

**MULTIDISCIPLINARY INTEGRATION: A DECISION  
METHODOLOGY AND PROCEDURE FOR INSTRUCTION**

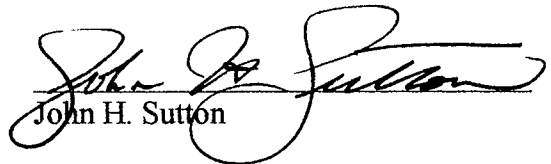
by  
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A thesis submitted to the Faculty and Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science (Petroleum Engineering).

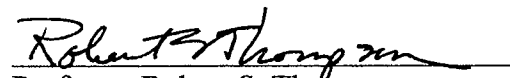
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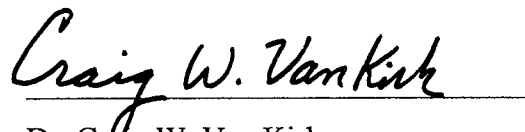
  
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## ABSTRACT

Organizations across industry are increasingly using teams to produce results. This is true within the petroleum industry. In the face of shrinking reserves and increasing costs, many United States oil companies are using self-directed and cross-functional work teams as a way of improving their competitiveness within the industry. The results of integrated teamwork have spurred study. The attributes of successful teamwork in reservoir management have been documented. Yet, a process to facilitate multidisciplinary teamwork and guide individual members through the process needs to be addressed. This thesis explores and develops a strategy for team integration.

The strategy for integration provides a powerful approach and way of thinking about problem solving in a multidisciplinary environment. The strategy does not include the words geology, geophysics, or petroleum engineering. Rather, the focus is on problem definition and objectives. Critical information needed to reach the objectives are identified. The identified critical information needs lead to data requirements. The economic scope and project objectives are revised as the available data and the data needs are assessed. Successful integration does away with the compartmentalization of the disciplines and places the focus on getting the best cost-effective solution to the problem. Therefore, data and people are integrated most efficiently. Criteria are developed to judge the economic viability of purchasing data needs since a cost-benefit analysis is paramount to successful integration. Finally, alternatives are identified and compared using quantitative criteria. The criteria establish the basis for recommendations and action plans. When used, the author believes this strategy provides

improved results through more effective integration by subordinating a parochial focus to an integrated focus.

The synergism of three sources of data and knowledge assisted in the formation of the strategy and instruction methodology. First, a thorough literature search was performed in the areas of multidisciplinary team management, decision analysis, and teamwork instruction theory. While theory did exist which supported the formation of the strategy, no example of a petroleum-specific decision process existed. Second, my advisor, Professor Robert Thompson, was instrumental in providing ideas and experience. His knowledge of oil-field projects and integrated teamwork provided the basis by which a general technique and teaching methodology were translated into oil-field terms. Third, the author's experience in decision analysis and team integration assisted in the strategy development.

The strategy was tested through its instruction to and implementation in a multidisciplinary design class at the Colorado School of Mines. The class consisted of seniors and graduate students from the disciplines of petroleum engineering, geology, and geophysics. The testing process included three phases: An instruction phase, an initial implementation phase, and an advanced implementation phase. The implementation phases consisted of the scenarios documented in chapters six and seven. At the end of each phase, "After Project Discussions" were held and student comments were documented. These comments served as feedback for how the strategy and its instruction could be improved.

The conclusion resulting from analysis of team comments and performances showed the strategy did assist in the integration and decision processes. End product

briefings and reports became more integrated. Conclusions and decisions were supported by increased justification and analysis. The understanding of sister discipline contributions increased. There were areas of concern, such as an overemphasis on the process and terminology confusion, which diminished the effectiveness of the process and quality of the product. However, overall results displayed an enhancement of team integration.

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## CHAPTER 1.

### INTRODUCTION

#### 1.1 Background

Organizations across industry are increasingly using teams to produce results. This is true within the petroleum industry. In the face of shrinking reserves and increasing costs, many United States oil companies are using self-directed and cross-functional work teams as a way of improving their competitiveness within the industry. Many different types of teams exist, ranging from specific short-term, problem solving teams, for operations such as an exploration play, to longer-term project teams, for operations such as reservoir management. Companies form these teams hoping for better results, shorter decision cycle times, reduced costs, and increased profits.

Multifunctional integrated teams do provide excellent, sometimes superior results. There are many cases which document these successes (Akinlawon, Nwosu, Satter, & Jespersen, 1996; Kelkar, 1996; Satter & Thakur, 1994). Yet a concern has been posed: Are results actually better? Also, another concern is how to measure a team's versus an individual's success, and evaluate both team performance and individual team members' performances. The basic question being asked: Are companies achieving their expectations?

The previous question carries over to another similar uncertainty. After a team's formation, do the team members know how to operate as a team. As an example,

is there a team synergy which facilitates interaction and information flow and therefore produces quicker, better, reduced-costs decisions? Or, does the team label simply facilitate the historical assembly-line sharing of information once the individual discipline analyses have been performed? If the latter point holds true, then it may be that individual member experience more so than an integrative process is the true reason for success.

While there is a wealth of documentation which states the requirements and attributes of a successful team operation, no procedure for team integration which facilitates achieving team expectations exist. This type of process would assist in evaluation and provide a framework which team members could follow to share knowledge and experience.

## **1.2 Problem Statement and Objectives**

The petroleum industry understands the need for integrated teamwork. The results of its use have spurred further study and application. The attributes of successful teamwork, and the management of teams have been researched. Yet, a process to facilitate multidisciplinary teamwork and guide individual members through the process needs to be addressed. This thesis explores and develops a process of integration through the following objectives:

1. Provide a decision methodology which improves team interaction and integration.
2. Provide a procedure for teaching the methodology.

3. Implement the methodology and record observations and recommendations for improvement of items one and two (above).

### **1.3 Method of Investigation**

To investigate and achieve the stated objectives, a literature search was performed, a methodology was developed, it was tested, and observations were recorded. These steps are described below.

A thorough search of literature was performed to determine what theoretical basis could be inferred to assist in the methodology development. The results of this search are recorded in Chapter 2: Literature Review.

Once the methodology and an approach to instruct it were developed, a multidisciplinary design class was used to implement the strategy. The class consisted of various experience levels: Fourth year college seniors with summer-hire experience to graduate students with industry experience. All students were taught the methodology as a class, then formed into teams for the scenario exercises.

Scenario exercises were used to reinforce the strategy's principles which had been taught. The intent was to place the students in a "real-world" industry setting and have them use the process to develop an integrated solution. The two scenario exercises presented to the students will be discussed in this thesis. The first scenario was a reservoir management exercise described in Chapter 5. The second scenario was an exploration play described in Chapter 6. The author's observations as well as professor

and student comments were recorded. From these observations and comments, conclusions and recommendations were formed.

## **CHAPTER 2.**

### **LITERATURE REVIEW**

This chapter serves to review the present knowledge contained in engineering, business, and educational literature regarding subjects related to this research. Six main topics are covered:

- 2.1 Multidisciplinary Teams in the Petroleum Industry
  - 2.1.1 Integrated Reservoir Management
  - 2.1.2 Reservoir Management Training
- 2.2 Problem Solving and the Design Process
- 2.3 Problem Solving Instruction
- 2.4 Team Evaluation and Performance Appraisals
- 2.5 Meeting Management

#### **2.1 Multidisciplinary Teams In the Petroleum Industry**

The use of multidisciplinary teams in the petroleum industry is not new. Major oil corporations have documented the use of teams in reservoir management since the 1960's (Satter & Thakur, 1994). Yet, the emphasis on teams has received increased attention in the last several years as independent oil companies have begun to understand teamwork benefits. These benefits have been sought as domestic oil and gas industry efforts have increasingly been directed toward exploitation of existing fields rather than



new exploration (Sessions & Lehman, 1989). In fact, this is a world-wide trend. The December 30, 1996, issue of the Oil and Gas Journal reported that, “ The most important reserves trend in the 1990’s has been the addition of large volumes through activities other than new-field exploration. While exploration continues to contribute to reserves, the proportion added by in-fill drilling, new pays in existing fields, and adjustments based on new data about producing reservoirs has been growing” (Kennedy, 1996, p. 37). Much of this new exploitation is being performed by interdisciplinary teams (Sessions & Lehman, 1989).

### **2.1.1. Integrated Reservoir Management**

As the amount of knowledge in the petroleum arena increases, very rarely can one person be an expert in all facets. Thus, the need to integrate the knowledge and experiences of several single-subject “experts” has arisen. Teams have been formed in the hope that the synergism of the whole produces greater results than the individual (Thakur, 1990b). Several authors have expounded increased results as a product of multidisciplinary team integration (Satter, Varnon, & Hoang, 1994; Sessions & Lehman, 1989; Thakur, 1990b; Wiggins & Startzman, 1990). Their writings have been incorporated within the subject of Reservoir Management which they have described, provided management processes, and identified necessary components.

Reservoir Management has been described as a set of operations and decisions by which a reservoir is identified, measured, produced, monitored, and evaluated from discovery through depletion (Wiggins & Startzman, 1990). The overlying goal in this set of operations is the maximization of profits by optimizing recovery through effective

integration of resources (Satter et al., 1994). Six basic reservoir management objectives are listed throughout the current literature, all attempting to assist in the goal of profit maximization:

- a. Identify all reservoirs in a given field;
- b. Predict reservoir performance;
- c. Minimize the drilling of unnecessary wells;
- d. Define wellbore and surface systems;
- e. Correctly initiate operating controls;
- f. Consider all economic and legal matters (Thakur, 1990b).

Teamwork is involved in all the above aspects as the management process must integrate all available information to make decisions which will lead to the accomplishment of the goals and objectives.

The process of reservoir management is methodical with one step building upon the former and leading to the next. Once initiated, the program follows the following general flow:

- a. Goal establishment;
- b. Development of a plan which optimizes economics;
- c. Program implementation;
- d. Surveillance and monitoring;
- e. Evaluation;
- f. Revision of plans and goals (Satter, Varnon, & Hoang, 1992; Wiggins & Startzman, 1990).

As represented by the last step, the process is dynamic not static. All component parts of the process are subject to change (Wiggins & Startzman, 1990). Therefore, for a program to be effective, all personnel involved must work as a team and share knowledge

as they view it through the lens of their discipline. This is especially true in the collection of data, since the amount, type, and interpretation of data directly influence decisions.

Data acquisition and analysis is crucial to successful reservoir management. Before the acquisition of data, questions will be asked such as: “Are the data necessary?”, “What will you do with the data once acquired?”, and, “What benefits do you expect to achieve, and how do we obtain the information at minimal cost?” (Thakur, 1990b). These questions should be asked as they help ensure economic optimization. The answers are easier to justify if the needs, costs, and benefits are defined. Two acquisition extremes are possible. One provides a mass of data which possibly wastes money, and could confuse the issue and consume needed time. The other, with cost reduction as a central theme, provides little data; the end result being a less than optimal result. Careful planning through integrated coordination between disciplines helps achieve a correct middle ground (Satter & Thakur, 1994).

Two distinct approaches (Thakur, 1990a) exist within the domain of reservoir management. These approaches concern the purpose for the formation of the management teams. A “comprehensive” approach begins at a point in time, preferably at the discovery of the reservoir, and continues to reservoir abandonment. All facets of the reservoir’s development and production are controlled by the team. With a “problem solving” approach, a management team is formed to achieve a specific focused purpose. The team develops a plan of action to evaluate and increase the net worth of the reservoir. Both approaches are presently being used successfully within industry.

The two approaches to reservoir management, explained above, have led to the formation of two managerial control systems. These procedures differ in respect to where team members are located, and in the team's supervisory control. In a "project-based" system, the historical separate discipline structure exists (Sessions & Lehman, 1989). Teams are not an entity in themselves. Team members organize as a team for a specific purpose or project, but are individually supervised by the department head where the member works full-time. Under a "team-based" system, the team is a separate entity (Sessions & Lehman, 1989). All team members work for the team project, and are supervised by a single project leader. While both approaches have benefits and drawbacks, such as focus and personnel utilization, all authors cited recommend a "team-based" approach.

The mere creation of a multidisciplinary team does not guarantee integration leading to success (Satter et al., 1992). As an example, team members may integrate only in the sense that they share what they have "accomplished." In these cases, "true integration," conducted through the sharing of knowledge within the periods of analysis and at decision points never or seldom occurs. In fact, Thakur (1990b, p. 336) states that "the most important reason why reservoir management programs fail is unintegrated group effort." To enhance the chances for successful integrated team effort, several key elements have been identified (Satter et al., 1994; Sessions & Lehman, 1989; Thakur, 1990b).

- a. Team members must understand the reservoir management process.
- b. Unconstrained communication between team members is essential.
- c. Cross-training between the disciplines assists in analysis and enhances communication.

- d. Team members should strive to view a problem or issue through an integrated perception.
- e. Teams should make integrated decisions by soliciting input from all team members.

Several questions have been suggested which, when combined with the above key elements, assist communications, cross-training, and integrated perceptions (Thakur, 1990b).

- a. What does the answer or interpretation mean?
- b. Does the answer concur or contradict current interpretations?
- c. Are there other possible interpretations?
- d. Are the assumptions and interpretations reasonable?
- e. Are data reliable?
- f. Are additional data necessary?
- g. Has the reservoir been adequately defined?

While the key elements and questions will not guarantee successful integration, their use should improve the chances.

The importance of team integration for the purpose of reservoir management abounds in current literature. Satter, Thakur, Wiggins, and others listed in the reference section have examined in detail the subject. They have established the need for integration. They have suggested essential elements for success, and shortfalls causing failure. They have described a management process. But, in the area of execution, the author discovered no literature describing a recommended process or procedure. How do or should teams integrate? What is the best way to share knowledge and ensure integrated decisions? These topics need to be addressed.

### **2.1.2 Reservoir Management Training**

Satter (1990) gives the components a multidisciplinary training program should include, and several essential results the training should impart to the students. The training program should include:

- a. Integrated, multidisciplinary, high-tech training;
- b. Identical training for all disciplines;
- c. Multidisciplinary courses with problem sessions and case studies (Thakur, 1990b);
- d. State-of-the-art concepts.

The essentials students should take away from the training include:

- a. An understanding of the management process;
- b. Knowledge of how to cross the boundaries of their discipline;
- c. Communication skills;
- d. Cooperation skills;
- e. Ability to work in a team.

The components and end-result goals provide the framework on which an integrated teamwork training program can be constructed.

### **2.2 Problem Solving and the Design Process**

The process of reservoir management requires decisions be made with the intent of solving a problem or as a result of solving a problem. Multidisciplinary teams must be able to make these decisions in an integrated manner. Therefore, a review of how we approach problems is relevant.

