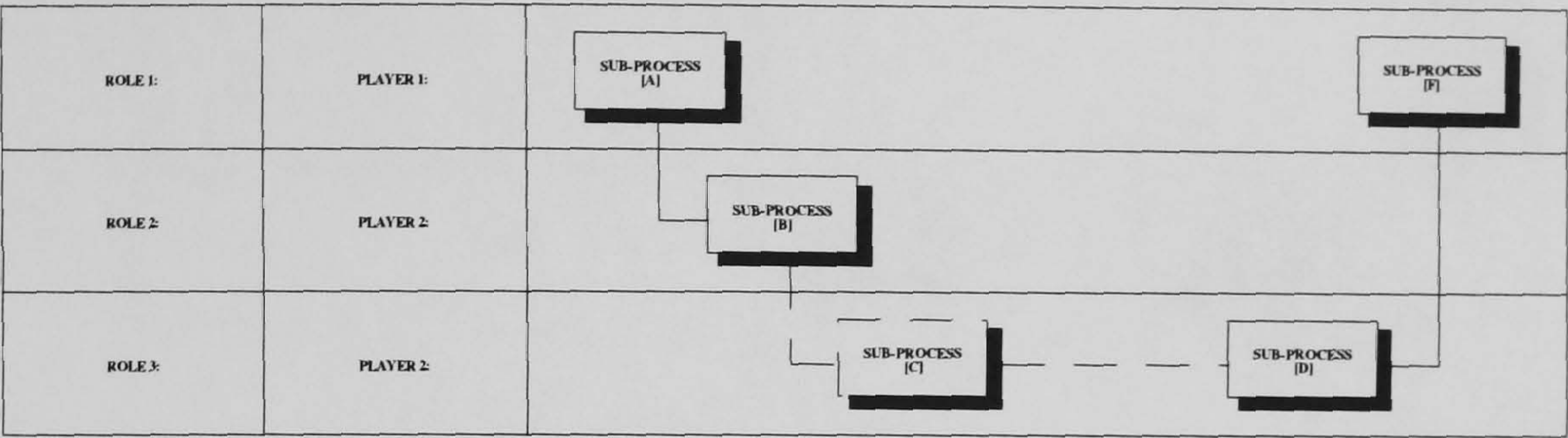
RPM will use an index of *negative-predictives* to identify hazardous event sequences that may exist within a *new-case*. See FIGURE 7.2.

- A *new-case* is added to the INPUT-MEMORY as a Process Model explanation.
- RPM uses index of *predictives* stored in PREDICTIVE-INDEX to identify hazardous event sequences of *new-case*.
- If the RPM is unable to recognise any hazardous event sequences, then RPM moves to Step 2: CASE SELECTION.
- RPM classifies identified hazardous event sequences as NEGATIVE-PREDICTIVES.
- RPM moves to Step 2: CASE SELECTION.

6. The INPUT-MEMORY is organised as a predictive function using a PREDICTIVE-INDEX of hazardous event sequences that have been shown in previous cases to develop into failure conditions. The RPM will use this PREDICTIVE-INDEX to interrogate the new case and identify those events that have (in previous cases) a proneness to failure. Identified hazardous event sequences are processed as

FIGURE 7.1(a) CONNECTIVITY MEASURES FOR IC₁

new-case IC₁



Connectivity measure defined by [attributes: NEGATIVE-PREDICTIVES, is-connected-to: NEGATIVE-PREDICTIVES]

{attributes}

{is-connected-to}

IC1	[B]	[C]	[D]
[B]	1	1	0
[C]	1	1	1
[D]	0	1	1

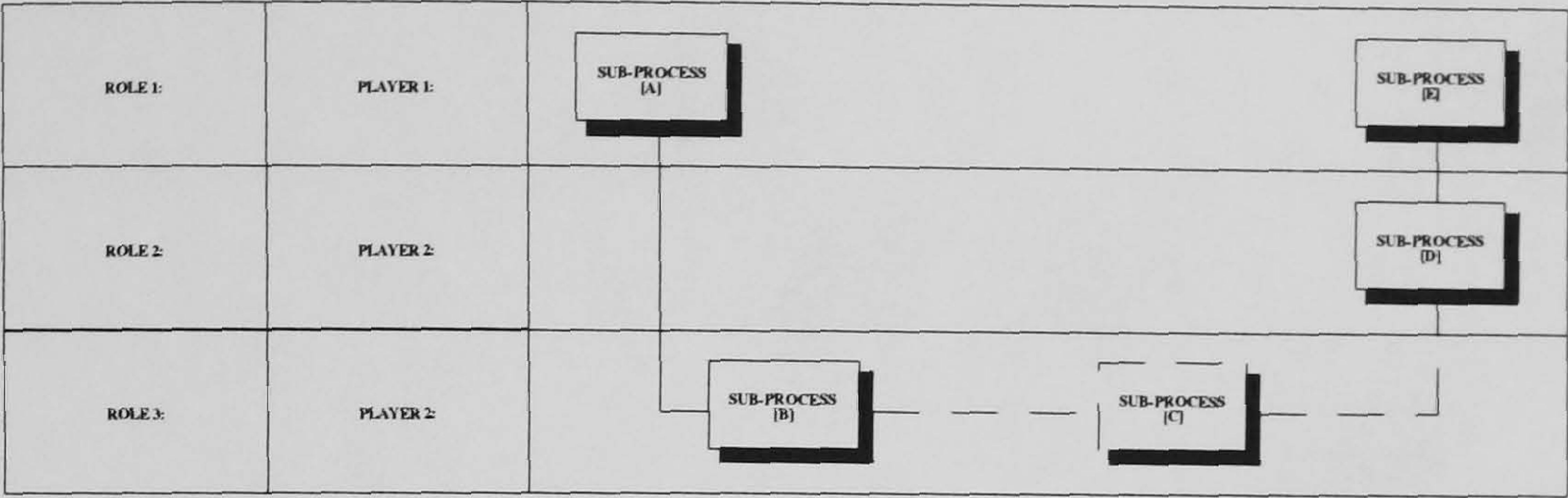
Connectivity measure defined by [attributes: SUB-PROCESSES, is-connected-to: SUB-PROCESSES]

{attributes}

{is-connected-to}

IC1	[A]	[B]	[C]	[D]	[F]
[A]	1	1	0	0	0
[B]	1	1	1	0	0
[C]	0	1	1	1	0
[D]	0	0	1	1	0
[F]	0	0	0	1	1

FIGURE 7.1(b) CONNECTIVITY MEASURES FOR SC₁



Connectivity measure for SC₁ as defined by [*attributes*: NEGATIVE-PREDICTIVES, *is-connected-to*: NEGATIVE-PREDICTIVES] of *new-case* (IC₁)

{*attributes*}

{*is-connected-to*}

SC1	[B]	[C]	[D]
[B]	1	1	0
[C]	1	1	1
[D]	0	1	1

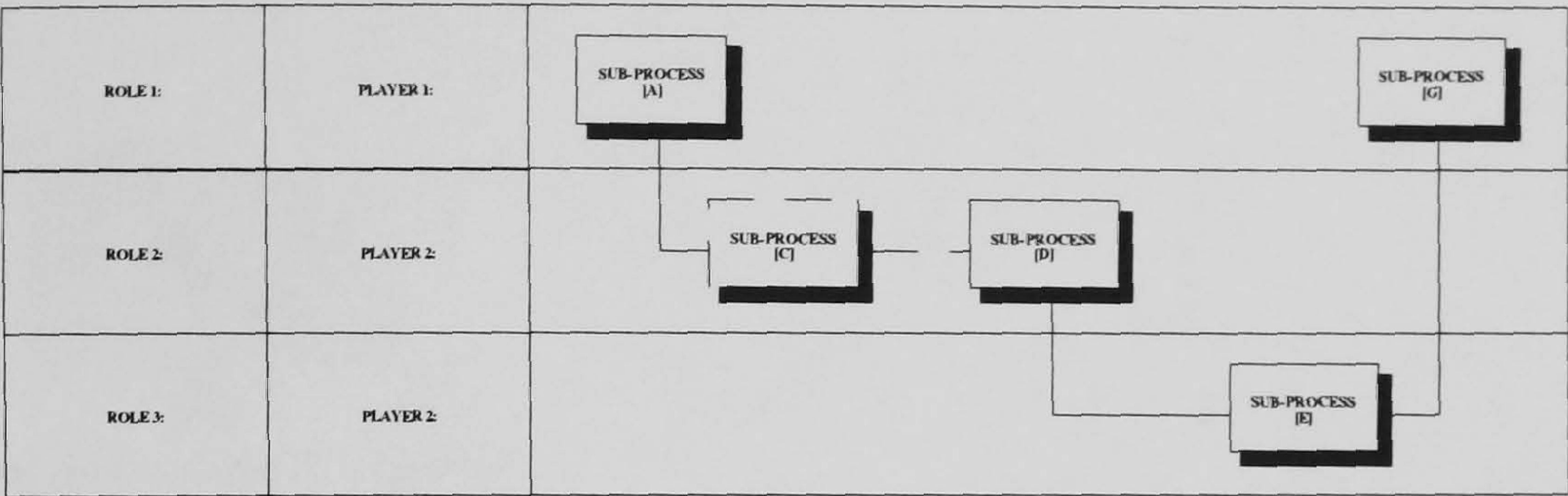
Connectivity measure for SC₁ as defined by [*attributes*: SUB-PROCESSES, *is-connected-to*: SUB-PROCESSES] of *new-case* (IC₁)

{*attributes*}

{*is-connected-to*}

SC1	[A]	[B]	[C]	[D]	[E]
[A]	1	1	0	0	0
[B]	1	1	1	0	0
[C]	0	1	1	1	0
[D]	0	0	1	1	1
[E]	0	0	0	1	1

FIGURE 7.1(c) CONNECTIVITY MEASURES FOR SC₂



Connectivity measure for SC₂ as defined by [*attributes*: NEGATIVE-PREDICTIVES, *is-connected-to*: NEGATIVE-PREDICTIVES] of *new-case* (IC₁)

{*attributes*}

{*is-connected-to*}

SC2	[B]	[C]	[D]
[B]	0	0	0
[C]	0	1	1
[D]	0	1	1

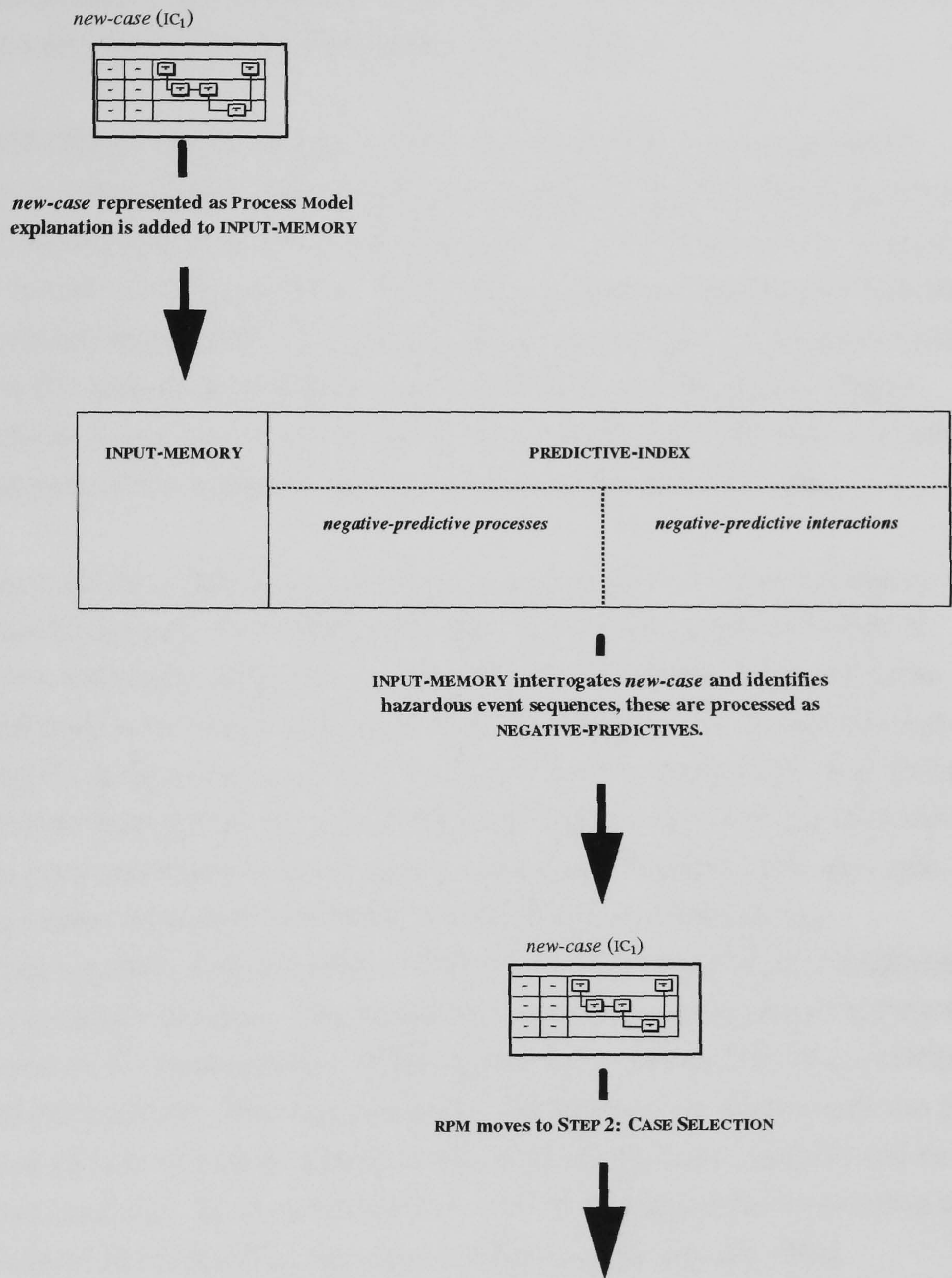
Connectivity measure for SC₂ as defined by [*attributes*: SUB-PROCESSES, *is-connected-to*: SUB-PROCESSES] of *new-case* (IC₁)

{*attributes*}

{*is-connected-to*}

SC2	[A]	[C]	[D]	[E]	[G]
[A]	1	1	0	0	0
[C]	1	1	1	0	0
[D]	0	1	1	1	0
[E]	0	0	1	1	1
[G]	0	0	0	1	1

FIGURE 7.2 PROBLEM IDENTIFICATION



NEGATIVE-PREDICTIVES. These NEGATIVE-PREDICTIVES may be sub-divided into *negative predictive processes* and *negative predictive interactions*. Negative predictive processes are specific events that have been shown to initiate a specific failure condition, whereas negative predictive interactions are specific interactions of those events that initiate a specific failure condition. If the RPM is unable to identify any hazardous event sequences and mark them as NEGATIVE-PREDICTIVES, then the RPM would move directly to Step 2: Case selection.

7. The PREDICTIVE-INDEX may be looked upon as dynamic and constantly evolving memory. During the integration and monitoring phase of the algorithm new cases will be integrated into the CASE-MEMORY. At this time and as part of the monitoring of completed case histories, additional predictive indices may well be added to the PREDICTIVE-INDEX. It is hypothesised that evidential measures of the effectiveness of the indices in predicting HAZARDS could also be added. These measures would be based on the experiential knowledge of the outcome of a new case and forms part of the integration and monitoring stage of the RPM.

8. The *new-case* (IC_1) represent a decision problem that the user wishes to match with case histories in the CASE-MEMORY. The initial input to the INPUT-MEMORY is a Process Model explanation of the decision problem. This will have been generated from a Process Model algorithm (see Chapter 5). In this example, the Process Model explanation consists of a set of five SUB-PROCESSES. See FIGURE 7.1(a). The PREDICTIVE-INDEX will highlight those *negative-predictives* that have been shown in previous cases to contribute to potential HAZARDS. For example, let some previous cases indicate that SUB-PROCESS [C] has contributed to a CONSEQUENTIAL HAZARD. Let the PREDICTIVE-INDEX highlight the SUB-PROCESS [C] as a negative predictive process. The PREDICTIVE-INDEX searches for SUB-PROCESS [C] in the Process Model explanation. If found, the index marks that SUB-PROCESS as a NEGATIVE-PREDICTIVE. Further, let some previous case histories indicate that the combination of SUB-PROCESSES [B & C] and [C & D] have also contributed to a CONSEQUENTIAL HAZARD. Let the PREDICTIVE-INDEX highlight the interaction of the SUB-PROCESSES [B-C], [C-D] as negative predictive interactions. The PREDICTIVE-INDEX searches for a combination of SUB-PROCESSES [B & C] and [C & D] in the Process Model explanation. If found the index will mark those SUB-PROCESSES as NEGATIVE-PREDICTIVES. These are shown with dashed lines in FIGURE 7.1(a). Having identified any hazardous events and marked them as NEGATIVE-PREDICTIVES, the Reflective Process Memory moves to Step 2: Case Selection.

7.3.2 CASE SELECTION

Step 2: CASE SELECTION

RPM uses the *negative-predictives* as selection indices. See FIGURE 7.3.

- RPM uses the identified *negative-predictives* of the *new-case* (IC_1) as discriminators in connectivity measure [*attributes*: NEGATIVE-PREDICTIVES, *is-connected-to*: NEGATIVE-PREDICTIVES] to select case(s) in CASE-MEMORY (FAILURES) that respond to the *negative-predictives* of the *new-case* (IC_1).
- RPM re-classifies selected case(s) as *failed-case(s)* and sends *failed-case(s)* to ACTUALITY-MEMORY.
- RPM uses totality of *process-interactions* of the *new-case* (IC_1) as discriminators in connectivity measure [*attributes*: SUB-PROCESSES, *is-connected-to*: SUB-PROCESSES] to rank *failed-case(s)* in ACTUALITY-MEMORY that respond to the *process-interactions* of the *new-case* (IC_1).
- RPM re-classifies ranked *failed-case(s)* held in ACTUALITY-MEMORY as *relevant-case(s)*.
- If RPM unable to identify any case(s) in CASE-MEMORY (FAILURES) that respond to the *negative-predictives*, then RPM use designated NEGATIVE-PREDICTIVES to interrogate CASE-MEMORY (NON-FAILURES).
- RPM uses the identified *negative-predictives* of the *new-case* (IC_1) as discriminators in connectivity measure [*attributes*: NEGATIVE-PREDICTIVES, *is-connected-to*: NEGATIVE-PREDICTIVES] to select case(s) in CASE-MEMORY (NON-FAILURES) that respond to the *negative-predictives* of the *new-case* (IC_1).
- RPM re-classifies selected case(s) as *failing-case(s)* and sends *failing-case(s)* to ACTUALITY-MEMORY.
- RPM uses totality of *process-interactions* of the *new-case* (IC_1) as discriminators in connectivity measure [*attributes*: SUB-PROCESSES, *is-connected-to*: SUB-PROCESSES] to rank *failing-case(s)* in ACTUALITY-MEMORY that respond to those *process-interactions* of the *new-case* (IC_1).
- RPM re-classifies ranked *failing-case(s)* held in ACTUALITY-MEMORY as *relevant-case(s)*.
- RPM moves to Step 3: MODIFICATION.

9. Case Selection functions at two levels. At the first level, the RPM uses those SUB-PROCESSES of the *new-case* (IC_1) that have been designated NEGATIVE-PREDICTIVES as a template. This template interrogates the CASE-MEMORY (FAILURES). The CASE-MEMORY (FAILURES) holds those case-histories that have suffered a complete process failure, these are termed *failed-case(s)*. The

FIGURE 7.3 CASE SELECTION

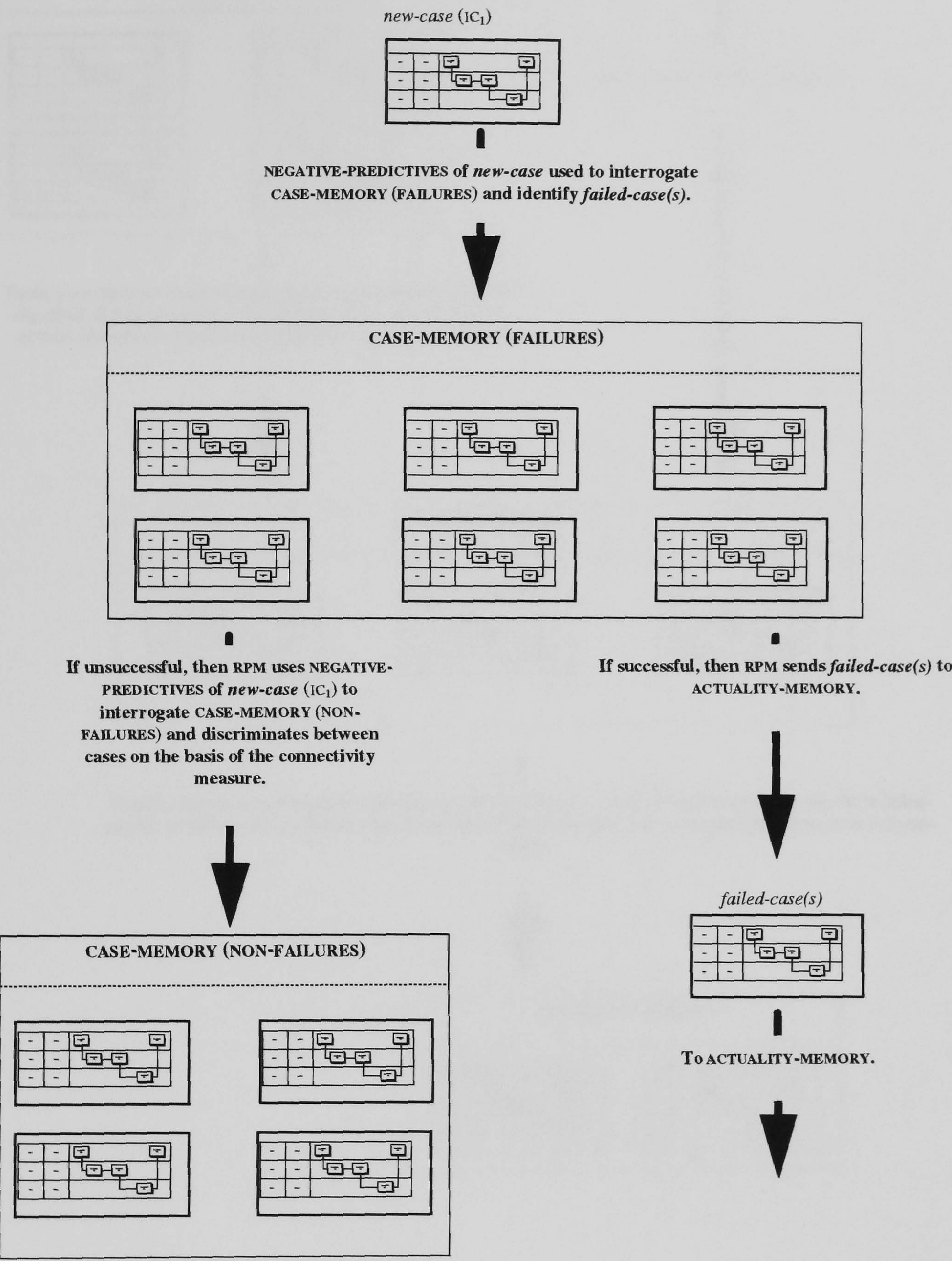
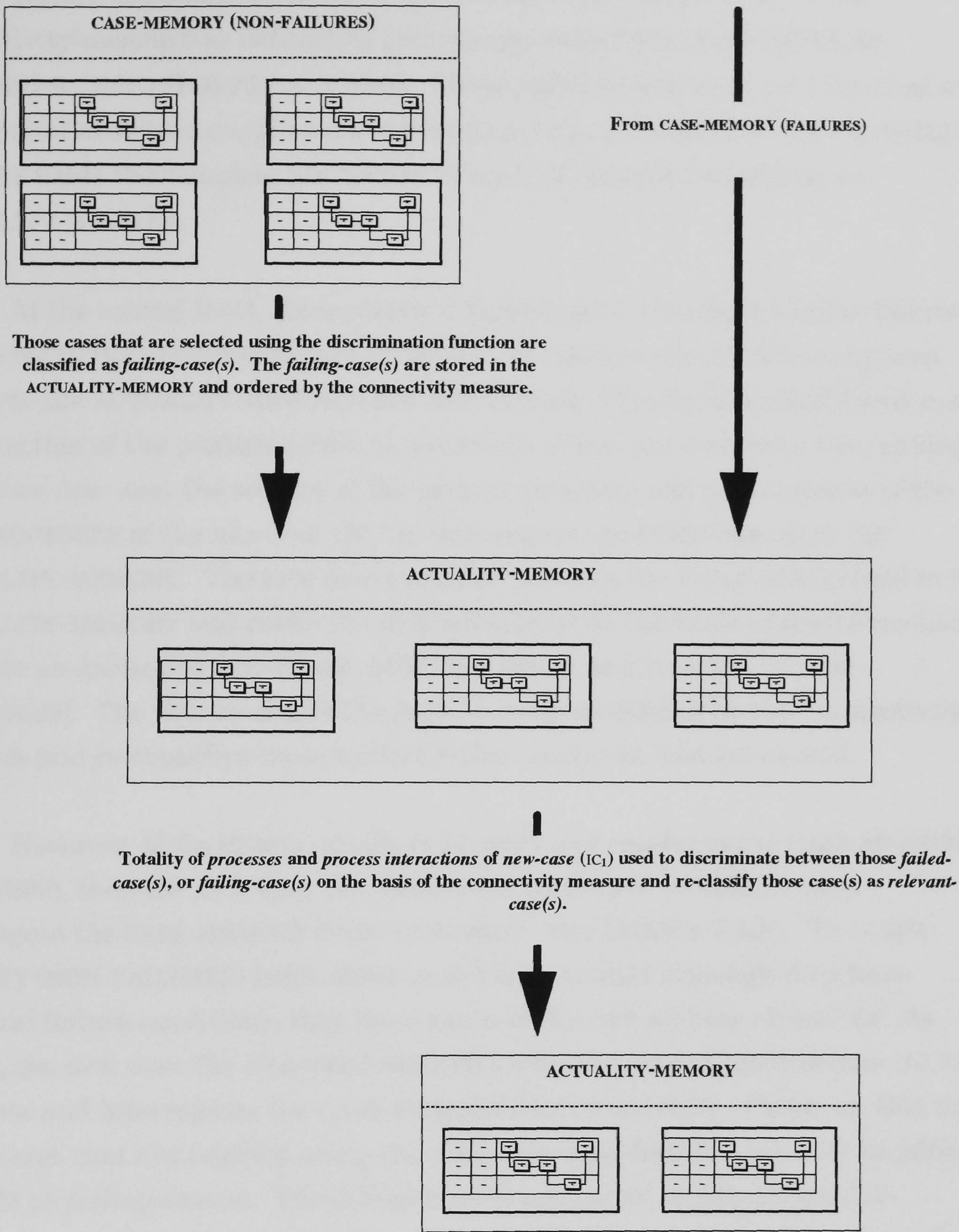


