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PERFORMANCE EFFECTIVENESS ANN THE WORK/REST CYCLE(U)  
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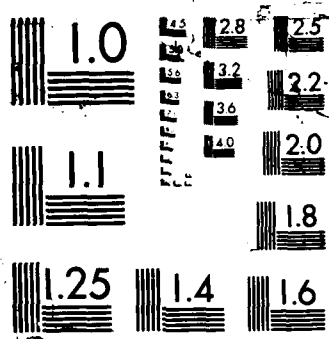
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## Body of Report

### A. Statement of the Problem Studied

Research on "Performance Effectiveness and the Work/Rest Cycle" is organized around the aim of increasing our understanding of behavior, and of human performance in particular, as it takes place in complex environments, especially those environments we characterize as "work" environments. Increased understanding of the complex behavioral processes that go on in complex environments can be expected to assist in designing more effective work environments wherever that is possible and to inform us about the limitations of performance in those work environments that cannot be changed.

Supervisors of today's man-machine systems are subjected to a set of circumstances where they must receive information, process it and send it on to other parts of the system continuously in real time. These dynamic environments can be very complex, yet they are circumscribed by structure. Parts of the structure are attributable to the requirements of the job itself--the particular task the supervisor must carry out within the system--but some of it can be found in the pattern of the flow of events that surround the supervisor. Often these events, or many of them, are scheduled by the nature of the overall system and this scheduling combines with the scheduling of behavior originating in the supervisor to result in a coherent sequence and pattern of activities of the supervisor over time. This report summarizes the results of research carried out under DAAG-29-83-K-0138, research that is both theoretical and empirical, directed to uncovering the nature of the structure that underlies the behavior of a person, such as a supervisor, in a complex working environment.

For convenience in presenting the results of the research, two facets of the overriding problem of identifying and understanding the structure of behavior in complex environments, considered across time, will be separated out and taken up individually. This division, like most, tends to divide up something that ultimately probably is not divisible at all but it does allow two different lines of research to be separated out and highlighted. One line pursues questions related to the organization and structure of working over time and the other to complex motivational and cognitive processes taking place under continuous task requirements. The primary difference between these two is that the first looks at organization and structure in

behavior as it arises from the scheduling of events across appreciable intervals of time whereas the second focuses in some detail on the motivational and cognitive processes present at the time a particular task is carried out--the first calls for analyses directed to questions concerning the integration of different task activities across time and the second the details of task performance as it is going on.

#### B. Summary of the Most Important Results

##### Organization and Structure of Working over Time

A good example of the way in which the nature of the task to be carried out imposes structure on the work performed is found in the first study to be reported. The task required that a long list of 6-character numerals be entered into a file of an Apple IIe P.C. The entries were data from another experiment unrelated to the present study and the operator was a graduate student in Psychology, paid by the hour. Accuracy rather than speed was important to the performance of the task and no time pressure was imposed. This fits the definition of "truly unpaced" work; i.e. "Truly unpaced--No internal or external pacing is imposed. The task is performed at a preferred and chosen pace by the operator." (Salvendy & Smith, 1981; p 7). Twenty four sessions were required to complete the task and the number of entries per session ranged from about 400 to 1200.

The data in each session are in the form of a double column of times: The first column contains the entry or typing times and the second the times between successive entries; i.e., the interval between making the last key stroke for one entry and the first key stroke for the next entry. It is convenient to refer to these times as "ontimes" and "offtimes," respectively. It is the offtimes that are of concern, both because the ontimes are quite short and unvarying (about 1.6 seconds) and because it is the offtimes that can reflect the presence of pauses and rests in the work session.

All 24 sessions produced distributions of offtimes of the same bimodal form, one mode at about 4.2 seconds and the other at about 5.4 seconds with a tailing off of the distribution on out to about 15 seconds. The aggregated distribution, shown in Figure 1, is fit well by two overlapping bell shaped distributions, the one to the left with mean and standard deviation of 4.2 and 0.3, respectively, and the one to the right with mean of 5.4 and standard deviation of 0.4. Roughly 64% of the observations fall in the lower

