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The Impact of Documentation Toward Electrical Mean Repair Time of CNC Machines

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THE IMPACT OF DOCUMENTATION TOWARD ELECTRICAL MEAN REPAIR TIME OF CNC MACHINES

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INTRODUCTION

Just in time (JIT) manufacturing has put maintenance under the gun. Poor up time and response time erode the competitive advantage JIT offers (Baldwin, 1994c). Numerous maintenance methodologies have been advanced to prevent equipment break down (Deutsch, 1993 and John Deere, 1994). Included are preventive maintenance, predictive maintenance, reliability maintenance, and operator maintenance. Preventive maintenance maintains equipment on a regular basis, thereby preventing catastrophic failure. Predictive maintenance monitors and predicts failure in time to schedule repair. Reliability maintenance tracks failures and engineers permanent solutions to problem prone equipment. Operator maintenance assures proper running maintenance--lubrication, cleaning and chip removal, for example--by making the operator the "owner," responsible for doing basic maintenance while ordering and overseeing more detailed repair.

However, the best of these maintenance methodologies only reduce failures. Equipment will break down (Hegland, 1981). When equipment breaks down three key elements determine repair time; (1) the tools available to determine the cause of the downtime or what is broken, (2) the tools available to affect the repair and (3) spare parts availability. Determining the cause of a breakdown hinges on trained and experienced personnel and effective documentation. Kearney (1992) found the best maintenance strategies did not use exclusive new maintenance technologies, but they did incorporate the basics very well. Nevertheless, effective maintenance documentation is so basic that it is often overlooked as a source for maintenance improvement. This is true, despite the fact that equipment is becoming more complex. The demands of JIT coupled with today's business paradigm of doing more with less (Baldwin, 1994a and 1994b) make effective maintenance documentation even more critical.

Statement of the Problem

There is a natural inclination to ask for everything (Hegland, 1981). When it comes to documentation, maintenance technicians are no exception. The problem of this study was to determine if documentation is related to timely problem analysis and repair. Is there any relationship between the existence of documentation and the use of documentation attributes or aids and timely CNC machine tool maintenance?

Statement of the Purpose

This study was designed to be used to:

1. foster an awareness of the criticality of having adequate machine tool documentation,
2. determine the level of documentation of a select number of critical CNC machines at John Deere,
3. provide input for the improvement of machine tool documentation specifications,
4. provide input to the design of a "new machine tool" documentation review process, and
5. to determine if the level of documentation significantly impacts electrical maintenance performance.

Today, maintenance organizations need to do more with less resources (Baldwin, 1994a). Utilization of proven documentation techniques is one way to meet that need. Documentation needs to provide the level of detail required for the job at hand as quickly as possible. The required detail is a moving target influenced by the situation, the experience of the technician on a given machine and the technician's general CNC knowledge. This study identified documentation levels and attributes and determined if they exist in a group of CNC machines. Page numbers, an index, adjustment procedures and on-line troubleshooting aids are examples of documentation attributes.

Significance of the Study

Complete documentation for a complex CNC machine tool should be very extensive. Documentation is not just printed or published communication, but any means of communicating machine status as well. This includes operator station indicating lights, internal status lights on circuit boards (hidden from view of the operator but available to the maintenance technician), and error and instructional messages to the operator, programmer and technician. Table 1 lists documentation commonly supplied with CNC machines. Unfortunately there is no standard for presenting this information. While some documentation schemes provide separate manuals for everything, others combine everything together.

Documentation impacts a technician's understanding and thereby his or her ability to react in a timely fashion to a machine's repair needs. Equipment in a poor state of repair is a drain on the bottom line. Ensuring availability of adequate documentation should reduce maintenance costs, improve machine availability for productive use and improve profits.

Time Essence

So what is wrong with today's documentation? The answer is, the process of using documentation wastes too much valuable time! The only other alternative is to ignore the documentation, which is even less efficient. Nevertheless, this is a strategy many technicians follow. The maintenance manuals are consulted last because experience has shown that empirical troubleshooting methods are often quicker. Stroessler, Clarke, Martin, and Grimm (1970) in a study of U.S. Navy manuals reported that finding maintenance information was a problem for the majority of those interviewed.

The following is an example of an actual situation that occurred with one of the CNC machine tools in the population of this study. The story begins with a problem the spindle

Table 1

Documentation Commonly Supplied with CNC Machines

Axis drive manual(s)	Lubrication system manual.
Control maintenance manual(s)	Machine installation manual
Control programming manual	Machine maintenance manual
Diagnostics manual	Machine parts manual
Diagnostics[a]	Machine programming manual
Display of I/O bit tables[a]	Operator control manual
Display of internal bit/word tables[a]	Operator machine manual
Electrical schematic	Operator messages display[a]
Electronics hardware status lights[a]	Operator station indicating lights[a]
Hydraulic schematic	Pneumatic schematic
Ladder (logic) diagram (hard copy)	Programmer messages display[a]
Ladder (logic) diagram display[a]	Spindle drive manual

Note: From empirical observations of CNC machines and their documentation at John Deere Waterloo Works.

[a]Internal - built into the machine hardware or software. In most cases must be supplemented by printed documentation to derive maximum benefit.

developed. Consulting the spindle drive manual proved useless. The manual provided with the machine was for a different spindle drive; a drive that the machine vendor had used in the past. Empirical troubleshooting took over, a blown fuse was found and the fuse was replaced. Also the correct manual was ordered from the machine vendor. The story resumes with the next spindle problem. Armed with the correct manual, the electrician set out to determine why another fuse had blown. However, the new manual was applicable to two similar drives made by the same manufacturer. Trying to determine which of these drives was actually installed; the electrician consulted the electrical schematic. Three separate prints were found; one for three different drives from three different manufacturers, but none that represented the drive actually installed!

This points out a common problem; i.e., missing documentation or generic documentation. Many machine manufacturers provide too much in the form of generic documentation. If this practice was avoided, time spent sorting out which generic documentation elements are applicable could be avoided. It is much more efficient to have the manufacturer sort and provide only applicable documentation, than to have the service technician sort every time while a machine is down.

When asked what would minimize downtime, twenty-two percent of respondents suggested better maintenance documentation as their first choice in a 1981 study (Hegland). Suggestions included troubleshooting guides, illustrations, flow charts, and self-diagnostics. Today's documentation, should be better since the advent of desktop publishing ("Creating First Class Repair Manuals," 1988). Photos and drawing can be included with textual instruction. Page numbers, an index, and a table of contents can be generated and spelling checked, all automatically (User's Guide Microsoft Word, 1993). Also a standardized format and style is readily automated. Manually generating manuals is no longer an option (von Koenigseck, Irvin, and Irvin, 1991). A 1990 Department of Defense mandate requires that all technical data be computer generated (von Koenigseck et al.).

On-line Documentation

On-line documentation utilizes the CNC control's computer to determine the informational needs of the operator, programmer, and maintenance technician in real-time. The information is typically displayed on a CRT. The advantage of on-line documentation, according to Cunningham and Cohen (1984), is that it can keep pace with the speed of the machine. Traditional technical manuals are time consuming, difficult, and do not target the intended audience well. While these techniques are very useful, they typically are not inclusive enough to take the place of traditional manuals.

Research Questions

This research project was designed to answer four questions:

1. What level of printed and on-line documentation exists for a group of CNC machines at John Deere?
2. Is there a relationship between the documentation level and electrical mean time to repair (EMRT) these CNC machines?
3. For the documentation that exists, what is the level of documentation attributes?
4. Is there a relationship between these documentation attributes and electrical mean time to repair (EMRT) these CNC machines?

Delimitations

The following are delimitations of this study:

1. The population of this study was delimited to critical CNC machine tools maintained by two of the four maintenance areas at the Westfield Avenue Site (WAS) of John Deere Waterloo Works. These are the CNC machines that are among a list of equipment identified by

production as being critical. It is a dynamic list, which stood at 139 CNC machines on February 6, 1995.

2. The study was delimited to repair during calendar year 1994 by maintenance electricians who service CNC machines in the population. Repair of spare components was specifically excluded from the study.
3. The study was delimited to documentation routinely used by maintenance electricians. This included axis drive, spindle drive, CNC control maintenance, operation, part programming, machine service, and machine parts documentation. Electrical prints and machine software logic documentation were also included. Other documentation was excluded, for example, tooling and lubrication documentation.