FIGURE 7.3 CASE SELECTION CONT/D



interrogation attempts to identify those *failed-case(s)* in the CASE-MEMORY (FAILURES) that have similar failure conditions to the predicted failure conditions of the *new-case* (IC_1) in the INPUT-MEMORY. It identifies those *failed-case(s)* that have similar failure conditions to those of the *new-case* (IC_1) on the basis of the connectivity-measure as defined by [*attributes*: NEGATIVE-PREDICTIVES, *is-connected-to*: NEGATIVE-PREDICTIVES]. Those *failed-case(s)* that are identified as having similar failure conditions are sent to ACTUALITY-MEMORY. The ACTUALITY-MEMORY holds the complete life-history of each of the *failed-case(s)* as an ACTUALITY-WINDOW.

10. At the second level, those selected *failed-case(s)* that have similar failure conditions to the predicted failure conditions of the *new-case* (IC_1) (having been moved to the ACTUALITY-MEMORY) are now ranked. Having identified *failed-case(s)* as a function of the predicted failure conditions of the *new-case* (IC_1), the ranking procedure now uses the totality of the overall structure and arrangement of the SUB-PROCESSES of the *new-case* (IC_1) to interrogate the *failed-case(s)* in the ACTUALITY-MEMORY. The RPM discriminates between the *failed-case(s)* held in the ACTUALITY-MEMORY and ranks those *failed-case(s)* on the basis of the connectivity measure as defined by [*attributes*: SUB-PROCESSES, *is-connected-to*: SUB-PROCESSES]. The RPM re-orders the *failed-case(s)* as defined by this connectivity measure and re-classifies those ranked *failed-case(s)* as *relevant-case(s)*.

11. However, if the RPM is unable to identify any case(s) in the CASE-MEMORY (FAILURES), then the RPM uses the designated NEGATIVE-PREDICTIVES to interrogate the CASE-MEMORY (NON-FAILURES). See FIGURE 7.2(b). The CASE-MEMORY (NON-FAILURES) holds those case-histories that although they have potential failure conditions, they have successfully met all case objectives. As before, the RPM uses the identified NEGATIVE-PREDICTIVES of the *new-case* (IC_1) as a template and interrogates the CASE-MEMORY (NON-FAILURES). However, this time, those cases that are selected using the discrimination function are now classified by the RPM as *failing-case(s)*. The *failing-case(s)* are stored in the ACTUALITY-MEMORY. As before, the ACTUALITY-MEMORY holds the complete life-history of each of the *failing-case(s)* as an ACTUALITY-WINDOW. As previously stated the ACTUALITY-MEMORY ranks the order of the *failing-case(s)* as defined by connectivity measure [*attributes*: SUB-PROCESSES, *is-connected-to*: SUB-PROCESSES] and re-classifies them as *relevant-case(s)*. In Chapter 1, it was suggested that the relevance of a solution may be defined by its ability in helping a decision maker to anticipate potential failures within the proposed decision path. In this respect a similar-and-successful solution may be less useful to the decision maker, than a similar-but-failed solution. Especially when a similar-but-failed solution can (i)

explain how a similar solution failed and; (ii) provide reflections on the why, where and when of that failure. In Chapter 5, it was argued that, (i) the use of a grounded methodology; (ii) the representation of emergent contextual properties within a Process Model explanation and; (iii) the subsequent selection, will yield explanations of the how, why, where and when of a failure-condition. Therefore, case selection (as defined by *process-interactions* and *failure-conditions*) is a function of the representational structure of the problem domain.

12. An example will illustrate the selection methodology. To simplify the description of the selection process, it has been assumed that no cases in the CASE-MEMORY (FAILURES) match the identified *negative-predictives* of the *new-case* (IC_1) and the selection procedure has moved to CASE-MEMORY (NON-FAILURES). Let the PREDICTIVE-INDEX highlight SUB-PROCESS [C] and the interaction of the SUB-PROCESSES [B-C], [C-D] as negative predictives. These are shown as dashed lines in FIGURE 7.1(a). The negative predictives are used as a selection template in an attempt to match the *new-case* (IC_1) with the *failing-case(s)* in the CASE-MEMORY (NON-FAILURES). The negative predictives are used as discriminators in the connectivity measure [*attributes*: NEGATIVE-PREDICTIVES, *is-connected-to*: NEGATIVE-PREDICTIVES] which selects from the *failing-case(s)* those cases that respond to those negative predictives of the *new-case* (IC_1). See matrix of connectivity measure [*attributes*: NEGATIVE-PREDICTIVES, *is-connected-to*: NEGATIVE-PREDICTIVES] in FIGURE 7.1(a).

13. Let the CASE-MEMORY (NON-FAILURES) contain the *failing-case* (SC_1) and *failing-case* (SC_2). See FIGURES 7.1(b) and 7.1(c). Using the methodology introduced in section 6.3, a connectivity measure [*attributes*: NEGATIVE-PREDICTIVES {B, C, D}, *is-connected-to*: NEGATIVE-PREDICTIVES {B, C, D}] defined by the predicted failure conditions of the *new-case* (IC_1) returns the following,

$$c_n[IC_1SC_1](p_{IC_1} p_{SC_1}) = \frac{(IC_1 \cap SC_1)}{(IC_1 \cup SC_1)} = \frac{7}{7} = 1.0$$

and for,

$$c_n[IC_1SC_2](p_{IC_1} p_{SC_2}) = \frac{(IC_1 \cap SC_2)}{(IC_1 \cup SC_2)} = \frac{4}{7} = 0.57$$

14. This represents the necessary support for a belief in the connectivity between process IC_1 and processes SC_1 and SC_2 . Note SC_2 does not include the sub-

process [B] and its associated process-interactions within its component sub-processes. See Figures 7.1(a) and 7.1(c) respectively. This may be viewed as evidence of non-connectivity between process IC₁ and process SC₂. The measure of connectivity as defined by the discrimination function [*attribute*: SUB-PROCESS {B}, *is-connected-to*: SUB-PROCESS {B}] returns the following,

$$\neg c_n[IC_1SC_1](p_{IC_1} p_{SC_1}) = \frac{(IC_1 \cap SC_1)}{(IC_1 \cup SC_1)} = \frac{0}{7} = 0.00$$

and for,

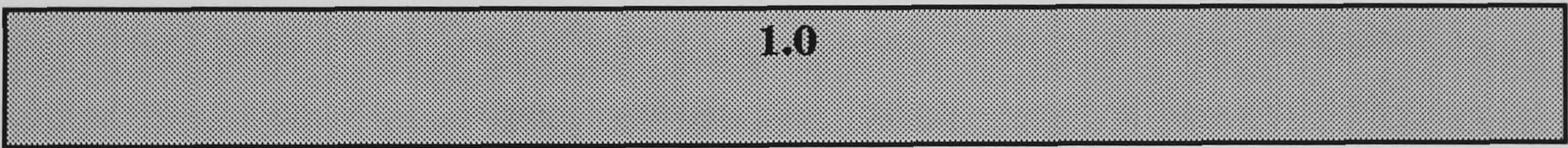
$$\neg c_n[IC_1SC_2](p_{IC_1} p_{SC_2}) = \frac{(IC_1 \cap SC_2)}{(IC_1 \cup SC_2)} = \frac{1}{7} = 0.14$$

15. Therefore a measure of connectivity between IC₁ and SC₁, SC₂ may be represented by the interval,

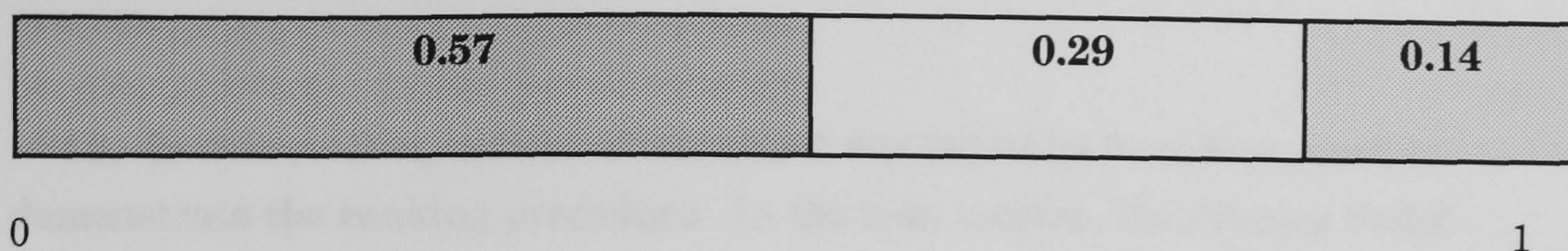
$$P_{xy} = [c_n(x,y), c_p(x,y)] \tag{18}$$

where,

$$P_{[IC_1 SC_1]} = [c_n(IC_1,SC_1), c_p(IC_1,SC_1)] = [1.0, 1-0.0] = [1.0, 1.0]$$



$$P_{[IC_1 SC_2]} = [c_n(IC_1, SC_2), c_p(IC_1, SC_2)] = [0.57, 1-0.14] = [0.57, 0.86]$$



16. Since there is no distinction between IC_1 and SC_1 , then IC_1 and SC_1 may be considered a *perfect* match. Note, SC_2 does not include SUB-PROCESS [B] within its component SUB-PROCESSES and since it cannot be included in the negative predictive interactions [B & C] and [C & D] of IC_1 , then this results in a *partial* match with IC_1 . Both SC_1 and SC_2 are moved to the ACTUALITY-MEMORY and a totality of process interactions can now be used to rank the relevance of SC_1 and SC_2 . The process interactions are used as discriminators in the connectivity measure [attributes: SUB-PROCESSES {A, B, C, D, F}, is-connected-to: SUB-PROCESSES {A, B, C, D, F}] which is then used to rank the *failing-case(s)*. Matrices of the connectivity measure [attributes: SUB-PROCESSES, is-connected-to: SUB-PROCESSES] for IC_1 , SC_1 and SC_2 are shown in FIGURES 7.1(a), 7.1(b) and 7.1(c) respectively. This discrimination function returns the following,

$$d_{[IC_1 SC_1]}(p_{IC_1} p_{SC_1}) = 1 - \frac{(IC_1 \cap SC_1)}{(IC_1 \cup SC_1)} = 0.37$$

and for,

$$d_{[IC_1 SC_2]}(p_{IC_1} p_{SC_2}) = 1 - \frac{(IC_1 \cap SC_2)}{(IC_1 \cup SC_2)} = 0.74$$

17. These results indicate that SC_1 is the *most-relevant-case* and SC_2 as the *next-most-relevant-case*. In these simple examples this can be seen by inspection. For example, (i) SC_1 consists of the negative predictive sub-process [C] and the negative predictive interactions [B & C] and [C & D]; (ii) out of the five component SUB-PROCESSES that make up IC_1 , SC_1 has four of them (these are [A], [B], [C] and [D]); (iii) the manner of their arrangement within the overall process structure closely mirrors that of IC_1 . On the basis of this level of connectivity, it is hypothesised that the quality of the Process Model explanation of SC_1 and the usefulness of the emergent questions will have more relevance to the management team of *new-case*

(IC₁) then that provided by SC₂. Note, in a manner similar to the measure of connectivity, the user may assign a degree of uncertainty across this selection process.

18. In this section, indices of NEGATIVE-PREDICTIVES have been used to demonstrate the ranking procedure. In the next section, the Process Model explanations of SC₁ (representing PROCESS: [*implementing time-depth conversion: TOM*]) and of SC₂ (representing PROCESS: [*implementing time-depth conversion: DICK*]) will be used in the modification of PROCESS: [*implementing time-depth conversion: HARRY*] and the subsequent re-evaluation & acceptance, integration & monitoring steps of the comparison algorithm.

7.4 MODIFICATION, RE-EVALUATION & ACCEPTANCE, INTEGRATION & MONITORING

19. SMYTH & KEANE [1993] have argued that case appropriateness is a function of case modification and that the automated modification of retrieved cases may be looked upon as one the last remaining problems of case-based reasoning. However, RIESBECK [1996]; MARK, SIMOUDS & HINKLE [1996]; HENNESSY & HINKLE [1992] take a different view and suggest that modification should be left to the user. For example, RIESBECK states that modification methodologies “*are hard to generalise, hard to implement, and quick to break*”, further these “*adaptation techniques have to be far more robust than they currently are, far easier to define and support, and of far greater value to the system as a whole*” [RIESBECK, 1996]. In a similar vein the work by MARK, SIMOUDIS & HINKLE on CLAVIER (Lockheed), indicated that “*automated adaptation of cases was not feasible*” [MARK, SIMOUDS & HINKLE, 1996]. The justification for using previous experience is based upon evidence of it having worked before, any “*ad hoc automated adaptation invalidates this justification*” [MARK, SIMOUDS & HINKLE, 1996] since there is no well-founded explanation to support that adaptation.

20. To overcome these problems, the Reflective Process Memory explicitly includes the user within the *reflective learning loop* as represented by the following stages, (i) modification; (ii) re-evaluation & acceptance and; (iii) integration & monitoring. It is felt that the ability of the Reflective Process Memory to present failures (or near misses) within the context of the reason for that failure (or near miss) and to provide explanations of that failure (or near miss) would be of more benefit in helping the user to modify the current case than some ad hoc automated

adaptation procedure. The success or otherwise of a Reflective Process Memory will rely on its ability to create an appropriate *problem-solution* environment between itself and the user. This forms part of a consensus on the dependability of the proposed solution and the interaction between the user and the Reflective Process Memory. In this section, the interaction between the user and the reflective process memory will be discussed with respect to the modification, the re-evaluation & acceptance and the integration & monitoring of the *new-case* (IC_1) as represented by PROCESS: [*implementing time-depth conversion*: HARRY].

7.4.1 MODIFICATION

21. Each of the cases in the ACTUALITY-MEMORY has an ACTUALITY-WINDOW attached. See FIGURE 7.4(a). FIGURE 7.4(a) represents the ACTUALITY-WINDOW OF PROCESS: [*implementing time-depth conversion*: TOM]. Each ACTUALITY-WINDOW displays the structure and arrangement of the component SUB-PROCESSES and the associated SCENARIOS and CONSEQUENTIAL OUTCOMES. Associated with each SCENARIO is a REFLECTION-WINDOW. See FIGURE 7.4(b). FIGURE 7.4(b) represents the REFLECTION-WINDOW of PROCESS: [*implementing time-depth conversion*: TOM]. The REFLECTION-WINDOW takes account of the hazardous event sequences and the SCENARIOS and CONSEQUENTIAL OUTCOMES of those hazardous event sequences as detailed in the ACTUALITY-WINDOW. It also includes, (i) REFLECTIONS on how the case history could have been re-structured to account for these hazardous event sequences; (ii) SUGGESTION on actions that may be deemed necessary to return the project to a normal state; (iii) EMERGENT-QUESTIONS that should have been asked at the project inception. The user interrogates the ACTUALITY-WINDOW of the *most-relevant-case* and decides (on the basis of this interrogation) whether the case selected by the RPM (defined by the discrimination functions as being the *most-relevant*) can be applied to the decision problem (as defined by the new case). If the *most-relevant-case* can be applied to the decision problem, then the user interrogates the REFLECTION-WINDOW of the *most-relevant-case* and attempts to modify the new case (held in the INPUT-MEMORY) in line with the suggestions of the REFLECTION-WINDOW. After updating the new case, the RPM re-classifies the new case as a *modified-new-case* and assigns the *modified-new-case* to the POTENTIALITY-MEMORY and moves to Re-evaluation & Acceptance. See FIGURE 7.5.

FIGURE 7.4(a) ACTUALITY WINDOW of PROCESS: [TOM]

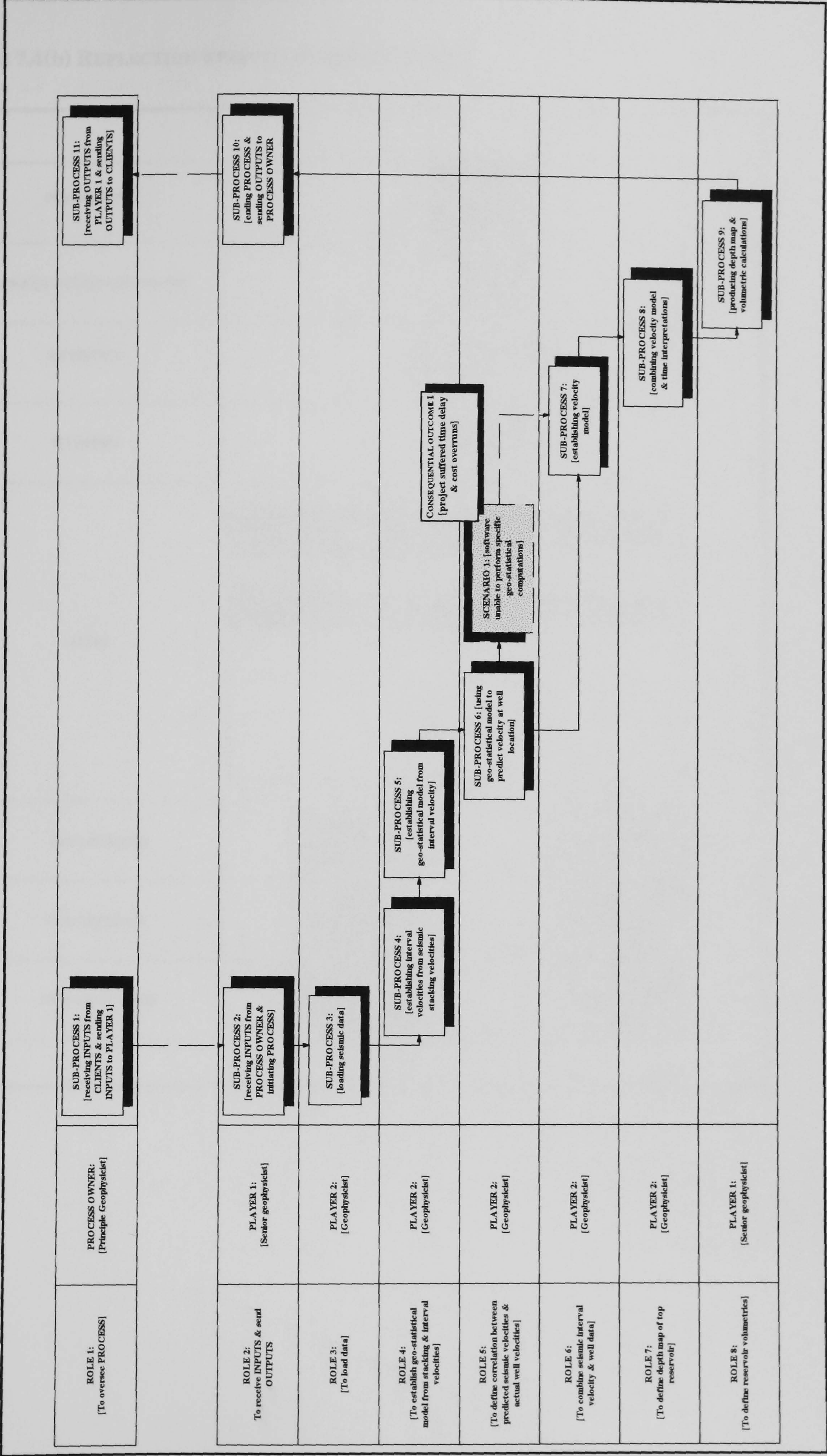


FIGURE 7.4(b) REFLECTION WINDOW OF PROCESS: [TOM]