Chamberlain (1931) in his essay, “ The Method of Multiple Working Hypotheses,” described three methods by which to approach a problem: The Ruling Theory Method, the Working Hypothesis or Scientific Method, and the Method of Multiple Working Hypotheses. In the Ruling Theory Method, all points used to identify and solve a problem emanate from an established proposition which is assumed to be true. The potential flaw in this method is apparent. If the established proposition, from which all other assumptions are based is false, it follows that all points arising from this proposition are false. The Working Hypothesis or Scientific Method attempts to avoid this trap through the use of facts to refute or prove an idea. The potential flaw in this method is the result of analyzing only one theory. If proven true, the theory may be assumed to be the sole contributing factor. Other alternatives which possibly contribute or could also be true, may be missed. Chamberlain suggested the use of multiple working hypotheses. All reasonable alternatives should be analyzed in the same manner as the working hypothesis.

The Method of Multiple Working Hypotheses requires two steps. First, all possible contributing or sole causing hypotheses should be identified. Next, assumptions, facts and evaluation criteria should be used in the critical thinking process to determine the hypotheses’ relevance to the problem. Through this process, there is a greater likelihood that all contributing factors will be identified.

Glaser (1976), describing the design process, closely parallels Chamberlain’s ideas. He writes that the design process is not merely creating a solution from what is known, but is the search for involved components. The components are then examined so that more promising ones are pursued and less promising ones are given a lower priority. Design, therefore, is characterized as an iterative process composed of two

steps: The generation of alternatives, and the testing of alternatives against constraints and values. This mimics Chamberlain's Method of Multiple Working Hypotheses.

The approach to solving a problem is comprised of processes which allow the mind to reach a logical resolution. Glaser (1976) identified a three phase model: (a) problem detection, in which a goal is formulated; (b) feature detection, in which clues are sought that might lead to appropriate actions; (c) goal analysis, in which the goals are continuously modified to yield subgoals which contribute to the solution of the problem. Similar to the problem solving approaches, the model is iterative. It is interesting to note, this model is believed to be similar to the processes involved in learning, and that instruction in these phases might increase an individual's learning capability.

### **2.3 Problem Solving and Design Instruction**

Chamberlain (1931) stated that the ultimate goal of problem solving instruction and use was the internalization of the process so that it would be used without formality. As mentioned in the previous section, a means by which to achieve this objective is to teach problem solving in the manner which the mind solves problems. Therefore, organizing curriculum in sequences which mimic the mind's natural approach to problem solving will provide structures which assist the novice to gain expertise (Glaser, 1976). An additional method is to teach general strategies that help students learn on their own. If instruction in general strategies is performed within the proper sequence structure, three advantages may result: The amount of information required to be absorbed in order to comprehend the subject can be reduced; the capacity to learn new things on the basis



of what has already been learned may increase; and the ability to quickly access stored information for thinking and problem solving may improve (Glaser, 1976). If correct, the combined teaching processes could assist in the internalization of the design process.

Two other methods are cited as tools which enhance problem solving and the learning process: verbalization and self-evaluation (Glaser, 1976). By stating goals and strategies at each point in the process, before the actual execution of those goals and strategies, the likelihood of problem solving is enhanced. In a team environment or team-classroom setting, this verbalization would be in the form of presentations. Presenting planned or executed courses of action to one's peers assists the self-evaluation process. As students and teams assess the consequences of their actions, the quality of those actions become apparent (Glaser, 1976). The self-assessment influences behavior because the assessment is immediately internalized. Used in conjunction, these two methods enforce the learning process and allow immediate feedback as to the quality of a student's or team's work.

#### **2.4 Team Evaluation and Performance Appraisals.**

This topic was investigated to determine if methods existed which allowed team members to receive individual assessments and feedback. In team environments, an evaluation of "needs improvement," explains little. Peer assessment is a method of evaluation, but may not work because of prejudice, a lack of peer respect felt by the person being evaluated, or a lack of understanding in how to correctly perform an evaluation. The measurement of team performance as well as individual performance in teams is difficult. The question arises, where does the team stop and the individual start?

One method, presented by Zigon (1994b), was derived for use in the oil industry. As with any performance appraisal system, individual or team, the most common reason for failure is unclear expectations. Therefore, the first step is to clearly define individual and team objectives (Zigon, 1994a). The best method by which to do this is to have the team and team members derive these themselves. The stipulation would be that the objectives must support company goals. The appraisal system would work within these objectives using a matrix framework. Team members would list their names down the left-most column of the matrix. Objectives or major tasks would be listed across the first row. In the row associated with their name, individuals would fill in what they were required to accomplish in order to complete the objective or task. Performance standards could then be associated with each requirement.

I felt this matrix framework contributed to integration. Using this system, not only could a manager or instructor see the individual's contribution, but the team could also see the integration which occurred to accomplish the objectives or tasks.

## **2.5 Meeting Management**

Productive meetings are a must in a multidisciplinary team environment. Much of the critical thinking, comparison, and evaluation occurs during the period of face-to-face interaction. Organization during these periods is essential. This does not imply that a formal structure must be adhered to. But, the team should know why they are meeting, and what needs to be accomplished during the meeting (Jay, 1995).

Three areas are repeatedly addressed throughout literature concerning meeting management. These three areas are: Meeting preparation, actions during meetings, and duties of a meeting facilitator. The guidelines within each of these areas imply a formal meeting structure. As previously stated, formality during preparation and conduct is not required. However, the principles expressed in each area should be given consideration. In a situation where all team members are very familiar with each other, and understand and accept individual idiosyncrasies, most formal measures may not be necessary. However, in a similar situation where the same familiarity exists but meetings are not achieving required results, formal measures should be implemented. Formal meeting measures are especially important when new teams or large teams are organized. The formal structure allows for a timely exchange of ideas, and provides a more productive use of time.

Meeting preparation is the single most important step to achieving productive meetings. While all team members should prepare themselves for the meeting, either a single person or the whole team should prepare the meeting for the participants. This includes preparation of an agenda and meeting objectives. As an example, the team leader or team members can designate someone to be in-charge of the next meeting. Similarly, objectives for the next meeting should be developed. Team members should understand what they need to prepare and accomplish. The designated meeting facilitator, person in-charge, would prepare for the meeting by designing an agenda and preparing the next location. Team members could communicate with the facilitator through e-mail, fax or telephone relaying pertinent information to be included for discussion. Before the meeting, the facilitator would communicate all agenda items to the team members. The meeting has been prepared for success.

The following steps are suggestions for meeting preparation. These steps should be agreed upon by the entire team or developed by the team leader dependent upon familiarity, working relationships, and formality of structure (Deepröse, 1995; Jones, Wilker, & Stoner, 1995; McNellis, 1992):

- a. Prepare an agenda and meeting objectives;
- b. Designate someone to be in-charge of the meeting;
- c. Designate someone to be in-charge of each discussion topic;
- d. Decide what must be accomplished;
- e. Develop a time schedule;
- f. Call or e-mail main points before the meeting.

During the meeting, actions which assist the proper use of available time should be performed. These actions can be performed by the meeting facilitator or discussed by the team.

- a. State the agenda and objectives for the meeting.
- b. Decide what must be accomplished by the end of the meeting.
- c. Develop a time schedule for the meeting.
- d. Give the background for each topic.

A meeting facilitator can help accomplish the above items. If designated, the facilitator would have the below listed duties. If not designated, the team should perform the following duties:

- a. Keep the meeting on focus;
- b. Keep the meeting on the time schedule;
- c. Frequently summarize key discussion points, accomplishments, and decisions;
- d. Develop questions to direct the work and stimulate discussion (Bradford, 1976).

Proper meeting management provides organization, focus, and effective time use. These three elements assist in the two primary purposes for meetings: Sharing information and making decisions. If a meeting accomplishes these two purposes, teams are more effective and integration is enhanced.

## **CHAPTER 3.**

### **DECISION METHODOLOGY**

#### **3.1 Description**

The decision methodology for improved team integration provides a powerful approach and way of thinking about problem solving in a multidisciplinary environment. The strategy does not include the words geology, geophysics, or petroleum engineering. Rather, the focus is on problem definition and objectives. Critical information needed to reach the objectives are identified. The identified critical information needs lead to data requirements. The economic scope and project objectives are revised as the available data and the data needs are assessed. The critical information needs are not intended to say for example, "Do a Geologic Study," but rather are intended to focus efforts on the integration of data and people that will answer the critical information needs. Successful integration does away with the compartmentalization of the disciplines and places the focus on getting the best cost-effective solution to the problem. Criteria should be developed to judge the economic viability of purchasing data needs since a cost-benefit analysis is paramount to successful integration. Finally, alternatives should be identified and compared using quantitative criteria. The criteria establishes the basis for recommendations and action plans. Similar to Chamberlain's, "The Method of Multiple Working Hypotheses," (1931) the General Strategy for Integration is more than a procedure within which to operate. It is a mode of thought when analyzing a multidisciplinary problem. When used, it provides improved results through more

effective integration by subordinating a parochial focus to an integrated focus without boundaries. Figure 1 graphically displays the strategy (Van Kirk et al., 1996).

Three main pillars support this process and should be followed:

**The method is iterative.** New information or decisions made may necessitate a modification in prior decisions or estimates. If this is the case, the process must be reworked and all steps evaluated again.

**The method is task / objective oriented, not discipline oriented.** All analysis and information procurement must relate back to the objective and critical information needs. The purpose is to best utilize available money, time, and personnel. As an example, while an engineer or geologist will work in their fields of expertise, the specific information each is to obtain should serve to answer the common objective and critical information need. Information should not be obtained with the “hope” it will enlighten an issue. Information should highlight the issue / need at hand. Therefore, it is essential that proper scoping of the problem, objective, and critical information be performed.

**The method relies on quantitative evaluation through decision criteria analysis.** Decision criteria are standards, qualifications, or tests by which alternatives can be compared to each other. Criteria analysis is the evaluation of alternatives using derived criteria. This analysis should be performed at each decision juncture such as, objective determination, critical information determination, and alternative evaluation. Criteria should be developed with which to evaluate competing choices. These criteria should relate to the major influencing factors and must be quantified. Quantification of a criterion allows the sound evaluation of competing decisions against that criterion.

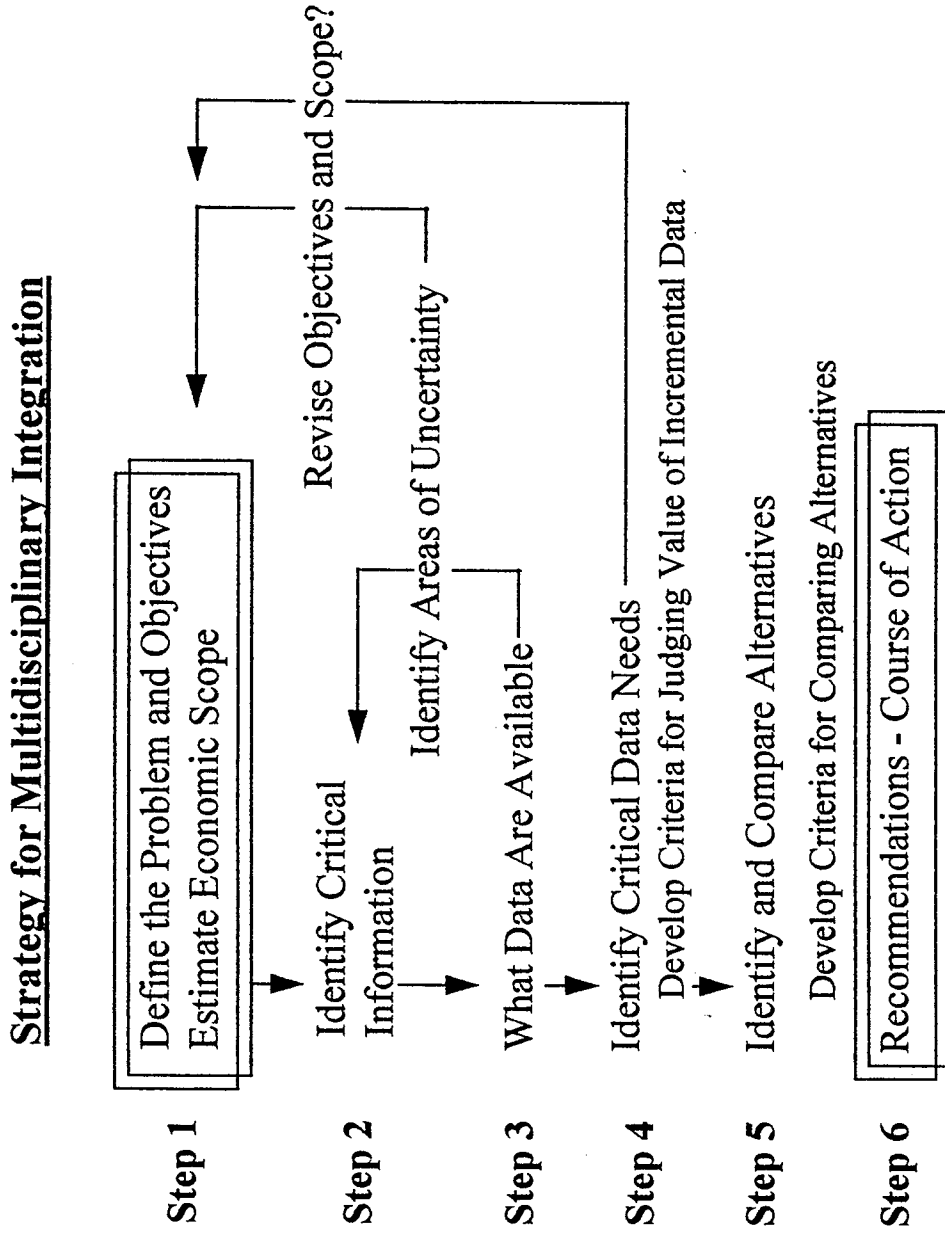


Figure 1: Schematic displaying the steps in the Strategy for Multidisciplinary Integration.



## 3.2 Problem Definition and Economic Scope

The initial step in the methodology involves definition of the problem to be solved, and determination of the objectives of the research. While performing these actions, consideration must be given to what influence the project's economic scope and time limitations will have on the study. It is imperative that time and effort be given and proper scoping be performed on these areas. If not, the ability of the methodology to work will be severely hampered. This initial scoping exercise, a concept explained in Chapter 4, helps to focus the team members efforts and thoughts and begins to create team synergy.

### 3.2.1 Defining the Problem and Establishing Objectives

A problem statement defines the issue at hand. The supporting objectives describe the intent of the research. As an example, a question which could help define the problem would be: What is the "bottom-line" issue to be solved? Objectives could be characterized by the question, what must be answered or done to solve the problem. There may be numerous objectives. Placed within the context of a scenario, the problem and related objectives could be defined in this manner;

Scenario: Given the present production decline of an older oil field,  
production operations will become uneconomical within three years.

Problem: What are the most economical actions to take regarding the field?

Objective: Determine if it is economical to invest any additional money into the field.