Definitions of Terms

The following definitions are unique to this study or provided for clarity.

Attribute	Documentation technique or aid whose existence can be determined by observation. This ordinal data is applicable to documentation for a machine sub-assembly or an entire given machine. Examples include page numbers, alignment procedures, table of contents and on-line diagnostics. Some are generic and some unique to the machine tool industry. Some elements are hard copy and exist on paper. Other elements are "on-line" and exist only with the execution of machine executive software. Real-time display of machine logic is an example of the latter.
Attribute level	This is a measure of availability of an attribute or group of attributes.
Characteristic	Qualitative assessments of documentation whose existence can not be readily determined by observation alone. Requires a specially designed instrument.

Some examples are accuracy, detail, and effectiveness. This was not a part of this study.

CNC Computer numerical control is a method for dimensionally controlling the movement of a machine tool and for controlling its sequence.

Component level repair

Repair done to spare components. The timeliness of component repair is not as great as that of the machine itself as production continues during this repair activity. Because the level of component repair varies by machine, it was not a part of this study.

Documentation level

This is a measure of how complete documentation is for the major parts of a typical CNC. This may be in separate manuals provided by the original equipment manufacturer or provided by the machine vendor in a manual or a set of manuals. This is ordinal data.

Documentation manual

This is a custom term for a scheme for classifying documentation by functional area. These functional areas included axis drive maintenance, spindle drive maintenance, CNC control maintenance, operation, part programming, machine service, and machine parts. In this study a documentation manual is a virtual manual. It can exist as a physical manual by the same functional name, but it may consist of one or more physical manuals with different names. A specific documentation manual is defined in terms of documentation attributes, for that specific manual. Documentation manual data was reduced to ordinal data by a simple yes or no observation response as to its existence.

Electrical mean time to repair or electrical mean repair time (EMRT)

Average time per work order spent on electrical maintenance repair activities for a given machine in the population. Calculated from historical labor data recorded in a maintenance database (MAIN). Does not include response time, preventive maintenance, predictive maintenance, or component level repair.

MAIN — Maintenance, Analysis and Information Network is a John Deere proprietary maintenance database.

Manual — Unless otherwise noted manual refers to functional area documentation manual in this study. See documentation manual.

Response time — Maintenance downtime waiting for an available technician or waiting for parts.

Chapter II

REVIEW OF RELATED LITERATURE

Two research studies related to this research. The first study dealt with technical documentation the same topic as this research. The second study investigated factors for adoption of CNC technology in three regions of the United Kingdom. Although this adoption study and this research on the impact of documentation on repair-time both dealt with CNC machines, the usefulness for this research was the adoption study's methodology. Chi-square statistical methods for determining differences between groups were used both by this adoption study and by this documentation impact study. Examples of useful and distractive or disruptive documentation entities were also reviewed.

Use of U. S. Navy Manuals

"Human Factors in the Design and Utilization of Electronics Maintenance Information" (Stroessler, et al., 1970) is a recommendation report of a study by the U. S. Navy Electronics Laboratory (NEL). This study of Navy maintenance manuals focused on human factors. For this study, interviewing techniques for determining human behavior were combined with a background of maintenance information and insight into the Navy's problems of training and utilizing electronic maintenance personnel.

Problem

Determining who uses Navy manuals, how they are used, for what tasks, and to what extent the manuals were adequate for those who used them was the purpose for this NEL study. The problem also included determining the functional relationship between maintenance manuals and other maintenance information. Manuals are only one piece of maintenance. Other factors are inter-related and therefore, manuals can not be studied in isolation. The most important of these related factors, which this study was sensitive to, are: (1) system complexity dictates to a large extent the complexity of a manual, (2) maintainability features such as diagnostic indicators increase the complexity of a manual, (3) the environment, such as the lighting available where the manual will be used and storage space available for storing it, influences physical characteristics of the manual, (4) tools and instruments available will influence the recommendation of what to use, (5) administration policy affects personnel turn-over rates and formation of technical policy, (6) training determines if maintenance personnel have the necessary basic skills and knowledge to be effective, and (7) distribution channels for updated maintenance information affect its usefulness.

Methods

This NEL study collected information from a field survey designed by two psychologists and two Chief Sonarmen. The experience of the Chiefs provided insight into problems and provided technical expertise. Interview questions were designed to meet two criteria: (1) questions would solicit similar experiences from a number of subjects such that results could be tabulated and compared and (2) questions would stimulate the subjects to remember and discuss their pertinent experience. Research reports, general literature and the practical experience of the Chief Sonarmen provided input into a set of questions, which were field-tested. From this a final set of 21 questions was developed. Many questions had sub-questions. Interview subjects were selected to represent a cross section of the Navy. A total of 216 people were interviewed, 135 Navy personnel and 81 civilians. Two teams, each comprised of a psychologist and a Chief Sonarman, conducted the interviews. The average time for each interview was 90 minutes.

Results

The following are the major results of the study:

1. Technical manuals should meet the needs of users ranging from third class Navy technicians with minimum training and experience to civilian electronic engineers.

2. Technical manuals are used for more than just repair. They are used to develop preventive maintenance procedures, to measure and adjust for peak performance, to facilitate installation, to design new equipment and to combine equipment into systems. They are also used by supply departments and for developing training.
3. Schematics and alignment, adjustment, and calibration information are the most widely used parts of technical manuals. Also block-diagrams, parts lists, theory of operation, installation procedures and installation drawings are often used.
4. Improvements and simplifications of technical manuals would increase the efficiency of Navy maintenance personnel. This in turn would lessen the reliance on civilian engineers for reducing the maintenance backlog. Separating information for each major maintenance task into separate manuals could reduce complexity.
5. Different functional groups perform different maintenance tasks. Separate manuals for preventive and corrective maintenance are needed. Also a separate manual for planning, design and installation is needed.
6. Improved organization and indexing are needed to facilitate finding information in the technical manuals. More time is typically spent searching for information than using the information once it is found. Present trouble-shooting guides are inadequate and not often used. Improved aids are needed.
7. Supplemental information is inadequate. Navy personnel are not provided updated information in a timely manner compared to civilians, which are provided information directly from their parent company.

<u>Recommendations</u>

The following summarizes the recommendations made:

1. Consider training to better familiarize technicians with the contents and organization of Navy technical manuals.
2. Develop a prototype installation manual, a prototype operation and preventive maintenance manual and a prototype corrective maintenance manual. Evaluate the functionality of each manual in actual use conditions.
3. Develop and evaluate an experimental corrective maintenance manual that incorporates the most promising of experimental attempts to rearrange and clarify information for better comprehension and utility.
4. Develop a loose-leaf book that incorporates supplementary maintenance data on equipment for a particular system. Also, develop a procedure for forwarding updates directly to the maintenance personnel responsible for the system.
5. Develop improved methods for correcting information in technical manuals and for making field changes to equipment.
6. Further investigate communications problems and set-up a system for better exchange of information between shipyard, ship, school, and the Bureau of Ships personnel.
7. Study the conditions surrounding the actual writing of technical manuals in order to provide better and more uniform manuals.

Regional Adoption of CNC Machine Tools

O'Farrell and Oakey (1992) in "Regional variations in the adoption of computer numerically controlled machine tools by small engineering firms: a multivariate analysis" investigates factors for adoption of CNC technology in three regions of the United Kingdom. The advantages of CNC are its consistent and accurate production, its reduction in machine setup and fixturing, and its flexibility. Also, parts can be cut that are too complex to be produced on conventional machines.

Problem

Many small engineering shops have considered implementing CNC technology. The decision to adopt this technology depends of many factors including size, growth rate, age of the facilities, potential profitability, types of markets served, and regional location, among others. The purpose of this study was to investigate those factors that determine the adoption of CNC machines and CNC lathes in particular by small independently owned engineering shops.