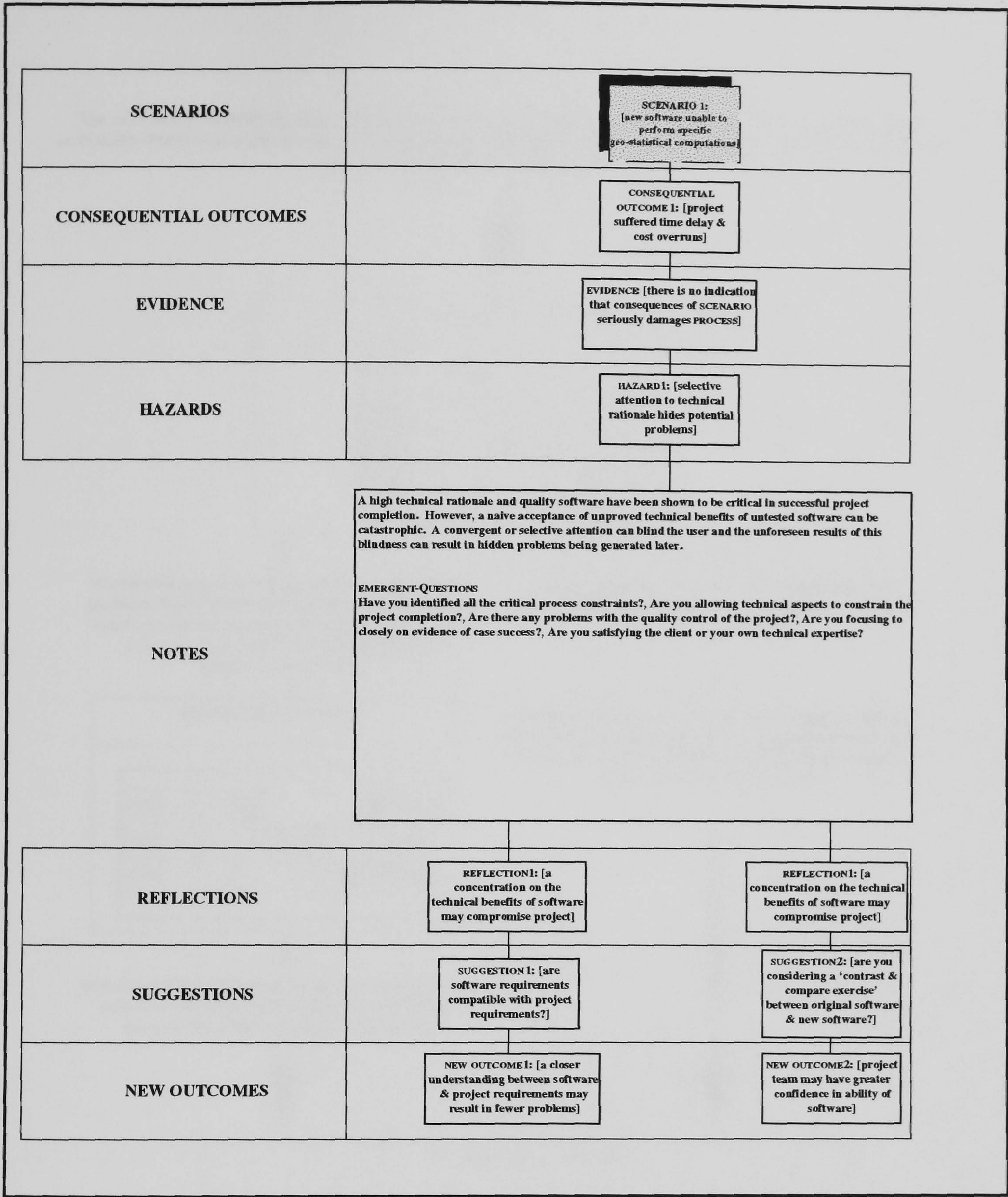
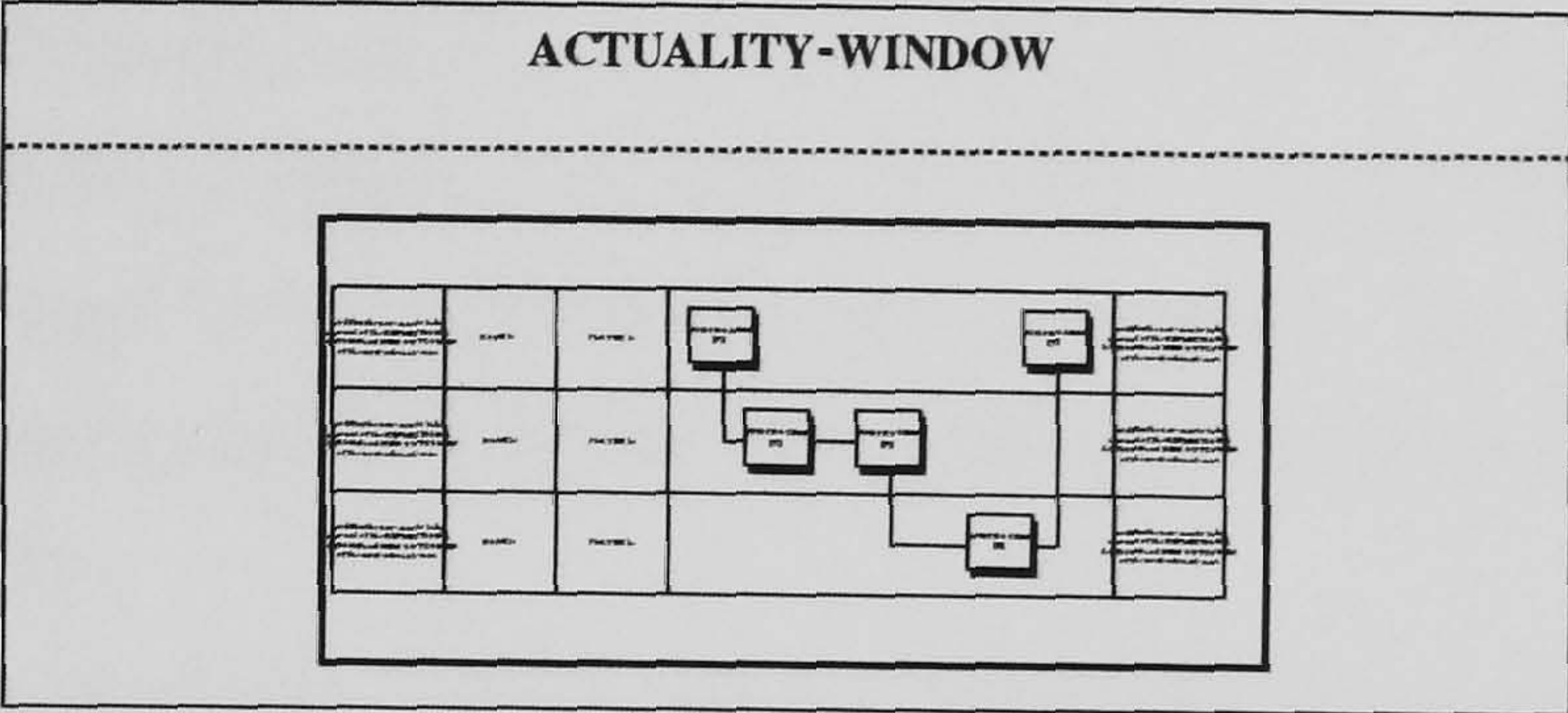


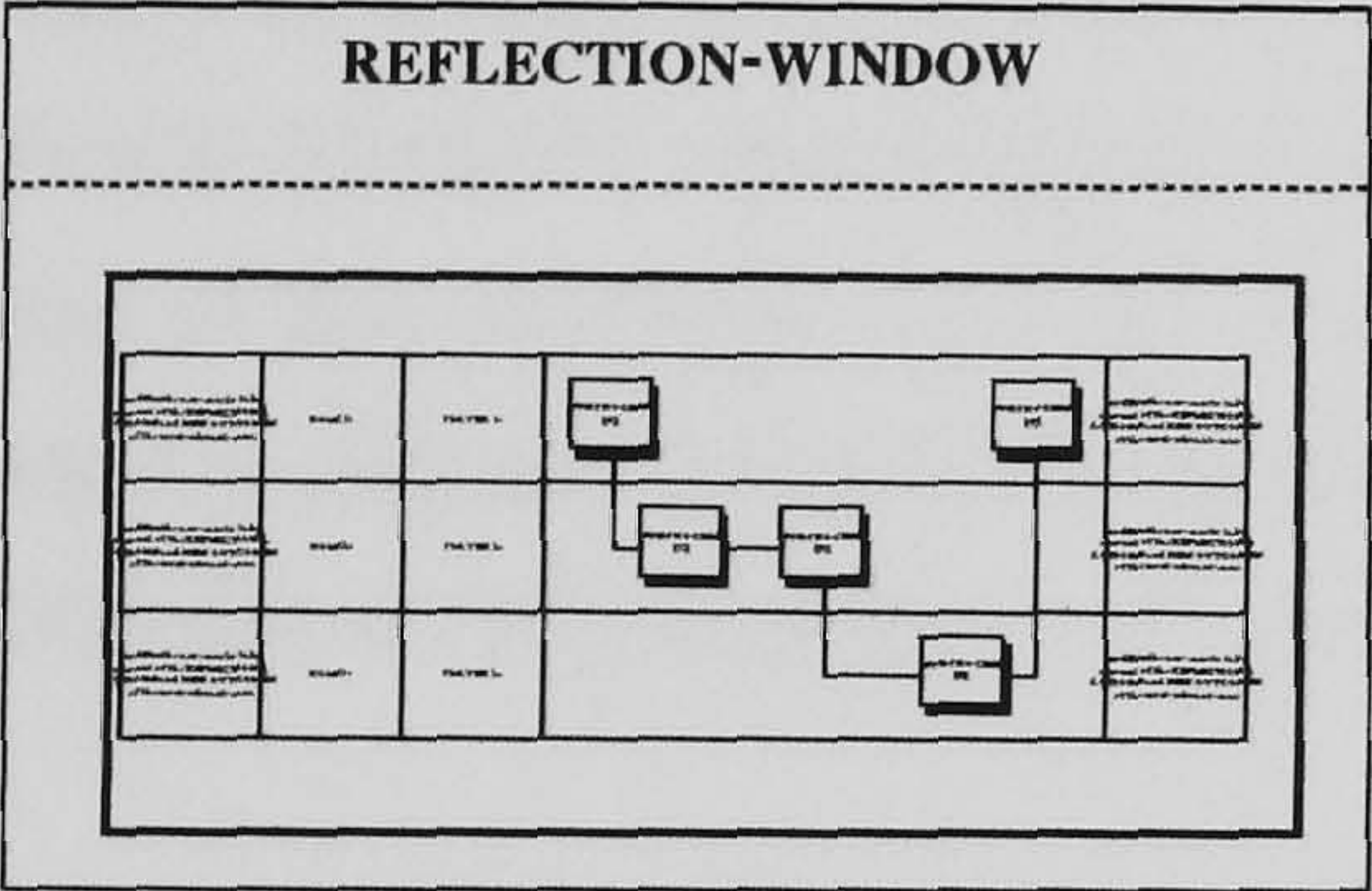
FIGURE 7.5 MODIFICATION

The ACTUALITY-WINDOW displays REFLECTIONS, ACTIONS & NEW OUTCOMES of each case. The user interrogates ACTUALITY-WINDOW of *most-relevant-case(s)* and decides whether the case selected by RPM as being the *most-relevant-case(s)* can be applied to the decision problem.



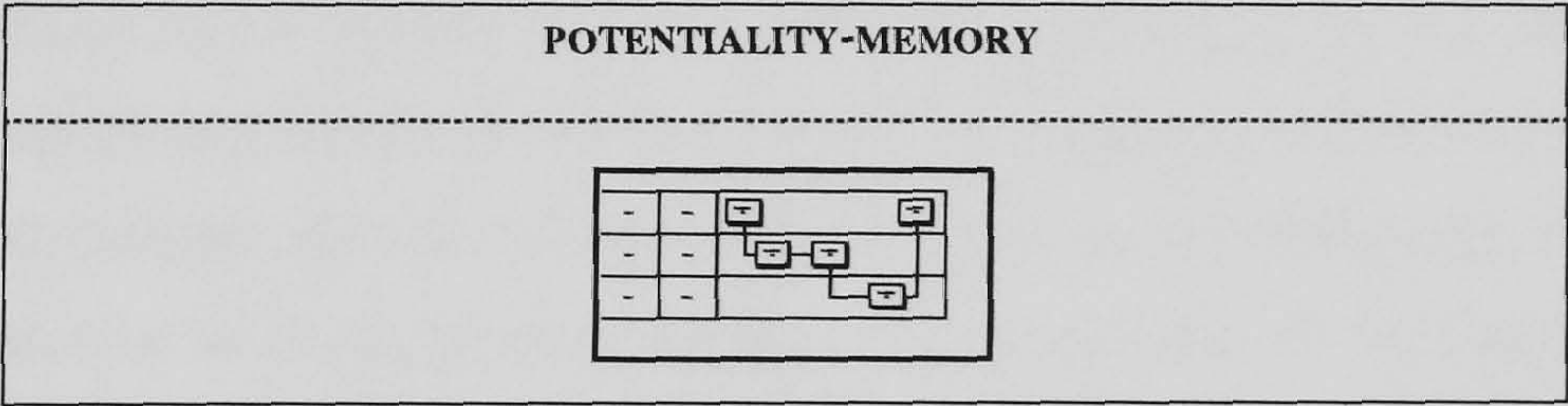
If *most-relevant-case* can be applied to the decision problem, then the REFLECTION-WINDOW of the *most-relevant-case* is accessed and the user modifies the *new-case* (IC₁) as defined by suggestions of REFLECTION-WINDOW.

If *most-relevant-case* CANNOT be applied to the decision problem, then the *next-most-relevant-case* is interrogated and so on.



If none of the *relevant-case(s)* can be applied, then the RPM stores the *new-case* (IC₁) as *unmodified-new-case* (UIC₁) in the POTENTIALITY-MEMORY and moves to INTEGRATION & MONITORING.

RPM stores the modified *new-case* (IC₁) as a *modified-new-case* (MIC₁) in POTENTIALITY-MEMORY and moves to RE-EVALUATION & ACCEPTANCE.



Step 3: MODIFICATION

On the basis of the Step 1: PROBLEM IDENTIFICATION, user selects what they consider to be most appropriate decision strategy from *relevant-case(s)* identified in Step 2: CASE SELECTION. If none of the *relevant-case(s)* can be applied, then the RPM stores the new case as a *unmodified-new-case* in the POTENTIALITY-MEMORY and moves to Step 5: INTEGRATION & MONITORING.

- RPM ranks cases in ACTUALITY-MEMORY in order of the *most-relevant-case(s)*. The ranking procedure is a function of combined connectivity measures, (i) [*attributes*: NEGATIVE-PREDICTIVES, *is-connected-to*: NEGATIVE-PREDICTIVES] and; (ii) [*attributes*: SUB-PROCESSES, *is-connected-to*: SUB-PROCESSES].
- The user interrogates ACTUALITY-WINDOW of *most-relevant-case* and decides whether the case selected by RPM as being the *most-relevant-case* can be applied to decision problem.
- If *most-relevant-case* can be applied to the decision problem, then user interrogates REFLECTION-WINDOW of the *most-relevant-case* and modifies *new-case* (IC_1) as defined by suggestions of REFLECTION-WINDOW.
- When modification of *new-case* (IC_1) is complete, the RPM re-classifies the *new-case* (IC_1) as a *modified-new-case* (MIC_1), assigns the *modified-new-case* (MIC_1) to the POTENTIALITY-MEMORY and moves to step 4: RE-EVALUATION & MONITORING.
- If none of the *relevant-case* held in ACTUALITY-MEMORY can be applied to decision problem, then RPM stores *new-case* (IC_1) as a *unmodified-new-case* (UIC_1) in POTENTIALITY-MEMORY and moves to Step 5: INTEGRATION & MONITORING.

22. Consider the *new-case* (IC_1) as represented in FIGURE 7.6. FIGURE 7.6 expresses the decision problem of the PROCESS: [*implementing time-depth conversion*: HARRY] as part of a hierarchical graphical Process Model explanation and represents the initial problem input. From the modification phase of the above algorithm, the user interrogates the ACTUALITY-WINDOW of the *most-relevant-case* and decides whether the Process Model explanation selected by the Reflective Process Memory as being the *most-relevant* can be applied to the decision problem. If the *most-relevant-case* cannot be applied, or if the user wishes to consider alternatives, then the *next-most-relevant-case* is interrogated by the user. In section 7.3, it was noted that SC_1 (PROCESS: [*implementing time-depth conversion*: TOM]) was the *most-relevant-case* and SC_2 (PROCESS: [*implementing time-depth conversion*: DICK]) was the *next-most-relevant-case*. The ACTUALITY-WINDOWS and REFLECTION-WINDOWS of PROCESS: [*implementing time-depth conversion*: DICK] are shown in FIGURES 7.7(a) and 7.7(b) respectively.

FIGURE 7.6 NEW-CASE (IC₁) PROCESS: [HARRY]

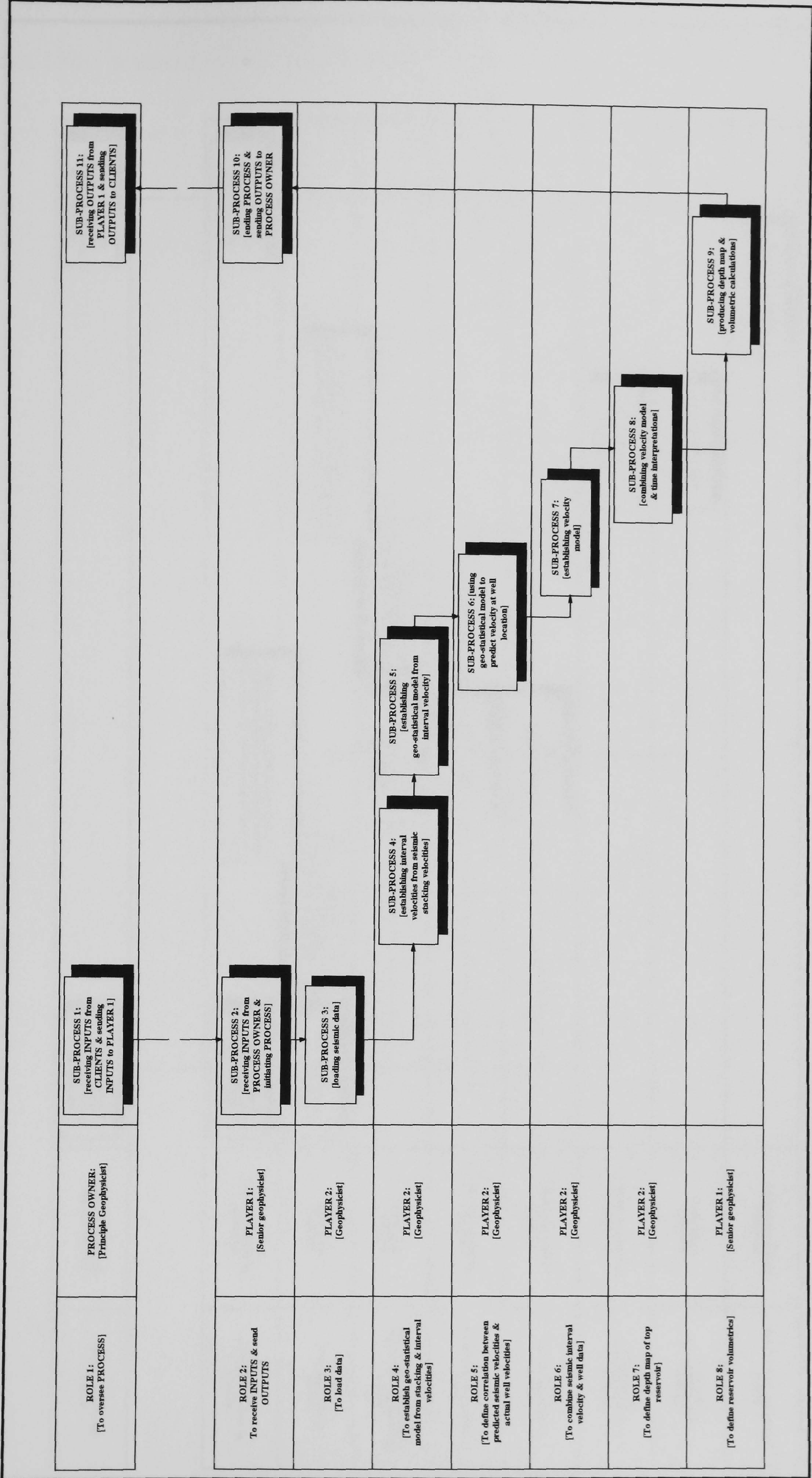


FIGURE 7.7(a) ACTUALITY WINDOW OF PROCESS: [DICK]

