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System Design Quality and Efficiency of System Analysts: An Automated CASE Tool Versus a Manual Method

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SYSTEM DESIGN QUALITY AND EFFICIENCY OF SYSTEM ANALYSTS:
AN AUTOMATED CASE TOOL VERSUS A MANUAL METHOD

by

Satomi H. Sugishita

A thesis submitted to the
College of Computing Sciences and Engineering
in partial fulfillment of the requirements for the degree of

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COLLEGE OF COMPUTING SCIENCES AND ENGINEERING

December, 1992
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ACKNOWLEDGMENT

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Table 11: Analysis of Variance: Number of Syntactic Errors .................... 23
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The purpose of the current research study is to find out if CASE tools help to increase the software design quality and efficiency of system analysts and designers when they modify a system design document. Results of the experimental data analysis show that only the experience level of subjects had an effect on quality of their work. Results indicated that the design methods, either CASE tools or manual, do not have a significant effect on quality of the modification task nor the efficiency of system analysts and designers.
1.1 System Design Error and Their Cost

An error which occurs in the early stages of the Systems Development Life Cycle (SDLC) costs much more than an error which occurs in the later stages. In the worst case, an early error could be propagated through the entire system if someone did not find it soon after it was made. One study done in 1980 showed that 64 percent of software errors arise during the analysis and design phases [cf. Suydam87]. Suydam also mentions a 1984 study from Hughes Aircraft which showed that error detection at the requirement analysis phase dramatically reduced the cost of correcting errors. According to Boehm, late corrections involve a much more formal change approval and control process, and more extensive activities to revalidate the corrections than corrections which need to be made early in the life cycle. These factors combine to make an error in a large project 100 times more expensive to correct in the maintenance phase than in the requirement phase [Boehm81]. High quality analysis and design work save unnecessary costs and improve the productivity of the system analysts and designers. Any change to the system during development and maintenance
cycles is, however, an obstacle to the quality of the system.

All systems are evolutional [Lehman83]. Though there may be defects introduced when changing a system, it is impossible to have a system without any change since system development is an iterative process. A system design document will be used repeatedly for maintaining a system and should be updated until the system is discontinued. There are two possible reasons that could cause system analysts and designers to make errors when they change a design. One is that system representations are hard to update. The other reason is that manual cross-checking within a large and complex system is very difficult to accomplish [Boehm84].

1.2 Graphic Representation and Errors

System design documents usually contain graphic representations. It is generally acknowledged that pictures can represent more information than text [Raeder85]. A research study shows that the more complex the system, the better people comprehend by graphic representations [Scanlan89]. Graphic representation, however, presents a significant obstacle; it is hard to update. Manually developed data flow diagrams (DFDs), for example, are difficult to modify and are seldom maintained [Chikofsky88]. A study by Wallace shows that the graphic-oriented design
representation is harder to modify than the textual-oriented design representation [Wallace90].

1.3 Cross-Checking and Errors

As Martin says, the human brain is very limited in its capacity to handle detail, complexity, and extensive cross-checking without error [Martin88b]. Even though system analysts or designers could check completeness and consistency of a system manually, the productivity would be terribly low. Deletion of one item from a database, for example, will cause changes in user input screens, transaction files, output reports, and processes. When system analysts or designers change the design of a large, complex system, the data flow diagram must be updated, the data dictionary changed, and any code design modified. It is beyond their memory capability to deal with all information in the system domain.

1.4 CASE Technology

Boehm mentions that a major motivation for improving software productivity is that software costs are large and growing larger [Boehm87]. In the US Air Force, the needed software system functionality is increasing at the rate of 25 percent per year [cf. Polack90]. While the demand for software systems is growing at an annual compound rate of 12
percent, the personnel available to develop software is
growing at only 4 percent annually [Case86]. Most
organizations have a large backlog of software systems
waiting to be developed. They cannot change systems fast
enough to meet changing user requirements [McClure89].

Luqi says that computer assistance is essential for
effective and reliable evolution of large and complex
systems because their representations and evolution
histories are too complex for unaided human understanding
[Luqi90]. Boehm also says that automation extends the power
of cross-referencing [Boehm84]. To increase the system
software quality and the efficiency of the system
developers, CASE (Computer Aided Software Engineering)
technology was introduced in the early 1980’s. It became
popular during the mid-1980’s [McClure89] [Schindler90].

Traditional software technology is separated into tools and
methodologies. CASE proposed to provide a set of well-
integrated, labor-saving tools, linking traditional tools
and methodologies, in order to automate all phases of the
software life cycle. CASE technology is a combination of
software tools and methodologies such as structured
analysis, design, and programming [McClure89]. For example,
one software tool allows designers to draw design
representations. CASE provides computerized support of
software development methods. In the system design phase,
CASE methods include a graphical notation along with
procedures that validate that a design is correct, complete, and consistent with design rules [Wasserman88]. It may be that CASE can help system developers to change systems by supporting easy modification of graphic design representations and cross-checking functions.

CASE technology is believed to increase the quality of software systems and the efficiency of system developers. Case [Case86] says there are three major advantages to implementing CASE technology: improving software quality, increasing developers’ efficiency, and increasing management control. Research indicates that speed of development and improved accuracy and quality are the most important reasons for acquiring CASE tools for MIS executives [Burkhard89]. Since most CASE tools have been introduced only recently, solid quantitative data is rarely available to show that a CASE environment will generate productivity increases [Lempp89]. Studies by Lempp [Lempp89] and Yellen [Yellen90] are examples of studies which examine quantitative data on the use of CASE tools. The focus of this paper is: 1) to examine the quality of the design documentation and the efficiency of system analysts and designers when they modify a system design using a CASE tool or by hand, and 2) to perform the same comparison with subjects of different experience levels.
Chapter 2
SUMMARY OF PREVIOUS STUDIES

Three studies related to the current research are discussed below. They were reported by Wallace, Lempp, and Yellen. Wallace’s study shows graphic-oriented design representation is harder to update than textually-oriented design. Lempp studied productivity of software system developers when CASE tools were employed. Yellen employed an experimental study to examine the productivity of system analysts using a CASE tool or by hand.

