A comparison of systems analysis techniques, the Data Flow Diagram (DFD) and part of the Integrated Definition Method (IDEF0), is done using a new developmental framework.

COMPARISON OF ANALYSIS TECHNIQUES FOR INFORMATION REQUIREMENT DETERMINATION

SURYA B. YADAV, RALPH R. BRAVOCO, AKEMI T. CHATFIELD, AND T. M. RAJKUMAR

It is widely recognized that determining a complete and correct set of requirements of an organization is vital to the design of an effective information system. To do this, however, one must first understand the organization [16, 17]. Organizations are generally complex systems, and this makes the task of determining requirements very difficult. In addition, Davis [8] suggests three other reasons for the difficulty in obtaining a complete and correct set of requirements:

1. The limitations of humans as information processors and problem solvers.
2. The variety and complexity of information requirements.
3. The complex patterns of interaction among users and analysts in determining requirements.

Some of these constraints, however, can be overcome by the use of a systematic method. Specifically, a structured modelling technique can help analysts manage the complexity of an organization by studying each part of the organization separately while not losing the overall context. Several structured techniques have been developed to help an analyst model an organization at the requirement determination level: Structured Analysis and Design Technique (SADT) [12], Data Flow Diagram (DFD) [9], Business Information Analysis Technique (BIAT), Integrated Definition Method (IDET) [2], [5], Interpretive Structured Modeling Software (ISMS) [10]. Some of these techniques compete with each other. It is not clear to educators and practicing professionals which techniques are better suited for requirement analysis.

Research to compare these techniques is scarce, although there are some articles [6, 11, 13] that report efforts to do so. Colter [6] has proposed a comparative framework for comparing systems analysis techniques. In his framework, he includes nine evaluative dimensions to compare structured systems analysis techniques with traditional analysis techniques. Whether a technique provides strong coverage, low coverage, or does not address the issue are the three classifications of these techniques. It is not clear from his paper, however, what the rationale is behind selecting the particular set of evaluative dimensions. Moreover, some of these dimensions, such as the structural dimension, provide little help in deciding what should be the final outcome of the requirement determination stage and which technique is more appropriate to document the
final outcome. Most of the existing comparisons are primarily based on the authors' experiences and intuitive thoughts about the techniques. There is no empirical research that has compared these techniques objectively.

This article presents a new framework to compare and contrast requirement analysis techniques. We provide rationale for the framework and develop criteria based on the dimensions of the framework. Also specified are the operational measures for each of the criteria on which techniques can be evaluated. The article also reports on an experiment to evaluate the two most widely used techniques—IDEFo (SADT) and DFD. IDEFo (the function modelling part of IDEF) [2] is a technique used to produce a functional model that is a structured representation of the functions of the object system (an organization) being analyzed. To model an object system in a top-down fashion, it provides five basic elements: function, input, output, control, and mechanism.

The DFD [9] technique is used to show the flow of data through a system. It uses concepts of dataflow, datastore, and process to model the flow of data through a system in a top-down fashion. These two techniques were compared in terms of their support for the modelling process and their final outcome. The experiment was conducted in a graduate class of systems analysis and design. An Expert Review Committee (ERC) was set up to evaluate the final outcome and aspects of the modelling process. The ERC applied the measures that we will discuss in detail to evaluate the models. The rest of the data were collected by administering questionnaires to the subjects of the experiment.

A FRAMEWORK FOR COMPARISON OF ANALYSIS TECHNIQUES
In this section we first develop the framework and then present hypotheses based on the framework.

The Framework
A framework to compare analysis techniques should address all aspects of requirement analysis. There are three basic questions with respect to requirement analysis. These are:

(1) What should requirements be?
(2) How should requirements be stated?
(3) How should requirements be derived?

The first question deals with the content, the second deals with the form of the content and the third deals with the process of determining the content. Very few researchers have addressed the first question. What are all the traits of a system that should be included in the requirement specification in order to make it a complete specification? For management people a verbal statement of requirement seems to be sufficient. Technical people usually include functional architecture, system context, performance specification, measurement, and test conditions as part of the total requirement specification.