Objective: Determine if secondary recovery operations will increase the performance of the field.

Objective: Determine if well stimulation techniques could increase production and the life of the field.

It should be understood, the initial problem statement and objectives change throughout the process. Again, the methodology is iterative. However, a proper problem statement and objectives description provide focus.

### **3.2.2 Estimating the Economic Scope**

An estimate of the project's economic scope provides the team with guidance on how much time, effort, and money should be allocated to the research and project. In other words, at what point in the expenditure of funds and time does the research and project reach an economic limit? This initial calculation can be performed quickly. A general estimate is what is required. As greater certainty is developed in the economic variables through analysis, the economic scope should be revised.

Listed below are several questions among the types needed to perform an initial economic scope:

1. What are the estimated hydrocarbon reserves?
2. What is the estimated maximum and minimum incremental benefit?
3. What is the equity interest?
4. What is the potential for reserves growth?

Once the economic scope is complete, a simple but very important question must be answered: Does the economic scope influence the project's objectives? If the answer is yes, objectives should be revised.

### **3.2.3 Defining Limitations**

Limitations affect the actual research operation and how the project will progress. In almost all situations, there are finite amounts of time, assets, and money available for analysis and decision implementation. It is important to understand these limitations before a course of action is developed which, because of its exceeding certain constraints, can never be implemented. This situation would result in a waste of time and money, something the team's company is attempting to avoid. Therefore, it is imperative that company management specify limitations on the project. It is just as important, that the team develop questions which when answered will help guide the analysis and evaluation of courses of action.

Listed below are several questions among the types needed to ensure understanding of the projects limitations:

1. How much time is available for the analysis phase? What is the estimated time required?
2. How much time is available for implementation of the project's agreed upon course of action? When does the project need to be completed?
3. How much money and capital is available? How should this be divided between analysis and implementation?
4. What type of assets, both equipment and people, are and will be available?

5. What is the company's risk tolerance?

Once the project's limitations are defined and understood, iteration should occur to assess the impact of the limitations on the derived objectives. Once the impact is understood, both a time plan and money-expenditure plan should be developed. This will keep the team focused and within the boundaries of the limitations.

### **3.2.4 Establishing Initial Priorities and an Action Plan**

Very similar to the management of meetings, the team must be provided organization and structure within which to accomplish the given tasks. This can be as simple as deciding what should be accomplished before the next meeting or as formal as a written document. What is important is to ensure the team members agree on what is expected of each other, what the team plans to accomplish, and what the priorities are. If understood, these three elements will allow for more efficient use of time and resources.

To summarize, the team should agree upon the following:

- a. What needs to be done;
- b. Priorities;
- c. Who should do what;
- c. A team plan of action.

### **3.3 Critical Information Identification**

Determine what must be known by the team in order to construct a course of action. This, “Critical Information,” is information without which analysis cannot be correctly or fully performed and therefore the objective cannot be achieved. The term, “information,” is defined in this context as knowledge, or analyzed data, which can be used to make a decision or form an assumption. As an example, unanalyzed well-test data is just that. Evidence of a barrier, gained from analyses of the test data, is information. The term, “critical,” narrows the focus to information which is necessary to make a decision. In order to decide what is necessary, justify each piece of critical information to ensure it relates directly to the appropriate objective.

### **3.4 Available Data Identification**

Once the critical information has been identified, the team must decide what means exist to obtain that information. The means or method will be defined as the “data source.” What the data source provides will be defined as “data.” As explained in section 3.3, analyzed data becomes usable information which can be utilized to achieve objectives. At this point in the process, the required information has been determined by the team. The team must decide what data sources can provide the proper data for analysis. There may be multiple data sources available. Because of this, the team needs to decide what sources provide data that presents the highest probability of obtaining the critical information needs.

Having determined what data sources the team would like to use, the team should determine what data has already been obtained and is available for use? Make the most of available data. Because it already exists, it is the most cost-effective potential source of information. But, caution should be used. Not all readily-accessible data or information may be useful. Screen the available data and information to ensure all relate directly to critical needs and the objective. Too much extraneous data and information may actually hinder the process or confuse the issue.

The available data should be analyzed with the intent of obtaining information necessary to answer or achieve objectives. Two key questions should be answered.

1. What facts can be established which answer / help answer critical information needs?
2. What assumptions can be made which answer / help answer critical information needs?

### **3.5 Initial Iterative Step**

At this point, the team should have worked through the first three steps. The problem and objectives should have been identified, the critical information to achieve the objectives should have been agreed upon, and available data should have been analyzed. This step requires an analysis of what is known in order to determine if objectives can be met at this point, if additional data is required, or if the problem, objectives, or critical information should be modified.

The following actions should be performed by the team:

1. Determine critical information areas of uncertainty, where facts or assumptions cannot be made.
2. Determine if existing facts and assumptions negate the need to obtain the unknown information? What is / would be the impact of not knowing / knowing the areas of uncertainty?
3. Decide if the list of critical information (step 2) should be modified (additions / deletions)? If so, again work through steps 2 and 3.
4. Decide if the developed facts and assumptions require a revision of the objective(s) or economic scope? If so, again work through the first three steps.

### **3.6 Data Needs Identification and Criteria Development**

At this point in the process, all analysis which is feasible to complete with available data should be performed. All information that can be extracted from the available data analysis should be obtained. The team can then determine what areas of uncertainty exist and what uncertainty should be resolved. Data sources which provide the greatest probability of obtaining information to clarify the uncertain areas can then be identified.

Within this process, the team should perform the following steps:

1. Determine the impact of not resolving the areas of uncertainty?
2. Determine the impact of resolving the areas of uncertainty?

3. Perform an analysis to judge the value of the needed information versus the cost to obtain the information (cost benefit analysis).
4. Perform an analysis to determine which method of obtaining the information is best for this situation. What is the reliability of the data source and therefore the information. There may be several methods by which to obtain the required data. The team must decide which data source is most reliable, provides the best chance of obtaining the needed information, and is the least costly. More than one source may be chosen.
5. Ensure the costs of obtaining the information are within the project's economic scope and limitations. Determine how much can be allocated to purchase the information.
6. If there are competing needs for limited resources, establish criteria for evaluation.
7. Resolve the uncertainty by purchasing information or determine the impact of keeping the areas of interest uncertain.

### **3.6.1 Examples of Criteria**

Criteria are standards, qualifications, or tests by which alternatives are evaluated, and on which decisions can be based. Criteria are developed to ensure comparisons and decisions are based on logical quantitative analysis. Very similar to Critical Information, criteria should be relevant enough in the decision process that quantitative measurements can be made in reference to them. Examples of criteria are:



1. Cost or price. How much does the procedure cost? How much money or capital is required?
2. Amount of information gained. In relation to what the team would like to determine, what percentage of that uncertainty will be resolved by this procedure?
3. Probability of success. What is the probability that the procedure will actually deliver the amount of information it is expected to deliver?

### **3.6.2 Criteria Evaluation**

Alternatives should be evaluated against each other in relation to the specified criteria. Therefore, if at all possible, criteria should be quantified. The need to minimize subjective conclusions, obtained without an attempt to quantify qualitative reasoning, cannot be overstated. As an example, using the above criteria:

1. Cost, could be evaluated as best, good, or poor. Best would quantitatively be equal to or less than \$99,999. Good would quantitatively be equal to between \$100,000 and \$199,999. Poor would quantitatively be equal to or greater than \$200,000.
2. Amount of information gained, could be evaluated as best, good, or poor. Although this criteria could be a subjective estimate, an attempt should be made to quantify the estimate. Best would quantitatively be equal to or greater than 70% of the information gained. Good would quantitatively be

equal to between 40% and 69%. Poor would quantitatively be equal to or less than 39%.

Once quantified, criteria can be used in various methods of comparisons. As an example, a single criterion analysis could be the basis for evaluation. In the above instance, the amount of information gained could be the only criterion that the decision is based upon. While single criterion analysis does occur, in most instances several criteria are used. Another example of criteria evaluation is economic criteria analysis. This includes net present value, rate of return, payout, and profit to investment ratio. A final example of criteria evaluation is risk analysis. This could be performed through decision tree, monte carlo or bayesian analysis. While these methods are not all inclusive, they demonstrate different techniques.

Because most decisions are not based upon one criterion, multiple criteria should be used for evaluation. A tool which facilitates the use of multiple criteria for analysis is the Decision Matrix (figure 2). The matrix uses a quantitative approach for evaluation. Alternatives are listed by rows in the far left column. Criteria are listed by columns in the second row. Weights, listed in the first row, are assigned to each criterion as to its importance in relation to the other criteria. Alternatives are evaluated against each other in relation to the criterion in an assigned column. Dependent upon whether the matrix is being minimized or maximized, best is either a one or the number of alternatives. A tie or equal evaluation is signified by the average of the subsequent possible evaluations. For example, if the matrix is to be minimized and 3-D seismic is thought to be best in the criteria category of information gained; 3-D seismic would be awarded a one. Continuing the example, if drilling a well and 2-D seismic were thought to be equal in this category, then the average of two and three, 2.5, would be awarded to each. Criteria

## Decision Matrix

<b>Weight</b>	<b>2</b>	<b>1</b>	<b>3</b>	
<b>Criteria → Options ↓</b>	<b>Cost</b>	<b>Information Gained</b>	<b>Probability of Success</b>	<b>Totals</b>
<b>Buy 2-D Seismic</b>	1	3	2	11
<b>Buy 3-D Seismic</b>	2	1	1	8
<b>Drill a Well</b>	3	2	3	17

Figure 2. The Decision Matrix. A tool which assists in the evaluation of multiple criteria

weights are awarded in a similar manner again dependent upon minimization or maximization. In our example, information gained is thought to be the most important criteria and is awarded a one. Evaluations are then multiplied by the weights and rows are summed by columns. Dependent upon minimization or maximization, the lowest or highest number is the best alternative. In our example, 3-D seismic is awarded the lowest number and is the best alternative. The advantage to using the decision matrix is the ability to confirm the rationality of decisions. One can visualize what is deemed important. Also, if a decision does not agree with the matrix answer, then evaluations or assigned weights are not truthful, or a criterion is absent.

### **3.7 Second Iterative Step**

At this point, the team should have worked through the first four steps. The problem and objectives should have been identified, the critical information to achieve the objectives should have been agreed upon, and all data should have been analyzed. The second iterative step requires an analysis of what is known in order to determine if objectives can be met at this point, if additional data is required, or if the problem, objectives, or critical information should be modified.

The following actions should be performed by the team:

1. Determine if there are areas of uncertainty where facts or assumptions cannot be made;
2. Determine the impact of not resolving the areas of uncertainty;
3. Decide if the list of critical information (step two) should be modified; If so, again work through steps one through four;

4. Decide if the developed facts and assumptions require a revision of the objective(s) or economic scope; If so, again work through the first four steps.

### **3.8 Alternatives and Criteria Development**

Having gathered and analyzed all pertinent data, formed assumptions, and developed a supportable interpretation of the situation, all alternatives which solve the objectives should be identified. Once identified, the alternatives should be evaluated through the use of criteria analysis. The development of criteria and use in evaluation is the same as stated in the section 3.6. Through the analysis, the course of action which best meets the objectives while not exceeding limitations or the economic scope should be chosen.

To summarize, the following sequence of actions should occur:

- a. Identify all alternatives or courses of action;
- b. Develop criteria for evaluation;
- c. Perform analysis:
  - (1) Economic analysis,
  - (2) Probability / risk analysis,
  - (3) Criteria / decision matrix analysis;
- d. Select the best alternative or course of action.

### **3.9 Presentation of Recommendations**

Recommendations and their support should be presented in an organized integrated manner. Requiring an integrated format for the end-product report and briefing enforces the entire process. Teams must continue to think in an integrated manner. As an example, an attempt should be made to avoid separate engineering, geology, and geophysical sections. Justification of recommendations and assumptions should be in the form of a story. An interpretation which places a fault between two wells could be justified because of well test data supporting log cross-sections, which support a seismic interpretation, which is supported by production data. Within the report, all analyzed alternatives should be identified and compared using derived criteria. Alternate interpretations should be presented if the alternative could impact the selected course of action. An economic analysis must be completed and the results displayed. The integrated format should assist in making the report and briefing succinct and focused. Extraneous information not impacting the course of action should not be included. The overall goal is to provide an organized, integrated, supported, easily understood end-product.

The following format is recommended for the final report and presentation. Greater detail should be provided in the written report.

- a. State the problem which was solved and the objectives reached.
- b. State the proposed recommendations and plan of action. Provide the strongest supports which justify each.
- c. Provide an integrated interpretation of the reservoir or situation.
- d. List any assumptions which allowed the construction of the interpretation.  
Explain why the assumptions were made, and provide support to justify the

reasonableness of the assumptions. Examples of assumptions are saturation values or fault locations.

- e. Describe any areas of uncertainty or alternate interpretations which would affect or change the proposed recommendation.
- f. Compare and evaluate all alternatives against the criteria which were established for analysis.
- g. Explain in detail the recommendations and plan of action. Provide the expected economic benefit, the time required for implementation, the required cost, and required assets.

## **CHAPTER 4.**

### **PROCEDURE FOR INSTRUCTION**

#### **4.1 Strategy**

The teaching procedure strategy is very simple. It involves the theory described by Glaser (1976) in his paper, *Components of a Psychology of Instruction: Toward a Science of Design*. Teach in small steps. Present examples. Allow the students to practice in “real-world” scenarios. Provide frequent feedback.

The first tenet of the strategy is to teach the methodology in stages, following the steps outlined in the procedure. Through this strategy, students begin to internalize the procedure’s step sequence. They also begin to learn how each step builds on the previous, how the steps are interlinked, and why iteration may be required.

The second tenet is to ensure mastery of one step before moving to another. This is accomplished through the use of small scenarios which emphasize the particular element being taught. Since each step in the process builds on the previous one, and iteration is so important to the successful operation of the procedure, it is imperative students understand each step before moving to the next.

Next, progress through the steps until understanding in each is achieved, and then place the students in a scenario-driven exercise requiring modification of initial steps through iteration. While the students must perform in their respective area of expertise,



the process of integration occurs during critical reasoning and thinking phases. In order to properly complete the integration strategy, a sharing of ideas and justification of theories must occur.

Finally, students must receive frequent feedback, both from instructors and peers. Feedback allows teams to view different perspectives and immediately understand the stronger and weaker points of their analysis. Through frequent feedback, teams have an opportunity to modify their assumptions throughout the process. Iteration is reinforced, and all teams have an opportunity to learn, revise, and succeed.

## **4.2 Sequence**

The sequence of instruction involves three stages comprised of smaller subsets. Each stage supports the next, and again follows a building block framework.