2.1 Wallace’s Study

Wallace and Solano [Wallace90] compared graphic-oriented design representation and textually-oriented design representation for an accurate modification of design documents and preference by subjects. All design representations were modified by hand with no computer assistance. They used students, novices, as subjects. All subjects were given three computationally equivalent problem designs and were asked to correct bugs placed in the designs. The results show that subjects performed more accurately with pseudocode than with the graphical representation. Except for those who had little experience,
subjects also preferred the textual representation, possibly because the textual representation was easier to modify.

### 2.2 Lempp's Study

Lempp's study was a historical, survey type of research which obtained data from two areas: the economic aspect of the CASE environment, and the human aspect with CASE tools [Lempp90]. The survey was based on mailed questionnaires which were completed during an on-site interview. Projects surveyed were actual medium-size to large-scale projects which were developed with the support of the CASE environment, EPOS. More than 80 percent of the subjects had at least two years experience in the use of CASE tools. Survey results show that greatest savings seemed to be in the subsequent maintenance. Other interesting findings are as follows:

1. Net savings by the use of CASE technology was about 9 percent over the entire development period.
2. The CASE environment made the conceptual design phase activities harder.
3. There was an increase in expenditures during the early stages of the projects: requirement definition, conceptual design, feasibility study, and system design.
4. The perceived benefits tended to be concentrated in the later phases of a project.
5. The greatest benefits were perceived to be in the area of project management and control.

6. The number of specification and design errors decreased 69.2 percent.

Through using CASE technology, there was an increase in expenditure in the early phases of the projects due mainly to two factors: the additional work of inputting textual information into the database (which has been done only sketchily in the non-CASE environment), and the enforcement of a structured approach which includes more detailed analysis in the beginning.

2.3 Yellen's Study

Yellen's [Yellen90] subjects were students who had completed a minimum of four information systems classes. These subjects were divided into two groups, one using a CASE tool and the other a manual method. Subjects were required to draw data flow diagrams and create data dictionaries (DDs) to represent a system which was described in a textbook narrative. All subjects were allowed 48 hours to complete the task and fifteen minutes to discuss the case with other subjects. The completed data flow diagrams and data dictionaries of the two groups were evaluated to determine the attributes of quality, correctness, completeness, and communicability. The result of his experiment showed that
the work of the CASE tool group was superior to the work of the manual group only in correctness. The CASE tool did not result in the user representing the problem more completely nor did it help the user to better understand the problem.
Chapter 3
EXPERIMENTAL DESIGN

The purpose of this experiment was to extend the previous studies to find out if CASE tools really help system analysts and designers to increase their efficiency and the software quality when they modify a system design in the system development process. The main differences between Yellen’s study and this research are found in subjects and tasks. Yellen used only university students as his subjects where this research used university students as novices and people from the computing industries as experts. Subjects of Yellen’s study designed a new system creating data flow diagrams and data dictionaries. The current study asked subjects to modify an existing design. This thesis extended Yellen’s study to the comparison of different experience levels of subjects and limited the study to the modification of a system design document to find out if CASE tools are effective in improving the quality of a system design and efficiency of system analysts and designers when they modify a system design.
3.1 Methodology

Subjects were asked to modify a system design document, a set of data flow diagrams, according to design change requests. They used either a CASE tool or the traditional manual method to modify the design representation. All subjects were offered the same original design document and the same requirement change request documentation.

Quality was operationally defined as the total number of errors which each subject made. Fewer errors meant better quality. Efficiency was operationally defined as the time required to complete a task. The dependent variables were the overall time to complete the task and the number of errors. The independent variables were the modification technique and the experience level of the subjects. The basic design of the study is given in the following chart:

<table>
<thead>
<tr>
<th>Subject</th>
<th>Method</th>
<th>Manual</th>
<th>CASE Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>novice</td>
<td>time</td>
<td>accuracy</td>
<td>time</td>
</tr>
<tr>
<td>expert</td>
<td>time</td>
<td>accuracy</td>
<td>time</td>
</tr>
</tbody>
</table>

Table 1: Basic Design of the Study

The following demographic information was collected from each subject: age, gender, eyesight, left/right handedness, computer experience by years, data flow diagram experience...
by years, CASE tool experience by years, Excelerator experience by years, and education. Each subject was asked about the ease of the task. The CASE tool group was asked if the CASE tool was helpful, and the manual group was asked if the task would have been easier with an automated tool. A sample of the questionnaire used to gather the demographic data can be found in Appendix C.

The research instruments for this exploratory study were Excelerator by Index Technology for the CASE tool group and a hard copy of the data flow diagrams for the manual group. Excelerator is one of the most commonly used PC-based CASE tools. It is based on data dictionaries with extensive graphical modelling capability and supports networked, multi-user development efforts. It features graphics, analysis tools, screen and report painting, and document production [Gane90] [Oman90]. In this study, it should be noted that Excelerator was used on a stand alone PC.

College students who had an understanding of system analysis and design but did not have more than one year of system analysis and design experience were used as novice subjects. Industry workers who had been involved in system development for more than five years were the subjects for the expert designers group. Each set of subjects was divided into another two sets of subjects: one was the group that would
use a CASE tool, the other would use hard copy design documents.