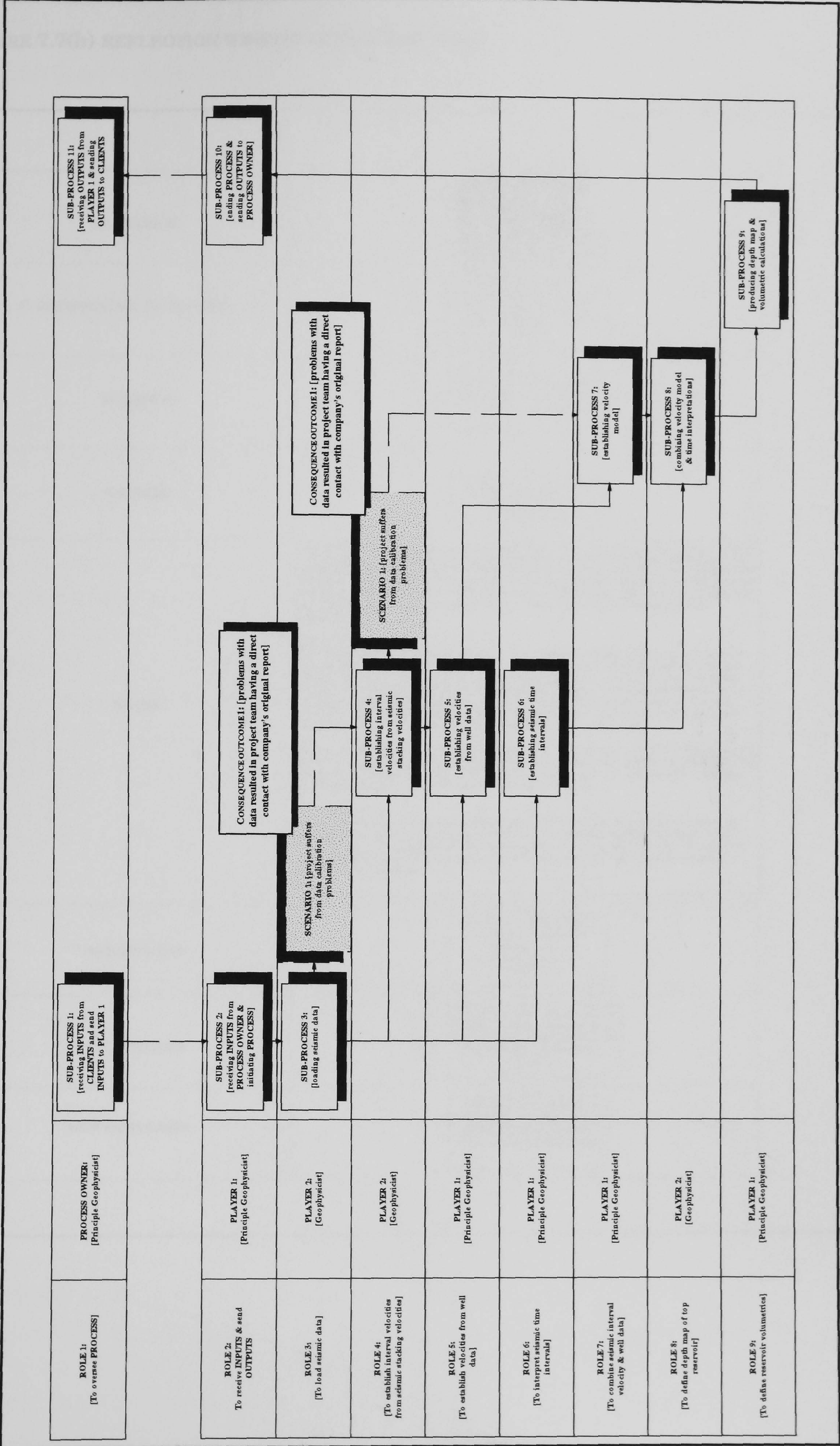
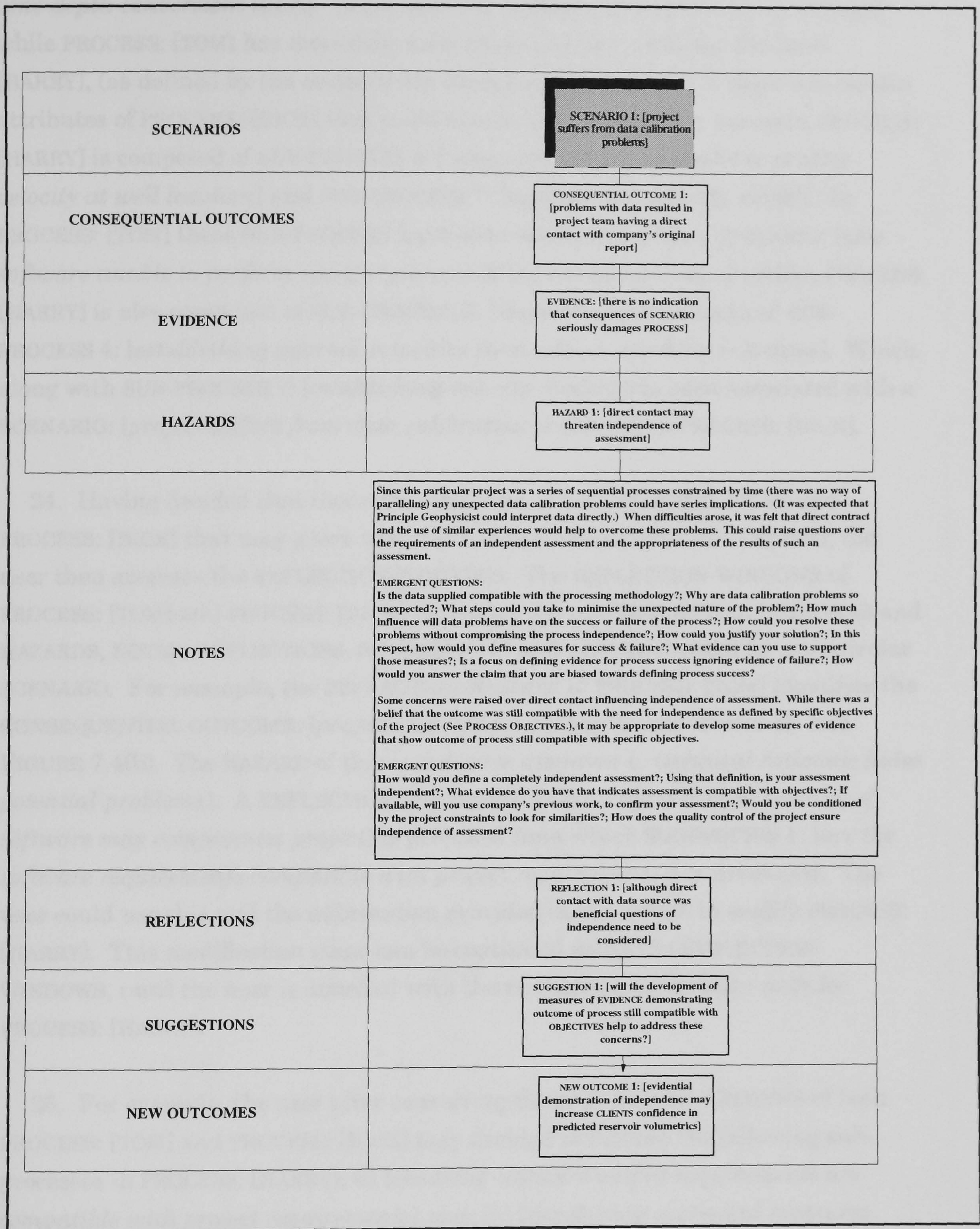


FIGURE 7.7(b) REFLECTION WINDOW of PROCESS: [DICK]

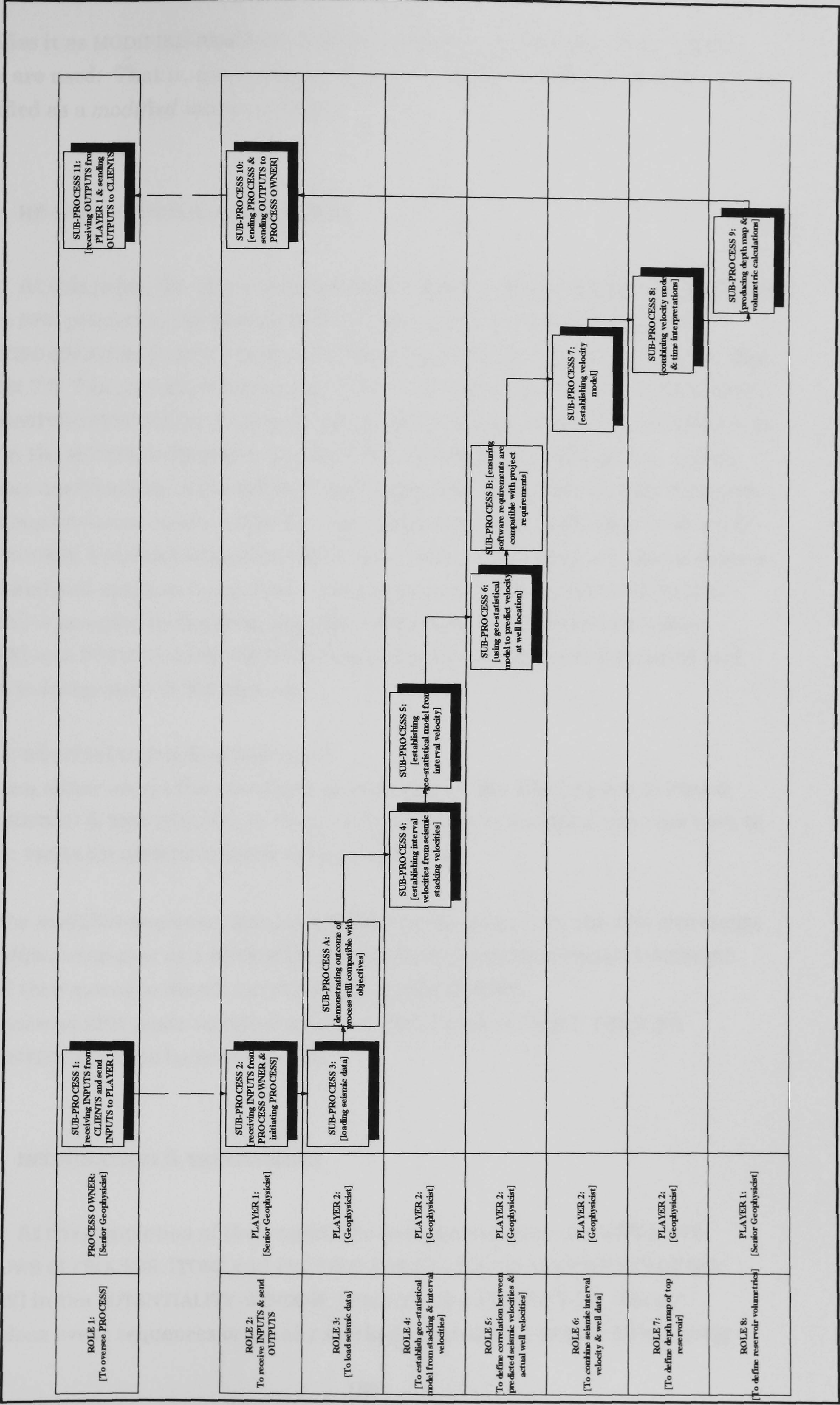


23. In this example, the user could interrogate the ACTUALITY-WINDOWS of PROCESS: [*implementing time-depth conversion: TOM*] and PROCESS: [*implementing time-depth conversion: DICK*]. After this interrogation, the user may decide that while PROCESS: [TOM] has more relevance to the current problem; PROCESS: [HARRY], (as defined by the connectivity measure; see section 7.3) there are certain attributes of PROCESS: [DICK] that could also be considered. For example, PROCESS: [HARRY] is composed of SUB-PROCESS 6: [*using geo-statistical model to predict velocity at well location*] and SUB-PROCESS 7: [*establishing velocity model*]. In PROCESS: [TOM] these SUB-PROCESS have been associated with a SCENARIO: [*new software unable to perform specific geo-statistical computations*]. Further, PROCESS: [HARRY] is also composed of SUB-PROCESS 3: [*loading seismic data*] and SUB-PROCESS 4: [*establishing interval velocities from seismic stacking velocities*]. Which along with SUB-PROCESS 7: [*establishing velocity model*] has been associated with a SCENARIO: [*project suffers from data calibration problems*] in PROCESS: [DICK].

24. Having decided that there are attributes of both PROCESS: [TOM] and PROCESS: [DICK] that may prove useful to the outcome of PROCESS: [HARRY], the user then accesses the REFLECTION-WINDOWS. The REFLECTION-WINDOWS of PROCESS: [TOM] and PROCESS: [DICK] represent the CONSEQUENTIAL OUTCOMES and HAZARDS, NOTES, REFLECTIONS, SUGGESTIONS and NEW OUTCOMES for a particular SCENARIO. For example, the REFLECTION-WINDOW of PROCESS: [TOM] identifies the CONSEQUENTIAL OUTCOME: [*project suffered time delay & cost overruns*]. See FIGURE 7.4(b). The HAZARD of this is [*selective attention to technical rationale hides potential problems*]. A REFLECTION [*a concentration on the technical benefits of software may compromise project*] is proposed from which SUGGESTION 1: [*are the software requirements compatible with project requirements?*] is developed. The user could use this and the information provided in the NOTES to modify PROCESS: [HARRY]. This modification stage can be continued using the REFLECTION-WINDOWS, until the user is satisfied with the re-engineered decision path for PROCESS: [HARRY].

25. For example, the user after consulting the REFLECTION-WINDOWS of both PROCESS: [TOM] and PROCESS: [DICK] may decided to include the following sub-processes in PROCESS: [HARRY]; (i) [*ensuring software output requirements are compatible with project requirements*] and; (ii) [*developing evidential measures demonstrating outcome of process still compatible with objectives*]. This can be seen in FIGURE 7.8. FIGURE 7.8 represents the ACTUALITY-WINDOW of the MODIFIED-PROCESS: [HARRY]. At this point the user can ask the Reflective Process Memory to store PROCESS: [HARRY] in the POTENTIALITY-MEMORY. In this example, since it is PROCESS: [HARRY] that has been modified, then the Reflective Process Memory

FIGURE 7.8 ACTUALITY-WINDOW OF MODIFIED PROCESS [HARRY]



classifies it as MODIFIED-PROCESS: [HARRY]. However, in FIGURE 7.5 the generic terms are used. That is, since a *new-case* (IC_1) has been modified, then it is classified as a *modified-new-case* (MIC_1).

7.4.2 RE-EVALUATION & ACCEPTANCE

26. At this point, the user can either accept the MODIFIED-PROCESS: [HARRY] and let the RPM proceed to Integration & Monitoring, or the user could send the MODIFIED-PROCESS: [HARRY] back to Problem Identification to be re-evaluated. See FIGURE 7.9 The procedure begins again with the RPM using the PREDICTIVE-INDEX of NEGATIVE-PREDICTIVES to identify potential hazardous event sequences that may exist in the MODIFIED-PROCESS: [HARRY]. This feedback loop attempts to ensure that any modifications undertaken at the suggestion of the REFLECTION-WINDOWS of the *most-relevant-case(s)* (PROCESS: [implementing time-depth conversion: TOM] and PROCESS: [implementing time-depth conversion: DICK]) have not produced some additional and spurious hazardous event sequences. If the MODIFIED-PROCESS: [HARRY] is accepted by the user, then the RPM stores the MODIFIED-PROCESS: [HARRY] as a POTENTIALITY-WINDOW: [HARRY] in the POTENTIALITY-MEMORY and moves to Integration & Monitoring.

Step 4: RE-EVALUATION & ACCEPTANCE

User can either accept the *modified-new-case* and let the RPM proceed to Step 5: INTEGRATION & MONITORING, or the user could send the *modified-new-case* back to Step 1: PROBLEM IDENTIFICATION to be re-evaluated.

- If the *modified-new-case* (MIC_1) is accepted by the user, then the RPM represents *modified-new-case* as a POTENTIALITY-WINDOW in the POTENTIALITY-MEMORY and then moves to Step 5: INTEGRATION & MONITORING.
- Otherwise RPM sends *modified-new-case* (MIC_1) back to Step 1: PROBLEM IDENTIFICATION to be re-evaluated.

7.4.3 INTEGRATION & MONITORING

27. At the completion of the project, the user can compare the ACTUALITY-WINDOWS of PROCESS: [TOM] and PROCESS: [DICK] with the MODIFIED-PROCESS: [HARRY] in the POTENTIALITY-WINDOW: [HARRY]. See FIGURE 7.10. Those hazardous event sequences originally marked as NEGATIVE-PREDICTIVES, along

FIGURE 7.9 RE-EVALUATION & ACCEPTANCE

At this stage, if the user can accept the *modified-new-case*, then the RPM represents the *modified-new-case* as a POTENTIALITY-WINDOW in the POTENTIALITY-MEMORY and move to INTEGRATION & MONITORING. Or the user could send the *modified-new-case* back to PROBLEM IDENTIFICATION to be re-evaluated.

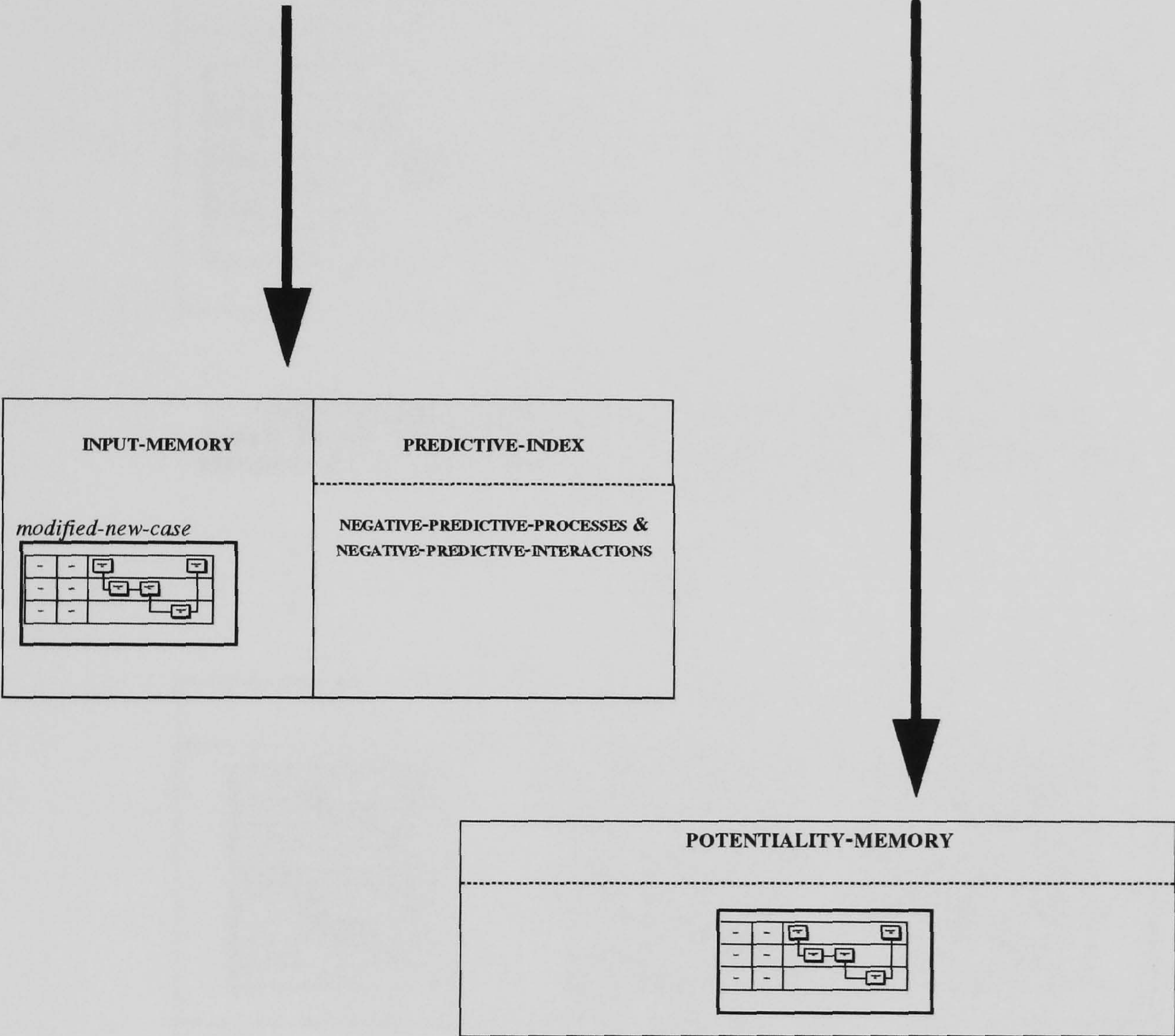
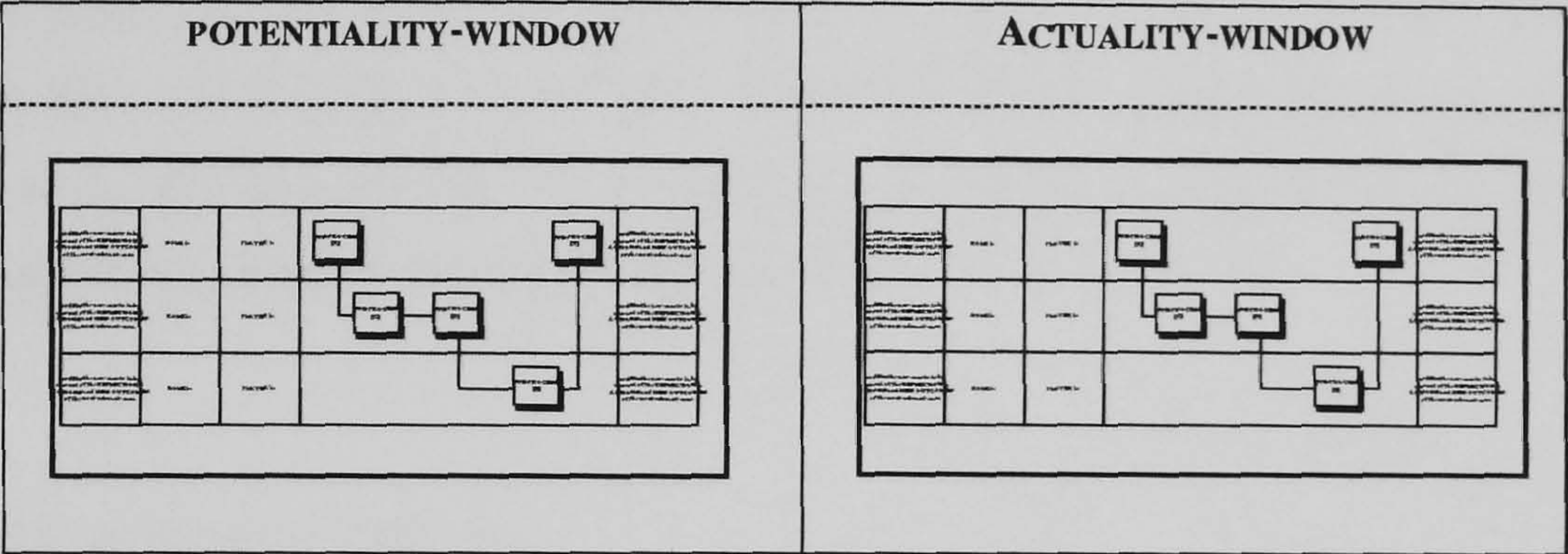
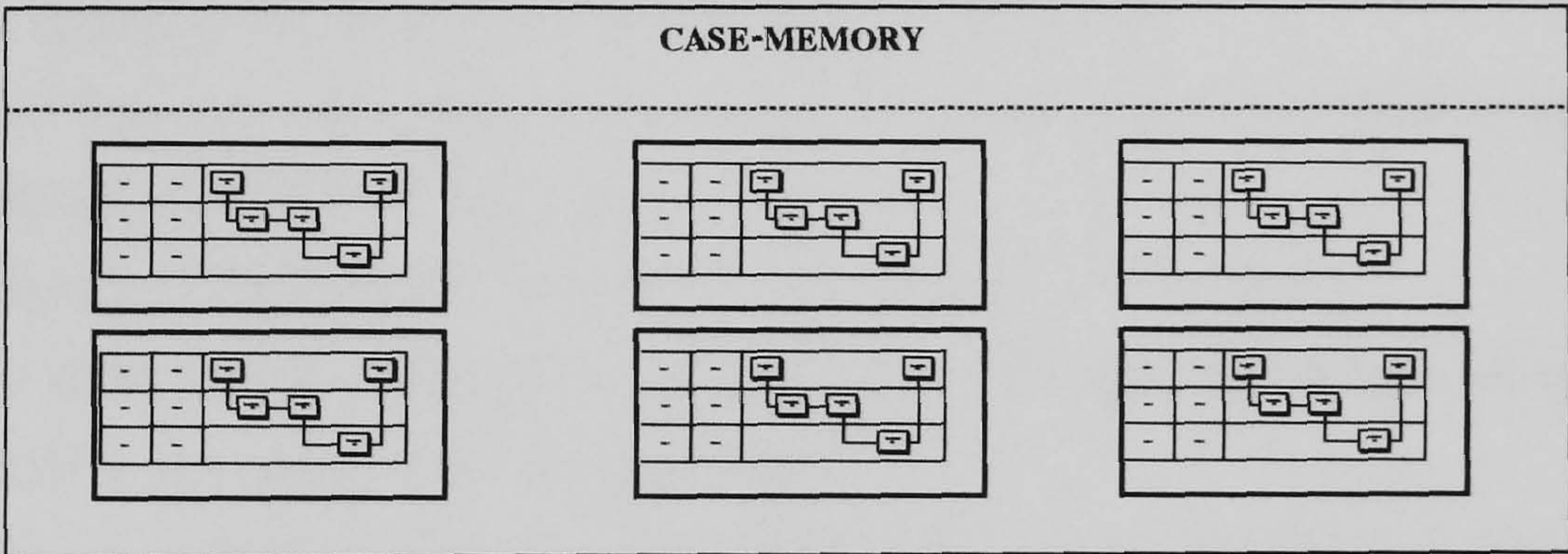


FIGURE 7.10 INTEGRATION & MONITORING

At project completion user compares ACTUALITY-WINDOW of selected *relevant-case(s)* with POTENTIALITY-WINDOW of either *modified-new-case*, or *unmodified-new-case*.