Methods

Three industrial regions were investigated: Scotland, South Wales, and South East of England. The study was limited to firms of 200 or less employees that were independently owned and machined metal. Regional government business directories identified firms that appeared to meet the criteria. Surveys were mailed (in 1989) to a random sample of 2046 firms. After elimination of those respondents that did not meet the selection criteria, 525 firms responded either to the mail survey or a randomly selected telephone contact of mail survey non-respondents. The survey provided information on size, age, ownership, major production activities, and the type and timing of CNC machinery installation. Adoption rates of all types of CNC machines grouped together, of all types of CNC machines except lathes, and of CNC lathes were each calculated for each of three categories: region, firm size, and firm size within regions. Chi-square tests verified statistical difference of adoption rates within each machine type and category pair. By using a cross-classification scheme, chi-square methods are useful for showing a relationship exists between two variables, but only a limited number of additional variables can be controlled for. To over come this limitation a logistic regression model for the probability of adoption of CNC lathes was developed that allowed for controlling region, age, firm size, and the proportion of production that was sub-contracted by other firms. Also a regression model for the date of first adoption of a CNC lathe was calibrated.

Results and Conclusions

The following is a summary of the results and conclusions made by O'Farrell and Oakey.

Of the 525 firms that returned valid questionnaires 41% adopted some type of CNC machine by 1989: 51% in South East of England, 39% in Scotland, and 26.5 % in Wales. The proportion of firms adopting CNC lathes by 1989 is 29% in South East of England, 27% in Scotland and 17% in Wales. Within each region there is a positive relationship between firm size and the percentage of CNC adoption as well as CNC lathe adoption in particular. Regional differences in adoption rates can in part be attributed to firm-level variables such as size, age, and production level of sub-contracting. However after adjusting for these firm-level attributes, regional adoption variances still exist. Adoption rates for Wales are significantly lower than in Scotland or South East of England. Age and sub-contracting level did not affect the date of first adoption of a CNC lathe, but large firms adopt earlier and Scottish firms adopted approximately two years earlier than those in South East of England and Wales. Regional developmental assistance may have been a factor in early adoption rates in Scotland. The increase in adoption rates in all regions between 1982 and 1984 is due at least in part to developmental assistance available to all regions.

Useful Documentation Entities

One of the most time consuming activities of this research was trying to determine what aspects were documented where. General Electric in their GE 2000 CNC series of manuals nicely provided this information in an appendix in each manual (Industrial Controls Department, 1986). Several other vendors listed the same information in an introductory chapter. Giddings and Lewis (n.d.) published a separate "Machine and Controls Manual List" for the 10VL vertical machining center. This is particularly useful when many manuals are provided or when documentation is grouped in a somewhat unorthodox manner as was the case with the 2000

CNC. Another useful technique was the placement of a note inside machine 9975's CNC control cabinet, which informed the maintenance electrician where the board level prints were kept.

A maintenance manual should to be written to a broad audience. The needs of the novice technician and the experienced technician can differ greatly. The novice needs detailed instructions and explanations without which he or she can not correctly complete the job. An experienced technician needs a checklist of the elements of a task. If given too much detail, an experienced technician often overlooks an important element of the task, which is buried in the fine detail. One method to target the needs of both technicians is using a two-column approach. The complete details, for example a step by step of how to turn the machine on, are written in the right-hand column. In the left column are the major elements of the task; "Start machine" is one example. The experienced technician knows how to turn on the machine; he or she just needs to be told when to do it. This technique leverages the experience of the experienced technician to get the job done quickly, yet still makes it possible for the less experienced technician to complete the task. John Deere uses this two-column approach to write calibration procedures for many production test machines (John Deere Waterloo Works, 1997).

Providing an index is another way to assist a broad audience. An index allows an experienced technician to quickly locate the information he or she needs without distracting others. This could happen if too much detail is referenced in the table of contents (TOC). General Electric's manuals for their GE 2000 CNC provide a very effective index (Industrial Controls Department, 1986).

<u>Distractive Documentation Entities</u>

The organization of the table of contents (TOC) is another key element in finding maintenance information quickly. One fairly common method is to provide a table of contents summary at the conventional front of the manual location and to provide a more detailed TOC at the beginning of each chapter. This is effective if tabs are provided for the chapters. However, this is very slow to use if tabs are omitted. Giddings & Lewis was guilty of this omission on a number of electrical service manuals reviewed. Besides organization and length, the amount of detail provided by the TOC is important. Too short and you risk missing the reference; too long and the reference is also lost. Allen Bradley published a manual for the 8400 CNC with a 24-page table of contents (Control Products, 1988). Searching through this manual's table of contents was very time consuming and probably not very effective.

Chapter III

DESIGN OF THE STUDY

Method

This study gathered data by observation from a stratified sample of the population. The population was stratified by low, medium and high values of the dependent variable, historical electrical mean repair time (EMRT). As EMRT was the basis for stratification, the EMRT was calculated for all machines in the population. Three groups were identified from this EMRT information. A checklist was developed, pilot tested, and used for the data gathering procedure. Documentation for machines in a random sample of the low and high stratified groups was observed. The observed data from the low and high EMRT groups was analyzed to determine if any statistical difference between groups existed.

Population

A number of machines in the Drive Train Division have been identified by production as being critical to their operation. Historical maintenance data is collected at John Deere Waterloo Works in a proprietary database which has been dubbed "Maintenance, Analysis and Information Network" (MAIN). However, machine availability for this select group of critical machines is tracked manually. This process is somewhat laborious, and therefore offers some assurance that only critical machines were included in this study. However, it is noteworthy that the criteria for critical varies somewhat. Some production departments view all CNC equipment as critical, while others use machine load and historical machine availability to determine what is critical. This critical machine dataset was collated with a dataset of CNC machines to identify the CNC machines in the population. These critical CNC machines were located in buildings H, Z, and 1020 at the Westfield Avenue Site of John Deere Waterloo Works.

EMRT Calculation

Only repairs performed by a machine maintenance electrician were utilized for determining the stratification of the population. This restricted the study to first level electrical maintenance activities. For example, component repair did not enter into the calculation of the mean repair time. The MAIN database was queried on February 6, 1995 with the following criteria:

1. CNC machines in the population.
2. Repair categories 4 and 5. (MAIN classifies maintenance activities. This allows differentiating between repairs and other activities such as preventive maintenance. Categories 4 and 5 are respectively utilized for non-downtime repair and for downtime repair.)
3. Calendar year 1994 maintenance activities.
4. Activities performed by maintenance electricians.

The following historical information was retrieved for each machine in the population:

1. Machine number.
2. Machine description.
3. Machine vendor.
4. Year acquired.
5. Production department.
6. Total number of work orders.
7. Minimum hours for any work order. (Work orders represent individual maintenance activities in the database.)
8. Maximum hours for any given work order.
9. Average hours per work order, EMRT.
10. Total repair time.

Population Stratification

Figure 1 shows the EMRT frequency distribution for the population. Table 2 shows descriptive statistics for the population. There were 139 machines in the population. The population minimum, maximum, and average EMRT were respectively 2, 16.4, and 5.54 hours. In order to divide the population, for convenience the population EMRT was assumed to be normal. EMRT endpoints for stratifying the population were determined by the population average plus and minus 0.43 standard deviations of the population (Avg ± 0.43 StdDevP). All machines in the population with an EMRT less than 4.7 hours were assigned to the low EMRT group. All machines in the population with an EMRT inclusively between 4.7 and 6.4 hours were assigned to the middle EMRT group. The remaining machines with an EMRT greater than 6.4 hours were assigned to the high EMRT group. Had EMRT actually been normally distributed, the Avg ± 0.43 StdDevP calculation would have yielded a middle group consisting of exactly the middle one-third of the population and the three stratified groups would have been equal in size. However, the EMRT distribution was skewed to the high end and leptokurtic. This resulted in the 139 machines in the population being stratified into low, middle, and high EMRT groups that were respectively sized at 44, 65, and 30 machines.

Sample Selection

A 50 percent random sample was chosen from each group. Table 3 lists descriptive statistics for the three stratified groups. The low, middle, and high samples consisted of 22, 32, and 15 machines respectively. There were 448, 1387, and 395 electrical work orders, respectively in these sample populations. Average mean hours in each group were 3.74, 5.47, and 9.41 hours respectively.

