SIMPLICITY IN COMMAND AND CONTROL SYSTEMS: A HUMAN FACTORS CONSIDERATION

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ABSTRACT

Simplicity in the Man Computer Interface (MCI) is a desirable feature. Hopefully, it makes the system containing the MCI “easier to use”. This paper uses results from a MCI study at the Jet Propulsion Laboratory (JPL) to identify an area where the system MCIs can be simplified. It identifies the circumstances where these simplifications are appropriate. The concepts of Cognitive simplicity and Process simplicity are presented as MCI design alternatives. The concepts of Understandability, Operation, Learnability, Level of learning, and Useability are presented as tools for the system designer. The use of these concepts to provide a systematic MCI design is discussed.

INTRODUCTION

The first thought many system designers have, when considering how to make the system easy to use, is to keep it simple. Unfortunately, what is simple to one, may not be simple to another. Very often, simplicity to the system designer means expressing the system in terms not at all simple to the user. It is not simple to the user because he does not understand the system to the same depth as the designer. In order then, to design a “simple” MCI, the designer needs to know the user’s characteristics. Very few systems designers are prepared by training, experience, or even by basic nature to evaluate the systems user population in human terms. The system designers often cannot rely on Human Factors Specialists because of their short supply. Typically, the system designer will have to carry the responsibility for human factors. Hopefully, this paper will be useful to the system designer in this capacity. This is a conceptual paper exploring MCI simplicity to the level below the over-simplistic “keep it simple” idea.

It was recognized at JPL, a National Aeronautics and Space Administration facility, that a need existed to improve the MCI in the command and telemetry systems at the Deep Space Network(DSN), a spacecraft tracking station network. A project was initiated to gain a better understanding of the MCI dynamics. The project consisted of a series of focus groups, a survey, and an experiment (1). The focus groups and the survey explored the operator's perception of the system. The experiment provided comparative measurements between different MCI characteristics in simulated system configurations. The concepts in this paper were distilled from the focus group results. It was observed that the effectiveness of the operator depends upon the operator understanding how to operate the system. The effectiveness also depends upon the operator being able to operate the system. These then are two of many dimensions which affect the system ease of use. The first is labeled Cognitive simplicity. It is characteristic of a system which is easy to use because the system is easy to understand. The designer can improve Cognitive simplicity by providing system features which aid the operator in understanding the system. The second concept is labeled Process simplicity. It is characterized by minimum physical or mental effort being required to operate the system. The concept that humans prefer operations with the least effort is attributed to Zipf(2). It has face validity and it was also supported by the DSN MCI study. The system designer can control the Cognitive and Process simplicities and thereby hopefully he can improve the effectiveness of the MCI design. These two concepts are by no means the only ones affecting the MCI design, but we are limited by boundaries of this paper to these two concepts.

The concepts of Understandability, Operation, Learnability, Level of learning, and Useability are presented in order to provide a conceptual framework for the use of the concepts of Cognitive and Process simplicities by system designers. They are used by the system designer to analyze the system environments and to develop the rationale to select either Cognitive or Process simplicity for a specific MCI design.

COGNITIVE SIMPLICITY

A process which has Cognitive simplicity is one which is easy to understand. The process may have Cognitive simplicity because it is basically simple. It may have Cognitive simplicity because it is compatible with the operators prior experience or knowledge. Cognitive simplicity may be due to cognitive aides being included in the design of the interface format. That is, aids which facilitate the operator's understanding of the MCI. They are typically structured aids such as menus or prompts which lead the operator through the MCI dialogue. They can also be structural elements in the MCI command formats which allow the operator to more easily separate the elements of the command format. Delimiters can be used in a command format to set off parameters and identify types of parameters.

For example:

MPC/36,2(10),18 (1)

the slash ("/") separates the mnemonic command name (MPC) from the argument parameters (36,2(10),18). The commas separate the parameters and the parenthesis identify an optional parameter. Conversely, command formats which are separated by only spaces are more cognitively complex because they do not provide the cognitive aids which help the operator understand the command structure.