What should the requirement be?
Yeh [18] answers this question as follows:
A system requirement is a set of precisely stated properties or constraints that a system must specify. A requirement should specify the function space of a problem. Boundaries of the solution space are set by the constraints and properties which can be used to test whether a proposed solution is indeed a valid one.

Ross [12] defines requirements as:
Requirements definition includes, but is not limited to, the problem analysis that yields a functional specification. It is much more than that. Requirements definition must deal with three subjects:

(1) Context analysis: The reason why the system is to be created, and why certain technical, operational and economic feasibilities are the criteria which form the boundary conditions for the system.
(2) Functional specification: A description of what the system is to be, in terms of the functions it must accomplish.
(3) Design constraints: A summary of conditions specifying how the required system is to be constructed and implemented.

We believe the requirement specification contains information for the user, designer, implementer, and tester of the system and should include:

(1) Functional specification: what functions a system must perform.
(2) System context, constraints, and assumptions. This establishes boundary for the system.
(3) Performance specification about the dynamic properties of the system.
(4) Measurement and test conditions—an organized testing process to verify that the system is behaving properly.

How Should Requirements Be Stated?
In the literature, there is very little agreement on how requirements should be stated. Different techniques emphasize different frameworks for stating requirements (PSL/PSA, RSL, Young [19]). For example, PSL/PSA emphasizes concepts such as INPUT, PROCESS, OUTPUT, and ENTITY, whereas RSL emphasizes the information flows through the system using the concepts of petrinets. In some techniques, processes are disguised in the definition of relationships among inputs and outputs [18]. A deeper analysis of these techniques however, reveals that all of them describe some or most of the following:

(1) activities
(2) inputs and outputs
(3) data definition
(4) processing requirements.

This leads us to conclude that a requirement specification should be described in the form of
(1) a functional model of the object system
(2) a data dictionary defining the various components of the functional model
(3) a set of performance and test specifications for the system.

How Should Requirements Be Derived?
We need to concentrate on the final outcome of the requirement analysis as well as on the process of arriving at the final outcome [17]. This implies that an analysis technique should support a modelling process to help derive information requirements. An analysis technique should address the three questions just discussed. It should provide mechanisms.

(1) to develop a functional model of the object system
(2) to define various components of the model
(3) to specify performance and test conditions.

In addition, since an analysis technique is used by a team of people, it should have communication ability and it should be easy to learn and easy to use.

Framework Dimensions
A framework to evaluate analysis techniques should include criteria for comparison. We propose a framework that provides criteria to compare techniques in terms of

(1) the modelling process supported by a technique
(2) the final outcome of the technique.

The proposed framework has four dimensions:

(1) syntactic
(2) semantic
(3) communicating ability
(4) usability

The syntactic dimension includes criteria that evaluates syntactical rules for the modelling process as well as for the final outcome of a technique. Similarly, the semantic dimension provides criteria to evaluate the meaning of the modelling process as well as the meaning of the final outcome. Table I summarizes the first two dimensions of the framework.

Syntactic Dimensions
Syntactic rules are constraints in the sense that they describe logically what is represented graphically. If the syntactic rules are not satisfied or are violated in the graphic display, the constraint has not been met, and the resulting model is deficient with respect to that particular constraint.

Five different types of syntactic criteria are distinguished depending on the decomposition process or the final outcome. In the area of modelling process we have:

**Consistent Level of Abstraction and Detail**
This criterion pertains to the consistency in decomposing one function into a set of sub-functions at the next lower level of refinement. All of the decomposed sub-functions should be at the same abstraction at a particular level. The measure for this criteria is the rating of the decomposition process by the ERC.

**Consistent Viewpoint and Purpose**
This criterion refers to the maintenance of the same viewpoint and purpose for all the levels of refinement in the model. The measure for these criteria is the rating by the ERC.

**Complexity of the Syntax**
This criterion relates to the understandability of the syntax rules of a technique. The measure for these criteria is a questionnaire response from users.

In the area of outcome we have:

**Syntactical Correctness of the Model**
This criterion relates to the degree to which a model has been accurately constructed, labelled, and identified; that is, the degree to which syntactic relations have been represented appropriately in the graphics and constraints obeyed. The measure for these criteria is the check for the adherence to constraints by the ERC.