Figure 1

Frequency Distribution of EMRT

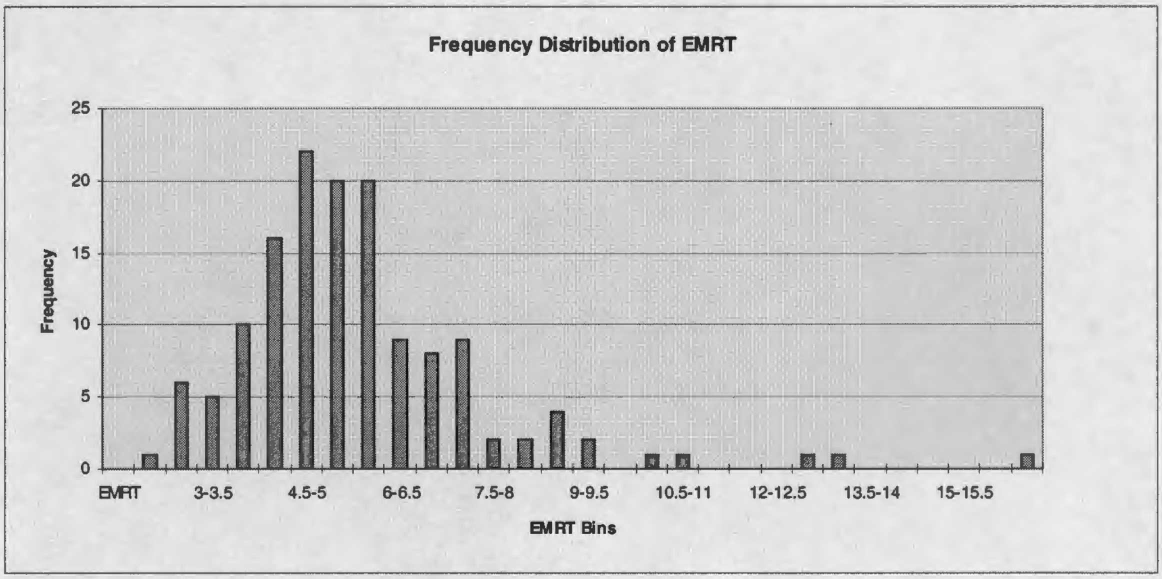

Table 2

Population Descriptive Statistics

EMRT	Value
Minimum	2.00
Maximum	16.40
Mode	4.70
Median	5.30
Average (Mean}	5.54
StdDevP	2.02
Count	139

Table 3

Descriptive Statistics of the Stratified CNC Machine Sample Populations

Statistic	Work Orders	Average Hours Per Machine	Hours
	Low EMRT - Less than 4.7 hours		
Total	448		1748.30
Minimum	1	2.5	2.90
Maximum	58	4.5	226.20
Median	16.5	2.85	63.55
Average (mean)	20.36	3.74	79.47
Stdev	15.00	0.62	61.84
Sample Size	22		
	Medium EMRT - Inclusively between 4.7 and 6.4 hours		
Total	1387		7468.30
Minimum	9	4.7	54.90
Maximum	128	6.4	640.00
Median	32	5.40	179.20
Average (mean)	43.34	5.47	233.38
Stdev	30.80	0.46	159.33
Sample Size	32		

Table 3 continued

Statistic	Work Orders	Average Hours Per Machine	Hours
	High EMRT - Greater than 6.4 hours		
Total	395		3646.50
Minimum	12	6.5	81.60
Maximum	109	16.4	1111.80
Median	17.00	8.90	171.00
Average (mean)	26.33	9.41	243.10
Stdev	25.80	2.82	253.04
Sample Size	15		

Developing and Pilot Testing the Data Gathering Checklist

Accuracy and completeness are perhaps the most important aspects of maintenance documentation. Measuring either of these directly would be very subjective and difficult to timely measure. However, an assumption was made that types or classifications of information located in maintenance manuals could be readily identified and verified by observation. Classifications chosen were (1) adjustment procedures, (2) theory or principles of operation, (3) troubleshooting guides and flow charts, and (4) illustrations and assembly drawings. Also to effectively use documentation, the technician must readily locate required information. A number of documentation locator-aids can facilitate readily finding information. Again it was assumed that the use of these locator-aids could be readily noted by observation. The locator-aids chosen were (1) cross-referencing, (2) an index, (3) page numbers, (4) a table of contents, and (5) non-generic information. The latter is a special locator in that it eases finding information by tailoring information to a specific machine or sub-assembly. This eliminates searching, through a generic document written for a family of similar machines or sub-assemblies, for information for a specific machine or sub-assembly. This study refers to these four classifications and five locator-aids as documentation attributes. Table 4 lists these nine documentation attributes.

Table 4

Pre-Piloted Documentation Attributes

	Documentation Attributes
1	Adjustment procedures
2	Cross referencing
3	Illustrations and/or exploded view assembly drawings
4	Index
5	Non-generic; applicable to only one model
6	Page numbers
7	Table of contents
8	Theory or principles of operation
9	Troubleshooting guides and/or flow charts

By applying applicable documentation attributes from Table 4 to each documentation item listed in Table 1 a pre-piloted checklist was developed. This checklist proved unworkable when pilot tested with machine 3697. Many requested observations were too open-ended; observing for adjustment procedures is one example. Adjustments are many and varied on CNC machines and required an exhaustive search through much documentation to verify if they existed. This produced inconsistent results. Timely observations were impossible with these open-ended observations. Also there was confusion because the naming of documentation in Table 1 from which the original checklist list was derived did not align exactly with the documentation provided for machine 3697. Pilot testing also showed that very little documentation was indexed. However, pilot testing did show that specific information, unless referenced by the table of contents, was very difficult to locate with any consistency.

A second checklist was developed which streamlined the search process. Observations were limited to either a table of contents (TOC) or an index reference to a specific item of information (attribute) in manuals for the following functional areas: (1) axis drive, (2) spindle drive, (3) control maintenance, (4) operation, (5) programming, and (6) service and parts. Also cross-referencing and pagination were only observed for in the electrical prints and logic diagram. And observing for non-generic documentation was limited to the electrical prints.

The original checklist was reduced from three pages to one page. The original checklist included observations for adjustment procedures in the axis drive, control maintenance, machine maintenance and spindle drive manuals. The new check list included observations for TOC or index references to maximum speed adjustments in manuals for the axis and spindle drive functional areas and included an observation for TOC or index references to control adjustments in the manual(s) for the control functional area. This new checklist was pilot-tested by the researcher and proved to be acceptable from a pragmatic timeliness perspective. The final checklist used for this study, checks for specific attributes that should be of interest to the electrical repair technician. This checklist is shown in Figure 2.

Data Gathering Checklist

The data collection checklist served two primary recording purposes, noting the existence of manual(s) for each functional area and noting the existence of attributes. The existence of documentation for functional areas was recorded on the right side of the form. Functional areas included axis drive maintenance, spindle drive maintenance, CNC control maintenance, operation, part programming, machine service, machine parts, electrical prints, and machine logic prints.

Observations of TOC entries for specific attributes in the manuals for a given functional area are recorded on the left side, center section. These functional areas are included: axis drive maintenance, spindle drive maintenance, CNC control maintenance, operation, part programming, machine service, and machine parts. Here, a positive response meant that (1) a documentation attribute was employed and (2) it was referenced by a TOC entry. A negative response implied that (1) the documentation attribute did not exist or (2) reference to it was not found in TOC entries in manual(s) for that functional area. To the right of an attribute TOC entry, an index reference to that attribute was recorded. To the right of this an entry was made for recording if an attribute was not applicable for a particular machine. The main purpose of the latter is for determining the level of on-line documentation.

Each documentation manual was not a unique manual, but merely a classification scheme. The actual information for one manual may be found in one or more manuals. One manual may have provided input for several manuals.