A set of task documents was prepared before data collection began. It included a general description of the system, data flow diagrams, a data items list, and a requirement change request document. One standard task was performed by all subjects of both the CASE tool group and the manual group. The sample design was adopted from an actual system produced by a local company and modified for use in the current research. The system which was used for this task was an ordering system for a business supply company which included four major processes: entering orders, printing bills, printing the sales report, and maintaining the order file. All of these processes were reflected in a set of data flow diagrams. The system change request document contained six requests: to handle discount prices, to issue bills based on the shipment, to show the branch office name and its phone number on bills, to print the sales report based on the sales file, to show branch office names and customer names on the sales report, and to create back-up files for the order file. A description of this design can be found in Appendix A. A PC, 386/486 machine, with a VGA monitor, was available for the CASE tool group.
Chapter 4
DATA COLLECTION

4.1 Subjects

Forty volunteers (ten per group) participated in this experiment. Of the forty people, twenty novice subjects were either students or recent graduates of the University of North Florida; the twenty expert subjects were from computing industries. All novice subjects had a basic knowledge of data flow diagrams and system analysis and design, but had less than one year of experience. Expert subjects had more than five years of system development experience. In addition, expert subjects in the CASE tool group had more than five years of CASE tool experience. The average age and experience of the subjects are listed in Table 2. Other characteristics of each subject group are shown in Table 3.
Table 2: Average Ages and Years of Experience of Subjects

<table>
<thead>
<tr>
<th>Subject Group</th>
<th>Age Computer</th>
<th>Experience System Analysis</th>
<th>DFDs</th>
<th>CASE Tools</th>
<th>Excelurator</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-Manual</td>
<td>26.7</td>
<td>5.2</td>
<td>0.9</td>
<td>0.4</td>
<td>0.0</td>
</tr>
<tr>
<td>N-CASE</td>
<td>28.1</td>
<td>4.5</td>
<td>0.9</td>
<td>0.6</td>
<td>0.1</td>
</tr>
<tr>
<td>E-Manual</td>
<td>34.7</td>
<td>9.5</td>
<td>8.3</td>
<td>4.1</td>
<td>0.3</td>
</tr>
<tr>
<td>E-CASE</td>
<td>39.0</td>
<td>13.1</td>
<td>10.8</td>
<td>9.4</td>
<td>6.6</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Demographic Information

<table>
<thead>
<tr>
<th>Subject Group</th>
<th>Gender</th>
<th>20/20 Sight</th>
<th>Handedness</th>
<th>Education</th>
<th>Level</th>
<th>Grad. Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>F</td>
<td>R</td>
<td>Y</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>N-Manual</td>
<td>8</td>
<td>2</td>
<td>10</td>
<td>5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>N-CASE</td>
<td>5</td>
<td>5</td>
<td>9</td>
<td>7</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>E-Manual</td>
<td>6</td>
<td>4</td>
<td>8</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>E-CASE</td>
<td>8</td>
<td>2</td>
<td>8</td>
<td>3</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>13</td>
<td>36</td>
<td>12</td>
<td>10</td>
<td>13</td>
</tr>
</tbody>
</table>

4.2 Procedure

Subjects were given written instructions which indicated procedures to follow: they had sixty minutes to complete the task, they should notify the researcher if they finished before the time limit, and they should modify only data flow diagrams. Then they received a set of three kinds of documents: system description, data flow diagrams of the current system, and system change requests. Subjects were directed to familiarize themselves with the current system. Prior to the task, a fifteen minute practice session was
given to the subjects of the CASE tool group to become accustomed to Excelerator. When each subject of the CASE tool group started his/her task, the highest level of data flow diagrams was shown on the monitor. After the task was over, demographic data were collected using questionnaires. The procedure for this experiment was as follows and was done one subject at a time:

CASE tool group:
1. A subject was given fifteen minutes to practice Excelerator using ten steps of a practice session.
2. After finishing the practice session, each subject was given a hard copy of the general information, original design of the system, and the requirement change request document.
3. The subject studied the original design and modified the original design according to the change requirements using Excelerator with a sixty minute limit.
4. When time was over, the subject was asked to end the research task by showing the highest context diagram on the screen.
5. The researcher then collected the hardcopy of the general information, original design, and the change requirements.
6. Each subject was given a questionnaire. The questionnaire contained demographic as well as other questions for additional analysis.
Manual group:
1. Each subject was given a hard copy of the general information, original design of the system, and the requirement change request document.
2. The subject studied the original design and modified the original design, according to the change requirements, on the original data flow diagrams or on blank pieces of paper. A sixty minute time limit was imposed.
3. The researcher then collected the hardcopy of the general information, original design, and the change requirements.
4. Each subject was given a questionnaire. The questionnaire contained demographic as well as other questions for additional analysis.

4.3 Practice Session for CASE Tool Subjects

Subjects of the CASE tool group were given a fifteen minute practice session before starting their tasks using a design unrelated to the test project. The practice session consisted of ten steps to modify data flow diagrams in order to get accustomed to the diagram modification operation using Excelerator. Subjects followed those steps to modify two levels of data flow diagrams. After finishing the ten steps of operations, they were allowed to practice for the rest of the time. The procedure of the practice session and the data flow diagrams is found in Appendix B.
Chapter 5
DATA ANALYSIS

The results of the data analysis consist mainly of three parts. The task completion time is discussed in the first part. The second part deals with the number of errors which each subject made in the task. The third part discusses trends or relationships among the demographic data. Throughout the analysis, significant correlations were defined as having a correlation coefficient greater than or equal to 0.3 and a probability less than 0.05. Statistical Analysis System (SAS), version 5.18 was used for data analysis.