**Syntactic Completeness of the Model**
The syntactic completeness refers to the degree to which all required field-entries, labels, boxes, arrows, and identifying notations are present in a model. The measure for these criteria is the check for adherence to the proper syntax.

**Semantic Dimensions**
Semantics is a term that has been applied to a wide range of factors that have each had some effect on the meaning of labels, functions, and the decomposition of a model. In order to establish criteria useful for evaluating models, those aspects of meaning that relate to the consistent and unambiguous naming of data and functions in IDEFo and DFD will be dealt with. Criteria for evaluating the overall story, message, or sense of a model.
will be addressed in terms of accessing complexity. As with syntax, semantic criteria are determined by the modelling process and the final outcome. In the area of the modelling process we have:

**Appropriate Level of Abstraction**
This criterion relates to the degree to which an abstraction (decomposition) is appropriate for a particular level. The measure for this criterion is the rating by the ERC.

**Proper Viewpoint and Purpose**
This criterion examines whether the viewpoint and purpose of the model is proper and meaningful. The measure for these criteria is the rating by ERC.

**Type of Decomposition**
This criterion relates to the quality of the decomposition—whether the decomposition is functional or by any other type. The measure for this criterion is again a rating by the ERC.

**Complexity/Understandibility**
*Understandibility* is an important but difficult criterion to measure in assessing model quality, mainly because of its abstract and subjective connotations. Another source of the problems associated with measuring understandability is the strong interrelationship of syntactic and semantic factors. Since we are defining understandability as a function of how well the content of the model is portrayed via the syntax, the relevant measures would be derived from both syntax and semantics. Thus, no single feature of semantics would appear to be a sufficient index of how well an evaluator could understand a complete model.

Measuring complexity, however, is a more feasible task. We are suggesting that understandability and complexity be viewed as dual measures—that is, something that is highly complex can be expected to be hard to understand; and similarly, something that has a low complexity value is probably much more accessible to a user and more easily understood.

We define these criteria as:

1. extent to which the purpose of a model is clear to the evaluator;
2. degree to which “what the model says” is accurately depicted via the syntax.

The measures are:

1. ease of finding the “main path”;
2. number of activations/boxes;
3. ease and success of “refining the layout.”

These measures are used by the ERC to evaluate techniques against this criteria.

**Semantic Correctness of the Model**
*Correctness* is perhaps the most subjective of the semantic characteristics presented in this section, chiefly because the final standard for assessment must come from the opinion of individuals who have the most complete knowledge of the subject matter being modelled. The ERC evaluates models for correctness based on the “extent to which information expressed in a model is an accurate description of the system being modelled.”

**Semantic Completeness of the Model**
*Completeness* refers to the sufficiency of information content to cover the subject matter. The ERC looks at the degree of adequate coverage of information with respect to the bounded context of the parent.

**Communicability Dimension**
The *communicability* ability of an analysis technique refers to the readability and understandability of the document produced by the use of the technique. Readers of the documents are asked to evaluate the communicability of the two techniques.

**Usability Dimension**
This dimension measures *how usable* a technique is. In other words, it relates to the degree of difficulty faced by an analyst applying a technique. The usability of a technique depends on its approach and its syntax. The usability of a technique can be hampered by a very rigorous or very vague syntax. The measure for this criterion is a direct response from the user.

**Research Hypotheses**
Hypotheses being investigated are derived from our conceptual framework for techniques comparison, which delineates the criteria used to compare two of the most widely used system analysis techniques. Specific hypotheses are stated in the null form. In light of the exploratory nature of this investigation, directions of alternative hypotheses are not specified. Instead, we employ two-tailed alternative hypotheses.

**Syntactic Hypotheses**
- H1: Syntactical correctness and completeness of final models does not significantly differ between DFD and IDEFo groups.
- H2: Syntactic consistency and appropriateness of modelling process does not significantly differ between DFD and IDEFo groups.

**Semantic Hypotheses**
- H3: Semantic correctness and completeness of final models does not significantly differ between DFD and IDEFo groups.
- H4: Semantic consistency and appropriateness of modelling process does not significantly differ between DFD and IDEFo groups.