Figure 2

Documentation Checklist

Department ____________
Location ____________
Manufacturer and /or model ______________________________
Control manufacturer and/or model ______________________________
Axis drives manufacturer and/or model ______________________________
Spindle drives manufacturer and/or model ______________________________

Referenced by table of contents	Referenced Yes	Referenced No	Indexed	N/A[1]	Documentation Yes	Documentation No
Axis drive specifications					axis drive	
Axis drive status indicators						
Axis drive maximum speed adjustment						
Axis drive theory or principles of operation						
Axis drive troubleshooting guides and/or flow charts						
Spindle drive specifications					spindle drive	
Spindle drive status indicators						
Spindle drive maximum speed adjustment						
Spindle drive theory or principles of operation						
Spindle drive troubleshooting guides and/or flow charts						
Control status indicators					control maint.	
Control adjustment procedures						
Control theory or principles of operation						
Changing control parameters						
Displaying of internal bit/word tables						
Displaying machine logic						
MDI (manual data input) operation					operation	
Machine homing procedure						
Programming code for inch/metric dimensions					programming	
Programming code for incremental/absolute positioning						
Programming errors						
Tool changer/turret sequence and/or maintenance					service/parts	
Setting (maintenance of) axis home position						
Machine parts manual has exploded view assembly drawings						

Figure 2 Continued

Main electrical prints and logic	Available Yes	Available No	N/A[1]	Documentation Yes	Documentation No
Electrical schematic contacts are cross referenced	____	____	____	electric prints	
Electrical schematic only applicable to installed options or readily marked with installed options	____	____	____	____	____
Electrical schematic is paginated	____	____	____		
Electrical schematic has table of contents	____	____	____	____	____
Logic diagram (hard copy) is paginated	____	____	____	logic prints	
Logic diagram is cross referenced	____	____	____	____	____

[1] Not applicable

Observation of attributes for the electrical prints and the machine logic, including cross-referencing and pagination were recorded in the lower left side of the checklist. To aid the search process entries for recording the machine location, control manufacturer and model, axis drive manufacturer and model, and spindle drive manufacturer and model were provided at the top of the checklist.

Data Collection Procedures

The validity of this study hinged on consistent search, observation, and recording criteria. The checklists were sorted by building in numerical order. The data was collected by one individual with twenty years experience in NC maintenance. A wide interpretation of a subject area was used for searching for table of contents (TOC) references. If necessary, information which a particular TOC entry pointed to, was researched for clarity of the TOC entry itself. To satisfy the existence of a functional area manual(s), documentation must have been found that should provide the requested information for the majority of its attributes. Only documentation located at the machine, machine cell or a maintenance library in the building where the machine was located was considered in existence. There were situations where documentation was pigeon holed someplace else, i.e., in an electrician's private library or some remote shelf or bookcase. But these publications were not considered because so located, they did not provide universal access to every electrician. Documentation that was found at a maintenance library was not limited to the machine or machines it was marked as belonging to. The knowledge of the observer was utilized to determine if a particular manual was applicable. In a few isolated situations the manual itself was researched to make a determination.

The organization of the 1020, H and Z building maintenance libraries differed considerably. The 1020 library was arranged by machine manufacturer, and by machine number. All documentation was grouped together. This library was the easiest to use. The H library was arranged by machine number for documentation also commonly used for mechanical maintenance, such as the operation, service, and spare part manuals. Machine numbers were given fixed locations on the shelves, therefore a number of manuals were not in numerical order due to additional machines being added. The collection of electrical specific manuals in the H library were grouped somewhat by manufacturer in no particular order. These were very difficult to use. The Z building library was also arranged somewhat in alphabetical order by machine or sub-component manufacturer. This was an improvement on the H building electrical library. Many manuals in the H library and even more in the Z library were not marked with the John Deere machine number of the machine they were originally provided for. To maintain consistency, despite the differences in ease of use, an attempt was made to be thorough when searching for a particular manual.

Analysis Procedure

All observations were summed together for each documentation attribute and for each functional area manual to provide observation totals for each sample. Attribute sub-totals by functional area were calculated for each sample. The total of all attributes, except those belonging to the electrical and the logical prints functional areas, was calculated for each sample. Also the total of all observations of functional area manuals was calculated for each sample. The checklist provided for noting that logic print attributes were not applicable if provisions for machine logic were not provided. The number of machines in each sample, which had machine logic provisions, was determined from this data.

For each affirmative and non-affirmative pair of data, Equation 1 shows the calculation used for determining the percentage of the total observations that were affirmative observations.

$$P = \frac{\text{Yes}}{\text{Yes} + \text{No}} \times 100\% \qquad (1)$$

Aggregate or composite totals of both samples were calculated by summing the observation data from each sample. Equation 2 shows the calculation for the composite percentage of total observations that were affirmative.

$$P_C = \frac{\text{Yes}_{\text{Low}} + \text{Yes}_{\text{High}}}{\text{Yes}_{\text{Low}} + \text{No}_{\text{Low}} + \text{Yes}_{\text{High}} + \text{No}_{\text{High}}} \times 100\% \qquad (2)$$

For each attribute and for each functional area manual observed a one degree of freedom chi-square test of independence with a significance level of 0.05 was used to determine statistical difference between sample populations (Kenkel, 1989). This tests the null hypothesis, which says that the observations for the low and high EMRT samples were independent. If the chi-square test statistic (X^2) was greater than 3.84146 (the critical value for $X^2_{0.05}$ for one degree of freedom) the null hypothesis was rejected and the alternate hypothesis was accepted. The alternate hypothesis, which says observations were not independent of their EMRT stratified group, implies observations were dependent with respect to the EMRT group to which they belong. If dependence exists and there was a higher percentage of the data item in the low EMRT sample as compared to the high EMRT sample, the study inferred a positive or desirable relationship exists. For each sub-total and for each total, additional one degree of freedom chi-square test of independence were also calculated.

Chapter IV

REPORT OF THE DOCUMENTATION DATA AND ANALYSIS

Presentation of Data

One machine in the high EMRT sample was sold before data from it could be collected. The documentation for the remaining 14 machines in the high population sample and the 22 machines in the low population sample were observed during the months of February through November in 1995. Tables 5, 6, 7 and 8 summarize the documentation study observations. A summary table for index references to attributes was not provided because there was only one observation noted for the low sample and nine observations noted for the high sample.

Documentation Manual Observations

In Table 5 the total of manuals found for each functional area for each sample are listed and percentages calculated for each. The table is arranged in the same order as the documentation checklist. Also the totals of all the observations of all functional area manuals are shown. The documentation composite total of both samples was 77 percent.

Machine Logic Capability

Table 6 shows the number of machines from each sample, which had machine logic capability. This was either in the form of printed machine logic documentation or in the form of on-line documentation, available within the software execution of the control, or both. In general, machine logic was not available because either the design of the control did not provide for it or the machine manufacturer has made it proprietary. Also shown is the percentage of each sample, which had machine logic capability. The composite of both samples was 81 percent.

Table 5

Documentation by Functional Area Summary

	Observations							
EMRT Stratification	Low			High				
Functional area	Yes	No	%[a]	Yes	No	%[a]	X^2	Result[bc]
Axis drive	20	2	91	8	6	57	5.6438	+ Dep
Spindle drive	18	4	82	8	5	62	1.7593	Indep
Control maintenance	13	9	59	11	3	79	1.4610	Indep
Operation	17	5	77	9	5	64	0.7193	Indep
Programming	15	7	68	11	3	79	0.4603	Indep
Service	18	4	82	10	4	71	0.5343	Indep
Parts	20	2	91	11	3	79	1.0889	Indep
Electric prints	20	2	91	11	3	79	1.0889	Indep
Logic prints	17	4	81	6	3	67	0.7187	Indep
TOTAL	158	39	80	85	35	71	3.6587	Indep
				Low and High				
				Yes	No	%[a]		
COMPOSITE TOTAL				243	74	77		

[a]% = yes / (yes + no)

Table 5 continued

[b] $\alpha = X^2_{0.05} = 3.84146$

[c]+Dep = positive dependence, -Dep = negative dependence, Indep = independent

Table 6

Machine Logic Available in Printed or On-line Form

	Observations							
EMRT Stratification	Low			High				
	Yes	No	%[a]	Yes	No	%[a]	X^2	Result[bc]
Logic availability	21	1	95	8	6	57	8.0171	+ Dep
				Low and High				
				Yes	No	%[a]		
COMPOSITE				29	7	81		

[a]% = yes / (yes + no)

[b] $\alpha = X^2_{0.05} = 3.84146$

[c]+Dep = positive dependence, -Dep = negative dependence, Indep = independent

Documentation Attribute Observations

In Table 7 twenty-four attributes for all functional areas, except for the electrical and logic prints, are summarized. The total of each attribute for each sample is listed and