1. Initially instruct how to “scope” and then narrow an issue. The term, “scope” refers to a process similar to brainstorming. The idea is to obtain ideas and perspectives from all team members and disciplines.
2. Work through the steps giving emphasis to and providing examples of critical information and critical data. Ensure team members understand the difference between the two terms.
3. Explain the importance of using criteria for comparisons. Demonstrate how to develop, quantify, and use for evaluation.

**CHAPTER 5.**  
**CRITERIA AND THE VALUE OF INFORMATION:**  
**A CASE STUDY**

**5.1 Introduction**

As presented in Chapter 3, criteria can be in several forms to include cost, reliability and the chance of success. If used correctly during analysis, criteria can help the decision process. One such example is presented in this case study. With cost as the overlying criteria, the probability of successfully obtaining the required information and reliability of that information once obtained are incorporated. In this case, bayesian analysis is used to help evaluate the uncertainty and obtain expected values for cost comparisons.

Operators have the opportunity to acquire many types of information; usually with the purpose improving profits by clarifying uncertainty. Several questions need to be addressed to answer this question. However a balance needs to be achieved between the cost of the information and the benefits derived from improved decision making. How much can we afford to pay to reduce uncertainty? When do the costs exceed the expected benefits? A method referred to as Bayesian analysis can be used to help answer these questions (Campbell, 1987; Clemen, 1991; Grayson, 1960; Hertz & Thomas, 1983; Newendorp, 1975; Thompson & Wright, 1994). The method was applied to the analysis of purchasing 3D seismic to resolve the uncertainty in reservoir quality and thus well selection (drill or don't drill). It is important to note that the seismic for the study area was not run with this objective. Current 3D seismic technology may have provided

different conclusions than the analysis included in the following section. The following case study provides an example of the methodology to analyze the purchase of information to resolve uncertainty.

## 5.2 Case Study

The data and analysis for this case study were taken from SPE paper 37968 which was co-authored by Sutton and Thompson (1997). The study was part of a larger Department of Energy Interdisciplinary Study of Reservoir Compartments and Heterogeneity conducted by the Colorado School of Mines (Van Kirk et al., 1996).

The Lambert-Aristocrat Field in the Denver Julesburg Basin in Colorado was selected for the case study analysis. Figure 3 displays the study area and highlights the area contained within the seismic survey.

The Lambert-Aristocrat Field was discovered in 1972 and produces oil and gas from the Cretaceous Terry Sandstone along the east side of the Denver Basin. The Terry Sandstone in the study area produces from a depth of approximately 4500 feet. The reservoir has been interpreted as elongated, discrete, linear bodies deposited in a shoreface environment. Wrench faults in the Denver Basin have resulted in northeast trending faults with a secondary trend of northwest faults (Van Kirk et al., 1996).

Three-dimensional (3-D) P-wave and S-wave seismic surveys were acquired over the eastern edge of the field to test the application of seismic prediction methods (December, 1981 - March, 1982). The surveys had identical acquisition geometries, with

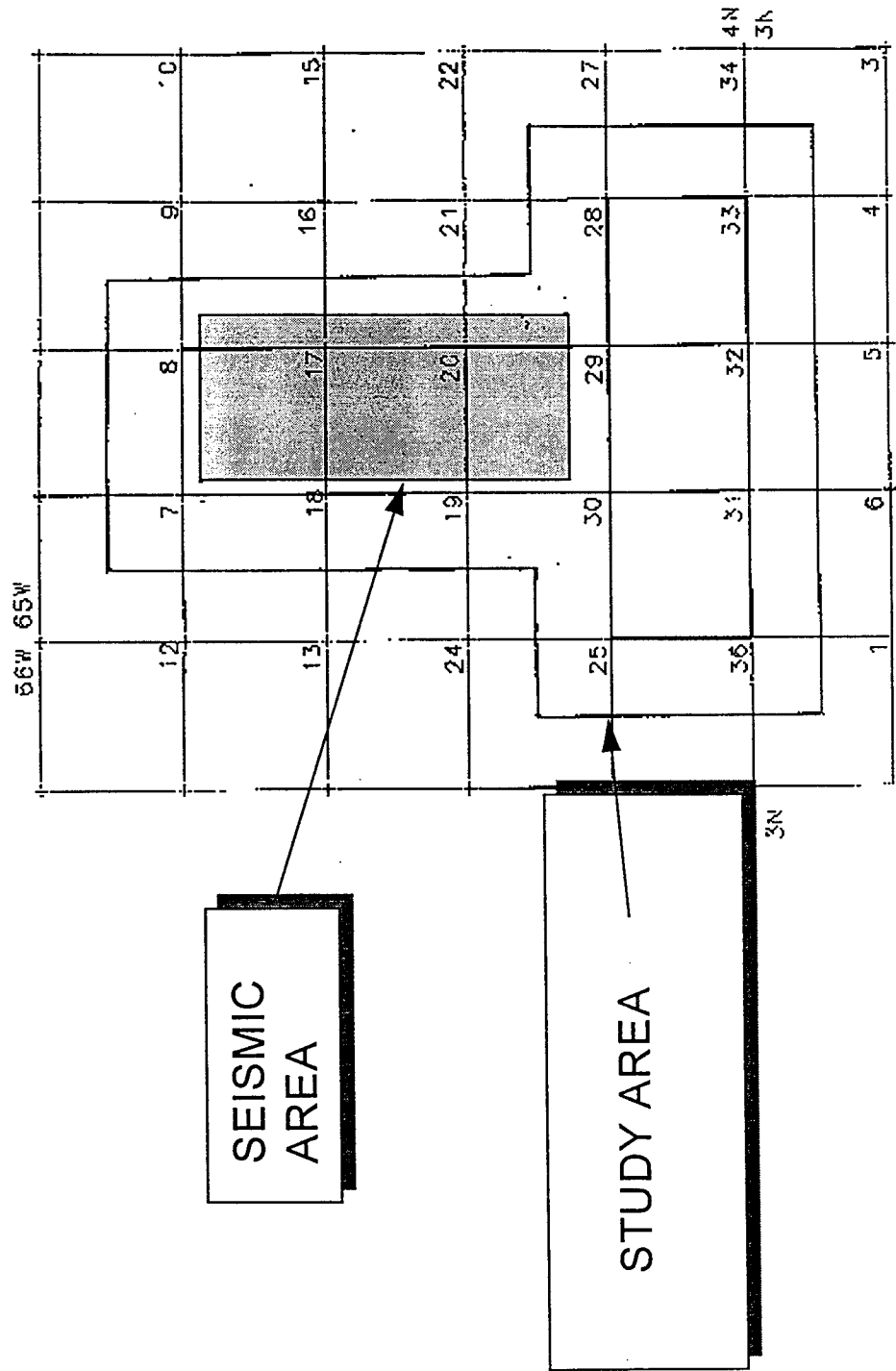


Figure 3. Study area for reservoir study and area covered by the 3-D seismic.

an extent of approximately three square miles. The P-wave survey was acquired first using vertical-component vibrators and geophones. The S-wave survey was acquired next with horizontal-component vibrators and geophones. All S-wave source and receiver motion was restricted to the east-west direction (Van Kirk et al., 1996).

After completing the 3-D acquisition, 2-D seismic lines were acquired. These lines were approximately ten miles in length and oriented in north-south direction. They were acquired to tie the 3-D surveys to a well six miles to the north that had been logged with a full-waveform sonic tool. The S-wave data was once again acquired with all S-wave source and receiver motion restricted to the east-west direction (Van Kirk et al., 1996).

Within the area of the seismic data, sixteen wells were drilled resulting in six positive NPV<sub>10</sub> wells and ten negative NPV<sub>10</sub> wells. Seismic data was procured after drilling was completed within the area. Early production performance, core analysis, and log derived data were coupled with the seismic data and form the basis for quantification of improved well selection from seismic data. The areas interpreted from the seismic data as either poor or good potential, based on the NPV<sub>10</sub>, are shown in Figure 4 (Van Kirk et al., 1996).

### 5.3 Analysis

For the analysis, it is assumed that the operator has three options:

1. Do not purchase seismic data and drill as many as sixteen wells, an economic constraint;

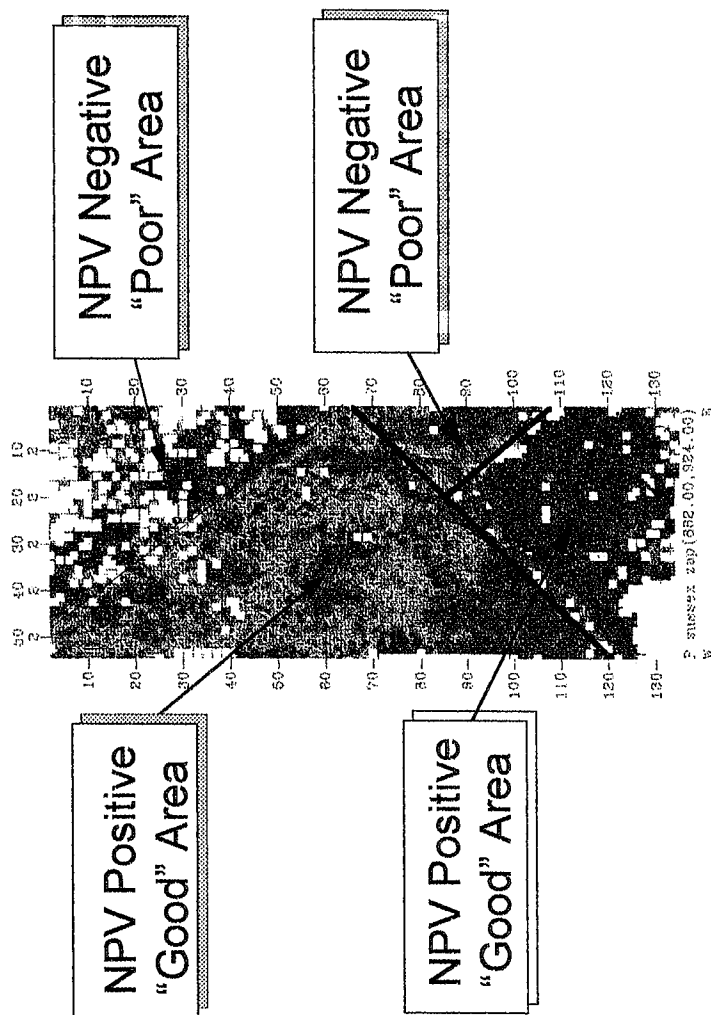


Figure 4. Graph displaying the seismic study region with predicted potentials annotated.

2. Purchase seismic data, then avoid drilling in areas which the seismic data has determined to have poor potential (negative  $NPV_{10}$ ), and drill only in areas which the seismic data has determined to have good potential (positive  $NPV_{10}$ );
3. Don't Drill.

In our hypothetical case, the operator would like to determine if a seismic data purchase is cost effective. The operator is interested in knowing if the purchase cost of seismic results in a greater expected  $NPV_{10}$  than could be expected without the benefit of the seismic interpretation. The operator analyzes his leases and determines there are sixteen locations where there is sufficient positive potential to drill. He then estimates the seismic survey cost to equal \$75,000. The operator then uses analogous relationships with adjacent fields / reservoirs and determines the following estimates. These estimates are based on the historical data in the study area.

1. The average dry-hole cost for this area is \$169,300.
2. The average producing well  $NPV_{10}$  is \$267,000.
3. The historical seismic accuracy in this reservoir in predicting well performance in areas identified as poor is 100%. In other words, if the seismic data predicts a negative  $NPV_{10}$  region, the probability of drilling a dry-hole is 100%.
4. The historical seismic accuracy in predicting well performance in areas identified as good is 46%. In other words, 46% of the wells in an area identified as good have a positive  $NPV_{10}$ .

5. The historical success rate in this area is 37.5%. Given this success rate, the operator expects to drill six producing wells and ten dry-holes on his lease if seismic data is not purchased.
6. The operator believes the minimum number of dry-holes the seismic data will predict to be within “poor” regions is three.

Using these estimates, the operator constructs an analysis to compare the expected values for each of the decision alternatives. The decision tree for these alternatives is presented in Figure 5.

Realize, at this point, the operator has made two assumptions in which he must have confidence: the accuracy of the seismic data and interpretation of that data, and the probable number of producing wells and dry-holes among his leases. Therefore, in purchasing the survey, he is relying on the data to identify whether his leases are in a positive  $NPV_{10}$  region or negative  $NPV_{10}$  region. The operator will attempt to avoid dry-hole costs by not drilling in the identified “poor potential” areas.

The expected value of the decision to drill without the seismic data is a negative \$91,000. The expected value of the decision to purchase the seismic data is \$253,731 and assumes a survey cost of \$75,000. The expected value of the decision to not drill is zero. Under these assumptions, the decision with the largest expected value is to purchase the seismic (Figure 5).



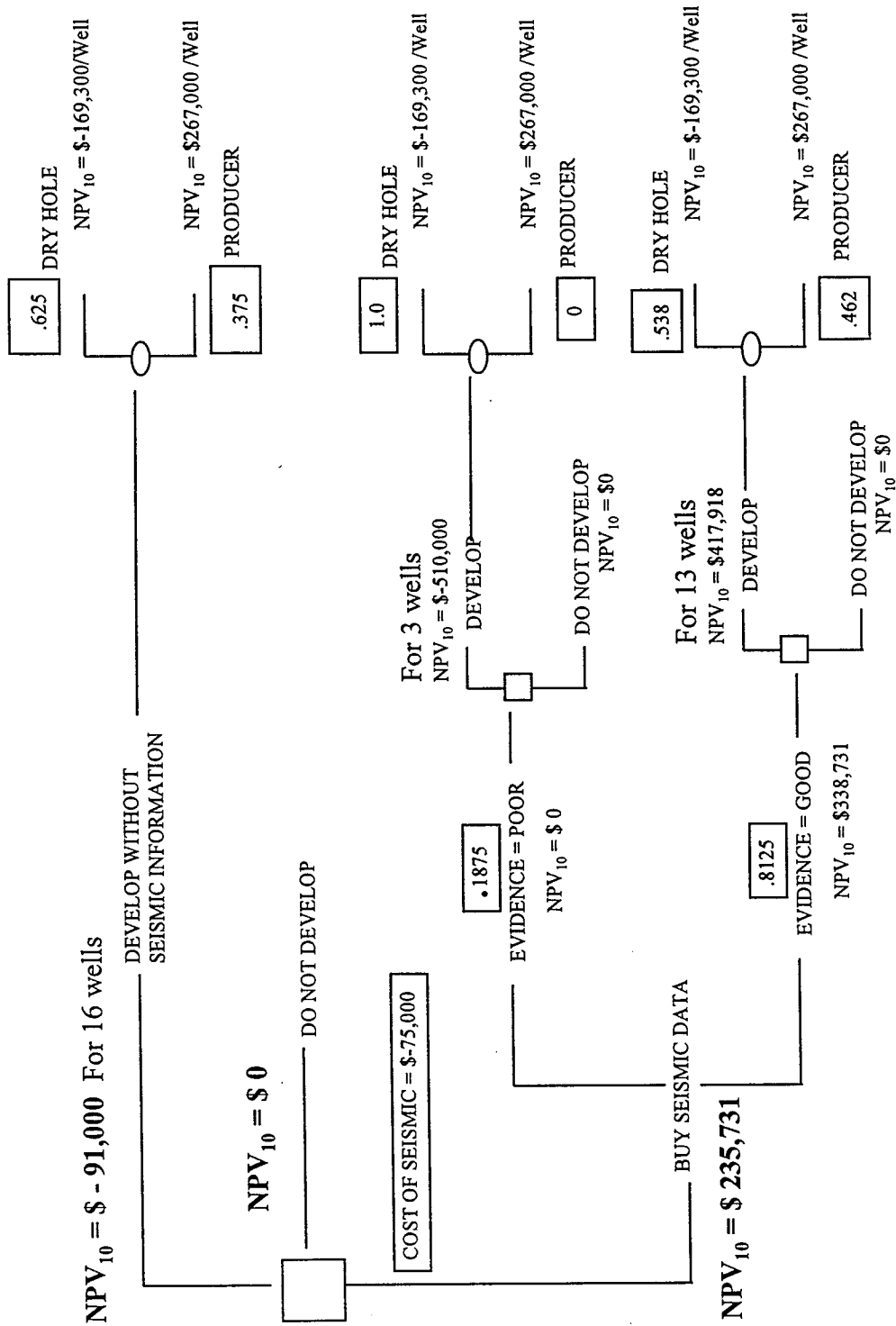


Fig. 5 Decision tree for the purchase of seismic data.