On the basis of this re-evaluation, user updates POTENTIALITY-WINDOW and assigns {unique_identifier} to the case represented by that window. RPM re-classifies POTENTIALITY-WINDOW as ACTUALITY-WINDOW. RPM re-classifies case held in ACTUALITY-WINDOW and sends to specified CASE-MEMORY.



RPM then deletes (i) all case(s) in INPUT-MEMORY; (ii) all case(s) in ACTUALITY-MEMORY; (iii) all case(s) in POTENTIALITY-MEMORY; (iv) processing ends.

with the SUGGESTIONS and NEW OUTCOMES of PROCESS: [TOM] and PROCESS: [DICK] are compared against the outcome of MODIFIED-PROCESS: [HARRY]. Consequently, in the light of that examination those SUB-PROCESSES originally marked as NEGATIVE-PREDICTIVES may need to be updated. For example, actions undertaken by the user at the suggestion of the REFLECTION-WINDOW: [DICK] may have reduced the HAZARD associated with the possible occurrence of SCENARIO 1: [*problems with data resulted in project team having a direct contact with company's original report*]. However, another SCENARIO associated with SUB-PROCESS 3: [*loading seismic data*] and SUB-PROCESS 4: [*establishing interval velocities from seismic stacking velocities*] may have developed instead. In which case, a REFLECTION-WINDOW for PROCESS: [HARRY] is required. The REFLECTION-WINDOW: [HARRY] would include the CONSEQUENTIAL OUTCOMES and HAZARDS, NOTES, SUGGESTIONS and NEW OUTCOMES for that particular SCENARIO.

Step 5: INTEGRATION & MONITORING

At project completion, user compares ACTUALITY-WINDOW of selected *relevant-case(s)* with POTENTIALITY-WINDOW of either *unmodified-new-case*, or *modified-new-case*.

- User compares the ACTUALITY-WINDOW with POTENTIALITY-WINDOW.
- User re-evaluates hazardous event sequences originally marked as NEGATIVE-PREDICTIVES, along with SUGGESTIONS & NEW OUTCOMES.
- On the basis of this re-evaluation user updates POTENTIALITY-WINDOW and creates REFLECTION-WINDOW for case.
- RPM re-classifies POTENTIALITY-WINDOW as ACTUALITY-WINDOW.
- Either user or RPM re-classifies case as CASE {unique_identifier} and sends CASE {unique_identifier} to specified CASE-MEMORY.
- RPM deletes (i) all case(s) in INPUT-MEMORY; (ii) all case(s) in ACTUALITY-MEMORY; (iii) all case(s) in POTENTIALITY-MEMORY
- Processing ends.

28. On the basis of this evaluation the user updates the POTENTIALITY-WINDOW: [HARRY]. After updating the POTENTIALITY-WINDOW: [HARRY] the user specifies whether the case displayed in the POTENTIALITY-WINDOW: [HARRY] is a *failed-case* [stored in CASE-MEMORY (FAILURES)] or a *failing-case* [stored in CASE-MEMORY (NON-FAILURES)]. Note, the CASE-MEMORY (FAILURES) holds those case-histories that have suffered a complete process failure and the CASE-MEMORY (NON-FAILURES) holds those case-histories that although they have potential failure conditions, they have successfully met all case objectives. The RPM re-classifies the

POTENTIALITY-WINDOW: [HARRY] as the ACTUALITY-WINDOW: [HARRY] and sends the PROCESS: [HARRY] to the specified CASE-MEMORY. The RPM deletes (i) all case(s) in INPUT-MEMORY; (ii) all case(s) in the ACTUALITY-MEMORY; (iii) all case(s) in the POTENTIALITY-MEMORY and (iv) processing ends.

7.5 DISCUSSION

29. Consider the Process Model explanation of a case as represented by the hierarchical Process Model in the ACTUALITY-WINDOWS. In section 6.4, the Process Model was defined as, (i) representing a process explanation and consisting of events and connections; (ii) these events may be classified as either super-processes, processes or sub-processes and each event may have associated attributes; (iii) process attributes are organised by a process model algorithm; (iv) however not all of the attributes defined by the algorithm will be necessary for a complete process explanation; (v) process attributes are generated from a grounded analysis of the expert testimony; (vi) process attributes form a language of commonalties; (vii) each event is connected to another event and each event is connected to itself; (viii) a connection represents either a positive or negative symmetrical interaction; (ix) time is positive towards the right. This can be seen in FIGURES 7.4 (a), 7.6 & 7.7(a) and represents a process flow.

30. However, there are other attributes of the ACTUALITY-WINDOW that also need consideration. Firstly, by inspection, some of the sub-processes are shadowed. See FIGURE 7.4(a). This indicates that the SUB-PROCESS has underlying sub-sub-processes. For example, while [*loading seismic data*] is a SUB-PROCESS of PROCESS: [*implementing time-depth conversion*: TOM], it is also a PROCESS: [*loading seismic data*: TOM] with sub-processes of its own. This forms the basis of the hierarchical Process Model explanation. The user could activate the SUB-PROCESS 3: [*loading seismic data*] at the PROCESS: [*implementing time-depth conversion*: TOM] level and then drop to the next level; PROCESS: [*loading seismic data*: TOM]. Secondly, the user could activate the ROLE boxes. These will form a hypertext link with the documented analysis of PROCESS: [*implementing time-depth conversion*: TOM]. This link to the documented analysis as represented in the Appendices [A] and [B] allows the user to browse through the expert testimony and the subsequent analysis behind the development of the Process Model explanation. Lastly, the SCENARIO is also shadowed. However, in this case it is a reverse shadow, indicating that the SCENARIO is associated with the surrounding sub-processes and that by activating

the SCENARIO the user develops a link between the ACTUALITY-WINDOW and the REFLECTION-WINDOW of the PROCESS: *[implementing time-depth conversion: TOM]*.

31. Consideration must also be given to the ACTUALITY-WINDOW of the MODIFIED-PROCESS: [HARRY] as represented by FIGURE 7.8. It can be seen by inspection that the additional SUB-PROCESS A: *[developing evidential measures demonstrating outcome of process still compatible with objectives]* and SUB-PROCESS B: *[ensuring software output requirements are compatible with project requirements]* are not shadowed. This indicates that these sub-processes are (i) additions to the original process description and; (ii) that they are linked to the REFLECTION-WINDOWS of the respective SCENARIOS from which the suggested actions were taken.

32. The REFLECTION-WINDOW represents the engineer's understanding and response to the SCENARIO and will include, (i) CONSEQUENTIAL OUTCOME; (ii) any associated EVIDENCE of possible damage suffered by the PROCESS; (iii) HAZARDS that may be associated with the SCENARIO; (iv) SUGGESTIONS made by the project team; (v) REFLECTIONS; (vi) the NEW OUTCOMES associated with those REFLECTIONS and; (vii) NOTES that explain the problem, including any EMERGENT-QUESTIONS that should have been asked at the time, but were not. Each of the boxes are hypertext links to the appropriate passage in the analysis of the expert testimony. The user could activate a particular attribute of interest and see how the attribute was defined and developed during the analysis.

33. The above represents a discussion on the physical aspects of the Reflective Process Memory. The following discussion concentrates on the notion of the decision developing from a dynamic reflective interaction between the physical aspects of the proposed system and the social world of the user. BRECHTEL [1990], has argued that solving problems and the way in which the problem solving task is performed appear to be dependent upon the nature of the problem and the way in which the individual understands the problem. This implies that the problem-solution process could be influenced both by the type of information given and the form of its presentation. Unfortunately, conventional decision support tools tend to present information as quantitative data rather than process flow. Clearly, the solution to a decision problem depends on the information models available to the decision maker. Quantitative data based decision tools are by their very nature limited since the models on which they are based are necessarily reduced versions of reality. Questions of the dependability, the usefulness and the sufficiency of these models in the situations in which they are actual used can be raised

34. To address these issues, it is suggested that models must help engineering practitioners articulate and reflect upon the processes and their interactions and the assumptions that can be derived from those interactions. Processes and their interactions, both within and between processes are the means through which individual and collective senses of reality are constructed. The representation of these processes are active agents in constructing process model explanations of the past and present and are instrumental in helping the user to decide about the future. The manipulation of these process and the interactions generated from that manipulation are the core activities of a Reflective Process Memory.

35. It is hypothesised that the proposed reflective process memory will help a decision maker identify incubating failure conditions that have occurred in previous case histories and the questions that need to be asked in order to manage those conditions away and to generate new opportunities. The key idea is that in any particular decision problem the questions that are raised by the stakeholders within the process are crucial to attaining eventual success and these can be facilitated by access to similar previous case histories.

36. The proposed reflective process memory will make available to a decision maker a *rich* set of the attributes of previous similar processes including the event sequences that have lead to previous failures or near misses. Thus dependable evidence of previous similar situations could be added to judgements about the present situation (say through an audit) and future projections (from engineering scientific predictions and judgements about future scenarios). This tool would be especially valuable if the diagnostic use of these event sequences could lead to the *anticipation* of potential problems in future engineering projects through the *identifying of relevant questions that perhaps should have been asked at the time but in fact were not*. The results of such a diagnoses presented as interactive graphical explanations of the decision paths will help in creating a dynamic problem-solution environment. This will encourage the user to make use of those explanations in testing the assumptions behind their initial decision path and thereby help the individual to falsify those assumptions.

7.6 CONCLUSIONS

- It has been shown how indices of NEGATIVE-PREDICTIVES can be used by a Reflective Process Memory to discriminate between Process Model explanations and identify those Process Model explanations that are *useful* to the user.
- It has been further shown how the totality of the processes and process-interactions (as defined by the SUB-PROCESSES of the problem) can be used by a Reflective Process Memory to discriminate between the *useful* Process Model explanations and identify those Process Model explanations that are *relevant* to the problem-solution environment as defined by the user.
- A comparison algorithm has been introduced that uses the indices of NEGATIVE-PREDICTIVES and the totality of the problem's component SUB-PROCESSES to compare Process model explanations and identify the *most-relevant* Process Model explanation.
- It is hypothesised that a Reflective Process Memory aids the creation of an appropriate problem-solution environment between the user and the system by making available to the user a rich set of alternative and relevant Process Model explanations. These explanations will include the emergent processes that have led to previous failures or near misses.

CONCLUSIONS:

CAPTURING CASE HISTORIES FOR CORPORATE MEMORY IN DECISION MAKING

OBJECTIVES

- To summarise how emergent properties of previous decisions are represented.
- To critique the representational appropriateness of this formal methodology and identify the challenges that the case-based Reflective Process Memory will face.
- To present some ideas on further work, particularly the use of a Reflective Process Memory in capturing corporate experiences and how this may aid organisational decision making.

CONCLUSIONS

The conclusions of this thesis are;

- Conceptual patterns are descriptive, explanatory and predictive processes and are used by individuals to understand and thus generate an analysis of the problem-solution environment. A set of interacting hierarchical conceptual patterns may be viewed as the associative nature of knowledge.
- The categorisation of a problem-solution environment is a function of its emergent properties. Some of these emergent properties will be culturally, contextual and content driven and so will emerge from the point-of-view of the individual. Others may emerge from the individuals understanding of the role-requirements of the problem-solution environment.
- When an individual uses a conceptual pattern to reason about an external object, he/she are testing the hypotheses about the meaning-values and dependence-conditions associated with the emergent properties of the object environment.

This testing is reflective and is a function of the individual using past knowledge in deciding if he/she has or has not seen this object environment before.

- Reflection is defined as, (i) accessing previous decision experiences; (ii) explaining those experiences; (iii) re-evaluating those experiences; (iv) defining the possible consequences of pursuing various courses of action; (v) evaluating the merits of those various courses of action and then; (vi) monitoring the performance of the selected decision.
- Reflection could be considered to be part of a learning loop, in which the individual uses their experiential memory to identify pivotal events of the current situation. Having constructed the conceptual pattern the individual will then attempt to select a set of alternative decision paths (as defined by the experiential memory of the individual), from which a response will be chosen.
- After selecting a decision path, the individual will then monitor that decision and compare the potentiality of the chosen decision with the actuality of that decision in the external world. This will contribute to the confidence that is assigned to the appropriateness of the selected decision.
- A conceptual pattern is a representation used by an individual to express their understanding of an external object. A formalised understanding is required for a machine-based representation. A Process Model explanation could be a formal representation of that understanding.
- The representational appropriateness of such a model depends upon the model being able to express not only the emergent properties of the external object, but also the interacting processes that connect those emergent properties. The structure of the model must be able to provide an description of the object in terms of an explanation of those emergent properties and process-interactions.
- A grounded theory analysis results in the generation of an array of conceptual patterns, their emergent properties and process-interactions. It provides the methodology for defining those aspects of a situation that are responsible for causing a particular problem. These conceptual patterns are represented (using a Process Model algorithm), as a Process Model explanation and provide the building blocks of the Reflective Process Memory.
- Aspects that are considered responsible for causing a problem may be categorised by a Reflective Process Memory as predictive of a problem. A Reflective Process Memory could create an index of predictives that are associated with previous

failure conditions. The recognition of predictives in a Process Model explanation may help a Reflective Process Memory to identified the occurrence of associated failure conditions.

- Process Model explanations that are selected could, (i) provide the user with relevant reflections and actions on how, when, where and why a problem has previously occurred; (ii) point out to the user which aspects are responsible for the problem and; (iii) suggest to the user relevant questions that were needed to be asked (but were not), during the initial decision path.
- The proposed Reflective Process Memory could make available to the user a rich set of alternative Process Model explanations and will include the emergent processes that have led to previous failures or near misses. Thus dependable evidence of failure surrounding similar situations can be added (by the user) to judgements about the present situation (through an audit) and future projections (from judgements about future opportunities).

COMMENTS ON RESEARCH CONTRIBUTIONS

1. It has been proposed that if case-based systems are to help human decision makers question the effectiveness of the proposed solution, then these systems must include a representational structure that can capture, identify and then recognise emergent processes in other case-histories. It was suggested that this representational structure must present to the user multiple explanations. Thereby encouraging the user to make use of those explanations, (i) to test the existing assumptions and preconceptions of their current decision path and; (ii) attempt to falsify those assumptions rather than confirm.

2. The approach taken by the author represents a new way of recognising and describing processes in case-histories of engineering projects and concentrates on three issues. Firstly the development of a graphical model for identifying and representing processes and hazardous event sequences. Secondly, the development of a diagnostic process model for generating the necessary action through which those hazardous event sequences can be managed. Lastly, the development of a reflective learning model that may be able to anticipate the occurrence of these hazardous event sequences. These models form part of the Reflective Process Memory.

3. It is hypothesised that the appropriateness of the Reflective Process Memory is a function of its ability to create a dynamic problem-solution environment

between the user and the system. An environment supported by a reflective loop between a Process Model explanation of previous decision solutions and the current decision problem. This environment may be characterised as follows, (i) the decision develops from dynamic interactions within the physical and social world, external to the decision maker; (ii) the decision building process begins as a pattern recognition and matching activity, whether the patterns are metaphors, analogies or images that the decision maker uses and updates from previous experiences; (iii) the decision building process forms part of a reflective learning loop, in which the individual constantly tests the dependability of existing assumptions and preconceptions of their current decision path and; (iv) in an attempt to falsify those assumptions, the individual accesses, re-evaluates and modifies those experiences; (v) the decision building process will produce emergent properties at many levels of definition; (vi) the effectiveness of the decision building process (accessing previous explanations, re-evaluating those previous explanations, modifying those explanations and monitoring the performance of the new decision path), depends on the overall structure of the interactions between the individual, their cultural identity and the problem-solution environment; (vii) the decision building process is composed of emergent properties and it is interactions within and between these emergent properties that act as a media through which individual and a collected sense of a decision are constructed; (viii) these emergent properties are active agents in constructing and explaining the experiences of the past and the present and are instrumental in helping the decision maker to decide about the future and; (ix) the questions that are raised by individuals within the decision building process are crucial in attaining the success of that process.

4. These questions are facilitated by the reflective aspects of the Process Model explanation. The model behind the Reflective Process Memory is one in which decision building, (i) is represented as a reflective process that acts on the relationship between previous decisions; (ii) an analysis of how those decisions actually performed and; (iii) the incorporation of new experiences. The nature of the Reflective Process Memory in decision making views decision building as an activity that questions and tests the users understanding of the external problem. Consequently, this interaction between the user and the Reflective Process Memory allows the Reflective Process Memory to develop a better understanding of how to avoid similar failures in the future. This model of decision making views learning as a questioning activity that reflects on the relationship between previous decisions, an analysis of how those decisions actually performed and the integration of new experiences. By using a series of negative-predictives and emergent-questions in an attempt to refute the Process Model explanation, the Reflective Process Memory is encouraging the user to engage in an activity of hypothesis testing. When the current process model explanation is found wanting, then the

Reflective Process Memory displays alternative decision paths. The use of alternatives encourages the user to engage in an activity of reflective induction. In which the individual begins to question, (i) his/her understanding of the current decision path, (ii) the way in which it relates to the current decision problem and; (iii) the inferred outcome of that decision path. This hypothesis testing and reflective induction may be viewed as a process of justification.

COMMENTS ON RESEARCH METHODOLOGY

5. One of the criticisms, that is often aimed at knowledge elicitation exercises is that of controlled direction or bias. Since, knowledge elicitation will involve some element of human judgement, then a tension between the subjective of the knowledge engineer and the objectivity required by the analysis will exist. As noted by PIDGEON, TURNER & BLOCKLEY [1991], *“the facets of the evidence collected will vary with the aims of the system being built and with the nature of the testimony offered by the domain expert, as well as being responsive in some degree to the individual perceptions of the investigator.”* However, there is a distinction between a system and a system description. The testimony of the domain expert represents their understanding of the problem domain. An analysis of this testimony will represent the knowledge engineer’s explanation of the expert’s understanding of the problem domain. Consequently, this analysis represents a meta-explanation. It is a representation of an explanation of an explanation and as this representation moves away from the actuality of the domain, then this representation will become more abstract.

6. In this respect, bias is a function of the abstraction; in which perceptions of the investigator may begin to dominate the representation of an explanation of an explanation. Everyone will have a point of view. However, it is the notion of agreement that sets the grounded approach apart. This stems from individuals, who over a long period of time test a statement about the defined meaning of a particular object.

7. There may be universal agreements. For example, one defining agreement of the object [*planet earth*] is that it {*orbits the sun*}. This universal agreement may be defined as a truth. However some agreements may not be universally accepted. For example, the argument {*causes cancer*} is not universally accepted as being a defining agreement of [*smoking cigarettes*]. In this example, an agreement may be more appropriately viewed as being dependable. In this respect, an agreement may be looked upon as a shared or collective responsibility in which there is a collective understanding associated with a particular object or process. This agreement may

act as a measure of dependability. For example, tests of dependability are defined by a set of rules that govern the way in which the object behaves. Measures of dependability governed by a collective agreement represent that behaviour. However, when an analysis of some testimony represents a knowledge engineer's explanation of the expert's understanding of a problem domain, then tests of dependability are more difficult to define and hence the tendency for associated bias. The tension between the subjective and the objectivity is dynamic and hence the difficulty in obtaining total agreement. In this respect, a grounded approach tries to minimise the bias. It is a collective process, that generates concepts and concept definitions by agreement between the knowledge engineer and the domain expert. This agreement can never be total and hence the generated concepts and concept definitions can never be true. But they can be dependable, a dependability that is governed by the degree of agreement that they excite.

8. Another criticism stems from an engineering perspective and is concerned with processes. During the author's use of the grounded approach during the development of a process model explanation he interviewed three geophysicists. Before beginning each case study the author discussed with the geophysicists the ideas behind the process centric view. This was very valuable, since it highlighted a universal confusion in the geophysicists between data and processes. For example, they had difficulty in understanding the distinction between data and processes and that while data is one of set of attributes of a process it also derives from a process. They focused almost exclusively on data and either misunderstood or ignored that the emphasis of processes is on managing a changing data set. A similar misunderstanding occurred with the definitions of dependability and success. For example, information was considered dependable if it could be relied upon. This suggested that dependability has an implicit meaning, defined as it is by the notion of responsibility. If success may be looked upon as a satisfying criteria, then consequently the criteria for success will be explicitly stated. However, in the process centric view dependability and success are inter-linked. Evidence is a measure in the dependability of a process to successfully achieve the objectives of the process. Evidence is a measure of the dependability of the process to reach the success event. The objectives of the process are the statements of the success event. Until these views are clearly represented, understood and demonstrated, then the engineering community will continue to view with suspicion the notion of processes and continue to confuse process with data transformation.

9. Finally, the fundamental question; *how good is the model presented in this thesis?* The model as presented is a hypothetical construct and is not yet in a testable form. It is suggested that the proposed methodology and model and the system that has been designed to implement and test that model represents a new

and novel way of representing the emergent properties and process interactions of previous decision. However, the representational appropriateness of this methodology and the dependability of the model will not be known empirically until the system can be tested.

FUTURE DEVELOPMENTS

10. The quality of decision making in organisations would be improved if there was a formal way of capturing and using the corporate memory of previous experiences and case histories. Such a memory currently exists informally in the paper and electronic files of the organisation and in the minds of past and present employees. A formal corporate memory would be at the heart of organisational learning. Clearly, the solution to a decision problem depends on the information models available to the decision maker. However, conventional data-focused systems may not meet the requirements of future corporate decision making. For example, quantitative data based decision tools are by their very nature limited since the models on which they are based are necessarily reduced versions of reality. So how do we represent the dependability of these models and their usefulness? How far do they fall short of sufficiency and can they be improved? Is the answer to obtain more data or develop improved methods for identifying, explaining and displaying the processes (and their associated data structures) that underlie the decision path? How can previous experience of decisions problems be captured to provide a corporate memory?

11. From the perspective of the work undertaken by the author at the University of Bristol, it is suggested that at a corporate level and in a manner similar, but also slightly different to that at the individual level, this organisational knowledge may also be composed of event sequences, in which processes and interactions between those processes are the media through which meaning and understanding are bestowed to the corporate body. These processes are active agents in constructing an experience of the past and present and may be instrumental in helping the organisation to decide about the future.

12. The key idea is to help practitioners articulate and reflect upon the processes and relations and the assumptions that they make. The manipulation (whether mental or physical) of the images of these processes are the core activities of a reflective memory. A corporate Reflective Process Memory will enable the organisation to learn from previous corporate experiences and distribute that expertise across the organisation. However, while these experiences become much more global, dynamic and even virtual, they will also become much more social and

involve large numbers of individuals across an organisation. The properties of such experiences will emerge from the interactions of its parts. For example, complex properties such as corporate identity and culture are built on corporate memory. At present that memory lies in the minds of the members and files of the organisation. Such memories are not easily accessible. A intranet-based corporate Reflective Process Memory will make the corporate memory more accessible, available and hence potentially of much greater usefulness and influence. It is important that this is done in a way that is organised for the corporate benefit. The Reflective Process Memory suggested here is the basis of one such way of doing that. It is hypothesised that the reflective process model will enable links to be made between technical factors and economic, environmental, cultural and social considerations of the decision building process. It is at this interface where so many difficulties tend to be found.