Cognitive simplicity can be enhanced in a system by providing complete and fully explanatory error and status messages, on-screen instructions, or on-call help instructions. Complete and fully explanatory means that the messages contain all the information necessary to understand the command process. It also means that the context is well established. English language characteristics can be used to enhance the understanding. Subject, verb, object forms can be used together with redundancy to increase understanding. This is the natural language concept suggested by many.

PROCESS SIMPLICITY

Process simplicity relates to the relative ease which tasks can be accomplished. This may deal primarily with anthropological characteristics of the computer system operators. For example, with typing tasks, issues such as finger reach, keystroke pressure, key cap size, key spacing, etc. (3) are important. The obstacles to Process simplicity are then physiological limitations, such as finger reach, arm movements, etc.

Process simplicity may also deal with the mental effort required to operate a system. The actions may be basically cognitive activities such as selecting an item out of a population of items. The obstacles to Process simplicity then are psychological limitations such as short term memory, motivations, etc. Note that this concept is different than Cognitive simplicity in which we are concerned with the mental effort required to understand the process. The difference between the concepts is the difference between the effort required to understand the process versus the effort required to accomplish the process.

UNDERSTANDABILITY

Understandability (Figure 1-A) is the ease of which the system can be understood by the population of operators. Understanding a system is the process of an individual developing a model of the system(4,5) within the his own mind. On one end of this dimension, the parts of the system and their interrelationships fit together well in the individuals mind. On the other end of the dimension, the individual cannot identify parts of the system ("it is a black box") or cannot determine the relationship between parts ("beats me how it works"). System Understandability then is an aggregate measure over the operator population of the state of individuals minds or their attitudes about the system's ease of understanding. it can be measured with a self-reporting questionnaire. This measure can provide a relative measure for comparing different systems, but does not provide an absolute measure.

OPERATION

The concept of Operation (Figure 1-B) can be described by considering the two ends of the dimension. On one end, the operator can operate a system based on his good understanding of that system. That is, he has a good internal model of the system. On the other end, he may not understand the system, but operates it by rote, or by previously established procedures. Either method is reasonable and can lead to effective system operation depending upon the existing environment. Again, the system can be characterized by the aggregate of measures taken over the operator population.

Understandability

(A) Low	High
Hard to Understand	Easy to Understand

Operation

(B) By Rote	By Functional Understanding
Uses Procedures Strictly	Does not Use Procedures

Learnability

(C) Low	High
Hard to Learn	Easy to Learn

Level of Learning

(D) Low					High
Under Learned	Must Use Documentation	Normally Uses Documentation	Seldom Uses Documentation	Has to Think About Operating	Over Learned

Useability

(E) Low	High
Hard to Use	Easy to Use

Figure 1. Concept Dimensions

LEARNABILITY

Learnability is one of those concepts which is easy to inadequately define. The difficulty is: learning what? In this paper, system Learnability is limited to learning how to operate the system. Note that Learnability and Understandability are separate concepts. An operator can learn to operate a system without understanding the system. He can operate from procedures (by rote). The dimension (Figure 1-C) varies from hard to learn to easy to learn. Easy to learn can apply to the idea that it is easy to learn the operating procedures or that it is easy to learn to operate the system by functional understanding. Learnability can be measured by the time required for an operator to attain some proficiency level. The system Learnability is an aggregate of the individual measures over the operator population.

LEVEL OF LEARNING

Level of learning (Figure 1-D) progresses from "underlearned" in which the operator essentially does not know how to operate the system to "overlearned" in which the operator can operate the system without having to think through each step (i.e. automatically). The concept can also be considered in terms of the mental effort required to operate the system. When an individual is "underlearned", extreme mental effort (6) is required. Increased Level of learning brings the individual to where he can operate the system with the help of documentation or assistance from other people. As his Level of learning increases, he required less help from the documentation or other sources. Until he reaches an overlearned condition in which he needs no external assistance and furthermore he does not even have to think about the process in order to operate the system. An example is touch typing, a trainel typist does not have to think about which finger is going to type a particular character, it is automatic.