The efficiency of each subject was measured by the time taken to complete the task. Accuracy was analyzed by the total number of both semantic and syntactic errors which each subject made. An error was defined as a change which caused the design not to meet the specification. Logical errors were categorized as semantic errors. Semantic errors, such as lack of the necessary information, wrong functional decomposition, and design errors, were those which did not satisfy user requirements. Errors against the rules of data flow diagrams were counted as syntactic
errors. If one part of the data flow diagram contained more
than one error, it was considered to contain just one error.

The time and the number of errors were analyzed by the type
of user (expert/novice) and by the type of method (CASE
tool/manual). All collected data were cross-correlated to
check for trends or relationships. Five analysis of
variances (ANOVAs) were computed using the experience level
and design modification technique as the independent
variables. First ANOVA used task completion time as a
dependent variable. The dependent variable of the next
ANOVA was number of errors. Two other ANOVAs were computed
using the number of syntactic errors and semantic errors as
dependent variables.

5.1 Task Completion Time

As mentioned above, the efficiency of each subject was
measured by the time required to complete the task. An
analysis of variance (ANOVA) with experience levels and
design methods as independent variables, and with task
completion time as the dependent variable, showed no
significant differences between methods or experience levels
of subjects. Probability of the model was less than 0.3181.
Table 4 and Table 5 list the means and standard deviations
along with the ANOVA summary.
### Table 4: Means and Standard Deviations of Task Completion Time (by Minutes)

<table>
<thead>
<tr>
<th>Experience - Method</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice - Manual</td>
<td>49.700</td>
<td>8.994</td>
</tr>
<tr>
<td>Novice - CASE Tool</td>
<td>51.700</td>
<td>11.842</td>
</tr>
<tr>
<td>Expert - Manual</td>
<td>55.900</td>
<td>5.152</td>
</tr>
<tr>
<td>Expert - CASE Tool</td>
<td>55.000</td>
<td>5.121</td>
</tr>
</tbody>
</table>

Table 5: Analysis of Variance: Task Completion Time

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>249.675</td>
<td>3</td>
<td>83.225</td>
<td>1.22</td>
<td>0.3181</td>
</tr>
<tr>
<td>Experience</td>
<td>225.625</td>
<td>1</td>
<td>225.625</td>
<td>3.29</td>
<td>0.0778</td>
</tr>
<tr>
<td>Method</td>
<td>3.025</td>
<td>1</td>
<td>3.025</td>
<td>0.04</td>
<td>0.5829</td>
</tr>
<tr>
<td>Exper*Method</td>
<td>21.025</td>
<td>1</td>
<td>21.025</td>
<td>0.31</td>
<td>0.8562</td>
</tr>
<tr>
<td>Error</td>
<td>2465.100</td>
<td>36</td>
<td>68.475</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 5.2 Number of Errors

The number of errors was used as a measurement of quality of each subject’s modification performance. An ANOVA was computed with experience levels and design methods as independent variables and the number of errors which each subject made as the dependent variable. The means and standard deviations of numbers of errors are listed in Table 6. The results of the ANOVA are shown in Table 7. These results indicated that the experience levels of these subjects had a significant effect on the number of errors (p < 0.0031), and the probability of the model was less than 0.0129; however the method aspect was not significant. Experts made significantly fewer errors than did the
novices. The mean number of errors for the experts was 3.05 while the mean number of errors for the novices was 6.25.

<table>
<thead>
<tr>
<th>Experience - Method</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice - Manual</td>
<td>5.800</td>
<td>4.638</td>
</tr>
<tr>
<td>Novice - CASE Tool</td>
<td>6.700</td>
<td>2.111</td>
</tr>
<tr>
<td>Expert - Manual</td>
<td>1.900</td>
<td>1.287</td>
</tr>
<tr>
<td>Expert - CASE Tool</td>
<td>4.200</td>
<td>2.529</td>
</tr>
</tbody>
</table>

Table 6: Means and Standard Deviations of Number of Errors

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>107.275</td>
<td>3</td>
<td>35.758</td>
<td>4.13</td>
<td>0.0129</td>
</tr>
<tr>
<td>Experience</td>
<td>87.025</td>
<td>1</td>
<td>87.025</td>
<td>10.05</td>
<td>0.0031</td>
</tr>
<tr>
<td>Method</td>
<td>18.225</td>
<td>1</td>
<td>18.225</td>
<td>2.10</td>
<td>0.1555</td>
</tr>
<tr>
<td>Exper*Method</td>
<td>2.025</td>
<td>1</td>
<td>2.025</td>
<td>0.23</td>
<td>0.6316</td>
</tr>
<tr>
<td>Error</td>
<td>311.700</td>
<td>36</td>
<td>8.658</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Analysis of Variance: Number of Errors

5.2.1 Semantic Errors

The errors which each subject made in the task were subdivided into semantic and syntactic errors. An ANOVA was employed using experience levels and design methods as independent variables and the number of semantic errors as the dependent variable. The ANOVA of variance indicated that only experience levels of subjects significantly affected the number of semantic errors. Here, again, expert subjects made fewer semantic errors than novice did. The mean number of semantic errors for the novices was 5.4 and
that for the experts was 3.04. The results of the ANOVA and the means and the standard deviations are listed in Table 8 and 9.