13. Clearly, this is a very complex area of development about which current ideas and benefits to be accrued are just emerging. For example, if corporate memory adds value to an organisation, then creating and sharing that knowledge will add more value. If corporate memory generates innovation, then creative solutions can lead to greater efficiencies. If corporate memory of the external environment can be used to spot organisational strengths and weakness, then it can also be used to spot opportunities and threats. However, there is one aspect of a corporate memory that may prove a limitation. For example, is hypothesised that a reflective corporate memory may be able to provide organisations with organisational knowledge and to distribute that expertise across the organisation. However, such knowledge changes over time. It will have a temporal dimension; new experiences are amassed and less relevant ones are forgotten. Consequently, as the organisation changes, so does the Reflective Process Memory. In a sense it acquires a corporate identity. The Reflective Process Memory becomes the organisation. In that situation, how will such a memory deal with a business environment that is characterised by a non-linear dynamic instability and uncertainty such as that seen in deterministic chaotic systems?

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APPENDIX A: RESULTS OF KNOWLEDGE ELICITATION EXERCISE

1. In this section the results of the knowledge elicitation exercise undertaken by the author are presented. Examples taken from interviews with expert geophysicists will show, (i) how a grounded analysis of the data helped the knowledge engineer to identify the necessary process definitions and; (ii) how the focus of the knowledge elicitation exercise concentrated on the human and organisational preconditions relating to failures (or near failures).

2. Please note, to demonstrate, (i) how processes and their emergent properties may be repeated in similar situations; (ii) how they may contribute to a process failure (or near miss) and; (iii) how a comparison with those failed (or nearly failed) cases can help a decision maker, it was necessary to restrict the sample space. In this example, the sample space was restricted to the petroleum engineering problem [*implementing time-depth conversion*]. Consequently, any further development of this methodology requires the technique to have applications over a wider engineering field, possibly even a generic application. It is argued that the Process Model explanation and the associated representational methodology is independent of the problem domain and that the analysis and representation of other domains may follow a similar approach. Complete and full accounts of the interview transcripts, the grounded analysis and the subsequent Process Model explanation of each case study are given in the following documents;

1. \juniper\year3\ikoda\tom\,
2. \juniper\year3\ikoda\dick\,
3. \juniper\year3\ikoda\harry\,

3. The following are used to demonstrate the comparison methodology and does not represent any judgement of any individual within IKODA Ltd.

CASE STUDY 1: [TOM]

4. The data in TABLE A1 represents the beginning of the concept labelling process. The process is a two stage activity in which the author developed and then refined the nature of the concepts that were needed to account for the relevance of a particular paragraph. For example, one concept highlighted in paragraph 1 was (i) *process overview*. (See TABLE A2). Note, this category is a reflection of a specific conceptual level and represents a highly specific term. This fixed the analysis to particular aspects of the case study. In this example the analysis focused on a descriptive [*process overview*] of the PROCESS: [*implementing time-depth conversion: TOM*]. Consequently, the analysis identified those sub-processes and their interactions as they related to the content and context of the [*process overview*] of the PROCESS: [*implementing time-depth conversion: TOM*]. Other concepts identified in paragraphs 2, 3 and 4 are, (i) *uncertainty is a function of seismic velocities*; (ii) *consequences of uncertainties may lead to minimum production* and; (iii) *position of depth control can be critical to seismic velocity estimation* respectively. Again these are specific terms that will fix the analysis to some particular aspects of the PROCESS: [*implementing time-depth conversion: TOM*].

5. TABLE A3.0 illustrates the card for the concept [*process overview: TOM*]. It can be seen that the concept [*process overview: TOM*] was identified in a number of

paragraphs. TABLE A3.0 also includes a number of possible connections with other emergent concepts and earlier concept labels. For example, the [process overview: TOM] has been connected to **CARD 14-PROCESS OBJECTIVES**. This card represents the specified objectives and emergent objectives of the PROCESS: [implementing time-depth conversion: TOM]. These specified and emergent objectives can be viewed as explicit and implicit statements. Explicit, in that it was explicitly stated by the project team and implicit, in that a grounded analysis identified it as an implicit requirement of the PROCESS: [implementing time-depth conversion: TOM]. For example, in this case study the explicitly stated objective was, (i) *the generation of best estimate of reservoir depth over field area*, while the implicit required objective was, (i) *testing of new software against the requirements of case* [TOM].

6. Another potential connection **CARD 20-IDENTIFYING CRITICAL PROCESS CONSTRAINTS** highlighted any constraints on the PROCESS: [implementing time-depth conversion: TOM]. Again some of these were explicit constraints that were part of the contract between the client and the company. Such constraints included, (i) *financial and budgetary controls*. Others only became clear after an analysis. For example, one emergent constraint included, (i) *the need to test the new software*.

7. TABLE A3.1 illustrates a provisional definition for the concept [process overview: TOM], for which a memo was generated, shown in table A3.2. Table A3.2 represents several important features. Firstly, the PROCESS OWNER, PLAYERS, ROLES and SUB-PROCESSES for PROCESS: [implementing time-depth conversion: TOM] are identified. Secondly, an indication of the possible decision problems that PROCESS: [implementing time-depth conversion: TOM] suffered are described. Lastly, the memo identifies those emergent questions that on reflection should have been asked at the time, but were not. In some situations an analysis of the concept definition may indicate that some of the recorded events may need to be re-categorised. For example, see Chapter 5, section 5.3.3 in which a number of different meanings were associated with [selective attention to technical rationale hides potential hazards: TOM]. These were defined as, (i) [stress escaping behaviour (encystment): TOM]; (ii) [narrow point of view (convergence): TOM]. If this occurs, then this can be classified as an *nota bene* (N.B.) and attached to the memo.

TABLE A1 PARAGRAPHS FROM INTERVIEW OF CASE-STUDY [TOM]

Interview with Giles_P; March 17 1998, Field [TOM]	
Para 1	The process is taking a time interpretation which you have derived from your seismic survey and converting that into a depth interpretation. <i>This can be used</i> for predictive purposes which you compare to other sources of data such as bore-holes. Volumetrics and all the rest of it has to be done in depth so the time interpretation is not a lot of use. The real process of depth conversion is one of velocity estimation. That is the key estimating the seismic velocity.
Para 2	<i>There are two uncertainties in this process.</i> There is how good your time interpretation is and your estimation of the seismic velocity. I think the key uncertainties are the seismic uncertainties. Because that is where the data is poorest or were you have little or less information to start with.
Para 3	If there is a lot of well-control. <i>For example</i> , it is an old field and you have wells into the field, then those <i>wells</i> are fixed depth points with very little uncertainty. They will control your final depth map. <i>However</i> , when you are talking about areas where you have very little well-control. <i>For example</i> , in an exploration prospect. If you get your depth conversion wrong you could be widely out. <i>This depends</i> on the situation. One of the other problems is that you will do a depth conversion to do a prognosis for a new well, to predict where you should put that new well. If your depth conversion is wrong then obviously you may put that well in completely the wrong place. You may not want to put a well there at all if your depth conversion is unsafe.
Para 4	You may have placed <i>the well control points</i> at what you may have think is the top of the structure. The velocity through the rocks to the top of the structure may be quite different from the velocity through the structure at the flanks, but your only control point is at the top. <i>Therefore</i> , estimating what is going on at the flanks could be quite difficult. <i>This</i> is usually the case, in that the hard information that you have is at the well locations. <i>Unfortunately well locations</i> are not randomly picked, they are picked for specific purposes. That is at <i>the</i> top of structure to maximise production. So your hard information is likely to be a bit biased.

TABLE A2 SIGNIFICANT CONCEPTS IDENTIFIED FROM TABLE A1

Interview with Giles_P; March 17 1998, Field [TOM]

- Para 1 *Process overview*
- Para 2 *Uncertainty is a function of seismic velocities*
- Para 3 *Consequences of uncertainties may lead to minimum production*
- Para 4 *Position of depth control can be critical to seismic velocity estimation*

TABLE A3.0 EXAMPLE OF CONCEPT CARD FOR [Process overview: TOM]

CARD 1	[Process overview: TOM]
Para 1	<i>A time interpretation (derived from seismic) is converted into a depth map, compared with well data and used to define reservoir volumes. Depth conversion is a function of velocity estimation.</i>
Para 3	Depth conversion aids well prognoses and is used to predict suitable well locations for increased production. Uncertainty in depth conversion can lead to incorrect prediction, unsuitable well location and increased expenditure with little return.
Para 6	PD was <i>ultimately responsible</i> for the process, in that he reported to Ikoda management, but GP <i>initiated</i> and <i>terminated</i> the process, although M did most of the work.
Para 7	PD is a Principal geophysicist, GP is a Senior geophysicist and M is a geophysicist.
Para 8	Ultimate responsibility is to client, with a secondary responsibility to IKODA senior management.
Para 16	Additional problem of unknown extension crossing block boundary, leading to equity situation.
Para 20	Key process is <i>seismic velocity estimation</i> . In which the area above reservoir (called overburden) is divided into layers and <i>estimates of the seismic velocity for those layers are made</i> . During seismic processing, a velocity field is generated in the processing sequence. These are known as <i>stacking velocities</i> . This is done on 1 km square grids. The <i>interval velocities (derived from stacking velocities)</i> are used in a <i>geo-statistical examination to define a geo-statistical model</i> . The model is used to <i>predict velocities at well locations which are compared to actual well velocities</i> . <i>Correlations are used to establish a velocity model of the structure from which a depth map is constructed</i> . Then <i>volumetrics are produced</i> .
Para 20	<i>Since information is optimised to enable best processing of seismic data, in terms of depth conversion, it may not be that accurate in helping to define interval velocity.</i>
Para 22	Estimation of depth map uncertainty is a function of the geo-statistical model, derived from seismic velocities. <i>If unable to use seismic velocities, or if inappropriate to use seismic velocities, than more difficult to define uncertainty.</i>
Para 32	IKODA are co-developing new software package. Theoretically, it offered several advantages over other packages and was considered by senior management to be a vast improvement over current software. Project team used pre-release version on field [TOM], unfortunately, it failed to live up to expectations.

TABLE A3.0 EXAMPLE OF CONCEPT CARD FOR [Process overview: TOM]

CARD 1	[Process overview: TOM]
Para 38	On route to commercialisation, software developers had changed comparison methodology (senior management hadn't been told). It was unable to krig between seismic velocities and what is happening at well locations.
Para 43	Velocity estimation is where the uncertainty does come in and without well control the more uncertain it becomes. <i>Relationships developed at the well locations will begin to fall-down further away from the well, they become more uncertain.</i>
Links with	CARD 2-DATA DERIVED FROM VELOCITY ESTIMATION CAN BE UNCERTAIN CARD 3-UNCERTAINTY CAN LEAD TO ERRORS IN [OIL-IN-PLACE] AND [GROSS ROCK VOLUME] ESTIMATES CARD 14-PROCESS OBJECTIVES CARD 16-IDENTIFYING KEY SUB-PROCESSES NEEDED TO MEET OBJECTIVES CARD 17-UNCERTAINTY IN SEISMIC VELOCITY ESTIMATION CARD 18-DESIRED END STATE CARD 20-IDENTIFYING CRITICAL PROCESS CONSTRAINTS CARD 22-SOFTWARE CRITICAL TO PROJECT COMPLETION CARD 28-SELECTIVE ATTENTION TO TECHNICAL RATIONALE HIDES POTENTIAL HAZARDS
(1)	<i>Process definition</i>

TABLE A3.1 PROVISIONAL DEFINITION FOR CONCEPT [Process overview: TOM]

CARD 1: [Process overview: TOM]

For field [TOM] the PROCESS was defined as [implementing time-depth conversion]. In this field the PROCESS: [implementing time-depth conversion: TOM] consisted of a time interpretation (derived from seismic velocities) being converted into a depth map, compared with well data and used to define reservoir volumes. The PROCESS: [implementing time-depth conversion: TOM] was used to predict suitable well locations for increased production. Note, any uncertainty in the PROCESS: [implementing time-depth conversion: TOM] can lead to incorrect prediction, unsuitable well location and increased expenditure with little return.

A description of the PROCESS: [implementing time-depth conversion] is as follows. The area above reservoir (called the overburden) is divided into layers and estimates of the seismic velocity for those layers are made. That is during the processing of these seismic velocities a velocity field is generated in the processing sequence. These are known as stacking velocities. Interval velocities are derived from the stacking velocities and using a geo-statistical examination produce a geo-statistical model of the reservoir. This model is used to predict velocities at well locations which are then compared to known velocities at well locations. If a relationship can be seen to exist, then this relationship is used to predict velocities at know time points throughout field. Having a velocity and a time gives the depth and volumetrics.

However, the geo-statistical methodology is not without some problems, (i) it is computational intensive; (ii) information is optimised to enable best processing of seismic data, but in terms of depth conversion it may not be that appropriate when being used to define interval velocities; (iii) the estimation of the depth map uncertainty is a function of the geo-statistical model derived from the seismic velocities and if seismic velocities can not be used or if it is inappropriate to use seismic velocities, than it is more difficult to define depth map uncertainty and; (iv) the relationships developed at the well locations can not be assumed to be uniform through-out the reservoir.

Identified SUB-PROCESSES in the PROCESS: [implementing time-depth conversion: TOM] are, (i) loading seismic data; (ii) establishing interval velocities from seismic stacking velocities; (iii) establishing geo-statistical model from interval velocities; (iv) predicting velocity at well location; (v) establishing velocity model of reservoir; (vi) combing velocity model and time interpretations and; (vii) producing depth map and volumetric calculations.

PROCESS: [implementing time-depth conversion: TOM] was not without some problems. For example, a selective attention was given to the theoretical aspects of data processing generated hidden hazardous event sequences that almost had serious consequences for the outcome of the project. The needs of the software user and the abilities of the software supplied became separated.

The minimum objectives were identified as, (i) best estimate of reservoir depth and; (ii) a measure of the uncertainty within that map.

PD was the PROCESS OWNER in that he reported to Ikoda management and oversaw the PROCESS: [implementing time-depth conversion: TOM]. GP was the PLAYER who received the inputs from the PROCESS OWNER, initiated the PROCESS, sent the outputs back to the PROCESS OWNER, terminated the PROCESS: [implementing time-depth conversion: TOM] and defined the reservoir volumetrics. However, it was another PLAYER, M who loaded the data, established the geo-statistical from the seismic stacking velocities, defined the correlation between the predicted seismic velocities and actual well velocities, combined the seismic interval velocity and well data and defined the depth map of top reservoir. PD is a Principal geophysicist, GP is a Senior geophysicist and M is a geophysicist.

TABLE A3.1 PROVISIONAL DEFINITION FOR CONCEPT [*Process overview: TOM*]

CARD 1: [*Process overview: TOM*] cont.

The responsibility was defined as being to the client with a secondary responsibility to IKODA senior management.

Identified roles for Principal geophysicist were, (i) to oversee process. Identified roles for Senior geophysicist were, (i) to receive data from process owner and send results of the process back and; (ii) to define reservoir volumetrics. Identified roles for geophysicist were, (i) to load data; (ii) to establish geo-statistical model from stacking and interval velocities; (iii) to define correlation between predicted seismic velocities and actual well velocities; (iv) to combine seismic interval velocity and well data and; (v) to define depth map of top reservoir.

See also:

CARD 2-DATA DERIVED FROM VELOCITY ESTIMATION CAN BE UNCERTAIN

CARD 3-UNCERTAINTY CAN LEAD TO ERRORS IN [OIL-IN-PLACE] AND [GROSS ROCK VOLUME] ESTIMATES

CARD 14-PROCESS OBJECTIVES

CARD 16-IDENTIFYING KEY SUB-PROCESSES NEEDED TO MEET OBJECTIVES

CARD 17-UNCERTAINTY IN SEISMIC VELOCITY ESTIMATION

CARD 18-DESIRED END STATE

CARD 20-IDENTIFYING CRITICAL PROCESS CONSTRAINTS

CARD 28-SELECTIVE ATTENTION TO TECHNICAL RATIONALE HIDES POTENTIAL HAZARDS

TABLE A3.2 SHORT NOTE FOR CARD 1 [TOM]

CARD 1: [*Process overview: TOM*]

The PROCESS OWNER: Principal geophysicist was responsible for sending data to the PLAYER: Senior geophysicist and sending results to client and was given the ROLE: [*to oversee PROCESS*]. The PLAYER: Senior geophysicist was held responsible for, (i) receiving the necessary data from the PROCESS OWNER and initiating the PROCESS and; (ii) terminating the PROCESS and passing the results of the PROCESS to the PROCESS OWNER] and was given the ROLE: [*to receive INPUTS and send OUTPUTS*]. The PLAYER: Senior geophysicist also had an additional ROLE: [*to define reservoir volumetrics*]. The PLAYER: geophysicist was given the ROLES: (i) [*to load seismic data*]; (ii) [*to establish geo-statistical model from stacking & interval velocities*]; (iii) [*to define correlation between predicted seismic velocities & actual well velocities*]; (iv) [*to combine seismic interval velocity & well data*]; (v) [*to define depth map of top reservoir*].

Identified SUB-PROCESSES in the PROCESS: [*implementing time-depth conversion: TOM*] are, (i) [*receiving data from clients and initiating PROCESS*]; (ii) [*loading seismic data*]; (iii) [*establishing interval velocities from seismic stacking velocities*]; (iv) [*establishing geo-statistical model from interval velocities*]; (v) [*predicting velocity at well location*]; (vi) [*establishing velocity model of reservoir*]; (vii) [*combing velocity model and time interpretations*]; (viii) [*producing depth map and volumetric calculations*] and (ix) [*terminating the PROCESS and passing results to client*].

Note, during the PROCESS: [*implementing time-depth conversion: TOM*] selective attention was given to the theoretical aspects of data processing. This selectivity generated hidden hazardous event sequences that almost had serious consequences for the outcome of the project and demonstrated that the needs of the software user and the abilities of the software supplied must not become separated.

EMERGENT QUESTIONS:

CASE STUDY 2: [DICK]

8. In this section some examples of the grounded analysis of the case study [DICK] are presented. TABLE A4 represents the beginning of the concept labelling process. For example, in paragraph 1, several concepts were identified, namely (i) *process constrained by time*; (ii) *process overview*; (iii) *definitions of responsibility*. These and other significant concepts identified during the initial labelling activity are shown in TABLE A5. Following the example of case study 1: [TOM] the concept [*process overview*: DICK] was identified in a number of different paragraphs. This is seen in TABLE A6.0 and includes a number of possible connections with other emergent concepts and earlier concept labels. The analysis revealed explicit and implicit properties of the concept [*Process overview*: DICK]. This can be seen in TABLE A6.1, in which explicit properties were identified as PROCESS OWNER, PLAYERS, ROLES and SUB-PROCESSES etc. However, one emergent property (or implicit property), were problems surrounding the loading of data leading to a close association between the oil company and the project team. The other emergent property, was the concern over the implications this close association may have for the degree of independence required by the financial considerations of the project. This is particular important since the two emergent properties, as represented by the concept definitions [*Data calibration problems*: DICK] and [*Independence of assessment*: DICK] form a connection with the concept definition [*Process overview*: DICK]. This is expressed in the concept **CARDS 11 & 24, DATA CALIBRATION PROBLEMS & INDEPENDENCE OF ASSESSMENT**, represented in TABLES A7.0 and A8.0 respectively and will be considered below. TABLE A6.2 represents the hypertext link between the results of the grounded analysis, represented by the short memo on definition [*Process overview*: DICK] and ACTUALITY WINDOW of the PROCESS: [*implementing time-depth conversion*: DICK] and will be discussed in section 7.4.