Table 7

Documentation Attribute Summary

	Observations							
EMRT Stratification	Low			High				
Attribute	Yes	No	%[a]	Yes	No	%[a]	X^2	Result[bc]
Axis drive								
Specifications	13	7	65	5	3	63	0.0156	Indep
Status indicators	13	7	65	5	3	63	0.0156	Indep
Maximum speed adjustment	18	0	100	6	2	75	4.8750	+ Dep
Theory or principles of operation	16	4	80	5	3	63	0.9333	Indep
Troubleshooting guides / chart	17	3	85	7	1	88	0.0292	Indep
Axis drive manual total	77	21	79	28	12	70	1.1470	Indep
Spindle drive								
Specifications	11	7	61	1	7	13	5.2662	+ Dep
Status indicators	13	5	72	2	6	25	5.0599	+ Dep
Maximum speed adjustment	18	0	100	7	1	88	2.3400	Indep
Theory or principles of operation	12	6	67	4	4	50	0.6500	Indep
Troubleshooting guides/ charts	18	0	100	6	2	75	4.8750	+ Dep
Spindle drive manual total	72	18	80	20	20	50	12.0481	+ Dep

Table 7 continued

	Observations							
EMRT Stratification		Low			High			
Attribute	Yes	No	%[a]	Yes	No	%[a]	X^2	Result[bc]
Control								
Status indicators	10	3	77	3	8	27	5.9164	+ Dep
Adjustment procedures	13	1	93	6	5	55	4.9570	+ Dep
Theory or principles of operation	6	7	46	6	5	55	0.1678	Indep
Changing parameters	11	3	79	4	6	40	3.7029	Indep
Display of internal bit/word tables	11	2	85	5	3	63	1.3352	Indep
Display of machine logic	11	2	85	2	2	50	2.0370	Indep
Control manual total	62	18	78	26	29	47	13.1221	+ Dep
Operation								
MDI (manual data input) operation	16	1	94	7	2	78	1.5393	Indep
Machine homing procedure	15	2	88	5	4	56	3.5403	Indep
Operation manual total	31	3	91	12	6	67	4.9400	+ Dep
Programming								
Inch/metric dimensioning code	15	0	100	6	5	55	8.4416	+ Dep
Incremental/absolute positioning	15	0	100	8	3	73	4.6245	+ Dep
Programming errors	6	10	38	2	9	18	1.1667	Indep

Table 7 continued

	Observations							
EMRT Stratification	Low			High				
Attribute	Yes	No	%[a]	Yes	No	%[a]	X^2	Result[bc]
Programming (continued)								
Programming manual total	36	10	78	16	17	48	7.5729	+ Dep
Service and Parts								
Tool changer/turret	15	3	83	5	4	56	2.4107	Indep
Axis home position setting	13	5	72	3	6	33	3.7585	Indep
Exploded view assembly drawings	6	14	30	3	8	27	0.0256	Indep
Service and parts manual total	34	22	61	11	18	38	3.9807	+ Dep
TOTAL	312	92	77	113	102	53	39.6866	+ Dep
				Low and High Combined				
				Yes	No	%[a]		
COMPOSITE TOTAL				425	194	69		

[a]% = yes / (yes + no)

[b] $\alpha = X^2_{0.05} = 3.84146$

[c]+Dep = positive dependence, -Dep = negative dependence, Indep = independent

percentages calculated for each. The table is arranged in the same order as the documentation checklist. Sub-totals of attributes by functional areas and the totals for all attributes, except for those in the electrical and logic prints functional area, are also listed. The composite total of both sample populations was 69 percent for these 24 attributes.

Electrical Print Attribute Observations

In Table 8 six attributes for the electrical and logic prints functional areas are summarized. The total of each attribute for each sample population is listed and percentages calculated for each. The table is arranged in the same order as the documentation checklist. The totals for all attributes in the electrical and logic prints functional areas are also summarized. The attribute composite total of both populations was 70 percent for the electrical and logic prints documentation.

Analysis

Table 5 lists the chi-square test statistic for each documentation functional area and for the total of all functional areas. The existence of axis drive documentation was dependent on its stratified group. The existence of documentation for all the remaining functional areas and for documentation as a whole was independent of its stratified group. The percentage of documentation located for the low EMRT group was higher than the high EMRT group for all categories, except control maintenance and programming, but the difference was not statistically significant.

The chi-square test statistic for machine logic availability indicates dependence between the existence of machine logic and an EMRT stratified group. See Table 6. With 95 percent availability for the low EMRT sample compared to 57 percent availability for the high EMRT sample, there appears to be a strong relationship.

Table 7 lists the chi-square test statistic for each of the 24 attributes for all functional areas, except the electrical and logic prints, for each functional area sub-total and for the total. One of five attributes in the axis drive functional area was dependent upon its stratified

Table 8

Electrical Prints Attribute Summary

	Observations							
EMRT Stratification	Low			High				
Attribute	Yes	No	%[a]	Yes	No	%[a]	X^2	Result[bc]
Electrical schematic								
Cross referenced	12	8	60	4	7	36	1.5876	Indep
Paginated	18	2	90	7	4	64	3.1601	Indep
Table of contents	15	5	75	4	7	36	4.4652	+ Dep
Logic diagram								
Paginated	16	1	94	5	1	83	0.6496	Indep
Cross referenced	12	5	71	4	2	67	0.0322	Indep
TOTAL	73	21	78	24	21	53	8.5405	+ Dep

	Low and High Combined		
	Yes	No	%[a]
COMPOSITE TOTAL	97	42	70

[a]% = yes / (yes + no)

[b] $\alpha = X^2_{0.05} = 3.84146$

[c]+Dep = positive dependence, -Dep = negative dependence, Indep = independent

group. Three of five attributes in the spindle drive functional area were dependent upon their stratified group. Two of six attributes in the control functional area were dependent. None of the two attributes in the operation functional area were dependent. Two of three attributes in the programming functional area were dependent. And none of the three attributes in the service and parts functional area were dependent upon their stratified group. The sub-totals of attribute observations for all functional areas except the axis drive functional area were dependent upon their stratified group. The observation totals of these 24 attributes were dependent upon their stratified group. The percentage of attributes observed for the low EMRT group was higher than the high EMRT group for 22 of 24 attributes but the difference was statistically significant for only 8 of these 22 attributes.

Table 8 lists the chi-square test statistic for each attribute and for the total of the attributes in the electrical prints and logic prints functional areas. One of three attributes in the electrical prints functional area was dependent upon its stratified group. None of the two attributes in the logic prints functional area were dependent. The observation totals of these six attributes were dependent upon their stratified group. The percentage of attributes observed for the low EMRT group was higher than the high EMRT group for all six attributes but the difference was statistically significant for only one of the six attributes.

Statistically Correct Observation Size

The chi-square test of independence is statistically correct for observation frequencies of 5 or greater (Kenkel, 1989). Fewer than 5 observation frequencies risk the statistic not following the chi-square distribution when the null hypothesis is true. All individual observations except for the operation manual observation and the control manual "theory or principles of operation" attribute observation have at least one observation frequency less than 5. Therefore, except for these two observations, any conclusion as the dependence of individual observations upon their stratified group is in question. However, the frequencies of all observation sub-totals and all totals were acceptable. In this study all conclusions made with statistical inferences were based on observation sub-totals and totals. These were statistically correct.

Chapter V

SUMMARY, CONCLUSIONS, RECOMMENDATIONS

Summary

Statement of the Problem

The problem of this study was to determine if documentation is related to timely problem analysis and repair. Is there any relationship between the existence of documentation and the use of documentation attributes or aids and timely CNC machine tool maintenance? This study was accomplished by gathering data by observation from a stratified sample of the population. The population was stratified by low, medium and high values of the historical electrical mean repair time (EMRT). A checklist was developed, pilot tested, and used for collecting the data. Documentation for machines in a random sample of the low and high stratified groups was observed to see if it existed for nine functional areas. Nine documentation attributes were identified. Specific instances of these attributes were observed to see if they were referenced by entries in the table of contents for manuals from seven of the functional areas. Specific instances of three of these attributes were observed for in the electrical prints and two of these three were observed for in the logic prints. The observed data from the low and high EMRT groups was analyzed to determine if any statistical difference between groups existed.

A higher percentage of documentation was available for the low EMRT group than for the high EMRT group but there was no statistical difference. A higher percentage of attributes was observed in the low EMRT group than in the high EMRT group. (There was statistical dependence between all attribute sub-totals, except one, and the stratified group to which they belong.) A relationship exists between the documentation quality for each functional area, except the axis drive, and the mean repair time of electrical problems. Better documentation, for the low EMRT group compared to the high EMRT group, resulted on average in less repair time for the machines in the low EMRT group.