<table>
<thead>
<tr>
<th>Experience - Method</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice - Manual</td>
<td>5.200</td>
<td>4.022</td>
</tr>
<tr>
<td>Novice - CASE Tool</td>
<td>5.600</td>
<td>1.713</td>
</tr>
<tr>
<td>Expert - Manual</td>
<td>2.200</td>
<td>1.687</td>
</tr>
<tr>
<td>Expert - CASE Tool</td>
<td>3.200</td>
<td>1.687</td>
</tr>
</tbody>
</table>

Table 8: Means and Standard Deviations of Number of Semantic Errors

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>90.475</td>
<td>3</td>
<td>30.158</td>
<td>5.11</td>
<td>0.0040</td>
</tr>
<tr>
<td>Experience</td>
<td>81.225</td>
<td>1</td>
<td>81.225</td>
<td>13.76</td>
<td>0.0007</td>
</tr>
<tr>
<td>Method</td>
<td>7.225</td>
<td>1</td>
<td>7.225</td>
<td>1.22</td>
<td>0.2759</td>
</tr>
<tr>
<td>Exper*Method</td>
<td>2.025</td>
<td>1</td>
<td>2.025</td>
<td>0.34</td>
<td>0.5617</td>
</tr>
<tr>
<td>Error</td>
<td>212.500</td>
<td>36</td>
<td>5.903</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9: Analysis of Variance: Number of Semantic Errors

5.2.2 Syntactic Errors

Syntactic error means and standard deviations are shown in Table 10. The results of an ANOVA with experience levels and design methods as independent variables and the number of syntactic errors as a dependent variable are presented in Table 11. Though no significant results were found in any category, subjects who did their task using a CASE tool tended to make more syntactic errors than subjects who modified data flow diagrams manually. The mean numbers of
syntactic errors for the experts and for the novices were the same, 0.85, while the mean number of syntactic errors for the manual group was 0.65 and 1.05 for the CASE tool group.

<table>
<thead>
<tr>
<th>Experience - Method</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novice - Manual</td>
<td>0.60</td>
<td>1.26</td>
</tr>
<tr>
<td>Novice - CASE Tool</td>
<td>1.10</td>
<td>1.10</td>
</tr>
<tr>
<td>Expert - Manual</td>
<td>0.70</td>
<td>0.82</td>
</tr>
<tr>
<td>Expert - CASE Tool</td>
<td>1.00</td>
<td>1.05</td>
</tr>
</tbody>
</table>

Table 10: Means and Standard Deviations of Number of Syntactic Errors

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>2.60</td>
<td>3</td>
<td>0.867</td>
<td>0.78</td>
<td>0.5108</td>
</tr>
<tr>
<td>Experience</td>
<td>0.10</td>
<td>1</td>
<td>0.100</td>
<td>0.09</td>
<td>0.7514</td>
</tr>
<tr>
<td>Method</td>
<td>2.50</td>
<td>1</td>
<td>2.500</td>
<td>2.26</td>
<td>0.1414</td>
</tr>
<tr>
<td>Exper*Method</td>
<td>0.00</td>
<td>1</td>
<td>0.000</td>
<td>0.00</td>
<td>1.0000</td>
</tr>
<tr>
<td>Error</td>
<td>39.80</td>
<td>36</td>
<td>1.102</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 11: Analysis of Variance: Number of Syntactic Errors

5.3 Demographics

The following demographic data was collected from all subjects after they completed their task: age, gender, eyesight, left/right handedness, their education level, computer experience by years, system analysis and design experience by years, data flow diagram experience by years, CASE tool experience by years, and Excelerator experience by years. A question about the ease of task was also asked. CASE tool subjects were asked whether the CASE tool helped
in the completion of the task (Question 12), and manual method subjects were asked if automated tools would have helped in the completion of the task (Question 13). Each number of replies to the ease of task (Question 11), question 12, and question 13 is listed in Table 12. Question 11 used the 5-point Likert scale (1 = very easy and 5 = very difficult).

<table>
<thead>
<tr>
<th>Subject Group</th>
<th>Question 11 (Ease of Task)</th>
<th>Question 12 CASE Group</th>
<th>Question 13 Manual Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td>Yes No Unk</td>
<td>Yes No Unk</td>
</tr>
<tr>
<td>N-Manual</td>
<td>0 3 5 2 0</td>
<td>---</td>
<td>8 1 1</td>
</tr>
<tr>
<td>N-CASE</td>
<td>0 1 5 4 0</td>
<td>9 1 0</td>
<td>---</td>
</tr>
<tr>
<td>E-Manual</td>
<td>0 7 3 0 0</td>
<td>---</td>
<td>5 0 5</td>
</tr>
<tr>
<td>E-CASE</td>
<td>4 4 2 0 0</td>
<td>10 0 0</td>
<td>---</td>
</tr>
<tr>
<td>Total</td>
<td>4 15 15 6 0</td>
<td>19 1 0</td>
<td>13 1 6</td>
</tr>
</tbody>
</table>

Table 12: Replies to Question 11, 12, 13 by Number

Several interesting and significant correlations were found. All correlations with more than 0.3 coefficient value and probabilities of less than 0.05 are listed in Appendix D. As expected from the results of ANOVAs, subjects with more experience with computers, system analysis and design, and data flow diagrams made fewer total errors and fewer semantic errors; however, there was no significant correlation coefficient with the syntactic errors. Among the previously listed experiences, system analysis and design experience had the largest correlation coefficient with both total number of errors (r = -0.46754) and the
number of semantic errors \((r = -0.48834)\). Another strong correlation was found between the number of semantic errors and the number of syntactic errors. The more semantic errors were made, the more syntactic errors were also made \((r = 0.32468)\).

Significant correlations were found between ease of task and all the categories of experience: computer, system analysis and design, data flow diagrams, CASE tools, and Excelerator. Correlation coefficients for each relationship are -0.65077, -0.65656, -0.54244, -0.55950, and -0.49494 respectively. Subjects with more experience felt the task was easier. Ease of task had another strong correlation with the education level \((r = -0.43349)\) and age \((r = -0.48375)\).

More experienced subjects in the manual method group were less sure if the task could be accomplished more easily with an automated tool. Computer experience and the answer to the question toward the manual method group (Question 13), "Do you think this task would be done easier with an automated tool?" had correlation coefficient of 0.55212. System analysis and design experience and Question 13 also had significant correlation (correlation coefficient = 0.53170).