## 5.4 Risk Analysis

In many cases, an operator may not have confidence in the estimate of producing wells and dry-holes within his leases, and in the reliability of seismic data to predict well performance. In these cases, the operator could perform a sensitivity analysis to determine at what point would it not be economically feasible to purchase the survey. This analysis can also give an estimate of the maximum value the operator should pay for the survey. Remember, the survey is only predicting whether leases are within good potential or poor potential regions. Also remember, a poor potential area will not be drilled; the operator is attempting to avoid dry-hole costs. Therefore, a sensitivity analysis can be easily performed by varying the number of wells in the good and poor potential regions.

Two steps were performed in the initial risk analysis. First, keeping the number of wells in the identified “good” and “poor” areas constant, and keeping the total well count and total dry-hole to producing-well ratio constant, the number of dry-holes and producing-wells within each identified region are changed. Second, again keeping the total well count and total dry-hole to producing-well ratio constant, the number of wells in the identified “good” and “poor” areas are changed. Once accomplished, an expected value is calculated using decision-tree decision methodology (Thompson & Wright, 1994). The steps are then repeated.

In determining the expected value, the decision-branch value to drill in the identified “poor” areas was always assumed to equal zero. Because, the operator is attempting to avoid dry-hole costs, poor potential areas will not be drilled. This assumption, therefore, does not consider opportunity costs. If good wells exist in

identified “poor” regions, their positive NPV<sub>10</sub> value may be greater than the dry-hole costs. The operator would lose potential profits. In the case presented, with a dry-hole to producing-well ratio of ten to six, this situation does not occur concurrently with an expected value analysis to buy the seismic survey. When the “poor” region’s expected value is greater than zero, the “good” region’s expected value is always less than zero. At that point, it is not cost effective to purchase the data.

Expected values were calculated for ranges of one to ten wells in the poor areas. The maximum amount that should be paid for seismic data is \$600,750. This assumes the seismic survey is 100% accurate in predicting poor wells. In this case, the identified poor regions would hold all ten poor wells. The identified good regions would hold all six good wells. Assuming the seismic accuracy is less than 100%, the minimum prediction accuracy to justify purchasing the survey must be greater than approximately 65%. If the seismic data identifies a region as having poor potential, 65% of the wells within that area should display poor results. If this accuracy could not be achieved, it would not be cost effective to purchase the information.

A second risk analysis was performed to determine sensitivity of results to changes in the initial dry-hole to producing-well state of nature. What is the effect if this reservoir exhibits a success rate greater than or less than the historical success rate of 37.5%? The number of expected dry-holes, ten, and producing-wells, six, were varied while keeping the total number of wells constant at sixteen. Once the success ratio was changed, the initial sensitivity procedure, described above, was repeated.

Effects on previous results occur as the success rate improves from the historical estimate. As more producing-wells and less dry-holes are available, the probability of

producing positive NPV<sub>10</sub> results increases. At a 50% success rate, the expected value of the decision to drill without the seismic data is \$781,600. At a 62.5% success rate, the expected value of the decision to drill without the seismic data is \$1,654,200. The more favorable odds have an impact on the value of the seismic data. At the 50% success rate, the minimum prediction accuracy of the seismic data, to justify purchasing the survey, must be greater than approximately 80%. At the 62.5% success rate, the minimum prediction accuracy to justify purchasing the survey must be 100% (perfect accuracy is required due to the integer nature of the analysis; i.e.: 1/3 of a well is impossible). Therefore, the greater the expected overall success rate, the greater the accuracy required from predictive information in order to justify its purchase.

As with the initial risk analysis, in determining the expected value the decision-branch value to drill in the identified “poor” areas was always assumed to be negative. Opportunity costs were not considered. In situations where the expected values to drill with seismic data in both the “good” and “poor” areas are both positive, misleading results could occur. In these cases, under the assumption that no drilling takes place in the “poor” areas, the expected value to drill with seismic data was less than the expected value to drill without the seismic data. Therefore, it was not cost effective to purchase the survey.

## 5.5 Results

Bayesian analysis concluded that it would have been economically feasible to purchase seismic data in order to avoid dry hole costs. The reliability was sufficient to warrant the expenditure to resolve the uncertainty in well selection.

Risk analysis provided four conclusions:

1. The maximum amount that could have been paid for the seismic data was \$600,750.
2. The minimum prediction accuracy to justify purchasing the survey must be greater than approximately 65%.
3. The greater the expected drilling success rate in the reservoir, the greater the accuracy required from the seismic data in order to justify its purchase.
4. The purchase of information at the required level of reliability and at a cost-efficient price made a “loosing proposition” a “winning” proposition. Had either the level of reliability been less than required or the price been greater than the cost-effective maximum, the proposition would have remained a “loosing proposition.”

It should also be noted that the data did provide other important information. The survey data confirmed the existence of the major Northeast to Southwest running fault in the study area. Had no seismic data been present, this major fault may have been missed. Not acknowledging this fault could have had dramatic effects on secondary recovery operations.

A number of seismic data acquisition and processing techniques have advanced since early 1982 when these data were acquired and processed. Modern acquisition geometry's would improve the offset, azimuth, and fold distribution of the seismic data. Detailed reprocessing of the seismic data would allow processing parameters to be fine tuned for the Terry Formation reservoir. Processing techniques used for S-waves have changed significantly since these data were processed. These improvements in acquisition and processing would result in greater resolution within the current zone of

interest, resulting in a more accurate and detailed seismic interpretation. This improved interpretation could increase the performance of the positive region prediction accuracy

## **5.6 Conclusion**

Bayesian analysis used to evaluate cost criteria is an effective tool operators can employ to help make economically sound decisions. Many types of information possess the potential to improve profits by clarifying uncertainty. This method assists in the cost versus benefit analysis. In most cases, 100% accuracy in results cannot be guaranteed. Bayesian analysis takes into account this less than perfect reliability. Sensitivity analysis can provide a maximum cost to purchase the information, and the minimum reliability required to provide economic benefits. By quantitatively analyzing uncertainty, better comparisons and analyses can be performed.

## **CHAPTER 6.**

### **RESERVOIR MANAGEMENT SCENARIO**

#### **6.1 Purpose and Intent**

The reservoir management scenario was the first scenario presented to the students. Its purpose was to provide a scenario in which the integration strategy can be implemented step by step. As in any “real-world” situation, ambiguity exists. Yet, proper integration and analysis will provide clues to resolve much of the ambiguity. During this scenario, emphasis was placed on the process and integration. Analysis and feedback, provided through a structure of briefings and critiques, are provided at every process step. The intent of this methodical process is to enforce the strategy’s procedure, and initiate the process of integration throughout the critical reasoning phases. Therefore, by the end of this scenario, students should begin to internalize the strategy in their decision analysis.

#### **6.2 Description**

Any reservoir management issue could be used for this scenario. The one chosen for the study involved secondary recovery and the cost effectiveness of converting two existing producers to injector wells. Students were organized into five multidisciplinary teams. Each team could choose one of at least four options: do not participate in the endeavor and receive a financial penalty; convert well A; convert well B; convert either

well A or well B, participate with no preference on well selection. Students could create other options limited only by their imagination.

The Sooner Unit Field in Colorado was used as the reservoir for study. Data was available through the Colorado School of Mines' Department of Petroleum Engineering, the Department of Energy (DOE) and Diversified Operators. A DOE study of the field had previously been conducted which provided data, analysis, and interpretation. Only data was presented to the students, although they were encouraged to use outside data sources such as the library and the Colorado Oil and Gas Conservation Commission.

This data included:

1. Well logs;
2. Pressure data;
3. Core data and actual cores from an analogous field;
4. PVT data;
5. Seismic data;
6. Well production data;
7. Well locations.

The following scenario was provided to the teams:

Your group is part of a company which is a non-operating working interest partner in the Sooner Field. The field has been unitized for secondary recovery operations. Waterflooding has been initiated by turning several producing wells into injection wells. The results of the waterflood have been mixed, with some areas of the reservoir responding better than others.

The controlling interest operator has presented you with a plan to turn either of two wells (11-21 or 3-28) into water injection wells. Your company can decide to go



along and join the proposed plan or reject the plan. If you join the plan, you must provide your working interest share of the needed capital to convert the well. If you decide to reject the plan and not join, you will face a 300% non-consent penalty.

Your company's management has requested several In-Progress Reports (IPR). The first is scheduled for (day, date). The other IPR dates are listed in the attached project schedule. You must respond with a final proposal / decision before (deadline).

You have at least three alternatives:

- Agree with the plan, no matter what well is converted.
- Agree with the plan only if a selected well is converted.
- Reject the proposal.

The following information is available for your immediate analysis:

- Attached Isopach map.
- Economic data:
  - Cumulative production up to 5/15/93: 1.131 MMBO;
  - Well conversion cost: \$30,000;
  - Water injection / disposal costs: \$ .50 per BBL;
  - Working interest: 30%;
  - Lease Revenue Interest: 87.5%;
  - Producing well operating costs: \$500/well/month.
- Reservoir description / properties:
  - "D" sandstone;
  - Average porosity: 4 - 16%;
  - Average permeability: .7 - 62 md;

- Area: 840 developed acres;
  - Gross thickness: 24 - 68 feet;
  - Fluvial sandstone filling an incised valley.
- Fluid Properties:
- 40° API oil.

The following data is available for your analysis upon request:

- Logs for all wells in the unitized area;
- Production data;
- PVT data;
- Core Data;
- Seismic Data;
- Well Test Data;
- Pressure Data.

### **6.3 Scenario Time Schedule**

This scenario was scheduled to last four weeks for a total of twenty class hours. The class met two periods a week for a total of five hours per week. Within this framework, students would have approximately three hours per week of in-class work time. Two hours a week, one hour per period, was devoted to briefings and feedback.

This scenario emphasized the decision methodology. It was important that the students fully understood and could implement the methodology at the end of this scenario. One method used to increase the students competence in multidisciplinary

teamwork was the use of frequent briefings and feedback. Except for one work session, every period included a status-briefing which reported work accomplished and the focus of the team. The sequence of required briefings followed the steps of the decision process. The intent was to provide quick feedback and an opportunity for self-assessment before actions at each step were taken. The class briefings also allowed students to learn from the ideas of the other teams.

The schedule and briefing sequence were as follows:

- a. Period 1: Introduce the problem and scenario to the students.
- b. Period 2: Teams brief steps one, two, and three of the integration strategy.
  - Problem definition and objectives identification.
  - Estimation of economic scope.
  - Identification of critical information.
  - Available data identification.
  - Instructors distribute all available data to the teams.
- c. Period 3: After initial review of the available data, teams brief the initial revision of steps one and two. Teams brief step four.
  - Initial revision of the problem and objectives.
  - Initial revision of the critical information.
  - Initial identification of required data not presently available.
- d. Period 4: Teams brief final revision of steps one and two. Teams brief step four.
  - Revision of the problem and objectives.
  - Revision of the critical information.
  - Identification of required data not presently available.
- e. Period 5: Teams brief initial alternatives and criteria for evaluation.

- f. Period 6: Teams brief final alternatives and criteria for evaluation.
- g. Period 7: In-class work period.
- h. Period 8: Teams brief the final recommendation and provide a written report.
- i. Period 9: Class conducts an after-project discussion with the instructors.  
Instructors return written reports and provide performance assessments.

## **CHAPTER 7.**

### **FIELD EXPLORATION SCENARIO**

#### **7.1 Purpose and Intent**

The field exploration scenario reinforces the techniques and tools the students learned in the first scenario. It requires that students make quick decisions, presentations, and written responses in an uncertain environment. A decision is required at every period which forces students to synthesize a large amount of material in a short period of time. They must use proper integration and meeting management to succeed. This scenario adds the variables of cost and limited assets. Students must choose between what may be wanted, what is available, and how much money they can afford to spend. Because the students must justify their actions in presentations and memorandums, they must develop and use criteria for analysis. Emphasis during this scenario begins to shift from process to end-product delivered. At the end of this scenario, teams should be using the integration strategy during their critical reasoning and decision analysis without the need for the formal structure. They should begin to understand how the strategy helps make quicker, more reasoned decisions.

#### **7.2 Scenario Description**

Students were provided the scenario described below. This could be changed according to the needs of the class. Cost values were taken from actual operators in the

Hambert-Aristocrat area. Students were provided an initial packet of geologic data, production data, drilling / completion data, and logs. An initial budget was provided to each team and audited throughout the scenario. "Situation" scenarios, given to spur discussion and additional learning were interjected once.

The following scenario was provided to the teams:

Six months ago, your company, Drill-Right Oil, began wildcat drilling in the Hambert-Aristocrat area of the Denver Basin. The formation being explored is the Terry Sandstone in the Sussex formation. Three producing wells have been drilled as of today. The location of these wells is annotated on the attached map and described below. Logs and production data from the producing wells is attached.

Yesterday, the drilling engineer and all drilling personnel shared the winnings of last night's \$75 million Colorado lottery drawing from a pooled purchase of tickets. Surprisingly, this morning no workers from this group arrived at work. Drill-Right Oil has hastily formed your team to take over and complete development of the field.

Drill-Right is wildcatting in other areas of this basin. Therefore, money and assets are limited and will be allocated on a substantiated, as-needed basis. The company requests you brief management and provide memorandums every six months (every Monday and Thursday - see schedule). These briefings and memorandums will specify proposals, progress / results, problems, and reservoir description. Additionally, the company has requested you present a reserve estimation at each briefing.