Ninety-five percent of machines in the low EMRT sample compared to fifty-seven percent of machines in the high EMRT sample were provided machine logic capability. A strong relationship between machine logic capability and repair time exists, despite statistical uncertainty introduced by the single non-affirmative observation (frequency less than 5) in the low sample.

Significance of the Study

Documentation for a complex piece of equipment such as a CNC machine should be extensive. Information should be readily available in order for a technician to quickly understand a problem and make repairs. This study has shown that there is a relationship between the documentation available and the technician's ability to quickly effect repairs. Understanding that this relationship does exist will impact future decisions for improving documentation and for purchasing new machines.

Conclusions

Four questions were answered by this study.

1. The documentation composite total of both sample populations was 77 percent. This indicates that 23 percent of necessary documentation for critical CNC machines was not readily available. (See Table 5.) The machine logic capability composite of both samples was 81 percent. This indicates that for 19 percent of the machines it was not possible to exactly determine which inputs to the machine logic controller controlled a given output. (See Table 6.)
2. Documentation was more readily available for the low EMRT group (80%) than the high EMRT group (71%). However, there was no statistical evidence that this difference was

significant. (See Table 5.) Ninety-five percent of machines in the low EMRT sample compared to fifty-seven percent of machines in the high EMRT sample were provided machine logic capability. It appears a strong relationship between repair time and machine logic capability exists. However, statistical uncertainty was introduced by the size of the non-affirmative observation frequency for the low sample and therefore, the result is statistically inconclusive. (See Table 6.)

3. For documentation, which was available, the attribute composite total of both sample populations was 69 percent for all except electrical and logic prints documentation. For the electrical and logic prints documentation the attribute composite total of both populations was 70 percent. This indicates that approximately 30 percent of the attributes, which this study tested, were not in the documentation or could not be readily found. (See Tables 7 and 8.)
4. The level of attributes found, for all except the electrical and logic prints documentation, was 77 percent for the low EMRT group and was 53 percent for the high EMRT group. The level of attributes found, for the electrical and logic prints documentation, was 78 percent for the low EMRT group and was 53 percent for the high EMRT group. Both of these differences were statistically significant. This suggests that documentation itself does affect the electrical repair time for machines in the population. (See Tables 7 and 8.)

Recommendations

Study Improvements

The observation frequencies of many of the individual observations were too small. Increasing the sample size would have improved the statistical correctness of these individual observations. Choosing a different measurement of central tendency, at least for this population would have better balanced the low and high sample population sizes. Using the median statistic instead of the mean would have stratified the population into low, middle, and high EMRT groups of 34, 72, and 33 machines, respectively.

CNC Machine End-Users

This study did not differentiate between documentation, which was not available because the machine or sub-assembly manufacturer did not provide it, and documentation, which was not available because the end-user poorly managed what was provided. However there were many instances where the latter was the case. These recommendations if implemented would better manage maintenance documentation:

1. Improve the organization of maintenance libraries and be consistent. Assign a maintenance person collateral duties to maintain the integrity of the maintenance library.
2. Maintain a record of what documentation was received with a machine.
3. Develop a checklist for reviewing documentation received with a new machine.
4. Consider storing all documentation at the machine or a designated area within the production department under control of the department processor or supervisor.

Despite the statistical uncertainty, it appears a strong relationship exists between machine logic capability and repair time. Machines should be purchased that enable the technician to determine the logical operation of the machine.

Equipment Manufacturers

This study showed that the quality of documentation does improve a technician's ability to timely repair a machine. The study showed that providing (1) adjustment procedures, (2) theory or principles of operation, (3) troubleshooting guides and flow charts, and (4) illustrations and assembly drawings and that providing an effective means to locate this information does make a difference. However, it did not differentiate between attributes, which contributed to this result. More research is needed to determine the specific needs of the technician and how to best provide information that can be timely utilized. These three simple recommendations would improve documentation:

1. Provide an effective table of contents. This seems so basic, yet in a surprising number of situations observed in this study this was not done.
2. Organization of information is important. The organization should cater to the needs of both the experienced and well as the novice technician.
3. Provide an index. An index is a valuable tool, which can be used by an experienced technician to quickly access information.

Ideally a CNC control would be capable of informing the operator or maintenance technician the exact cause why something had failed for every possible aspect of the machine, which could ever fail. This immediate diagnostic capability has been greatly improved since the computer became a part of numerical control. However even with this improvement, there are many failure modes, which diagnostics fail to adequately detect. In such a situation when machine logic is not provided, the technician must use his experience to guess why something is malfunctioning. Alternately the technician could get assistance from the service department of the machine manufacturer, which presumably does have access to the machine logic. However, either process is extremely time consuming. Therefore, complete and accurate access to the logic design programmed into the machine controller should be provided for the end-user. Ideally, this is provided in printed and on-line form.

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Appendix A

Sample Populations

Table A1

Low Stratified CNC Machine Sample Population With EMRT Less Than 4.7 hours

Machine	Work Orders	Average Hours	Total Hours
1066	14	2.9	40.6
1177	22	2.5	55
1812	38	3.7	140.6
2422	32	4.0	128.0
2641	17	4.0	68.0
2882	12	3.1	37.2
2930	17	3.9	66.3
2931	6	2.9	17.4
3360	22	4.5	99.0
3373	47	3.8	178.6
3386	16	3.8	60.8
3697	15	4.5	67.5
4179	1	2.9	2.9
4425	28	4.5	126.0
4430	23	4.3	98.9
4453	4	3	12
4496	8	3.3	26.4
4693	11	4.4	48.4
4694	5	3.7	18.5

Table A1 continued

Machine	Work Orders	Average Hours	Total Hours
4857	10	4.1	41.0
8864	58	3.9	226.2
8868	42	4.5	189.0

Descriptive Statistics	Work Orders	Average Hours	Hours
Total	448		1748.30
Minimum	1	2.5	2.90
Maximum	58	4.5	226.20
Median	16.5	3.85	63.55
Average	20.36	3.74	79.47
Stdev	15.00	0.62	61.84
Count	22	22	22

Table A2

Middle Stratified CNC Machine Sample Population With EMRT Inclusively Between 4.7 And 6.4 hours

Machine	Work Orders	Average Hours	Total Hours
1176	5	5.2	26
1356	27	5.6	151.2
1537	9	6.1	54.9
1554	31	6.4	198.4
1703	47	6.0	282.0
1737	21	5.6	117.6
1872	52	5.2	270.4
1955	20	4.9	98.0
2297	13	4.9	63.7
2338	62	5.4	334.8
2411	18	5.6	100.8
2419	128	5	640
2505	65	5.3	344.5
2748	13	5.8	75.4
2762	23	5.8	133.4
2792	34	5.3	180.2

Table A2 continued

Machine	Work Orders	Average Hours	Total Hours
2986	25	6.2	155.0
3248	41	5.4	221.4
3420	33	5.4	178.2
3424	82	6.2	508.4
3667	22	5.5	121.0
4379	72	5.8	417.6
4420	25	4.7	117.5
4423	12	4.9	58.8
4440	12	5.5	66.0
4494	15	5.5	82.5
7872	24	6.3	151.2
8865	106	5.2	551.2
8866	94	5	470
8867	78	4.8	374.4
8870	49	5.2	254.8
8876	76	5.1	387.6
8877	58	5.3	307.4

Table A2 continued

Descriptive Statistics	Work Orders	Average Hours	Hours
Total	1387.		7468.3
Minimum	9.	4.7	54.9
Maximum	128.	6.4	640.0
Median	32.0	5.4	179.2
Average	43.3	5.5	233.4
Stdev	30.8	0.5	159.3
Count	32.	32.	32.