TABLE A4.0 EXAMPLE PARAGRAPHS FROM INTERVIEW OF CASE-STUDY [DICK]

Interview with Peter_D; May 13 1998, Field [DICK]	
Para 1	<p>The client required it to be done quickly. It was a ten day time frame in which, there was loading the seismic on the work station, interpreting the seismic time horizons depth, converting those time horizons and then producing volumetrics on the depth converted maps. Because it was a land case there were problems with the land seismic aspect of it, the time interpretation as well as the depth conversion. Having done the very quick interpretation, I then began looking at the refining of that initial depth conversion. In summary, it was quick look and then a refinement option. I was given it by the client and was responsible for it, but another person helped in the mapping side of it. Since the job was being done through IKODA, I was really responsible to IKODA management. However, to get the job done on time I acted directly with the client.</p>
Para 2	<p>I have at least 25 years in this type of work with a major oil company. Currently, as an independent consultant and working for IKODA. I would describe myself as fully qualified to do all the necessary work and to take the necessary decisions for the whole process. I am an applied scientist, since most of my career has been involved in the application of science to problems. I would say that I am a geophysicist.</p>
Para 3	<p>The process objectives as given by the client, were to do an independent interpretation and volumetrics for a field which had just been discovered. The reason that it had to be independent assessment <i>was its use as a financial justification for another company. This required an independent technical assessment of this field, rather than an operators assessment.</i> It was an audit of the operators work. It was just that, an independent assessment and independent interpretation and making a judgement <i>based on that assessment and interpretation.</i> It was auditing the original interpretation. Therefore, as well as doing an independent assessment, it was also a comparison process.</p> <p>The first process was data loading. That is, loading the data (in the rawest possible form as un-intrepretated seismic data, but still fully processed) onto a workstation and thereby produce an interpretation of that data. This interpretation would include a time map of the structure. The time interpretation was very standard and there were not to many problems with that. Then there was the decision to be made as to how to take that interpretation of the seismic data and actually map it. There was a number of options available there. Finally how to take that time interpretation and depth convert it. That was essential the procedure.</p>

TABLE A4.0 EXAMPLE PARAGRAPHS FROM INTERVIEW OF CASE-STUDY [DICK]

<p>Para 3 cot/d</p>	<p>I was given the oil company's previous interpretation of that data, all the information they had on the wells and the ties to the seismic, they also gave me the time frame involved. I admit that there was a mixture of how much of their knowledge I actually took and used in the project and how much I did independently. Although I felt that there was a balance between a completely independently interpretation and using some of the information they had correlated. This was really dependent upon the time and that it was compatible with the specific objectives that I was given. It was recognised that I would have to use a lot of the information that they had already put together and also take it on face value. However, this was not a problem, it was the loading of the data which was problematical. There were a few problems that had to be overcome. The minimum objectives would be a depth map on each of the perspective horizons (and there were two horizons) independently arrived at and a short file note two or three pages describing how the interpretation was arrived at and how it compared to the interpretation of the company who owned the field. That is the client of <i>the company that initially approached IKODA</i>.</p>
<p>Para 4</p>	<p>The initial stage, was a essentially a phone from the company who asked <i>IKODA</i> to do the work <i>and</i> to tell <i>IKODA</i> what was needed. <i>I</i> went and discussed it over a meeting. They provided <i>me</i> with information on the field, with a report that their client had done and the data to work on. The first thing was to load the data on to the work station (which <i>I</i> didn't do <i>myself</i> but somebody in <i>IKODA</i> did). It was sub-contracted to somebody in the <i>IKODA</i> staff. <i>Then</i>, there was a the first quick look at the data to make sure that it made sense. There was <i>some significant data processing at this point</i>. Because there was problems with the data, <i>I then had to contact the client</i>. However, to get the information that <i>IKODA</i> needed, they had to go back to their client. <i>This could be very time consuming, so it was agreed very quickly that the only sensible thing to do it in the time was for me to contact the oil company directly</i>. This worked very well. <i>I</i> could actually question <i>about the data already</i> given and they could supply <i>me</i> with extra data as needed. This was necessary in order to do thing in the time.</p>

TABLE A5.0 SIGNIFICANT CONCEPTS IDENTIFIED FROM TABLE A4.0

Interview with Peter_D; May 13 1998, Field [DICK]	
Para 1	<i>Process constrained by time</i> <i>Process overview</i> <i>Definitions of responsibility</i>
Para 2	<i>Defining point-of-view of PROCESS OWNER</i>
Para 3	<i>Process objectives</i> <i>Process overview</i> <i>Independence of assessment</i>
Para 4	<i>Initial contact with client</i> <i>Process overview</i> <i>Data calibration problems</i> <i>Process constrained by time</i>

TABLE A6.0 EXAMPLE OF CONCEPT CARD FOR [Process overview: DICK]

CARD 1	[Process overview: DICK]
Para 1	The process consisted of <i>loading the seismic</i> on the work station, <i>interpreting the seismic time horizons</i> , <i>depth converting those time horizons</i> and <i>producing volumetrics on the depth converted maps</i> . PD was responsible (<i>process owner</i>), but M helped in the mapping (<i>processing interval velocities and combining velocity model with time interpretations</i>).
Para 3	The first process was <i>loading the data</i> (in the rawest possible form as un-intrepretated seismic data, but still fully processed) onto a workstation. An <i>interpretation of the interval velocities from the stacking seismic velocities</i> was produced, this included an <i>interpretation of the seismic time intervals</i> of the structure. The time interpretation was very standard and there were not to many problems with that. At this stage it would be necessary to decide on how the mapping (<i>defining the velocity model</i>) of the seismic data interpretation would be accomplished, how to <i>combine the velocity model and time interpretation</i> and <i>depth convert it</i> .
Para 4	After M <i>loaded the data</i> , PD checked to make sure that it made sense and to ensure that the data could be processed. However, there was problems with the original data and PD had to contact the client.
Para 7	The project finished with the team producing two depth maps and PD writing a report on the methodology used, how the maps compared to the originals and any recommendations for further work.
Para 8	The initial checking was considered to be the beginning of the process quality control. PD states that, " <i>it was a technical assessment of the best way to do the depth conversion, then actually carrying out the depth conversion, deciding on the way to do it and carrying out that work and finally writing a report at the end of the whole process.</i> "
Para 9	Time constraints did dictated the method used.
Para 10	It was a sequential process there was no way of paralleling.
Para 13	PD suggested that IKODA were " <i>lucky</i> " with this project. It confirmed the original work done. If it had " <i>found something significantly different from the oil company's interpretation, then perhaps it would have been difficult in the time available to justify and to examine those differences.</i> "
Para 20	While there were data uncertainties, different vintages, processed differently, data missing and difficulties in tying data together, at the end PD was satisfied that the project team had produced the best technical estimate within the limits of the available data

TABLE A6.0 EXAMPLE OF CONCEPT CARD FOR [Process overview: DICK]

Para 24	The main objective was to come up with a volume for this structure. In working out gross rock volumes, the depth conversion has a major effect on this and is usual one of the major uncertainties. As well as producing a time-depth conversion, the project team also looked at different scenarios of min possible and max possible oil-water contacts to produce a range of oil-water contacts.
Para 25	There were calibration problems with the data on the work station. It was found that an interpretation of the seismic lines could not be made, since they did not appear on the screen properly. They needed some further processing. This required bulk shifting of each of the surveys to a common datum. These unexpected problems were overcome by a combination of working within the work station and contacting the oil company to get advice and ideas on how to correct those problems.
Para 28	The use of the clients experience proved very useful in overcoming those problems. It enabled the project team to resolve the difficulties with the data very quickly. It was felt that without that help, the project team would not have managed to resolve the problems quickly enough to get the project done in time.
Para 36	The project team focused on one method very early on in the project's life. It is possible that as a consequence of doing something this quickly, individuals may overlook critical aspects of the problem. As a result of the tight framework alternative scenarios and the implications of those alternative scenarios were not considered. While PD suggests that <i>"within the time frame available, it could not have been done any better"</i> , nonetheless <i>"it is a concern that the output may not be the best estimate"</i> . There may be some unforeseen problems or circumstances that the project team have not addressed or have not identified.
Links with	CARD 2-PROCESS INITIATION CARD 3-IDENTIFYING CRITICAL DEPENDENCIES CARD 5-AREAS OF UNCERTAINTY CARD 10-UNCERTAINTY ASSOCIATED WITH THE DEPTH MAP CARD 11-DATA CALIBRATION PROBLEMS CARD 13-RESOLVING PROBLEMS CARD 14-PROCESS OBJECTIVES CARD 16-CONFIDENCE IN PREDICTIONS CARD 20-IDENTIFYING CRITICAL PROCESS CONSTRAINTS CARD 23-QUALITY CONTROL CARD 24-INDEPENDENCE OF ASSESSMENT
(1)	<i>Process definition</i>

TABLE A6.1 PROVISIONAL DEFINITION FOR CONCEPT [Process overview: DICK]

CARD 1: [Process overview: DICK]

For field [DICK], PROCESS was defined as [implementing time-depth conversion]. In this field the PROCESS: [implementing time-depth conversion] consisted of interpreting the seismic time horizons, converting those time horizons and then producing depth converted maps. Volumetrics on the depth converted maps were used to define reservoir volumes. Since there are financial considerations when defining reservoir volumes an independent technical assessment was required. In this respect the PROCESS: [implementing time-depth conversion] was a re-assessment of the original interpretation of the reservoir volumetrics.

Identified key SUB-PROCESSES for PROCESS: [implementing time-depth conversion: DICK] are, (i) loading seismic data; (ii) establishing interval velocities from seismic stacking velocities; (iii) establishing velocities from well data; (iv) establishing seismic time intervals; (v) establishing velocity model of reservoir; (vi) combining velocity model and time interpretations and; (vii) producing depth map and volumetric calculations.

PROCESS: [implementing time-depth conversion: DICK] was not without some problems. For example, the process was heavily constrained by time and this coupled with problems surrounding the loading of data led to a close association with the oil company. Note, this close association may have implications for the notion of independence required by the financial considerations of the project.

The minimum objectives were identified as, (i) a depth map on each of the perspective horizons (and there were two horizons), independently derived; (ii) a short report describing how the interpretation was derived and how it compared to the original interpretation.

Although M loaded the data, established the interval velocities from the seismic stacking velocities and defined depth map of top reservoir, PD had ultimate responsibility for the PROCESS: [implementing time-depth conversion: DICK]. PD was the PROCESS OWNER and M a PLAYER. PD is a Principal geophysicist and M is a geophysicist.

Identified ROLES for Principal geophysicist were, (i) to oversee the process; (ii) to receive data from the client and send the results of the process back; (iii) to establish velocities from well data; (iv) to interpret the seismic time intervals; (v) to combine seismic interval velocity and well data and; (vi) to define reservoir volumetrics. Identified ROLES for geophysicist were, (i) to load data; (ii) to establish interval velocities from seismic stacking velocities and; (iii) to define depth map of top reservoir.

See also

CARD 2-PROCESS INITIATION

CARD 3-IDENTIFYING CRITICAL DEPENDENCIES

CARD 5-AREAS OF UNCERTAINTY

CARD 10-UNCERTAINTY ASSOCIATED WITH THE DEPTH MAP

CARD 11-DATA CALIBRATION PROBLEMS

CARD 13-RESOLVING PROBLEMS

CARD 14-PROCESS OBJECTIVES

CARD 16-CONFIDENCE IN PREDICTIONS

CARD 20-IDENTIFYING CRITICAL PROCESS CONSTRAINTS

CARD 23-QUALITY CONTROL

CARD 24-INDEPENDENCE OF ASSESSMENT

TABLE A6.2 SHORT NOTE FOR CARD 1 [DICK]

CARD 1: *[Process overview: DICK]*

The PROCESS OWNER, Principal geophysicist was responsible for overseeing the PROCESS: *[implementing time-depth conversion: DICK]* and was given the ROLE, (i) *[to receive INPUTS and send OUTPUTS]*. The Principal geophysicist was also a PLAYER in the PROCESS: *[implementing time-depth conversion: DICK]* and had the additional ROLES, (ii) *[to establish velocities from well data]*; (iii) *[to interpret the seismic time intervals]*; (iv) *[to combine seismic interval velocity and well data]* and; (v) *[to define reservoir volumetrics]*. The PLAYER, geophysicist was given the ROLES, (i) *[to load data]*; (ii) *[to establish interval velocities from seismic stacking velocities]* and; (iii) *[to define depth map of top reservoir]*.

Identified key SUB-PROCESSES for PROCESS: *[implementing time-depth conversion: DICK]* are, (i) *[to receive the necessary data from the clients and initiating the PROCESS]* (ii) *[loading seismic data]*; (iii) *[establishing interval velocities from seismic stacking velocities]*; (iv) *[establishing velocities from well data]*; (v) *[establishing seismic time intervals]*; (vi) *[establishing velocity model of reservoir]*; (vii) *[combing velocity model and time interpretations]* and; (viii) *[producing depth map and volumetric calculations]* and; (ix) *[to terminate the PROCESS and passing the results of the PROCESS to the client]*.

Note, PROCESS: *[implementing time-depth conversion: DICK]* was heavily constrained by time and this coupled with problems surrounding the loading of data led to a close association with the oil company. This close association may have implications for the notion of independence required by the financial considerations of the project.

EMERGENT QUESTIONS:

9. TABLES A7.0, A7.1 & A7.2 represent the results of the grounded analysis of the concept [*Data calibration problems*: DICK]. This particular problem was highlighted in a number of paragraphs and in paragraph 26 it was stated by the project team that, “*it could have been an area of potential failure.*” To overcome these difficulties within the specified time constraints, the project team felt it necessary to develop a direct contact with the original data source. See paragraph 25, TABLE A7.0. This was also highlighted in TABLES A7.1 and A7.2. However, while the project team acknowledged that the clients experience proved very useful in overcoming these problems, what they failed to realise was the contradiction surrounding this direct contact and the implications this may have had for the independence of the project results. This was considered in more detail in the concept [*Independence of assessment*: DICK].

10. TABLES A8.0, A8.1 & A8.2 represent the results of the grounded analysis of the concept [*Independence of assessment*: DICK]. Again this particular problem could be seen in various paragraphs. For example, in paragraph 3 the project acknowledged the need for an independent assessment. However, further on it was admitted *that a lot of the information provided would have to be used without checking*. While the project team may have felt that this was compatible with the overall requirements of the project objectives, questions of independence can be raised. An admission of the evaluation not being totally independent is presented in TABLE A8.1 and in TABLE A8.2 the idea that some measures of evidence to show that outcome of PROCESS: [*implementing time-depth conversion*: DICK] is still compatible with the specific OBJECTIVES of [*implementing time-depth conversion*: DICK] is raised.

TABLE A7.0 EXAMPLE OF CONCEPT CARD FOR [Data calibration problems: DICK]

CARD 11	<i>[Data calibration problems: DICK]</i>
Para 1	Problems with the land seismic lead to problems with time interpretation as well as depth conversion.
Para 4	Problems with the original data forced PD to contact client.
Para 10	Since process was sequential, then problems at data loading phase would have a knock-on affect at interpretation, volumetrics and depth conversion phase. This could have serious implications, since project was time constrained.
Para 20	It was reported, that there was a lot of uncertainty associated with the data, it was of different vintages and it had been processed differently.
Para 24	Although the project team felt that there was a way to quantify the uncertainty associated with the depth map, it wasn't done because it couldn't have been done in the time available.
Para 25	There were calibration problems with the data on the work station. It was found that an interpretation of the seismic lines could not be made, since they did not appear on the screen properly. Being land data they had used different data means for registering the data and they needed some further processing. This required bulk shifting of each of the surveys to a common datum. These unexpected problems were overcome by a combination of working within the work station and contacting the oil company to get advice and ideas on how to correct those problems.
Para 26	"It could have been an area of potential failure."
Para 28	The use of the clients experience proved very useful in overcoming those problems. It enabled the project team to resolve the difficulties with the data very quickly. It was felt that without that help, the project team would not have managed to resolve the problems quickly enough to get the project done in time.
Para 34	"The problem with the loading of the data could have developed into some more serious." Previous data loading problems had occupied a project team for over a month. Such a delay would have upset the clients timetable and have serious implications for IKODA.

TABLE A7.0 EXAMPLE OF CONCEPT CARD FOR [*Data calibration problems*: DICK]

Links with	CARD 2-PROCESS OVERVIEW CARD 3-IDENTIFYING CRITICAL DEPENDENCIES CARD 5-AREAS OF UNCERTAINTY CARD 10-UNCERTAINTY ASSOCIATED WITH THE DEPTH MAP CARD 12-ANY SIGNS OF PROJECT FAILING CARD 13-RESOLVING PROBLEMS CARD 15-DID YOU LEARN ANYTHING? CARD 20-IDENTIFYING CRITICAL PROCESS CONSTRAINTS CARD 23-QUALITY CONTROL CARD 24-INDEPENDENCE OF ASSESSMENT
(1)	<i>Problems with data loading</i>
(2)	<i>Unexpected data calibration problems</i>
(3)	<i>Uncertainty associated with loading data</i>

TABLE A7.1 PROVISIONAL DEFINITION FOR CONCEPT [*Data calibration problems: DICK*]

CARD 11: [*Data calibration problems: DICK*]

Supplied data was found to be calibrated incorrectly. When load onto work station some of the seismic lines could not be interpreted. (They did not appear on the screen properly.) The originators of the data had used a different data means for registering the data. Each of the surveys had to be shifted to a common datum before interpretation could start. This required re-processing and re-calibration. To overcome these problems within the specified project time it was felt that a direct contact with original source would be beneficial.

See also;

CARD 1-PROCESS OVERVIEW

CARD 3-IDENTIFYING CRITICAL DEPENDENCIES

CARD 4-MEASURES OF EVIDENCE FOR SUCCESS & OF FAILURE

CARD 5-AREAS OF UNCERTAINTY

CARD 10-UNCERTAINTY ASSOCIATED WITH THE DEPTH MAP

CARD 12-ANY SIGNS OF PROJECT FAILING

CARD 15-DID YOU LEARN ANYTHING?

CARD 20-IDENTIFYING CRITICAL PROCESS CONSTRAINTS

CARD 23-QUALITY CONTROL

TABLE A7.2 SHORT NOTE FOR CARD 11

CARD 11: [*Data calibration problems: DICK*]

Since this particular project was a series of sequential processes constrained by time (there was no way of paralleling) any unexpected data calibration problems could have series implications. (It was expected that Principal Geophysicist could interpret data directly.) When difficulties arose, it was felt that direct contract and the use of similar experiences would help to overcome these problems. This could raise questions over the requirements of an independent assessment and the appropriateness of the results of such an assessment.

EMERGENT QUESTIONS:

Is the data supplied compatible with the processing methodology?

Why are data calibration problems so unexpected?

What steps could you take to minimise the unexpected nature of the problem?

How much influence will data problems have on the success or failure of the process?

How could you resolve these problems without compromising the process independence?

How could you justify your solution?

In this respect, how would you define measures for success & failure?

What evidence can you use to support those measures?

Is a focus on defining evidence for process success ignoring evidence of failure?

How would you answer the claim that you are biased towards defining process success?

TABLE A8.0 EXAMPLE OF CONCEPT CARD FOR [*Independence of assessment*: DICK]

CARD 24	<i>[Independence of assessment: DICK]</i>
Para 3	The client required an independent interpretation and volumetrics for a field. The reason that it had to be independent assessment <i>was its use as a financial justification for</i> another company. <i>This required an</i> independent technical assessment of this field, rather than an operators assessment. However, the project team admit that there was a mixture of how much of the clients knowledge they used in the assessment and how much they did independently. It was accepted that a lot of the information provided would have to be used without checking and that given the time constraints a balance between a completely independent assessment and using information provided by the client would have to be struck. The project team still felt that this was compatible with the specific objectives.
Para 9	Time constraints did dictated the method used.
Para 15	Quality control function of, (i) discussing with management on methodology to be used and; (ii) ensuring management reviewed results of interpretation and associated report.
Para 20	Having a direct link to the oil company proved beneficial.
Para 24	The oil companies data and report highlighted significant uncertainties.
Para 25	Unexpected data problems overcome by combination of, (i) data processing within work station and; (ii) contacting oil company directly for advice on how to correct these problems.
Para 28	The use of the clients experience proved very useful in overcoming those problems. It enabled the project team to resolve the difficulties with the data very quickly. It was felt that without that help, the project team would not have managed to resolve the problems quickly enough to get the project done in time.
Para 36	Project team feel that within the time constraints, the generated reservoir estimate was the best possible.

TABLE A8.0 EXAMPLE OF CONCEPT CARD FOR [*Independence of assessment*: DICK]

Links with	CARD 2-PROCESS OVERVIEW CARD 3-IDENTIFYING CRITICAL DEPENDENCIES CARD 5-AREAS OF UNCERTAINTY CARD 10-UNCERTAINTY ASSOCIATED WITH THE DEPTH MAP CARD 11-DATA CALIBRATION PROBLEMS CARD 13-RESOLVING PROBLEMS CARD 14-PROCESS OBJECTIVES CARD 16-CONFIDENCE IN PREDICTIONS CARD 20-IDENTIFYING CRITICAL PROCESS CONSTRAINTS CARD 23-QUALITY CONTROL
(1)	<i>The need for an independent audit</i>
(2)	<i>Admission that evaluation not being totally independent</i>
(3)	<i>Questions raised over independence of assessment</i>

TABLE A8.1 PROVISIONAL DEFINITION FOR CONCEPT [*Independence of assessment*: DICK]

<p>CARD 24: [<i>Independence of assessment</i>: DICK]</p> <p>The Principal Geophysicist admitted that “there was a mixture of how much of their knowledge I actually took and used in the project and how much I did independently.” The Principal Geophysicist stated that “there was a balance between a completely independent interpretation and using some of the information they had correlated together.” This may be looked upon as an admission of the evaluation not being totally independent. However, there was a belief that the outcome was still compatible with the need for independence as defined by specific objectives of the project. (See PROCESS OBJECTIVES.)</p> <p>See also;</p> <p>CARD 2-PROCESS INITIATION CARD 3-IDENTIFYING CRITICAL DEPENDENCIES CARD 5-AREAS OF UNCERTAINTY CARD 10-UNCERTAINTY ASSOCIATED WITH THE DEPTH MAP CARD 11-DATA CALIBRATION PROBLEMS CARD 13-RESOLVING PROBLEMS CARD 14-PROCESS OBJECTIVES CARD 16-CONFIDENCE IN PREDICTIONS CARD 20-IDENTIFYING CRITICAL PROCESS CONSTRAINTS CARD 23-QUALITY CONTROL</p>
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TABLE A8.2 SHORT NOTE FOR CARD 24 [DICK]

<p>CARD 24: [<i>Independence of assessment</i>: DICK]</p> <p>Some concerns were raised over direct contact influencing independence of assessment. While there was a belief that the outcome was still compatible with the need for independence as defined by specific objectives of the project (See PROCESS OBJECTIVES.), it may be appropriate to develop some measures of evidence that show outcome of process still compatible with specific objectives.</p> <p>EMERGENT QUESTIONS:</p> <p>How would you define a completely independent assessment?</p> <p>Using that definition, is your assessment independent?</p> <p>What evidence do you have that indicates assessment is compatible with objectives?</p> <p>If available, will you use company’s previous work, to confirm your assessment?</p> <p>Would you be conditioned by the project constraints to look for similarities?</p> <p>How does the quality control of the project ensure independence of assessment?</p>
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CASE STUDY 3: [HARRY]

11. In this section some examples of the grounded analysis of the case study [HARRY] are presented. [HARRY] is a on-going project and represents the *new-case* (IC₁). TABLE A9 represents the beginning of the concept labelling process. For example, in paragraph 1, several concepts were identified, namely (i) *process constrained by field geology*; (ii) *process overview*. These and other significant concepts identified during the initial labelling activity are shown in TABLE A10. The concept [*process overview*: HARRY] was identified in a number of different paragraphs. This is seen in TABLE A11.0 and includes a number of possible connections with other emergent concepts and earlier concept labels. The analysis revealed explicit and implicit properties of the concept [*Process overview*: HARRY]. This can be seen in TABLE A11.1, in which explicit properties were identified as PROCESS OWNER, PLAYERS, ROLES and SUB-PROCESSES etc.

TABLE A9 EXAMPLE PARAGRAPHS FROM INTERVIEW OF CASE-STUDY [HARRY]

Interview with Giles_P; July 27 1998, Field [HARRY].

1. When we took it over, the idea was to try and use the seismic velocities and the well velocities. The difficulty is that while it is a producing field, the geology is very complex. It is a central salt dome which causes a lot of problems. Consequently, while there is a lot of well data, it is not that useful. So that was quite limiting, also we have to treat the field in two halves. So it is almost like doing two separate conversions. We have tried taking the seismic velocities, and extracting the interval velocities from those (sort of global stacking velocities) and then using those as the basis of the geo-statistics. The geo-stats are then used to predict the velocities at the well locations (based on those seismic velocities). These predicted velocities are compared with the velocities we are actual seeing at the wells. *A correlation between the seismic interval velocities and well data is used to define a velocity model of the reservoir. This is used to produce a depth map which is then used to define the volumetrics of the field.* So far the results have been fairly disappointing. The derived correlations have been in most cases very bad, almost like scatter plots.
2. There are quite a few possible explanations for this problem,
 - (i) the well picks themselves may not be very accurate. This is a problem, which we occasionally have (particularly in the shallower intervals). Sometimes in the shallower intervals, the depth picks are not made on full sets of data. Sometimes, they are made on very sparse sets of data and often compromised data. So they can actually be wrong.
 - (ii) the more likely explanation is that the structure of the field is so complicated. That is, skewing the seismic velocities. Because of the way in which they pick the seismic velocities, it is essentially to get the best seismic image. For example, since we do not have the influence of the actual rock velocity which is want we want, but a lot of other influences which skew it in different directions. Depending on what it is, the seismic velocity is simply related to the rock velocity only in a very simple geometrical situation. So when you get complicated geometry's things cease to be simply related. If it is not simply related than that is going to scatter your points.
3. There is a possibility, that it is not so much a software problem, but the use of the software in that we may not be using exactly right data model. There is always that possibility. However, we are not using the software we used in TOM. We are using the old software that does have that ability. So we have no reason to doubt the integrity of the results from the software. There is always doubt as to whether you are using it in the best way, but that is not a problem with the software but the user. It is probably more likely to be a problem with the data itself.
4. Some of the intervals are not as bad as others. In the case [tom] we actual bundled together a lot of the overburden into one unit, which gave us a good result. This is what we used in one of the sides of this field. (The field has two flanks). As in [tom], bundling also gives a reasonable result. The problem is that we only have three wells to control it. While it looks good, there is not much evidence. *However, this method will be used on the other flank.* But I don't think that it is quite as good *as the first flank.* As in the case of [tom] we have a top interval and a middle interval, my feeling is that we may still have to use Dave's original velocity map for that layer just above the target horizon. We may just have use his map because I am not sure we can produce another map that has any sort of reasonable basis. The current situation in terms of process flow, *is that we have failed at getting a correlation between the well velocities and the seismic velocities.* If we cannot resolve that in a satisfactory manner, then we will have to abandon the attempt. If it is so noisy that it looks likely *then* it is not going to be of any use. If you cannot match the seismic velocities to the well velocities, then you cannot use the *geo-statistical* method. We are not sure how we are going to progress with this until we have spoken to the client.