Although CASE tools never improved efficiency and quality in this experimental study, all CASE tool subjects except one answered that the CASE tool helped them to complete the
task. Most of novices of the manual method group also thought that the task would have been done easier with an automated tool. Other demographic information which include gender, eyesight, and left/right handedness had no special correlation with other items.
Chapter 6
DISCUSSION

The results of the current research did not show that the choice of design methods had any significant effect on either the task completion time or the number of errors in a design modification task. Only the experience level had a significant effect on the number of errors. The time required to complete the task was not affected by either design methods or experience levels of subjects. Research results indicate two possible reasons that there was not a significant difference between the CASE tool and the manual method:

Reason 1. The task of this experimental study was purposefully limited. In this experimental study, a CASE tool was not used as an integrated tool, but just as a diagram editor. As Perry says, CASE tools must be integrated to cover various phases of system development to gain significant improvements in productivity [Perry87]. CASE technologies have strength when they are used for the whole project development life cycle.

Reason 2. Martin says that current CASE tools require system analysts/designers to become graphic artists. They
have to make many decisions about symbols and layout in a page. A data flow diagram that can be drawn in twenty minutes by the manual method commonly takes an hour or two with an interactive graphics tool [Martin88a]. Several subjects indicated that it was hard to draw a data flow in a desired place. Excelerator requires the user to perform at least four actions in order to move a data flow arrow:

1. Select "MOVE" from the menu.
2. Touch a small box on the data flow in order to move the arrow by means of a mouse.
3. Touch a small square on either end of the arrow which the user desires to move.
4. Draw a line marking the point where he/she wants to make a curve until the arrow reaches the destination.

These actions are not required when people draw data flow diagrams by hand. They simply erase an unnecessary arrow and draw a new one.

There were some interesting relationships found in this experimental research: the number of syntactic errors and design methods, and task completion time and experience levels. Though no significant results were found by the ANOVA with design methods and experience levels as independent variables and the number of errors as the dependent variable, subjects who completed the task using a
CASE tool tended to make more errors than subjects who modified data flow diagrams manually. Excelerator has a function called Data Flow Diagram Verification which examines data flow diagrams to determine if they are free of structural errors. However, it cannot prohibit users from drawing data flow diagrams against the rules if they do not use the function. Some syntactic errors such as overlapped or duplicated figures were seen only on the works of the CASE tool group.

There might be two ways to make fewer syntactic errors when a CASE tool is employed to modify a design document. One is to train and force users to use the verification function when they finish drawing diagrams. The other way is to make the CASE system to be able to verify the document when a user is drawing diagrams. Users of Excelerator have to get out of the diagram editing menu to verify diagrams.

Experience level had no significant effect on task completion time. The average task completion time of expert subjects was three to five minutes longer than the average task completion time of novice subjects. This might be because the experts tended to take more time to check their work. Checking their work may account for a significant portion of the experts' time. Additional research is needed to verify this.
According to a survey done by Software Quality Research Inc. in 1989, CASE tool users experienced as much as a 10 percent decrease in productivity during the first six months after installation of CASE tools and then the productivity gain started from the sixth month [cf. Fried91] [Kemerer92]. Another report says that programmers, analysts, and designers spend an average of 69 hours learning to use CASE tools on their own [Loh89]. The lower productivity of the novice CASE tool group than that of the novice manual method group could be explained by this learning curve. The results of the current research shows, however, no better efficiency or the task quality from expert CASE tool subjects with five or more years of Excelerator experience than expert subjects who did their task by hand. It may be possible to say that CASE tools would never offer better system design quality and efficiency of system analysts or designers even after they get accustomed to using them if CASE tools are applied to a system as small and limited as the task of this experimental study.
A major motivation for improving software productivity is that software costs are growing larger [Boehm87]. The demand for software systems is growing faster than the supply [Case86]. CASE technology was introduced to improve software quality and the efficiency of system developers. It is easy to pick up some survey examples that show CASE tools improve the productivity of those who develop software systems [Burkhard89] [Lempp89] [McClure89]. On the other hand, many low end CASE tools are only diagram editors. The basic findings from the current research suggest CASE tools should not be used just as diagram editors, and should not be applied for a very small and limited system.

7.1 Future Directions

Even though much is expected from CASE tools, few experimental research studies have been done to provide quantitative data comparing the manual method and CASE tools. Most of the available figures which indicate that CASE tools are superior to the manual method are derived from survey type research. More experimental research studies are necessary to verify the efficiency of system
developers and quality of their work when they use CASE tools. There are several ways to extend the current experimental study. Modification of data flow diagrams and entity relationship diagrams would be a good example, since these kinds of tasks require system analysts and designers cross-checking and to access to the data dictionary, in which CASE tools are thought to be superior to the human being [Martin88b].

This research used only accuracy as a quality measurement. Quality of system documents includes extendability, transferability, maintainability, reliability, security, efficiency, and usability [Sneed90]. It is necessary to check the quality of system analysts and designers’ work from these various aspects. Another possible subsequent study would be a multiple modification which asks the subjects to modify data flow diagrams once, then lets them modify the updated data flow diagrams again later. Since it is quite common to modify system documentation several times, maintainability and usability are other important quality measures of diagrams. Multiple modifications by the manual method may make it harder to create a clear diagram than by the CASE tools method.