**Analyst Response Hypotheses**
- H5: Analyst's perception of ease of learning syntactic rules does not significantly differ between DFD and IDEFo groups.
- H6: Analyst's perception of ease of drawing diagrams does not significantly differ between DFD and IDEFo groups.
H7: Analyst’s perception of ease of understanding the diagrams drawn by his team member does not significantly differ between DFD and IDEFo groups.

H8: Analyst’s overall confidence in the syntactic correctness and completeness of final models does not significantly differ between DFD and IDEFo groups.

H9: Analyst’s overall confidence in the semantic correctness and completeness of final models does not significantly differ between DFD and IDEFo groups.

H10: Analyst’s overall confidence in the utility of the technique to specify the requirement analysis does not significantly differ between DFD and IDEFo groups.

H11: Analyst’s preference of a technique he can choose for a similar future project does not significantly differ between DFD and IDEFo groups.

H12: Analyst’s assessment of the utility of the technique to enhance communication between team members does not significantly differ between DFD and IDEFo groups.

EXPERIMENT METHOD

Experimental Subjects
An experiment was conducted to test these hypotheses. In this exploratory experiment, the subjects were graduate students enrolled in the graduate level systems analysis course offered by the Information Systems and Quantitative Sciences Department of the College of Business Administration at Texas Tech University.

Experimental Treatment
In the systems analysis course, DFD and IDEFo were taught to a class of 20 students, using four class periods each, in the order of the DFD and then the IDEFo. Assignments were given to all students to ensure the required level of competency for each technique. After learning the two techniques, subjects were classified into high, medium, and low cognitive style categories based upon the Group Embedded Figures Test (GEFT) scores [15]. Scores ranged from 10 to 18, with a median score of 17 and a mean of 15.85. The lower score was associated with the cognitive style characterized by heuristic orientation whereas the higher score was associated with that characterized by analytic orientation. Since the score distribution was highly skewed to the right, we identified 12 subjects as analytic cognitive style, four as mixed cognitive style, and four as heuristic cognitive style.

Two subjects were then randomly selected from each cognitive style category to form a team. A total of 10 teams were formed and then randomly assigned to use either DFD or IDEFo to develop a requirement analysis specification for a hypothetical case involving an organization of medium complexity. Teams assigned to the DFD technique or the IDEFo technique are henceforth referred to as the DFD group or the IDEFo group, respectively.

Each technique group had three analytic teams, one mixed team, and one heuristic team. In an effort to determine that the DFD group (a total of five teams) and the IDEFo group (a total of five teams) did not significantly differ in any way other than the different technique to which they were assigned, the Analyst Background Survey was administered. Statistical tests performed on the survey items showed that they did not differ in important dimensions such as age, educational background, work experience, and knowledge or use of systems analysis techniques prior to this experiment. Teams had a total of four weeks to work on the case. At the end of each week, teams were encouraged to submit their intermittent models to the ERC for comments. At the end of the four-week experiment, teams were required to turn in their final models.

Since a significantly large weight was given to the outcome of the final models in determining the course grade, all teams demonstrated high motivation throughout the four-week experiment. Determination of levels of diagrams necessary to specify the requirements analysis was left to each team. In other words, some teams produced four levels of decompositions, whereas others produced three levels. Instruction as to the required levels of decompositions was not given since systems analysts working on any practical project have to make this decision themselves.

At the termination of the experiment, all subjects were given the Analyst Response Questionnaire, whose objective was to assess the analyst’s subjective evaluations of the technique. This questionnaire was administered to individual subjects, not to a team. The dimensions of the technique outlined earlier were assessed. Although the psychometric properties of the questionnaire were, at this point, not evaluated, the content validity [7] was established by the ERC.

Diagrams drawn by teams were reviewed independently by each of the four members of the ERC. In reviewing the final models, each ERC member followed a set of criteria as shown in Table II. A set of weights were assigned to the criterion of each dimension according to the perceived importance, also shown in Table II. A final score could theoretically range anywhere from zero to 20 on the continuum. After each member independently assigned a final score to each team, the ERC as a group came to a consensus on the final score for each team using an iterative method very similar to the Delphi method.