TABLE A10 SIGNIFICANT CONCEPTS IDENTIFIED FROM TABLE A9

Interview with Giles_P; July 27 1998, Field [HARRY].

- | | |
|---------------|---|
| Para 1 | <i>Process constrained by field geology</i>
<i>Process overview</i> |
| Para 2 | <i>Possible explanations for disappointing results</i>
<i>Well picks not accurate</i>
<i>Process constrained by field geology</i> |
| Para 3 | <i>Possibility that problems with derived correlations influenced by inappropriate data model</i> |
| Para 4 | <i>Problems with correlation between the well velocities and the seismic velocities may force team to abandon to project</i> |

TABLE A11.0 EXAMPLE OF CONCEPT CARD FOR [Process overview: HARRY]

CARD 1	[Process overview: HARRY]
Para 1	The process consisted of <i>loading the seismic on the work station, interpreting the seismic time horizons, extracting the interval velocities which are the basis of the geo-statistics. The geo-statistics are used to predict velocities at well locations. Predicted velocities are compared with actual well velocities and a correlation is derived. A correlation between the seismic interval velocities and well data is used to define a velocity model of the reservoir. This is used to produce a depth map which is then used to define the volumetrics of the field. However the results of the derived correlations have not been encouraging.</i>
Para 6	The approach taken determined by problem
Para 10	I was the PROCESS OWNER in that I initiated the process. The PLAYER would be M and M would do all the geo-statistical analysis. I would be responsible to Ikoda management.
Links with	CARD 3- CRITICAL DEPENDENCIES CARD 5-AREAS OF UNCERTAINTY CARD 13-RESOLVING PROBLEMS CARD 14-PROCESS OBJECTIVES CARD 16-CONFIDENCE IN PREDICTIONS CARD 20-PROCESS CONSTRAINTS CARD 23-QUALITY CONTROL

TABLE A11.1 PROVISIONAL DEFINITION FOR CONCEPT [*Process overview: HARRY*]

CARD 1: [*Process overview: HARRY*]

For field [HARRY], PROCESS was defined as [*implementing time-depth conversion*]. In this field the PROCESS: [*implementing time-depth conversion*] consisted of interpreting the seismic time horizons, converting those time horizons and then producing depth converted maps. Volumetrics on the depth converted maps were used to define reservoir volumes.

Identified key SUB-PROCESSES for PROCESS: [*implementing time-depth conversion: HARRY*] are, (i) loading seismic data; (ii) establishing interval velocities from seismic stacking velocities; (iii) establishing geo-statistical model from interval velocity; (iv) using geo-statistical model to predict velocity at well location; (v) establishing velocity model; (vi) combining velocity model and time interpretations and; (vii) producing depth map and volumetric calculations.

The minimum objectives are, (i) a depth map on the perspective horizon.

GP was the PROCESS OWNER and had ultimate responsibility for the PROCESS: [*implementing time-depth conversion: HARRY*]. M was a PLAYER and loaded the data and did all the geo-statistical analysis. GP is a Senior geophysicist and M is a geophysicist.

ROLES for Senior geophysicist were, (i) to oversee the process; (ii) to receive data from the client and send the results of the process back; (iii) to define reservoir volumetrics. Identified ROLES for geophysicist were, (i) to load data; (ii) to establish interval velocities from stacking & interval velocities; (iii) to define correlation between predicted seismic velocities & actual well velocities; (iv) to combine seismic interval velocity & well data and; (v) to define depth map of top reservoir.

See also

CARD 3- CRITICAL DEPENDENCIES

CARD 5-AREAS OF UNCERTAINTY

CARD 13-RESOLVING PROBLEMS

CARD 14-PROCESS OBJECTIVES

CARD 16-CONFIDENCE IN PREDICTIONS

CARD 20-PROCESS CONSTRAINTS

CARD 23-QUALITY CONTROL

TABLE A11.2 SHORT NOTE FOR CARD 1 [HARRY]

CARD 1: [*Process overview: HARRY*]

The PROCESS OWNER, Senior geophysicist was responsible for [*overseeing*] the PROCESS: [*implementing time-depth conversion: HARRY*] and was given the ROLE, (i) [*to receive INPUTS and send OUTPUTS*]. The Senior geophysicist was also a PLAYER in the PROCESS: [*implementing time-depth conversion: HARRY*] and had the additional ROLE, (ii) [*to define reservoir volumetrics*]. The PLAYER, geophysicist was given the ROLES, (i) [*to load data*]; (ii) [*to establish geo-statistical model from stacking & interval velocities*]; (iii) [*to define correlation between predicted seismic velocities & actual well velocities*]; (iv) [*to define depth map of top reservoir*] and; (v) [*to define depth map of top reservoir*].

Identified key SUB-PROCESSES for PROCESS: [*implementing time-depth conversion: HARRY*] are, (i) [*to receive the necessary data from the clients and initiating the PROCESS*] (ii) [*loading seismic data*]; (iii) [*establishing interval velocities from seismic stacking velocities*]; (iv) [*establishing geo-statistical model from interval velocities*]; (v) [*using geo-statistical model to predict velocity at well location*]; (vi) [*establishing velocity model*]; (vii) [*combing velocity model and time interpretations*] and; (viii) [*producing depth map and volumetric calculations*] and; (ix) [*to terminate the PROCESS and passing the results of the PROCESS to the client*].

EMERGENT QUESTIONS:

APPENDIX B: RESULTS OF PROCESS MODEL EXERCISE

1. In this section the form of the process events of the case studies [*implementing time-depth conversion*: TOM] and [*implementing time-depth conversion*: DICK], are expressed as a vocabulary and organised by a Process Model algorithm. In section 7.4 completed Process Model explanations of all three case studies are presented as graphical representations of hierarchical models of processes and process interactions with ROLES, PLAYERS, SCENARIOS, CONSEQUENCES, HAZARDS, REFLECTIONS, SUGGESTIONS and NEW OUTCOMES.

TABLE B1 PROCESS: [implementing time-depth conversion: TOM].

1.	[PROCESS: <i>implementing time-depth conversion: Tom</i>]
2.	[ROLE 1: <i>to oversee</i> PROCESS, PROCESS OWNER: <i>principal geophysicist</i> , RESPONSIBILITY: <i>to receive</i> INPUTS <i>from</i> CLIENTS & <i>initiate</i> PROCESS <i>by sending</i> INPUTS <i>to</i> PLAYER 1; <i>to receive</i> OUTPUTS <i>from</i> PLAYER 1 & <i>terminate</i> PROCESS <i>by sending</i> OUTPUTS <i>to</i> CLIENTS, SUB-PROCESS 1: <i>receiving</i> INPUTS <i>from</i> CLIENTS & <i>sending</i> INPUTS <i>to</i> PLAYER 1, SUB-PROCESS 9: <i>receiving</i> OUTPUTS <i>from</i> PLAYER 1 & <i>sending</i> OUTPUTS <i>to</i> CLIENTS]
3.	[ROLE 2: <i>to receive</i> INPUTS & <i>send</i> OUTPUTS, PLAYER 1: <i>senior geophysicist</i> , SUB-PROCESS 2: <i>receiving</i> INPUTS <i>from</i> PROCESS OWNER, SUB-PROCESS 8: <i>sending</i> OUTPUTS <i>to</i> PROCESS OWNER] [ROLE 3: <i>to load seismic data</i> , PLAYER 2: <i>geophysicist</i> , SUB-PROCESS 3: <i>loading seismic data</i>] [ROLE 4: <i>to establish geo-statistical model from stacking & interval velocities</i> , PLAYER 2: <i>geophysicist</i> , SUB-PROCESS 4: <i>establishing interval velocities from seismic stacking velocities</i>] [ROLE 4: <i>to establish geo-statistical model from stacking & interval velocities</i> , PLAYER 2: <i>geophysicist</i> , SUB-PROCESS 5: <i>establishing geo-statistical model for interval velocities</i>] [ROLE 5: <i>to define correlation between predicted seismic velocities & well velocities</i> , PLAYER 2: <i>geophysicist</i> , SUB-PROCESS 6: <i>using geo-statistical model to predict velocity at well location</i>] [ROLE 6: <i>to combine seismic interval velocity & well data</i> , PLAYER 2: <i>geophysicist</i> , SUB-PROCESS 7: <i>establishing velocity mode</i>] [ROLE 7: <i>to define depth map of top reservoir</i> , PLAYER 2: <i>geophysicist</i> , SUB-PROCESS 8: <i>combining velocity model & time interpretation</i>] [ROLE 8: <i>to define reservoir volumetrics</i> , PLAYER 2: <i>senior geophysicist</i> , SUB-PROCESS 9: <i>producing depth map & volumetric calculations</i>]
4.	[CLIENTS: <i>senior management</i>] [STAKE-HOLDERS: <i>field owners</i>]
5.	[POINT OF VIEW: <i>proneness to failure</i>]
6.	[BEGIN STATE 1: <i>budget is known</i>] [BEGIN STATE 2: <i>completion date is known</i>] [BEGIN STATE 3: <i>time interpretations are known</i>] [BEGIN STATE 4: <i>well data is known</i>] [END STATE 1: PROCESS <i>will undergo</i> TRANSFORMATIONS] [END STATE 3: PROCESS <i>will meet all</i> OBJECTIVES]
7.	[INPUTS: <i>time interpretations are known, well data is known</i>] [OUTPUTS: <i>as defined by</i> OBJECTIVES] [CONTROLS: <i>as defined by</i> TRANSFORMATIONS] [CONSTRAINTS: <i>budget is known, completion date is known</i>]
8.	[ENVIRONMENT: CLIENTS, STAKE-HOLDERS]

9.	[CURRENT STATES: CLIENTS <i>have</i> OBJECTIVES, OBJECTIVE 1: <i>generate best estimate of depth to reservoir</i> , OBJECTIVE 2: <i>ensure depth values are appropriate for defining structure of reservoir</i> , OBJECTIVE 3: <i>quantify uncertainty of depth map</i>]
10.	[SUCCESS: <i>of CURRENT STATES is given by</i> EVIDENCE, EVIDENCE: <i>as defined by</i> NECESSARY EVIDENCE & POSSIBLE EVIDENCE]
11.	[TRANSFORMATION: BEGIN STATES <i>to</i> END STATES, SUB-PROCESS 3: <i>loading seismic data</i> , SUB-PROCESS 4: <i>establishing interval velocities from seismic stacking velocities</i> , SUB-PROCESS 5: <i>establishing geo-statistical model for interval velocity</i> , SUB-PROCESS 6: <i>using geo-statistical model to predict velocity at well location</i> , SUB-PROCESS 7: <i>establishing velocity model</i> , SUB-PROCESS 8: <i>combining velocity model & time interpretations</i> , SUB-PROCESS 9: <i>producing depth map & volumetric calculations</i>]
12.	[SCENARIO 1: <i>software unable to perform specific geo-statistical computations</i> , SUB-PROCESS 6: <i>using geo-statistical model to predict velocity at well location</i> , SUB-PROCESS 7: <i>establishing velocity model</i> , CONSEQUENTIAL OUTCOME 1: <i>project suffered time delay and cost overruns</i> , HAZARD 1: <i>selective attention to technical rationale hides potential problems</i>]
13.	[NECESSARY EVIDENCE: [] [POSSIBLE EVIDENCE: []]
14.	[PROCESS: <i>implementing time-depth conversion: Tom</i> , SUB-PROCESS 3: <i>loading seismic data</i> , SUB-PROCESS 4: <i>establishing interval velocities from seismic stacking velocities</i> , SUB-PROCESS 5: <i>establishing geo-statistical model for interval velocity</i> , SUB-PROCESS 6: <i>using geo-statistical model to predict velocity at well location</i> , SUB-PROCESS 7: <i>establishing velocity model</i> , SUB-PROCESS 8: <i>combining velocity model & time interpretations</i> , SUB-PROCESS 9: <i>producing depth map & volumetric calculations</i>]
15.	<p>[EVIDENCE: <i>there is no indication that consequences of SCENARIO seriously damages</i> PROCESS, CONSEQUENTIAL OUTCOME 1: <i>project suffered time delay & cost overruns</i>, HAZARD 1: <i>selective attention to technical rationale hides potential problems</i>, REFLECTION 1: <i>a concentration on the technical benefits of software may compromise project</i>]</p> <p>[REFLECTION 1: <i>a concentration on the technical benefits of software may compromise project</i>, SUGGESTION 1: <i>are the software requirements compatible with project requirements?</i>, SUGGESTION 2: <i>are you considering a 'contrast and compare exercise' between original & new software?</i>]</p> <p>[SUGGESTION 1: <i>are the software requirements compatible with project requirements?</i>, NEW OUTCOME 1: <i>a closer understanding between software and project requirements may result in fewer problems</i>]</p> <p>[SUGGESTION 2: <i>are you considering a 'contrast and compare exercise' between original & new software?</i>, NEW OUTCOME 2: <i>project team may have greater confidence in ability of software</i>]</p>

TABLE B2 PROCESS: [implementing time-depth conversion: DICK].

1.	[PROCESS: <i>implementing time-depth conversion: DICK</i>]
2.	[ROLE 1: <i>to oversee PROCESS, PROCESS OWNER: principal geophysicist, RESPONSIBILITY: to receive INPUTS from CLIENTS & initiate PROCESS by sending INPUTS to PLAYER 1; to receive OUTPUTS from PLAYER 1 & terminate PROCESS by sending OUTPUTS to CLIENTS, SUB-PROCESS 1: receiving INPUTS from CLIENTS & sending INPUTS to PLAYER 1, SUB-PROCESS 11: receiving OUTPUTS from PLAYER 1 & sending OUTPUTS to CLIENTS</i>]
3.	<p>[ROLE 2: <i>to receive INPUTS & send OUTPUTS, PLAYER 1: principal geophysicist, SUB-PROCESS 2: receiving INPUTS from PROCESS OWNER & initiating PROCESS, SUB-PROCESS 10: ending PROCESS & sending OUTPUTS to PROCESS OWNER</i>]</p> <p>[ROLE 3: <i>to load seismic data, PLAYER 2: geophysicist, SUB-PROCESS 3: loading seismic data</i>]</p> <p>[ROLE 4: <i>to establish interval velocities from seismic stacking velocities, PLAYER 2: geophysicist, SUB-PROCESS 4: establishing interval velocities from seismic stacking velocities</i>]</p> <p>[ROLE 5: <i>to establish velocities from well data, PLAYER 1: principal geophysicist, SUB-PROCESS 5: establishing velocities from well data</i>]</p> <p>[ROLE 6: <i>to interpret seismic time intervals, PLAYER 1: principal geophysicist, SUB-PROCESS 6: establishing seismic time intervals</i>]</p> <p>[ROLE 7: <i>to combine seismic interval velocity & well data, PLAYER 1: principal geophysicist, SUB-PROCESS 7: establishing velocity model</i>]</p> <p>[ROLE 8: <i>to define depth map of top reservoir, PLAYER 2: geophysicist, SUB-PROCESS 8: combining velocity model & time interpretation</i>]</p> <p>[ROLE 9: <i>to define reservoir volumetrics, PLAYER 1: principal geophysicist, SUB-PROCESS 9: producing depth map and volumetric calculations</i>]</p>
4.	<p>[CLIENTS: <i>senior management</i>]</p> <p>[STAKE-HOLDER 1: <i>field operators</i>]</p> <p>[STAKE-HOLDER 2: <i>business partner of field operators</i>]</p>
5.	[POINT OF VIEW: <i>proneness to failure</i>]
6.	<p>[BEGIN STATE 1: <i>budget is known</i>]</p> <p>[BEGIN STATE 2: <i>completion date is known</i>]</p> <p>[BEGIN STATE 3: <i>previous assessment of reservoir volumetrics are known</i>]</p> <p>[BEGIN STATE 4: <i>previous well data & ties to seismic are known</i>]</p> <p>[END STATE 1: <i>PROCESS will undergo TRANSFORMATIONS</i>]</p> <p>[END STATE 3: <i>PROCESS will meet all OBJECTIVES</i>]</p>
7.	<p>[INPUTS: <i>previous assessment of reservoir volumetrics are known, previous well data & ties to seismic are known</i>]</p> <p>[OUTPUTS: <i>as defined by OBJECTIVES</i>]</p> <p>[CONTROLS: <i>as defined by TRANSFORMATIONS</i>]</p> <p>[CONSTRAINTS: <i>budget is known, completion date is known</i>]</p>
8.	[ENVIRONMENT: <i>CLIENTS, STAKE-HOLDERS</i>]
9.	[CURRENT STATES: <i>CLIENTS have OBJECTIVES, OBJECTIVE 1: to determine best technical</i>

	<i>assessment of depth to reservoir, OBJECTIVE 2: to determine best technical assessment of reservoir volumetrics, OBJECTIVE 3: to ensure that technical assessment was independent, OBJECTIVE 4: to quantify uncertainty of assessment]</i>
10.	<i>[SUCCESS: of CURRENT STATES is given by EVIDENCE, EVIDENCE: as defined by NECESSARY EVIDENCE & POSSIBLE EVIDENCE]</i>
11.	<i>[TRANSFORMATION: BEGIN STATES to END STATES, SUB-PROCESS 3: loading seismic data, SUB-PROCESS 4: establishing interval velocities from seismic stacking velocities, SUB-PROCESS 5: establishing velocities from well data, SUB-PROCESS 6: establishing seismic time intervals, SUB-PROCESS 7: establishing velocity model, SUB-PROCESS 8: combining velocity model & time interpretation, SUB-PROCESS 9: producing depth map and volumetric calculations]</i>
12.	<i>[SCENARIO 1: project suffers from data calibration problems, SUB-PROCESS 3: loading seismic data, SUB-PROCESS 4: establishing interval velocities from seismic stacking velocities, CONSEQUENTIAL OUTCOME 1: problems with data resulted in project team having a direct contact with company's original report]</i>
13.	<i>[NECESSARY EVIDENCE: [] [POSSIBLE EVIDENCE: []]</i>
14.	<i>[PROCESS: implementing time-depth conversion: DICK, SUB-PROCESS 3: loading seismic data, SUB-PROCESS 4: establishing interval velocities from seismic stacking velocities, SUB-PROCESS 5: establishing velocities from well data, SUB-PROCESS 6: establishing seismic time intervals, SUB-PROCESS 7: establishing velocity model, SUB-PROCESS 8: combining velocity model & time interpretation, SUB-PROCESS 9: producing depth map and volumetric calculations]</i>
15.	<p><i>[EVIDENCE: there is no indication that consequences of SCENARIO seriously damages PROCESS, HAZARD 1: direct contact may threaten independence of assessment, REFLECTION 1: although direct contact with data source was beneficial questions of independence need to be considered]</i></p> <p><i>[REFLECTION 1: although direct contact with data source was beneficial questions of independence need to be considered, SUGGESTION 1: will the development of measures of evidence demonstrating outcome of process still compatible with objectives help to address these concerns?]</i></p> <p><i>[SUGGESTION 1: will the development of measures of evidence demonstrating outcome of process still compatible with objectives help to address these concerns?, NEW OUTCOME 1: evidential demonstration of independence may increase clients confidence in predicted reservoir volumetrics]</i></p>

TABLE B3 PROCESS: [implementing time-depth conversion: HARRY].

1. The below represents the known inputs of the case study 3: HARRY. These inputs form the basis of the hierarchical graphical representation shown in FIGURE 7.6 in section 7.4.

1.	[PROCESS: <i>implementing time-depth conversion: HARRY</i>]
2.	[ROLE 1: <i>to oversee PROCESS, PROCESS OWNER: senior geophysicist, RESPONSIBILITY: to receive INPUTS from CLIENTS & initiate PROCESS by sending INPUTS to PLAYER 1; to receive OUTPUTS from PLAYER 1 & terminate PROCESS by sending OUTPUTS to CLIENTS, SUB-PROCESS 1: receiving INPUTS from CLIENTS & sending INPUTS to PLAYER 1, SUB-PROCESS 11: receiving OUTPUTS from PLAYER 1 & sending OUTPUTS to CLIENTS</i>]
3.	<div>[ROLE 2: <i>to receive INPUTS & send OUTPUTS, PLAYER 1: senior geophysicist, SUB-PROCESS 2: receiving INPUTS from PROCESS OWNER & initiating PROCESS, SUB-PROCESS 10: ending PROCESS & sending OUTPUTS to PROCESS OWNER</i>]</div> <div>[ROLE 3: <i>to load seismic data, PLAYER 2: geophysicist, SUB-PROCESS 3: loading seismic data</i>]</div> <div>[ROLE 4: <i>to establish geo-statistical model from stacking & interval velocities, PLAYER 2: geophysicist, SUB-PROCESS 4: establishing interval velocities from seismic stacking velocities</i>]</div> <div>[ROLE 4: <i>to establish geo-statistical model from stacking & interval velocities, PLAYER 2: geophysicist, SUB-PROCESS 5: establishing geo-statistical model for interval velocities</i>]</div> <div>[ROLE 5: <i>to define correlation between predicted seismic velocities & well velocities, PLAYER 2: geophysicist, SUB-PROCESS 6: using geo-statistical model to predict velocity at well location</i>]</div> <div>[ROLE 6: <i>to combine seismic interval velocity & well data, PLAYER 2: geophysicist, SUB-PROCESS 7: establishing velocity model</i>]</div> <div>[ROLE 7: <i>to define depth map of top reservoir, PLAYER 2: geophysicist, SUB-PROCESS 8: combining velocity model & time interpretation</i>]</div> <div>[ROLE 8: <i>to define reservoir volumetrics, PLAYER 1: senior geophysicist, SUB-PROCESS 9: producing depth map and volumetric calculations</i>]</div>
4.	<div>[CLIENTS: <i>senior management</i>]</div> <div>[STAKE-HOLDERS: <i>field owners</i>]</div>
5.	[POINT OF VIEW: <i>prone to failure</i>]
6.	<div>[BEGIN STATE 1: <i>budget is known</i>]</div> <div>[BEGIN STATE 2: <i>completion date is known</i>]</div> <div>[BEGIN STATE 3: <i>time interpretations are known</i>]</div> <div>[BEGIN STATE 4: <i>well data is known</i>]</div> <div>[END STATE 1: <i>PROCESS will undergo TRANSFORMATIONS</i>]</div> <div>[END STATE 3: <i>PROCESS will meet all OBJECTIVES</i>]</div>

7.	[INPUTS: <i>time interpretations are known, well data is known</i>] [OUTPUTS: <i>as defined by</i> OBJECTIVES] [CONTROLS: <i>as defined by</i> TRANSFORMATIONS] [CONSTRAINTS: <i>budget is known, completion date is known</i>]
8.	[ENVIRONMENT: CLIENTS, STAKE-HOLDERS]