Table A3

High Stratified CNC Machine Sample Population With EMRT Greater Than 6.4 hours

Machine	Work Orders	Average Hours	Total Hours
1069	58	6.5	377.0
1175	14	6.9	96.6
1738	37	7.1	262.7
1182	109	10.2	1111.8
2387	19	9.0	171.0
2629	12	6.8	81.6
2642	17	9.2	156.4
2802	16	6.7	107.2
3158	15	16.4	246.0
4493	17	8.9	151.3
4561	15	8.4	126.0
4628	12	8.6	103.2
4765	19	10.9	207.1
4766	16	12.6	201.6
9975	19	13.0	247.0

Table A3 continued

Descriptive Statistics	Work Orders	Average Hours	Hours
Total	395.		3646.5
Minimum	12.	6.5	81.6
Maximum	109.	16.4	1111.8
Median	17.0	8.9	171.0
Average	26.3	9.4	243.1
Stdev	25.8	2.8	253.0
Count	15.	15.	15.

Appendix B

Cross-reference of Attributes to Applicable Documents

Table B

Cross Reference of Documentation Attributes and Applicable Documentation for Development of the Original Pre-Piloted Checklist.

Documentation Attributes[a,b]		
1	Adjustment procedures	1, 2, 8, 12
2	Cross referencing	5, 7
3	Illustrations and/or exploded view assembly drawings	1-3, 8-12
4	Index	1-4, 8-12 / 13-20
5	Non-generic; applicable to only one model	1-12
6	Page numbers	1-12 / 13-20
7	Table of contents	1-5, 7-12 / 13-20
8	Theory or principles of operation	1, 2, 12
9	Troubleshooting guides and/or flow charts	1, 2, 8, 10, 11

Documentation (printed)	
1	Axis drive manual(s)
2	Control maintenance manual(s)
3	Control programming manual
4	Diagnostics manual
5	Electrical schematic

Table B continued

Documentation (printed)	
6	Hydraulic and/or Pneumatic schematic
7	Ladder (logic) diagram (hard copy)[c]
8	Machine maintenance manual
9	Machine parts manual
10	Operator control manual
11	Operator machine manual
12	Spindle drive manual
Documentation (on-line or built into control)	
13	Diagnostics
14	Display of I/O bit tables
15	Display of internal bit/word tables
16	Electronics hardware status lights
17	Ladder (logic) diagram display[c]
18	Operator and/or programmer messages
19	Operator station indicating lights
20	Programmer messages display

Note: Various documentation attributes are listed in the first section of this table.

Documentation list from Table 1 is split into printed and on-line or control based groups. A specific attribute is applicable to some or all of the printed and control based documentation entities.

[a]Technique observed for in printed documentation as noted with numbers that follow.

[b]Printed documentation uses these techniques to reference information on these specific control based or on-line items.

[c]Ladder logic or any other machine logic programming method.

Appendix C

Pre-Piloted Checklist

Documentation Checklist

Department ______________________

Location ______________________

Manufacturer and /or model ______________________

Control manufacturer and/or model ______________________

Axis drives manufacturer and/or model ______________________

Spindle drives manufacturer and/or model ______________________

Documentation (printed)	Available Yes	Available No
Axis drive manual(s)	____	____
Adjustment procedures	____	____
Illustrations and/or exploded view assembly drawings	____	____
Index	____	____
Non-generic; applicable to only one model	____	____
Page numbers	____	____
Table of contents	____	____
Theory or principles of operation	____	____
Troubleshooting guides and/or flow charts	____	____
Control maintenance manual(s)	____	____
Adjustment procedures	____	____
Illustrations and/or exploded view assembly drawings	____	____
Index	____	____
Non-generic; applicable to only one model	____	____
Page numbers	____	____
Theory or principles of operation	____	____
Table of contents	____	____
Troubleshooting guides and/or flow charts	____	____
Control programming manual	____	____
Illustrations and/or exploded view assembly drawings	____	____
Index	____	____
Non-generic; applicable to only one model	____	____
Page numbers	____	____
Table of contents	____	____
Diagnostics manual	____	____
Index	____	____
Non-generic; applicable to only one model	____	____
Page numbers	____	____
Table of contents	____	____
Electrical schematic	____	____
Cross referencing	____	____
Non-generic; applicable to only one model	____	____
Page numbers	____	____
Table of contents	____	____

	Available Yes	Available No
Hydraulic and/or Pneumatic schematic	______	______
Non-generic; applicable to only one model	______	______
Page numbers	______	______
Ladder (logic) diagram (hard copy)	______	______
Cross referencing	______	______
Non-generic; applicable to only one model	______	______
Page numbers	______	______
Table of contents	______	______
Machine maintenance manual	______	______
Adjustment procedures	______	______
Illustrations and/or exploded view assembly drawings	______	______
Index	______	______
Non-generic; applicable to only one model	______	______
Page numbers	______	______
Table of contents	______	______
Troubleshooting guides and/or flow charts	______	______
Machine parts manual	______	______
Illustrations and/or exploded view assembly drawings	______	______
Index	______	______
Non-generic; applicable to only one model	______	______
Page numbers	______	______
Table of contents	______	______
Operator control manual	______	______
Illustrations and/or exploded view assembly drawings	______	______
Index	______	______
Non-generic; applicable to only one model	______	______
Page numbers	______	______
Table of contents	______	______
Troubleshooting guides and/or flow charts	______	______
Operator machine manual	______	______
Illustrations and/or exploded view assembly drawings	______	______
Index	______	______
Non-generic; applicable to only one model	______	______
Page numbers	______	______
Table of contents	______	______
Troubleshooting guides and/or flow charts	______	______
Spindle drive manual	______	______
Adjustment procedures	______	______
Illustrations and/or exploded view assembly drawings	______	______
Index	______	______
Non-generic; applicable to only one model	______	______
Page numbers	______	______
Theory or principles of operation	______	______
Table of contents	______	______

	Available Yes	No
Documentation (on-line or built into control)	______	______
Diagnostics	______	______
Hard copy documention	______	______
Index	______	______
Page numbers	______	______
Table of contents	______	______
Display of I/O bit tables	______	______
Hard copy documention	______	______
Index	______	______
Page numbers	______	______
Table of contents	______	______
Display of internal bit/word tables	______	______
Hard copy documention	______	______
Index	______	______
Page numbers	______	______
Table of contents	______	______
Electronics hardware status lights	______	______
Hard copy documention	______	______
Index	______	______
Page numbers	______	______
Table of contents	______	______
Ladder (logic) diagram display	______	______
Hard copy documention	______	______
Index	______	______
Page numbers	______	______
Table of contents	______	______
Operator and/or programmer messages	______	______
Hard copy documention	______	______
Index	______	______
Page numbers	______	______
Table of contents	______	______
Operator station indicating lights	______	______
Hard copy documention	______	______
Index	______	______
Page numbers	______	______
Table of contents	______	______
Programmer messages display	______	______
Hard copy documention	______	______
Index	______	______
Page numbers	______	______
Table of contents	______	______

Appendix D

Final Post-Piloted Checklist Used for Study

Documentation Checklist

Department ____________
Location ____________
Manufacturer and /or model ________________________________
Control manufacturer and/or model ________________________________
Axis drives manufacturer and/or model ________________________________
Spindle drives manufacturer and/or model ________________________________

Referenced by table of contents	Referenced				Documentation	
	Yes	No	Indexed	N/A[1]	Yes	No
Axis drive specifications					axis drive	
Axis drive status indicators						
Axis drive maximum speed adjustment						
Axis drive theory or principles of operation						
Axis drive troubleshooting guides and/or flow charts						
Spindle drive specifications					spindle drive	
Spindle drive status indicators						
Spindle drive maximum speed adjustment						
Spindle drive theory or principles of operation						
Spindle drive troubleshooting guides and/or flow charts						
Control status indicators					control maint.	
Control adjustment procedures						
Control theory or principles of operation						
Changing control parameters						
Displaying of internal bit/word tables						
Displaying machine logic						
MDI (manual data input) operation					operation	
Machine homing procedure						
Programming code for inch/metric dimensions					programming	
Programming code for incremental/absolute positioning						
Programming errors						
Tool changer/turret sequence and/or maintenance					service/parts	
Setting (maintenance of) axis home position						
Machine parts manual has exploded view assembly drawings						

Main electrical prints and logic	Available		N/A[1]	Documentation	
	Yes	No		Yes	No
Electrical schematic contacts are cross referenced				electric prints	
Electrical schematic only applicable to installed options or readily marked with installed options					
Electrical schematic is paginated					
Electrical schematic has table of contents					
Logic diagram (hard copy) is paginated				logic prints	
Logic diagram is cross referenced					

[1] Not applicable