Listed below are specifics on the exploration program:

<b>Well Name</b>	<b><u>Wells Drilled to Date</u></b>	
	<b>Location</b>	<b>Producer / Dry-Hole</b>
2 Musick McClintock	NW 4N 65W SEC 32	Producer
3 Musick McClintock	NW 4N 65W SEC 32	Producer
6 Musick McClintock	NW 4N 65W SEC 32	Producer

Land Leasing: The company landman assures you that he can probably get almost any property lease you want.

Number of rigs / assets: 3 rigs and 10 personnel per rig (more rigs and crews can be made available if justified).

Amount of money available: \$600,000, additional money will be made available upon justification and success.

Costs:

- a. Drilling and Completion (does not include fracturing or perforating):  
\$200,000;
- b. Basic Log Suite: \$3,000 (Includes gamma, resistivity, induction);
- c. Dry-hole Cost : \$60,000;
- d. Seismic Survey Data: \$75,000;
- e. Core Data: \$20,000;
- f. Fracture Job: \$35,000;
- g. Perforation Cost at 4 shots per foot: \$5,000 per 20 feet;
- h. Horizontal Well: \$500,000;
- I. Fixed Cost: \$400 / Mo / gas well and \$600 / Mo / oil well;

- j. Lease Cost: ranges from \$3-5 / acre.

Economic Variables:

- k. Working Interest: 100%;
- l. Net Revenue Interest: 87.5%;
- m. Price of oil for economic estimates: \$18 / BBl;
- n. Price of gas for economic estimates: \$1.20 / Mcf;
- o. Severance and Advaloren Taxes: 13% of revenue.

**Requirements:**

- a. Drilling: Specify location of wells, mud type, perforation depth, completion method;
- b. Logs: Specify type required and what information will be gained from each;
- c. Core: Specify why, which well, and what tests will be performed on the core;
- d. Seismic: Justify why and what information will be extracted;
- e. Fracture Job: Specify fluid type, proppant type, volumes, pad size, procedure.

### **7.3 Situation Scenarios**

In addition to exploration decisions, “situation” scenarios are issued to the teams at period two. These situations incorporate problems into the overall scenario and include subjects such as Environmental Protection Agency (EPA) violations, swelling clays and stuck drill pipe, and initiation of a fracture program. The answers to these situations were designed to be briefed to the class so that all class members could learn from the research of that single team. The intent was to increase learning through research and discussion.



- a. Scenario A: The Colorado Bureau of Land Management (BLM) just performed an audit of your drilling sites this weekend. When asked to see your EPA and land management paperwork, you realized it was in the briefcase of the former drilling engineer (now Bahamas bar owner). Furthermore, arrowheads and stone pots were found near your site. The BLM will give you two weeks to turn in the proper paperwork and survey information. What paperwork is required? What safeguards need to be performed during drilling operations to ensure EPA compliance? What actions need to occur to ensure the drilling site is within BLM compliance?
- b. Scenario B: The company was interested in learning the results of your acid job. In fact, the company president decided to show up on site to observe the operation. There were no problems while pumping down the acid. The company president was so happy she offered you a pay raise.
- However, once the well was put on production, everything turned for the worse. Production ceased. Further examination revealed a gel-like substance in the zone of acid injection. The company president denied she ever offered you a pay raise and left the site.
- It is suspected that the area of acid injection contained iron bearing clays.
- What could have caused this problem? What could have been done to avoid the problem? What can be done now to fix the problem?
- c. Scenario C: The Hambert-Aristocrat area is suspected to have low resistivity, low contrast, variable  $R_w$  clays. If this is the case, what would you change in your analysis of logs to compensate for this situation? What additional

tools might you need for this situation? Also, stylolites were observed.

What is the significance?

- d. Scenario D: While drilling with water based mud, a zone of swelling clays was invaded. Guess what? You now have a stuck drill pipe! What do you do? What could have been done to avoid this situation?
- e. Scenario E: The company is interested in instituting a fracture program for all completed wells in the Hambert-Aristocrat area. What issues need to be resolved before initiating this program? What factors need to be considered before fracturing a well? Is the Hambert-Aristocrat area a good reservoir for fracture consideration?

#### **7.4 Field Description**

The Hambert-Aristocrat Field in the Denver Julesburg Basin in Weld County Colorado was discovered in 1972 and produces oil and gas from the Cretaceous Terry Sandstone along the east side of the Denver Basin. The Terry Sandstone in the study area produces from a depth of approximately 4500 feet and there are approximately 100 Terry completions (Van Kirk et al., 1996).

#### **7.4.1 Department of Energy Study**

The United States Department of Energy commissioned an interdisciplinary study of reservoir compartments and heterogeneity in the Lambert-Aristocrat Field, Weld County, Colorado in order to document the process of integration (Van Kirk et al., 1996). The Colorado School of Mines' Departments of Petroleum Engineering, Geological Engineering, and Geophysics integrated efforts to complete the study and characterize the reservoir. A case study approach was used to achieve two project goals: demonstrate how a multidisciplinary approach can be used to detect reservoir compartmentalization and improve reserve estimates, and derive a general strategy for integration for independent operators.

The resulting reservoir data sets and analysis were used to construct this scenario exercise. As an example, production data, logs and core analysis, and derived maps originate from the works of individual people or departments. The data sets included: geologic interpretation, geophysical data, petrophysical data, well test and production data, reservoir simulation, and economic evaluations. The available data and information were combined to facilitate implementation of the exercise and student learning.

#### **7.4.2 Reservoir Characteristics**

A detailed description of the Terry Sandstone reservoir in Lambert-Aristocrat Field is presented in the Final Technical Report of the Department of Energy - Colorado School of Mines Interdisciplinary Study of Reservoir Compartments and Heterogeneity

(Van Kirk et al., 1996). The following is a summary of the reservoir's characteristics presented in the report.

The Terry Sandstone in the Hambert-Aristocrat area is a low-porosity, low-permeability sandstone. The reservoir has been interpreted as elongated, discrete, linear bodies deposited in a shoreface environment. Wrench faults in the Denver Basin have resulted in northeast trending faults with a secondary trend of northwest faults. Horizontal continuity is broken by this faulting where some of the faults are sealing. Continuous transgressive marine shales that separate shoreface parasequences are probably vertical barriers to flow. The layers near the well bore are likely in vertical communication as a result of hydraulic stimulation. Net pay is difficult to determine because of the high shale content and the thin sandstones. Correlations between log analyses, production data, permeability measurements, and stratigraphic interpretation present a gradually decreasing reservoir quality to the northeast (paleooffshore direction) (Van Kirk et al., 1996).

#### **7.4.3 Well Performance Histories**

Production from 100 wells within the study region were used for the scenario exercise. This production included historical production data and simulation projection data. Historical production data was obtained through the operators, Dwight's Energy, and the Colorado Oil and Gas Conservation Commission records.

The reservoir was separated into two separate predominate oil and gas production areas. The separation was supported through production gas-oil ratios. Within these

separate areas five regions were identified in the reservoir. Each region exhibited compartmentalization from the others, and distinct reservoir characteristics.

Furthermore, each region displayed varied recovery efficiencies in oil and gas production with an average total reservoir recovery efficiency of 4.2 % for oil and 67.5 % for gas.

These recovery efficiencies include projected recovery from simulation data. Table 1 lists the recovery efficiencies by region and the estimated ultimate recovery of oil and gas by region.

Table 1. Summary of recovery efficiencies and the estimated ultimate recovery of oil and gas.

Region	Gas Recovery Efficiency	Oil Recovery Efficiency	EUR Gas (MMSCF) / Oil (MSTB)
1	65.7%	0.7	17484 / 93
2	91.2%	13.6	4335 / 520
3	96.1%	7.2	4882 / 263
4	77.7%	3.9	11797 / 474
5	11.5%	5.0	756 / 101
Total Study Area	67.5%	4.2	39254 / 1391

#### 7.4.4 Economic Variables

Twelve companies operating in the study region were contacted to obtain drilling, completion, and production costs. Oil and gas prices, production tax rates and net

revenue interest rates are assumed to remain constant over the life of a well. All wells are assumed to have the same costs (i.e.: drilling and completion, fracturing, etc.).

## 7.5 Scenario Time Schedule

The time schedule is organized into six class periods. Every period constitutes a six months time span. As an example, at period two, six months have theoretically elapsed since period one. Therefore, production data is provided in six month increments.

As specified earlier, an objective of the scenario is to force quick decisions using the available data. This is accomplished by providing new data at each period, and requiring a decision be made. Dependent upon the period, the decision is delivered either in the form of a memorandum or presentation.

### a. Period 1

#### Instructor duties:

- Introduce the scenario and guidelines of the problem.
- Distribute the initial data to include six months of production from the three wells, logs from the three wells, and geologic information.
- Allow the purchase of seismic data and core data.

#### Student requirements:

Provide a memorandum describing the team's planned course of action detailing how the budget will be allocated. The planned course of action

should include any initial drilling and purchase of data. All actions should be justified in the memorandum.

b. Period 2

Instructor duties:

- Provide logs of selected wells.
- Provide the second six months of production for the initial three wells.
- Provide the “situation” scenarios.
- Once perforation depths are selected by the teams, provide a dry-hole or producer status for each well. Provide production data if appropriate.

Student requirements:

Analyze well logs and provide perforation depths for selected wells. Brief the results of current drilling operations and the team’s planned course of action. The planned course of action should include any planned drilling operations and justification for the purchase of data.

c. Period 3

Instructor duties:

- Provide logs of selected wells.
- Provide the third six months of production for the initial three wells.
- Once perforation depths are selected by the teams, provide a dry-hole or producer status for each well. Provide production data if appropriate.

Student requirements:

Analyze well logs and provide perforation depths for selected wells. Provide a short report detailing drilling results and the status of all

operations. Include in the report an initial reserve estimation and description of the reservoir.

d. Period 4

Instructor duties:

- Provide logs of selected wells.
- Provide the fourth six months of production for the initial three wells.
- Provide production data for team selected wells as appropriate.
- Once perforation depths are selected by the teams, provide a dry-hole or producer status for each well. Provide production data if appropriate
- Initiate the construction of a reservoir development and management plan. The plan should include well locations, time and asset requirements, and cost requirements. Allow each team to drill up to three additional wells during this period.

Student requirements:

Analyze well logs and provide perforation depths for selected wells. Select the locations for up to three additional wells. Provide a memorandum describing the team's planned course of action detailing new drilling locations and how the reservoir development plan will be constructed.

e. Period 5

Instructor duties:

- Provide logs of selected wells.
- Provide the fifth six months of production for the initial three wells.
- Provide production data for team-selected wells as appropriate.



- Once perforation depths are selected by the teams, provide a dry-hole or producer status for each well. Provide production data if appropriate.

Student requirements:

- Analyze well logs and provide perforation depths for selected wells.
- Work period for reservoir development plan.

f. Period 6

Students should brief the results of the exploration program, and the reservoir development plan recommendation. The presentations should include solutions to the situation scenarios, a reserve estimation, and a reservoir description. A written report detailing the above should accompany the briefing.

g. Period 7

Class conducts an after-project discussion with the instructors. Instructors return written reports, and provide performance assessments

## **7.6 Data Organization**

All data for the scenario is organized with the intention of being easily accessible. Logs and scout cards are organized by section, township and range. Maps are organized by subject matter of interest. Production data is listed by well API number.

## **CHAPTER 8.**

### **TEAM INTEGRATION OBSERVATIONS**

Through observations of interactions between team members, evaluation of project end-products, and the recording of team comments, three areas of emphasis were determined which most contributed to the success or failure of team integration. These three areas are a parochial versus an integrated view when solving problems, cross-training of team members in adjacent disciplines, and proper organization and management of meetings. If these areas are emphasized in instruction and focused upon within teams, chances of successful team integration leading to a high quality end-product are greatly improved. Because of their importance, each area is discussed in the following sections.

#### **8.1 Parochial Versus Integrated Perceptions**

Team members can approach the solution to a problem through two approaches: Using all assets available to them, or using all assets available within their discipline. Members of integrated teams must strive to approach a problem using the former method. Simply translated, this means valuing the input from other disciplines. Team members need to be involved in the sharing of information and interpretation of data. They should solicit input and provide input. Through the exchange of ideas, true integration occurs and a single-tracked focus dissolves. Not viewing a problem in this manner, can severely disrupt the progress of a team.

In only one team did I observe this type of behavior. The behavior was not intentional in the sense of being disruptive. The team member was a hard worker and eager participant. Yet, the person held a belief that almost all answers could be derived from one discipline. The result was a team member others found difficult to work with, and a discounting of the individual's input and the benefit the individual's discipline had to offer.

In another situation, certain team members performed analysis, but would not participate in the critical reasoning sessions of team meetings. Because of those absences, their contributions to integration were lost. This situation was precipitated by a breakdown in project organization, and lasted just a short period until organization was restored. But, the team was never able to overcome the lost time and weakness in integrated analysis created by the lack of participation.

## **8.2 Cross-Discipline Development**

A perception of inferiority leads to a lack of participation within groups (Lamm & Trommsdorff, 1996). This was evident at the start of the design class. Certain people perceived there was a knowledge disparity between engineers, geologists, and geophysicists. To some students it was a very important concern. Real or not, this possible disparity in knowledge curtailed team interaction. Team members did not understand terms being used or capabilities of data-sources being requested. Some team members would not challenge justification provided by other team members or ask questions for fear of exposing what they did not understand. Integration was hampered.

The solution was initiated through two cross-training periods. Subject areas from each discipline were assigned to each team. After a period of research a team member, selected at random, would teach the entire class the appointed subject material. Once knowledge was shared, and questions were asked, the feelings of inadequacy began to diminish.

This example illustrates what would be true in any group situation. Team members must feel confident enough to give input and seek justification from other team members. Cross-discipline education can help build that confidence. It also provides a basis for higher quality questions, interaction, and analysis. The education may be formal, as in the above example, or informal through simple discussions and questions. The strategy for integration attempts to force this sharing of knowledge through the use of criteria analysis.

The use of criteria analysis in the strategy for integration is an attempt to enforce logical reasoning and increase communication between team members. It is hoped that the question, "why," and the statement, "explain that, I don't understand," are spoken often. If spoken, they will help increase communication, help ensure a logical thought process, and help create a learning environment. Student teams agreed, the use of criteria provided this result. Comments after the first set of presentations included the need to justify all assumptions and requests. Comments from the initial scenario's after-project discussion included the feeling that the strategy had facilitated the learning process and the ability to justify all actions. The use of criteria is very important in enhancing integration through the education of team members.