Another way of expanding this study is to focus on each subject’s behavior while they complete the task. The task completion time might be sub-divided by following three
stages: study time, modification time, and review time. Study time is the period to read and understand the design documentation. The time when a subject actually modifies the design document is categorized as modification time. Review time is the period to check his/her work after the subject has modified a diagram. This kind of research may find out the reason why the expert subjects tended to take more time to complete the task than the novice subjects did.
REFERENCES

[Boehm81]

[Boehm84]

[Boehm87]

[Burkhard89]

[Case86]

[Chikofsky88]

[Fried91]

[Gane90]

[Kemerer92]
[Lempp89]

[Lehman83]

[Loh89]

[Luqi90]

[Martin88a]

[Martin88b]

[McClure89]

[Oman90]

[Perry87]

[Polack90]

[Raeder85]
[Scanlan89]

[Schindler90]

[Sneed90]

[Suydam87]

[Wallace90]

[Wasserman88]

[Yellen90]
Appendix A

THE RESEARCH TASK

This package is based upon a slightly modified version of an actual system which had been used at a local company. It contains three documents: the system description, data flow diagrams of the current system, and system change requests.
The Research Task

This research task is based upon the design of a system which had been used at a local company with some modification.

The Original DFD description

This system was developed for an office product supply company to handle order entry and billing processes. This company had established solid reliability among its customers during fifty years of its history. For long time, it had been possible for them to sell their products without any discount.

This system is called COS system (the Company Ordering System). COS system handles editing order entry data, issue of internal order to the warehouse system (W/H system), printing bills, generating monthly sales report, and maintaining the order file. The detail description is as follows.

1. Order entry

1-1. Editing user input data before it is put in the order file.

* Editing includes alpha/numeric check for all data items.
* Order number must be checked with order file. In case of new order, the same order number should not be in the order file. In case of rental stop order, the same order number must be in the order file.
* Customer number should be in the customer file.
* Product number must be registered in the product file.
* Branch office number should be in the branch office file.

In case of any error, the user input data is not registered in the order file, and an error message should be returned to the user.

1-2. Registering order record

If the input data successfully passed the edit, it will be registered in the order file.
1-3. Issue internal order to the warehouse system.

When order entry is successful, the system will send an internal order to the warehouse system to ship the ordered products.

2. Print out bills and make sales records.

2-1. Print out daily bills and make sales records.

* Bills should be based on the order records. If the purchase/rental date arrives or passes and the order is not billed yet, put all orders together in one bill for a same customer in customer# order.

Following information should be printed on the bill.
- Customer number
- Customer name
- Customer address
- Branch office number
- Bill issue date
  (=current date on the calendar file)
- Product number
- Product name
- Unit price
- Quantity
- Amount for the product
- Total amount to charge
- Pay due date (=bill issue date + 15 days)

following items are for rental orders only
- From date
- To date
  (=last day of the month)

* Every order record except rental stop orders will be written to the sales record when it is billed.

2-2. Print out monthly bills and make sales records.

Monthly bills will be printed on the first day of each month. Rental order on the order file without rental stop order should be selected to issue a monthly bill. All orders for a customer should be combined in a single bill. Information on the bill is the same as the daily bill.

3. Print out the monthly sales report.

Monthly sales report is sorted by branch office and by customer at the last day of each month.

The following information will be put on the report.
- Branch office number
- Customer number
- Sales amount
the amount of all purchase orders and rental orders for the customer
Branch office total
Grand total

4. Maintain the order file.

If the rental stop order comes, then erase the original rental order record. After printing out the monthly sales report, all purchase order records which have been billed can be erased.
Data items

Product record
  product#
  product name
  unit price

Customer record
  customer#
  customer name
  address
    street
    city
    state
    zip
  telephone#

Branch Office record
  branch office#
  branch name
  address
    street
    city
    state
    zip
  telephone#

Order record
  order#
  order type
    * 1 ... purchase order
    * 2 ... rental order
    * 3 ... rental stop order
  customer#
  product#
  quantity
  purchase/rental date
  branch office#
  billed flag
    * "Y" ... billed
    * not "Y" ... not billed

Sales record
  order#
  order type
  customer#
  product#
  quantity
  rental/purchase date
  branch office#
  selling amount

Calendar record
  current date
  last day of the month
System change requirements

This company could not keep pace with the change of the industry's business environment. The competition had been harder. The revenue of this company started to drop rapidly.
The management decided to introduce discount prices. Since COS system was developed before this company started the discount business, clerks at branch offices had to take care of discount orders manually.

Recently the information systems group of this company received system change requirements from system users.

Requirements from branch offices

1. Allow COS system to handle discount orders.
   Whenever branch managers approve, discount prices are applicable for each order. Individual discount approval is required when more than one order are received from the same customer.

2. Issue bills based on shipment.
   Current system issues bills on the purchase/rental date in the order file even if the shipment of products is delayed.
   Branch offices have received complaints from customers about this matter. COS system should print bills when products are shipped from warehouse.

   (MEMO) Mr. Smith who is in charge of W/H system guaranteed that they can offer shipment transaction. Contents must be negotiated with them.

3. Add the branch office name and telephone numbers on bills. This gives customer the phone number to contact whenever they have any questions about the bill they receive.

Requirements from managers

1. Print the sales report based on the sales file.
   Sales amount should be taken from the sales file. Currently the order file is used even though there is the sales file existing.

   (MEMO) This seems to be a system analysis and design bug of the recent modification project. They were required to create the sales file and they just created it and left it unused.
2. Put branch office names and customer names on the sales report. It is easier to use the report with BO names and customer names on it than with just numbers.