Level of learning is a characteristic of the operator population and thus is an environmental factor to system design. However, the Level of learning measure of the operator population is influenced by the Learnability concept which is a system factor. When the Learnability of a system is high, we can expect that the Level of learning will be higher for that system with any given operator population than for a system with low Learnability.

USEABILITY

Useability (Figure I-E) is concerned with the ease of operating the system. It varies from hard-to-use to easy-to-use. The measure of useability for system is an aggregate measure of the operator population's perception of how easy it is to operate the system. It is obtained through a self-reporting questionnaire. Useability is related to both cognitive effort required (i.e. mental effort) and to physical effort required. When the system is being operated at a relatively low Level of learning, Useability is primarily a cognitive issue. That is, the operator must think through each step of the process and he has to exert extreme effort to understand what he is attempting to accomplish. When the system is being operated at a relatively high Level of learning, it is principally a minimum effort issue. The operator does not have to expend effort to learn the system. He wants to expend the least physical effort in accomplishing the task, i.e. keying in data, etc. And also wants to expend the least mental effort in evaluating conditions and making decisions.

COGNITIVE SIMPLICITY VERSUS PROCESS SIMPLICITY

Cognitive simplicity or Process simplicity within the man-computer interface design are alternates available to the system designer. The interface can be designed to aid the understanding of the process or it can be designed to aid accomplishing the process. The choice of using a menu interface versus a mnemonic interface is an example of these choices. Several authors have suggested that menu interface designs are useful when the user is learning the system, but he tends to become impatient when he knows the system and what he has to do (4,7). Menu interfaces usually are examples of Cognitive simplicity. They tend to be easy to understand and easy to learn. They tend to not have Process simplicity, because it often requires more effort to traverse through a series of menus than to enter a single mnemonic command to accomplish a task. Also, waiting for the menu to be displayed tends to destroy the operator's mental pacing.

Process simplicity in a MCI design is related to the effort required to accomplish the task. For example, Process simplicity is obtained by minimizing the number of key strokes or the effort required to accomplish the keystrokes. Mnemonics with single characters provide Process simplicity because of the minimum keystrokes. But a longer mnemonic (when properly designed) may have Cognitive simplicity, that is, it is easier to understand. For example, "D" for display request can be keyed with only one keystroke, but "DISPLAY" for display request is easier to understand. Which is better? It depends on the complexity of the task and the Level of learning associated with the operator population. A simple system task should allow a man-computer interface design which is both cognitive and process simple. Martin (8) describes an airline reservation system which uses single character mnemonics and each mnemonic is clearly related to its subject (ie, "E" for End). However, for a system MCI which is more complex, that is, it has a greater repertoire of commands, the single character loses its Cognitive simplicity because of the large discrimination space in which the operator has to work. He has more things to scan in deciding which command to use. And also, chances of ambiguity increase. For example, does "D" mean Display or Delete? In the DSN tracking station system man-computer interface study, the operators felt that three character mnemonics were about right. This was influenced by the fact that the system that they were normally use has three character mnemonics. What was interesting was that they did feel comfortable with the mnemonics.

Three character mnemonics were appropriate for the command complexity of that specific system.

The system, which the operators in the DSN study normally use, is a mnemonic design. A mnemonic MCI design uses a command identifier, the mnemonic, and a list of arguments to apply to the commanded action. The operator has the option of using commas, slashes, colons, etc., or spaces for delimiters.

For example:

XYY/26,15:46:24	(2)
XYZ 26 154624	(3)

The first example has Cognitive simplicity, the second has Process simplicity. The delimiters in the first example provide Cognitive simplicity because they clearly delineate the mnemonic from its arguments (/), the arguments themselves (,), and the subparts of the time word (:) for hours, minutes, and seconds. The spaces used as delimiters in the second example provide Process simplicity in that they are considerably easier to use than the other deliminters. The space key is larger than the other keys. Fitts law (9) indicates better accuracy will be attained with a larger key, because the operator is less likely to miss the key. For operators who touch type, the space bar is hit with the thumb which has no other responsibilities. And the space bar does not require a shift key. Keystrokes which require shifting are particularly bothersome. They greatly reduce the Process simplicity. The Level of learning for the DSN system indicated better effectiveness for the Process simplicity alternative (space delimiter option). A different system with a lower Level of learning would suggest that the delimiter option with greater Cognitive simplicity would be more effective.