### **8.3 Meeting Management**

The ability to manage team meetings will either enhance or destroy a team's effectiveness. The inability to manage meetings and its effect were displayed by a single team. The team became dysfunctional and ineffective, and could not accomplish needed tasks, make decisions, or meet goals. The result was the worst performance by a team in the class.

In this situation, the inability to manage meetings came from a lack of meeting management education. Several team members understood the problem, but did not know how to correct it. To correct this situation, a short class was presented instructing students in meeting management techniques. The improvement in meeting productivity was apparent during the field exploration scenario. As some of the meeting management techniques were used, and the process became more familiar, quicker decisions were made and more analysis performed in a shorter time period. This was essential for the exploration exercise.

The objectives of most meetings are to share information and make decisions. If these objectives cannot be accomplished, the integration strategy will be ineffective. Providing a proper organization and focus to every meeting allows the strategy for integration to work. Decisions must be made at every step in the process. Managing meetings is not difficult, but the results provided in time utilization and personnel morale are very important.

**CHAPTER 9.**  
**MULTIDISCIPLINARY STRATEGY**  
**OBSERVATIONS AND DISCUSSION**

Feedback and analysis of the multidisciplinary strategy's effectiveness were gathered from three class after-project discussions, observations of team performance and interaction, and evaluation of team end-product deliveries. The after-project discussions (APD) were conducted in a whole class rather than separate team format. I posed questions, listed in section two, and solicited responses and discussion. The feedback quantity and quality were high, allowing for insightful analysis. Observations of team performance were recorded with a weekly synopsis of class and team actions. These actions included questions posed by students, observations of how teams integrated in their decision processes, and the amount of integration displayed and structured in class briefings and memorandums. End product briefings and reports were evaluated by the class instructors. Critiques, both positive and negative, were recorded and used to gauge improvements and general trends.

**9.1 Sources of Error in the Conclusion**

Conclusions are based upon personal observations and instructor critiques. Therefore, the results are subjective and based upon qualitative evaluations. Although an attempt was made to be unbiased, the possibility exists for some prejudice in viewpoint.

Two constraints confronting student-teams may not impact industry-teams to the same extent. These constraints are available time and work location. Student-team members do not share common work schedules. Outside-of-class work time competes with other classes and requirements. Likewise, team members do not share a common work location such as a building or an office. Therefore, the scheduling and execution of out-of-class meetings may be difficult at best, and may occur without all team members at worst. These two constraints may create imperfect integration and end-products. Consequently, results from this study may not reflect what could be achieved in an industry setting.

## **9.2 Success of the Strategy**

Success was evaluated by an analysis of whether or not the strategy positively influenced team integration. Once exposed, could the process be used as a tool to assist teams in making better decisions, shorten cycle-time, and improve integration? Team responses to APD questions, team performance observations, and instructor critiques were recorded and used for the success determination.

During the first APD, the class was asked the following three questions:

- a. Rate your team's performance on a scale from one to ten with ten being best. Evaluate the performance on whether all questions were answered and the quality of those answers.
- b. What problems did you have working together?
- c. What did you learn from briefing presentations, both your team's and the other teams'.

During the second and third APD's, the class was asked the following five questions:

- a. Rate your team's performance on a scale from one to ten with ten being best. Evaluate the performance on whether all questions were answered, and the quality of those answers.
- b. What problems did you have working together?
- c. What did you learn from briefing presentations, both your team's and the other teams'.
- d. In retrospect, what could you have done differently to improve?
- e. What did you learn about integration and teamwork?

The recording of changes in the decision-making abilities of teams was thought necessary to provide an accurate analysis of the methodology's effectiveness. However, determining how to do this was difficult. All observations, even if performed through a test, would be qualitative. Therefore, measures which could be translated from qualitative analysis to quantitative analysis were required. Also, I felt the best way to observe changes in decision behavior, would be on a weekly basis. To achieve both goals, quantitative evaluation and observation of changes over time, I decided to use the evaluation measures already established: Presentations and reports. These would presumably be the student's best efforts. Also included in the evaluation would be an analysis of questions asked by students, and student responses to questions asked by instructors. By evaluating end-products, questions, and responses with a set of parameters, a quantitative scale could be established

The recording of these evaluation observations occurred on a weekly basis. The entire ten week evaluation period included the two-week instruction period, the five-



week reservoir management exercise, and the three-week exploration scenario. Presentations, reports, and questions were evaluated against set parameters described below. Comments summarizing group and class performances were also recorded. All parameter data were translated into weekly quantified results. These evaluation results could then be displayed graphically.

The following parameters were established for evaluation:

- a. Process questions (questions concerning clarification of the methodology);
- b. Data analysis questions (questions concerning interpretation or analysis of logs, core samples, production data, seismic data, etc.);
- c. Degree of integration in the team's analysis;
- d. Process understanding (understanding the intent of process steps, and how to correctly use the process as a decision tool);
- e. Support provided for team decisions or recommendations.

### **9.2.1 Qualitative / Quantitative Analysis**

All parameters were evaluated on a scale from zero to ten. Ten signified either a high rating or many occurrences, five signified either a medium rating or moderate occurrences, and zero signified either the lowest rating or no occurrences. All parameters were normalized to a zero to ten standard, because the ability to view trends during the ten week period was important. Therefore, standards for rating values were established for each parameter. All parameters were evaluated independent of each other. However, observations of the results could lead one to infer an interdependence

between process understanding, degree of integration, and decision support. The following explains the rating standards for the five parameters.

a. Process questions. This was a weekly summation of the number of questions teams raised in reference to the methodology. The evaluation was based upon the average number of questions per team. A low rating, one, equated to one question per team. A medium-low rating, three, equated to two to three questions per team. A medium rating equated to four to five questions per team. A medium-high rating, seven, equated to six to seven questions per team. A high rating equated to greater than eight questions per team.

b. Data analysis questions. This was a weekly summation of the number of questions teams raised in reference to the analysis and interpretation of data. The evaluation was based upon the average number of questions per team. A low rating, one, equated to one question per team. A medium-low rating, three, equated to two to three questions per team. A medium rating equated to four to five questions per team. A medium-high rating, seven, equated to six to seven questions per team. A high rating equated to greater than eight questions per team.

c. Degree of integration. This was a subjective analysis of weekly presentations and reports. Did teams use information obtained from various disciplines in their analyses? How many disciplines were cited in a decision justification? Did information from the different disciplines support an interpretation or was information contradictory? The full rating scale from zero to ten was used for evaluation. A rating of ten equated to a high degree of integration. A rating of one equated to a low degree of integration. Ratings between ten and one reflected intermediate levels of integration.

d. Process understanding. This was a subjective analysis of student responses to questions posed by instructors and student peers during weekly presentations and class-preparation sessions. Was the methodology being used? Did the teams understand how to use the methodology? Did the students understand the intent of the methodology's steps? The full rating scale from zero to ten was used for evaluation. A rating of ten equated to a high degree of understanding. A rating of one equated to a low degree of understanding. Ratings between ten and one reflected intermediate levels of understanding.

e. Decision support. This was a subjective analysis of weekly presentations and reports. How much support was provided for recommendations, requests, or interpretations? Was the justification of high quality, rational and researched, or of low quality, no-basis and shallow? Was a comparison of alternatives, using criteria, performed? The full rating scale from zero to ten was used for evaluation. A rating of ten equated to a high degree of support. A rating of one equated to a low degree of support. Ratings between ten and one reflected intermediate levels of support.

### **9.2.2 Examination of Quantitative Results**

The weekly assessments showed an improvement in integration and support for decisions as exposure to the process increased. The results of the weekly assessments are displayed graphically in Figures 6 - 8.

The type and frequency of questions asked throughout the ten week period are represented in Figure 6. Initially, throughout the learning phase and into the reservoir

**Comparison of the Amount of Questions Concerning the Process versus  
Questions Concerning Data Analysis**

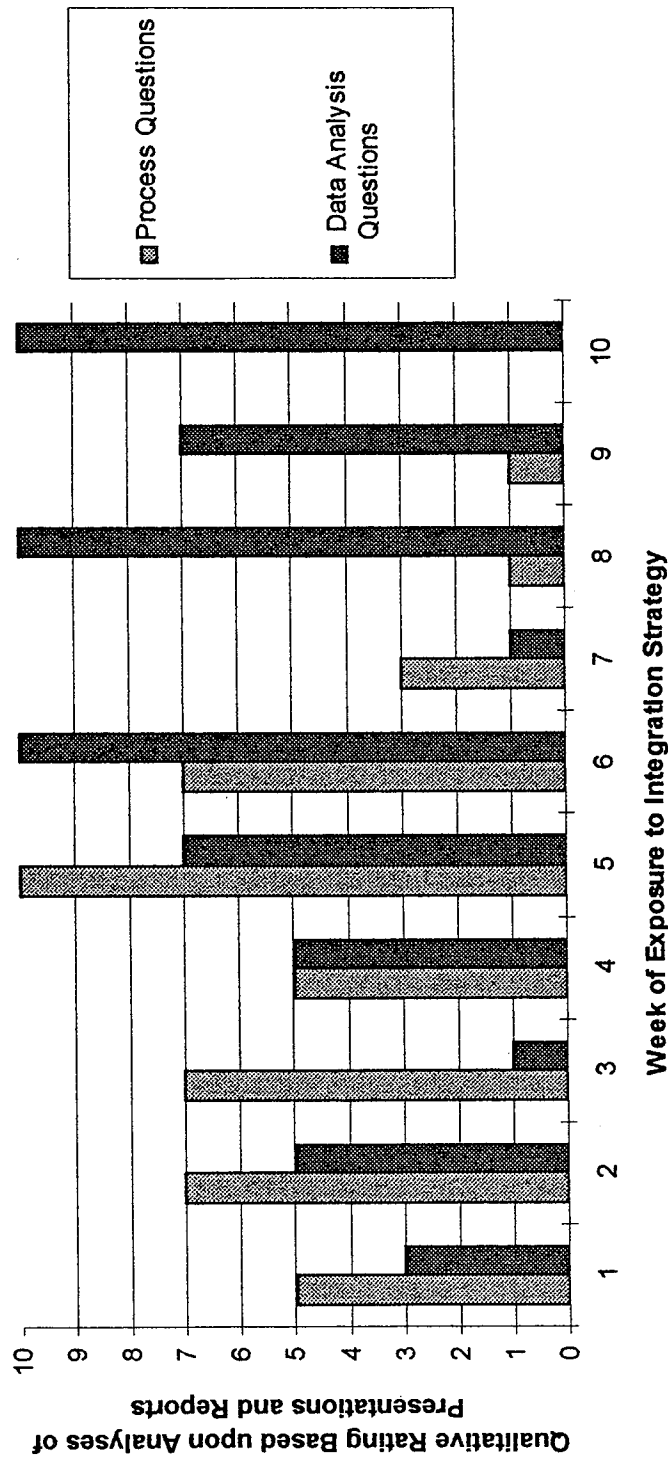


Figure 6: Comparison of process questions versus data analysis questions.

management scenario, more methodology questions were asked. This could be expected because the emphasis during these periods was process instruction. The frequency of questions concerning methodology peaked during the week in which alternatives were compared using criteria. After this peak, the number of questions concerning methodology decreased. As students were confronted with increased uncertainty within the scenarios, questions concerning data and their interpretation increased. The number of data analysis questions remained high at week ten.

Figure 7 is a comparison of three assessment parameters: Process questions, process understanding, and degree of integration. As previously examined, the frequency of questions concerning the methodology generally increased throughout the first five weeks. These five weeks included the two week instruction period and the first three weeks of the reservoir management scenario. After the five week mark, questions concerning methodology decreased until no such questions were encountered at week ten. During the same ten week period, the integration and process understanding steadily increased. As the students presented their ideas and delivered written reports, their ability to verbalize methodology concepts improved. Likewise, the quality of integration in analyses and decisions improved. The period of weeks seven through nine should be noted as the parameters fluctuated in values. The final recommendation, written and oral, was delivered in week seven. Some teams had difficulty weaving an integrated story into the final products. Weeks eight and nine brought the new scenario, the exploration play. Process understanding and degree of integration initially increased as new teams were formed and were immersed in an unfamiliar situation. A combination of new team members and scenario unfamiliarity resulted in an initial reliance on the methodology to help produce results. However, the exploration scenario created some initial confusion as to how to use the methodology to select well sites and produce a

### Weekly Performance Summary Chart

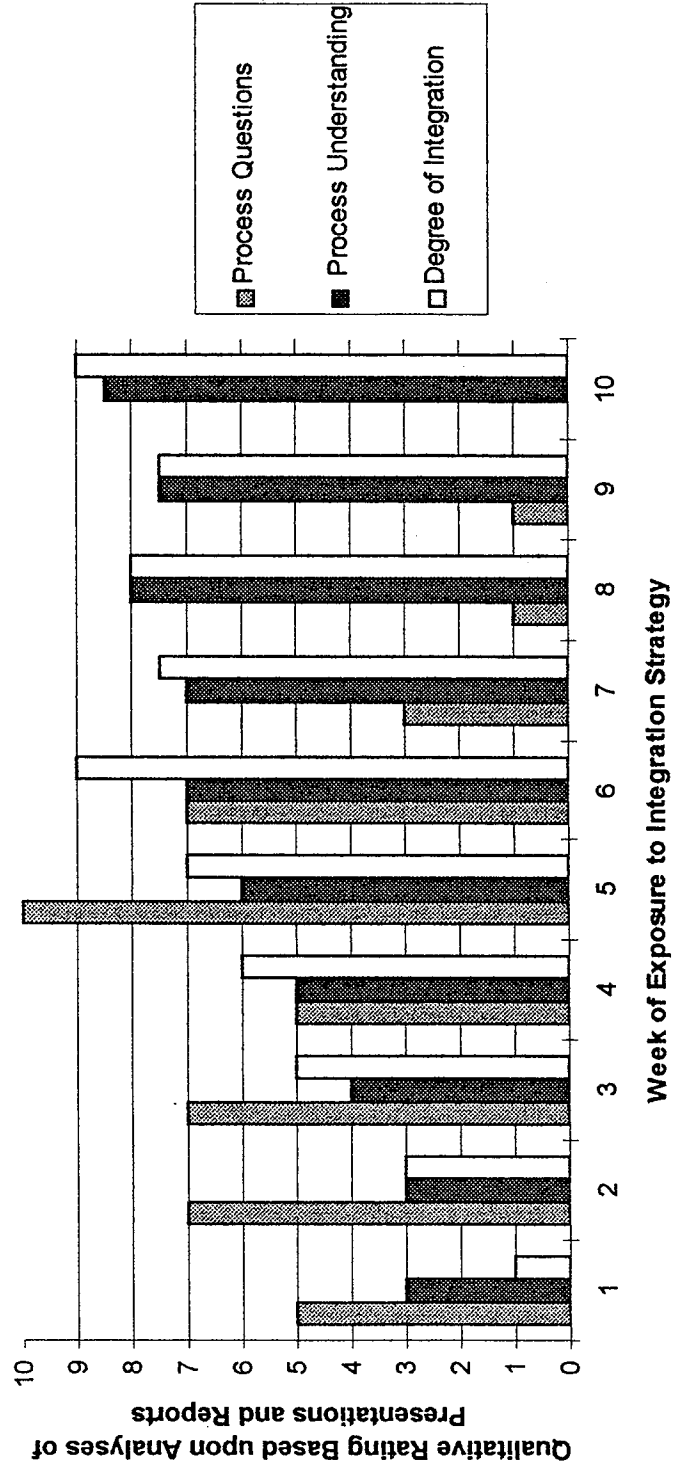


Figure 7. Comparison of changes in the degree of integration, understanding of the methodology, and questions concerning the methodology over time.

reservoir development plan. This confusion diminished as represented by an increase in parameter values during week ten.