There are many factors that may violate internal validity. External validity, causing experimental data to be invalid [4, 7]. Care was taken to control external factors that might bias Ss, including the experimenter bias. Throughout the experiment, each team used the team code assigned in submitting any models. Thus the ERC member was kept blind to any information pertaining to an experimental subject such as name, cognitive style, work experience, or academic performance. This
was necessary to minimize the invalidating experimenter bias.

**EXPERIMENTAL RESULTS**

**Syntactic Hypotheses**
Table III shows F-values for each hypothesis. Neither H1 nor H2 was statistically significant using the SAS General Linear Models Procedure two-factorial with interaction. The ERC assigned final scores on the dimensions of syntactic correctness and completeness of the final models and the syntactic consistency and appropriateness of modelling process as discussed in the methodology section of this paper. In both modelling process and final outcome dimensions, the IDEFo group (2.2 out of 3 on the modelling process and 5.3 out of 7 on the final outcome respectively) and the DFD group (2.0 out of 3 on the modelling process and 4.8 out of 7 on the final outcome respectively) received very similar scores.

**Semantic Hypotheses**
Neither H3 nor H4 was statistically significant using the same test. The ERC assigned final scores on the dimensions of semantic correctness and completeness of the final models and the semantic consistency and appropriateness of modelling process dimension. The IDEFo group (1.8 out of a possible 3) and the DFD group (1.6 out of a possible 3) received very similar scores. On the final outcome dimension the DFD group (5.3 out of a possible 7) and the IDEFo group (5.0 out of a possible 7) received very similar scores.

**Analyst Response Hypotheses**
H5 was statistically significant (PROB > CHISQ = .0730) using the Kruskal-Wallis test. In order to test this hypothesis an individual subject was asked to rate his or her perception of the mechanical ease of drawing diagrams using the technique assigned. IDEFo users found it more time-consuming to draw diagrams than did DFD users. This finding was not surprising in light of the more rigorous set of syntactic rules required by IDEFo.

**TABLE II. Scoring Weights for Various Criteria**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Modelling process</th>
<th>Final outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syntactic</td>
<td>1. Consistent level of abstraction and detail—2 points</td>
<td>1. Correctness and completeness of the model—7 points</td>
</tr>
<tr>
<td></td>
<td>2. Consistent viewpoint and purpose—1 point</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1. Appropriate level of abstraction—1 point</td>
<td>1. Correctness and completeness of the model—7 points</td>
</tr>
<tr>
<td></td>
<td>2. Proper viewpoint and purpose—1 point</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Type of decomposition—1 point</td>
<td></td>
</tr>
<tr>
<td>Semantic</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TABLE III. F-values for Various Hypotheses**

<table>
<thead>
<tr>
<th>Hypotheses tested</th>
<th>Observed F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syntactic Hypotheses:</td>
<td></td>
</tr>
<tr>
<td>H1: Syntactical correctness and completeness of final models</td>
<td>0.65</td>
</tr>
<tr>
<td>H2: Syntactical consistency and appropriateness of modelling process</td>
<td>1.41</td>
</tr>
<tr>
<td>Semantic Hypotheses:</td>
<td></td>
</tr>
<tr>
<td>H3: Semantic correctness and completeness of final models</td>
<td>2.74</td>
</tr>
<tr>
<td>H4: Semantic consistency and appropriateness of modelling process</td>
<td>1.55</td>
</tr>
<tr>
<td>Analyst Response Hypotheses:</td>
<td></td>
</tr>
<tr>
<td>H5: Ease of learning syntactic rules</td>
<td>4.78*</td>
</tr>
<tr>
<td>H6: Ease of drawing diagrams</td>
<td>4.60*</td>
</tr>
<tr>
<td>H7: Ease of understanding the diagrams drawn by others</td>
<td>0.30</td>
</tr>
<tr>
<td>H8: Overall confidence in the syntactical correctness and completeness of final models</td>
<td>1.21</td>
</tr>
<tr>
<td>H9: Overall confidence in the semantical correctness and completeness of final models</td>
<td>0.70</td>
</tr>
<tr>
<td>H10: Overall confidence in the utility of the technique to specify the requirement analysis</td>
<td>0.93</td>
</tr>
<tr>
<td>H11: Preferred technique for a similar future project</td>
<td>4.00*</td>
</tr>
<tr>
<td>H12: Utility of the technique to enhance communication</td>
<td>0.67</td>
</tr>
</tbody>
</table>