Error and status messages are another area in which the system designer can exercise his design prerogatives. He can design the system error and status messages to be either short and concise or long and explanatory. They can be in the operators terminology or the designers terminology. The messages can explain the system fault only or they can additionally suggest recovery actions. The previous concepts can be used to help the designer choose the error and status messages characteristics.

Systems operating in a low Level of learning environment call for Cognitive simplicity. The system messages should be easy to understand. They should be long enough to be self-explanatory. Systems operating in a high Level of learning environment can be designed with Process simplicity. The frequency in which the message appears generally determines the Level of learning for that message. When a message appears very often, the operator recognizes the message immediately. Often, he recognizes it by its form rather then its content. That is, he recognizes the pattern, say the number of words or the size of words. This condition calls for a message with Process simplicity. It should be short so that it does not tie up the Input/Output terminal and it does not make the operator wait for its completion. Messages which are infrequent, call for Cognitive simplicity. They should be complete in their content, because the operator requires the content, in order to understand the message. These messages tend to be longer. A special case is a message which warns of a high risk system condition. When the risk associated with misunderstanding a system message is high, that message should be cognitively simple. It should be complete and self-explanatory even though it may be long and may appear often.

Cognitive simplicity and Process simplicity are not mutually exclusive. A system message may have both Cognitive and Process simplicity, i.e. it can be high in both dimensions. It can be short and completely understandable. Of course that is preferable, but not always obtainable. The opposite can also be true. The message may be low in both dimensions. It may be long and difficult to understand.

Whether the message is cognitively simple or complex is determined largely by whether it is presented in the operators terminology or the designer's terminology. That is, whether it fits the operator's internal model or the designer's internal model. Consider for example the following messages:

> "The telemetry data rate is exceeding the system capacity."
>
> "Step 26a is aborted."
>
> "TLM buffer overflow."

The first message is appropriate to an operator's internal model when operating by functional understanding. It refers to the functional process of the system. The second message is appropriate to an operator's model when operating by procedures. It refers to a procedure step rather than the system itself. The third message is inappropriate because it is presented in terms of the systems internal design. It represents the designer's internal model not the operator's.

Error, warning, or fault messages can enhance cognitive simplicity by suggesting recovery action. The first message might also say "Reduce spacecraft telemetry data rate." The second message might go on to tell the operator to "Go to Anomoly Procedure M54." Again, the action suggested is in terms of the operating method expected. When operating by functional understanding (Figure 1-B), the recovery action should be given in terms of the system functions (i.e. reduce telemetry data rate). When operating by procedures (Figure 1-B), the recovery action should be given in terms of the procedures being used.

DISCUSSION

Concepts such as have been presented in this paper are only good when they can be used. This discussion will address the issue of how these concepts can be used in system design. Initially, the system designer must analyze the system goals. In addition, to the functional, cost, and schedule requirements, human factor goals should be analyzed. Usually, this is fairly simple. We want to maximize useability and hopefully thereby gain the most from the operator staff. However, other goals may be important, possibly political goals for example. This analysis will affect later design efforts.

The environment factors which influence the system design can be analyzed in terms of the previous concepts. The Operation concept is influenced by management desires. The military very often operates by rote or procedure ("Don't try to understand it, just do what you are told.") The Operation concept is influenced by such factors as personal turnover rates. For operations with low turnover, operation by functional understanding is appropriate; especially when the operators are well trained, experienced, and the operations task is somewhat unstructured. The JPL DSN has a relatively low operator turnover and the operators are well trained and are experienced. However, the high risk of failure in spacecraft operations make a combination of operating by procedures and by functional understanding appropriate.

The Level of learning is determined by the interaction of the operator population skill levels and the Learnability of the system. The type of user influences the expected Level of learning. Novice user will probably operate the system in an underlearned state. Casual users would operate the system with a higher Level of learning. They would have a basic understanding, but would require relearning details every time that they operate the system. Dedicated and experienced operators would probably operate the system at an overlearned level.