Finally, Figure 8 shows the changes in the degree of integration and support for decisions in presentations and reports. These two parameters may provide the best evidence of changes in the way students approach decisions. If the degree of integration in decisions did not increase, the methodology would have had little effect on team integration. If the amount of support for decisions and interpretations did not increase, the methodology would have had little effect on team decision analysis. The results showed a positive relationship between exposure and use of the methodology and increases in these two parameters. Integration of disciplines in reports and presentations increased from week one to ten. Support for decisions and interpretations increased from week one to ten. The one drastic anomaly occurred in week nine. The decision support parameter dropped. This was the week before spring-break. The drop could be a result of student distraction.

Analyses of parameter results, indicate the implementation of the methodology resulted in an improvement in multidiscipline integration and decision analysis. One possible hypothesis would be: As students learned the process, they transferred emphasis to data analysis; as process understanding increased, the degree of integration increased; as integration and data analysis emphasis increased, the support for decisions increased. The methodology provided greater integration and improved decision analysis.

Changes over Time in the Degree of Integration and Support for Decisions

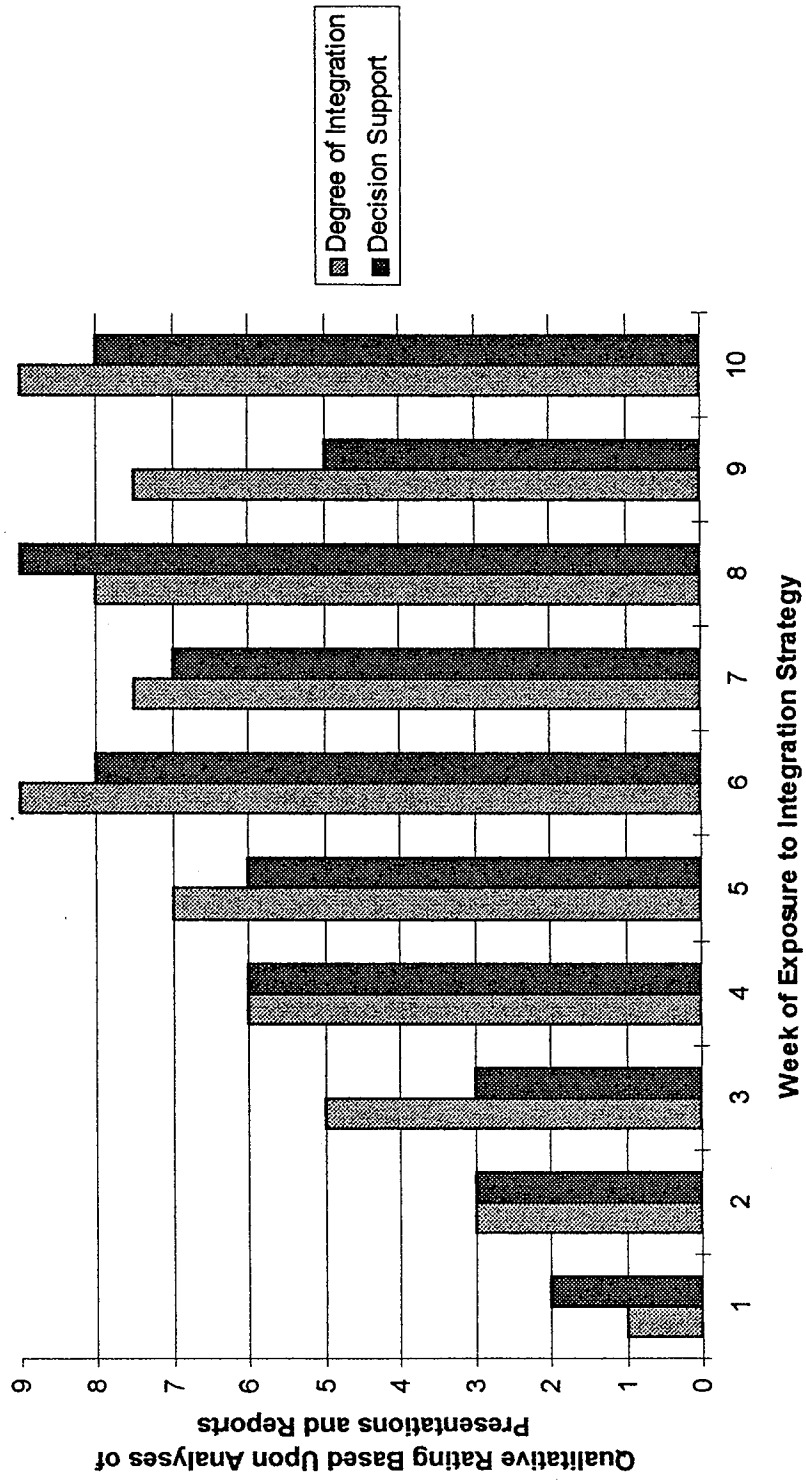


Figure 8: Comparison of changes in the degree of integration and support for decisions over time.



### 9.2.3 Impact on Integration and Decision Analysis

The multidisciplinary strategy will ensure integration of thought and people, but will not ensure a high quality end-product. This observation was derived from analysis of the class's first project, the reservoir management scenario. In four out of five teams, the ability to integrate directly correlated with end-product quality. But, in one team, this correlation did not exist. During intermediate progress briefings, this group displayed the best understanding of the process and use of criteria. Their analyses throughout the intermediate stages were excellent. But, only two team members, both from the same discipline, participated in the construction of the end-product report. The result lacked quality, an integrated flow, and relied heavily on a single criterion analysis. The multidisciplinary strategy must be followed from start to finish for it to be effective.

In APD responses, students felt the strategy did assist in integration and decision analysis. They also reflected that without the integration of pertinent data, their decisions would have been different. Integration provided a better interpretation of the situation, and created better decisions. Several teams felt two specific tools were beneficial in this regard: The decision matrix and the evaluation matrix. The decision matrix was detailed in Chapter 3. The evaluation matrix is described below.

The evaluation matrices, shown in Figures 9 and 10, are attempts to visually document the integration process. Two matrices were presented for student use. The first is a team evaluation matrix. Teams list members names in the first column, and then record completed tasks associated with the individual under the critical information sections. Once constructed, teams have a visual representation of the integration involved in making the final decision. From this representation, teams can easily

## TEAM EVALUATION MATRIX

		Critical Information					
		Connectivity / Compartmentalization		Oil - in - Place		Mobility Ratio	
Team Members		Data for Analysis	Analysis Performed	Data for Analysis	Analysis Performed	Data for Analysis	Analysis Performed
Petroleum Engineer							
Geologist							
Geophysicist							

Figure 9. Example of a team performance matrix used to visualize integration in the decision process.

## INDIVIDUAL EVALUATION MATRIX

Name of Team Member			
Critical Information	Data For Analysis	Analysis Performed	Value in Making Final Decision
Connectivity / Compartmentalization			
Oil - in - Place			
Mobility Ratio			

Figure 10: Individual evaluation matrix used for self-evaluation of work performed.

construct integrated reports. The second matrix is an individual evaluation matrix. This is another tool for self-evaluation. Dependent upon what analyses the individual performed, a self-evaluation is made regarding the value of the information toward the establishing a final recommendation. These matrices assist integrated teams through a visualization of the entire process.

#### **9.2.4 Process to Product**

During the first project's after-project discussion, several teams expressed they had become so concerned with the process, that they underestimated the analysis involved. Teams and individuals varied on the point in time when the strategy became more than just a process and transformed into a tool which facilitated integration and analysis. There is a danger that teams will become obsessed with the process and lose vision of the larger goal. This focus on process alone seems to only happen once within a team. After the "transformation," the students described, process overemphasis ceases and the strategy becomes a tool. But, an instructor or team leader needs to be aware of this concern. An attempt to produce a smooth transition from process focus to product focus should be made. Instructors and team leaders can assist in this transition through the use of questions and evaluation of the quality in the team's criteria analysis.

#### **9.2.5 Internalization of the Process**

Integration improved throughout the periods of the two scenarios. This was demonstrated in reports and memorandum writing. Analysis used to justify conclusions

and decisions became more of an interwoven mesh of the three disciplines. The lack of justification and support for suggested actions, initially prevalent throughout every teams' products, decreased until the last memorandums contained fully supported recommendations. Students highlighted the benefit of the self-evaluation and feedback techniques, such as briefings and matrices. They felt the requirements assisted in the improvement of their integration procedures. The briefings provided instant instructor and peer feedback, required all team members to understand the material, and allowed insight into new ideas and approaches. The matrices provided a visual aid, and necessitated communication within teams.

### **9.3 Impacts of Group Dynamics**

The dynamics of people working together played an important part in the performances of the teams. The group attitude with which a team approaches a problem and the ability to deal with uncertainty influence a team's final product. Students felt the dynamics of their teams played a major role in facilitating or hindering progress. This included a spectrum of issues such as an initial hesitancy to ask questions, the inability to cooperate, and a "group-think" atmosphere. The examples of three teams are provided for illustration.

Team A was assumed to have a mixture of the more technically competent people within the class. Expectations were high that this group would excel in the given project. But, team individuals, working extremely well together, could not accept the uncertainty within the project. Instead of making assumptions correlated to the most

reliable data, the team felt they could not provide any answer. The result was a substandard product in relation to what other groups delivered.

Team B was assumed to have a mixture of highly technically competent and less technically competent people. From the beginning, the team was unorganized. The lack of focus led to a team inability to make decisions. Under deadline pressure, they hastily began to cooperate. The effort was not sufficient to improve the resulting substandard product.

Team C was assumed to have a mixture of technically competent people. The attitude within the team was very positive and focused. The team followed the integration strategy's steps, and made assumptions where uncertainty existed. The group dynamics exhibited success. Their end-product was the best in the class.

#### **9.4 Areas of Process Improvement**

Two areas were identified which may provide improvement to the implementation of the process. The areas are clarification of strategy terminology and initial use of the evaluation matrix. The terms, "information" and "data" and their definitions within the context of the multidisciplinary strategy, confused many students. Some students could not understand the difference between the two terms. Other students did not understand a need for the differentiation. While I feel the terminology may be changed to assist understanding, I do not feel the differentiation can be obscured. It is important to understand and consider the different ways information can be obtained

for use in decision analysis. Large variances, dependent upon situations, can exist in cost and reliability. These variances must be evaluated.

Several teams felt the evaluation matrix should have been provided earlier in the process. The visual aid would have assisted in a quicker understanding of the team integration process. I agree with this assessment, and feel the matrix's introduction early-on will assist process understanding.

### **9.5 Areas of Instruction Improvement**

Two improvements are suggested to increase the effectiveness within the learning environment. The first involves demonstrating proper techniques and expectations. The second involves industry interaction with students during the scenario exercises.

Examples of integrated briefings and reports should be provided to the students initially. Although a format was described, a visual aid would have assisted in communication and comprehension. Because students are not accustomed to writing in an integrated format, examples of such a format would have resulted in better initial results.

The second recommendation would require a commitment from industry personnel to interact with students. This interaction would occur through electronic-mail (e-mail) transactions. Using the situation scenarios already established, students could receive information from industry personnel on current techniques being used to solve related problems. A synopsis of the suggested program follows:

Students would interact through the Internet with industry professionals on questions of current industry interest. The time commitment from industry personnel would be minimal. Professors would monitor and regulate message traffic from student-teams. The hope is that a positive result would be obtained by both the students and industry personnel.

The purpose of the program would be to prepare senior level students to enter the workforce as professionals understanding current issues, communicating in corporate vernacular, presenting effective, thoroughly considered questions and recommendations, and appreciating and utilizing industry experience.

The intent of the program would be to provide students with issues currently being worked within industry. The industry participants would provide these problems.

Once presented with the situations, the students would analyze and provide recommendations to solve the issue. The industry advisors would serve as additional resources for the students.

There are four principle objectives of the program:

- a. Improve written communication skills of students;
- b. Expose students to exterior ideas while in an academic environment in order to spur discussion;
- c. Initiate the transition from an academic to industry setting;
- d. Provide a closer relationship between academia and industry.



To aid in proper communication, student correspondence would be transmitted in the following format:

- a. Situation / Description;
- b. Problem / Issue;
- c. Student-team's analysis and proposed course of action;
- d. Student's questions.

## **9.6 Application of the Strategy within Industry**

The strategy for multidisciplinary integration would be applicable in any situation involving the integration of teams. As presented in Chapter 2, the emphasis on multidisciplinary teamwork is increasing within industry. Within the framework of integrated reservoir management, the strategy could assist in goal selection, plan development, and evaluation. Once understood by industry personnel, the strategy would facilitate the organization of teams and production of quick decisions. The procedure for instruction would allow businesses to incorporate actual on-going operations as the scenario exercises. Therefore, instruction could occur while required operation decisions were being made. Finally, the use of the strategy could assist managers in determining what experts are required and how much analysis is needed. A higher assurance that benefits outweigh costs could be obtained.

## **CHAPTER 10.**

### **CONCLUSIONS AND RECOMMENDATIONS**

#### **10.1 Conclusions**

Based upon the observations of this class, the following conclusions have been reached.

- a. The strategy for multidisciplinary integration was effective in enhancing the integration of teams.
- b. The strategy for multidisciplinary integration provided teams with methods for making better analysis and decisions.
- c. As with any environment involving teamwork, group dynamics have a large impact on a team's ability to work together and produce a high quality end-product.
- d. Cross-discipline instruction is required for effective multidisciplinary teamwork.
- e. There is a danger of focusing exclusively on process which inhibits product development.

- f. Briefings, frequent instructor and peer feedback, and matrix tools assisted in the internalization of the process.
- g. Confusion in terminology inhibited quick understanding of the process.

## **10.2 Recommendations**

- a. Introduce the evaluation criteria at the start of the scenario exercises.
- b. Provide a short segment of instruction on meeting management.
- c. Institute an industry-student interaction program to be used in conjunction with the multidisciplinary class scenario exercises.
- d. Provide additional instruction and insight into personalities and group dynamics and their affect on successful teamwork.

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