* Significant at 0.05 level or less

H6 was also statistically significant (PROB > F = 0.0476) using the SAS General Linear Models Procedure. In order to test this hypothesis, an individual subject was asked to rate his or her perception of the mechanical ease of drawing diagrams using the technique assigned. IDEFo users found it more time-consuming to draw diagrams than did DFD users. This finding was not surprising in light of the more rigorous set of syntactic rules required by IDEFo.
When \( H_6 \) was analyzed using a two-factorial model with interaction, two main effects, Technique (\( PR > F = .04776 \)) and Cognitive Style (\( PR > F = .06000 \)), and the interactive effect Technique \( \times \) Cognitive Style (\( PR > F = .06022 \)), were all statistically significant. All IDEFo users, regardless of their cognitive style, thought it was time-consuming to mechanically draw diagrams. Nevertheless, there were some response differences among DFD users depending on their cognitive style.

Heuristic subjects of the DFD group generally thought that it was as equally time-consuming as did all IDEFo users. Analytic subjects of the DFD group rated it less time-consuming than did IDEFo users, while mixed cognitive style subjects rated it more time-consuming. Mixed cognitive style subjects fall somewhere in the middle of the continuum of cognitive style dimension whose bipolar ends are characterized by highly analytic orientation and highly heuristic orientation. It is possible that two subjects assigned into a team exhibit different degrees of mixed orientations (i.e., one possessed more analytic than heuristic orientation while the other more heuristic than analytic orientation). It is also possible to speculate that two mixed cognitive style subjects find it more difficult to incorporate different perceptions on diagrams.

\( H_1 \) was statistically significant (\( PROB > F = .0715 \)) using the SAS GLM two-factorial with interaction. In order to test this hypothesis, an individual subject was asked to choose between IDEFo and DFD as a preferred technique for a similar future project. All subjects could choose IDEFo as the preferred technique, even though only half of them were assigned to use IDEFo. Similarly, all subjects could choose DFD. Neither of these occurred. An analysis showed that IDEFo users tended to choose the IDEFo for similar future projects, while DFD users tended to choose the DFD. In selecting the preferred technique for a future project both technique groups were equally certain about the technique choice. It was interesting to note, however, that a higher proportion of IDEFo group (four IDEFo users out of 10) chose DFD instead, in comparison to the DFD group, where two DFD users out of 10 chose IDEFo. Neither cognitive style effect nor interaction effect was statistically significant.

\( H_8 \) was not statistically significant using the two-factorial SAS GLM procedure. In order to test this hypothesis, an individual subject was asked to rate his or her overall confidence in the syntactic correctness and completeness of the team’s final models using the same five-point scale. Both the IDEFo group (mean confidence level of 72.5 percent) were fairly confident about the semantic correctness and completeness of the final models they submitted. Although it was not statistically significant, the IDEFo group, on the average, exhibited a slightly higher confidence level than did the DFD group.

\( H_7 \) was not statistically significant. An individual subject rated the degree of ease of understanding the diagrams drawn by his or her teammates using the five-point scale. Both the IDEFo group and the DFD group found it fairly easy to understand the diagrams drawn by others.

Neither \( H_{10} \) nor \( H_{12} \) was statistically significant. Both groups agreed that the technique they used was useful to specify the information requirement analysis and communicate their understanding of the case to their teammates.

CONCLUSIONS

We presented a comparative framework to compare analysis techniques for information requirement determination. We also conducted an experiment to compare IDEFo and DFD modeling techniques using the framework. With a limited sample, it is difficult to make any definitive statements on the results. Based upon our experiment, however, it seems that DFD is easier to learn and easier to use. It is not clear which technique produces a better result. Further experiments are necessary to determine whether any of these techniques will produce a better model.

REFERENCES


Additional Key Words and Phrases: Framework for comparing analysis techniques, information requirements, systems analysis, design, systems analysis techniques

Received 9/87; accepted 12/87

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