Cognitive simplicity and Process simplicity are used to tailor the operation of the system to match the environment as analyzed with the preceeding concepts. For example, the tracking stations of the JPL DSN operate at close to an overlearned condition. Some procedures are available for operations, but the operators normally work by functional understanding. The tracking station operational systems that are used everyday to track spacecraft, mostly have Process simplicity. The initial surveys conducted by the Human Factors Project indicated that the MCI design was appropriate for the existing Level of learning and the type of Operations except for one area. The initialization of the systems require a sequence of inputs to set up the system configuration. Some operators felt uncomfortable because the sequence required a higher level of understanding than existed and the process was prone to operator errors. The recommendation was to change the initialization from a mnemonic design to a prompted design in order to gain Cognitive simplicity. Another area that requires greater Cognitive simplicity is the systems which are used infrequently, such as the utility programs, dump programs, test programs, etc. The users must relearn them each time they are used. It is not cost effective to develop procedures for their use, they are used infrequently and very often are used on rather unstructured tasks (i.e., troubleshooting). An MCI design with greater Cognitive simplicity is more appropriate, such as a menu or prompted design.

CONCLUSIONS

This paper has presented a series of concepts which hopefully provide a theoretic foundation for one small area of man-computer interface design. The concepts provide an analytic tool for specific MCI design projects. Admittedly, this design approach may present difficulty to the MCI designer. Concepts are much harder to use than guidelines. Theoretical analysis places a greater burden on the designer to understand and properly use the concepts. Assuming that the concepts and their relationship are realistic and that the added analytic complexity is mastered, the benefit is a more systematic MCI design which will hopefully lead to a better MCI design.

The concepts of Cognitive and Process simplicity provide the MCI designers with specific design alternatives. The concepts of Operation and Level of learning provide the framework for selecting either Cognitive or Process simplicity for the MCI design. The concepts of Understandability and Learnability provide tools for the evaluation and comparison of different MCI designs. And the Useability concept provides an analysis and evaluation tool for the MCI design in terms of the system objectives.

RECOMMENDATIONS

The concepts of Understandability, Learnability, Operation Level of learning, and Useability are presented in this paper to support system analysis in developing the rationale for selecting either Cognitive or Process simplicity. The depth of this paper predicated limited discussion of these concepts. Further conceptual refinement is recommended. And in order to provide working tools for the system designer, it is recommended that guidelines be developed for specific application areas and measuring instruments be developed for each concept.

REFERENCES

1. Chafin, R.L. "A Man-Computer Interface Study for Command and Control Computer Systems", Proceedings of the 1979 International Conference on Cybernetics and Society, Denver, Colo. Oct. 1979.

2. Zipf, G.K. The Principle of Least Effort, Addison-Wesley Press, Inc., Cambridge, Mass. 1949.

3. Alden, D.G., Daniels, R.W., & Kanarick, A.F., "Keyboard Design and Operation: A Review of the Major Issues", Human Factors, Vol.14, No. 4, 1972, pp 275-293.

4. Cheriton, D.R., "Man-Machine Interface Design for Timeshare Systems", Proceedings of the Annual Conference, Association for Computing Machinery, New York, 1976.

5. Watson, R.W., "User Interface Design Issues for a Large Interactive System", Proceedings of the National Computer Conference, Vol. 45, 1976, pp 357-364.

6. Treu, S., "Interactive Command Language Design Based, on Required Mental Work", International Journal Man-Machine Studies, Vol.7, 1975, pp 135-149.

7. Bennett, J.L., "Incorporating Usability into System Design", Proceedings of the International Conference on Cybernetics and Society, Tokyo, Japan, Nov. 1978.

8. Martin, J., Design of Man-Computer Dialogues, Prentice Hall, Inc. Englewood Cliffs, N.J., 1973.

9. Fitts, P.M., "The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement", Journal of Experimental Psychology, Vol. 47, 1954, pp 381-391.

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under NASA Contract NAS7-100.