Requirements from both branch offices and managers

1. Generate back up files for the order records. Currently once the bill is issued, the order record is deleted at the end of the month. It is impossible to refer back the order record after the record is deleted.
Original Design (DFD ID: 1)
2: Print bills (DFD ID# 4)

user

bills

ORD order file

order recor

order recor

2.1
Print daily bills

ord recor

calen recor

CAL calendar

calen recor

2.2
Print monthly bills

ord recor

calen recor

custo recor

CUS cust file

custo recor

Print recor

Prod recor

PRO Prod file

Prod recor

sales recor

SAL sales file

sales recor

bills
2.1: Print Daily Bills (DFD ID# 5)

- CAL calendar
- CUS cust file
- PRO Prod file
- ORD order file

CAL
  ↓
  calendar

CUS
  ↓
  cust file

PRO
  ↓
  Prod file

ORD
  ↓
  order file

2.1.1 Print daily bills
  ↓
  bill

2.1.2 write on sales file
  ↓
  sales file

user

- 48 -
2.2: Print Monthly Bills (DFD ID# 6)

- CAL: calend
- CUS: cust file
- PRO: Prod file
- ORD: order file

2.2.1: Print monthly bills
- custo recor
- produ recor
- order recor

2.2.2: Write on sales file
- sales recor

bill

user

SAL: sales file
3: Print Sales Report (DFD ID: 7)

ORDER order file
CAL calendar
PRO Prod file

order record

calendar

Print sales report

report

manager
4: Maintain Order File (DFD ID# 8)

CAL | calendar

| calen
| recor

| 4.1
| maintain
| order
| file

| order
| recor

ORD | order file
Appendix B

PRACTICE SESSION FOR CASE TOOL SUBJECTS

This practice session is designed to let subjects get accustomed to using Excelerator to modify existing data flow diagrams.
Practice Session  (15 minutes)

1. Explode a process named "Course Registration System".
2. Add a data store named "student file".
3. Add data flows from P1.0 and P2.0 to the student file.
4. Delete the course file and a data flow from it.
5. Add external entity named "finance" and a data flow labeled "report" from P2.0 to "finance".
6. Select "refresh" in the menu, "other". It redraws the DFD.
7. Return to the upper layer. (Save your work.)
8. Move the process, P0 to somewhere under the student.
9. Save the change.
10. Practice until time is up.
Practice: Course Registration System
Practice: PO CRS
Appendix C

QUESTIONNAIRES

Each subject was asked to answer these questionnaires after he/she finished their task.
Research Questionnaire *** Please answer these questions.

1. Age

2. Gender
   1: Male
   2: Female

3. Is your eye sight 20-20 (either natural or corrected)?
   1: Yes
   2: No

4. Are you right handed or left handed?
   1: Right
   2: Left

5. Your education level
   1: Finished high school
   2: Currently enrolled in undergraduate
   3: Finished college
   4: Currently enrolled in graduate school
   5: Finished graduate school
   6: Other (Please specify.) Major______________

6. Experience of computer (in years)

7. Experience of system analysis and design (in years)

8. Experience of DFDs (in years)

9. Experience of CASE tools (in years). And what kind?
   Experience:
   CASE tools:

10. Experience of Excelerator (in years)

11. Ease of this task
    1: Very easy
    2: Easy
    3: Moderate
    4: Difficult
    5: Very difficult

12. (CASE tool group) Was CASE tool helpful for this task?
    1: Yes
    2: No
    3: I don’t know.

13. (manual method group) Do you think this task would be
    done easier with an automated tool?
    1: Yes
    2: No
    3: I don’t know.

Thank you very much for participating with this research.
Appendix D

LIST OF SIGNIFICANT CORRELATIONS

All demographic data were cross correlated to see trends or relationships among them. Following pages show all correlations which coefficients were greater than or equal to 0.3 and which probabilities were less than 0.05.
<table>
<thead>
<tr>
<th>Correlation</th>
<th>Coefficient</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience Level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* Age</td>
<td>0.65803</td>
<td>0.0001</td>
</tr>
<tr>
<td>* Education</td>
<td>0.56131</td>
<td>0.0002</td>
</tr>
<tr>
<td>* Computer experience</td>
<td>0.66010</td>
<td>0.0001</td>
</tr>
<tr>
<td>* System Analysis and Design Experience</td>
<td>0.88147</td>
<td>0.0001</td>
</tr>
<tr>
<td>* Data Flow Diagram Experience</td>
<td>0.72784</td>
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</tr>
<tr>
<td>* CASE Tools Experience</td>
<td>0.59412</td>
<td>0.0001</td>
</tr>
<tr>
<td>* Excelerator Experience</td>
<td>0.58482</td>
<td>0.0001</td>
</tr>
<tr>
<td>* Ease of Task</td>
<td>-0.60850</td>
<td>0.0001</td>
</tr>
<tr>
<td>* Number of Errors</td>
<td>-0.45575</td>
<td>0.0031</td>
</tr>
<tr>
<td>* Semantic errors</td>
<td>-0.51778</td>
<td>0.0006</td>
</tr>
<tr>
<td>Design Method</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* Data Flow Diagram Experience</td>
<td>0.32025</td>
<td>0.0439</td>
</tr>
<tr>
<td>* CASE Tools Experience</td>
<td>0.55917</td>
<td>0.0002</td>
</tr>
<tr>
<td>* Excelerator Experience</td>
<td>0.56465</td>
<td>0.0003</td>
</tr>
<tr>
<td>Age</td>
<td></td>
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Satomi H. Sugishita graduated from Senshu University, Tokyo, Japan in 1983 with a Bachelor of Arts degree in Literature. She expects to receive a Master of Science in Computer and Information Sciences from the University of North Florida in August, 1992. She is a member of Upsilon Pi Epsilon. Dr. Layne Wallace of the University of North Florida is serving as Satomi's thesis advisor.

Prior to the graduate study, Satomi had worked as an information systems engineer at IBM Japan for seven years. She has experience in various environments, PL/I, COBOL, C, Basic, SIMSCRIPT, MVS, VM, IMS DB/DC, DB2 and various application software. Her major interest is the project management and the quality control.

Satomi is a native of Tokyo, Japan who moved to the United States in 1990. She enjoys Florida's lovely weather, playing tennis and swimming. Satomi has been married for two years.