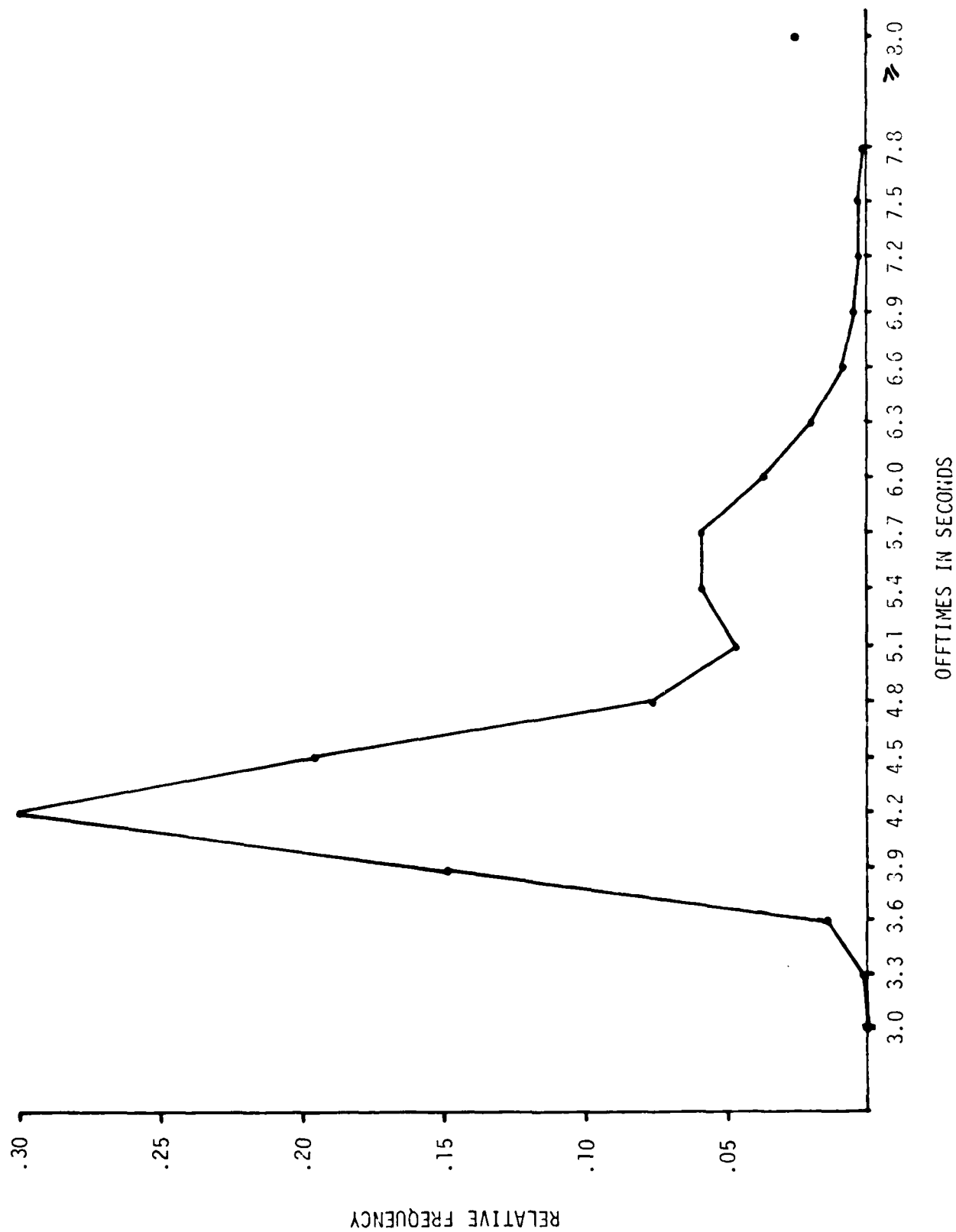


Figure 1. Frequency distribution of "offtimes" in extended work sessions on a highly structured "list of items" task

distribution, 32% in the upper and the remaining 4% in the tail. The overall bimodal distribution can be interpreted to arise from a dominant unimodal reference offtime distribution centered around 4.2 seconds replaced upon occasion by a unimodal pause distribution centered around 5.4 seconds. Infrequently (i.e. only for 4% of the data points), there occurs a rest of 8 seconds or more.

Offtimes are not vacuums or dead intervals in overall working time--carryover from the just previous item entered and preparation for typing the next item are surely present--but they can be used as the basis for identifying pauses and rests. The lower mode, around 4.2 seconds, can be used as an offtime expectation against which the upper mode, around 5.4 seconds, and hypothesized to include a pause, can be contrasted. The distribution of values around the upper offtime mode need not be conceived of exclusively as a pure pause of 1.2 seconds added on to the standard offtime interval of 4.2 seconds but rather may be any combination of "spontaneous pauses, disguised pauses and pauses arising from the nature of the work" (Grandjean, 1981; p230). It is not possible to distinguish among these types of pauses in the present data, however.

That 64% of the offtimes reside in the lower, reference distribution and 32% in the upper, pause distribution means that, on the average, a pause occurred after every third item entered and therefore about every 13.2 seconds (arrived at by the sum of 3 item entries of 1.6 seconds each and two offtimes of 4.2 seconds each). When the pause time of 5.4 seconds is included the time becomes 18.6 seconds which translates into an average rate of about 3.2 pauses per minute. Interestingly, this value is very similar to those found by Bills (1931) for a variety of repetitive tasks with a structure that required successive responses to items over extended periods of time. It may well be that it is the "list of items" task structure that is responsible for the clearly defined scheduling of pauses in the work period found in these studies.

The 64% reference frequency and 32% pause frequency can also be interpreted as a 2:1 ratio of the two types of offtimes for the data averaged over the whole set of 24 sessions. There is, however, a pattern to this ratio across the sessions; ratios are higher early and late than they are midway. Specifically, the reference frequency to pause frequency ratio is

2.7:1 over the first 8 sessions, 1.3:1 for the middle 8 and 2.5:1 over the last 8 sessions. This is a pattern quite compatible with the hypothesis that motivation declines initially as sessions go on, giving rise to more frequent pauses, but then rises as the final end of the overall task comes in sight.

For certain well specified sets of conditions it is possible to give a formal statement of the scheduling of events, environmental or behavioral. This has been accomplished in a model (Birch, 1984) that is based on the fixed activation time scheduling of events. Activation time is defined as the time needed for an event to regain dominance in the stream of events measured from the point in time at which it lost dominance. The fixed activation time scheduling rule states that some event must be ongoing at all times, that an ongoing event will continue until interrupted by another event, that every event has a predetermined activation time and that fulfilling the activation time requirement is the necessary and sufficient condition for an event to interrupt an ongoing event. The last condition sets this rule apart from those employed in queuing theory since it does not allow events to be completed or queues to form. Derivations can be made from the model concerning the dynamic organization of the stream of events, written in terms of the frequency and duration of events and the transitions between pairs of events. Issues that arise in deciding on the coding of events can be addressed using the model, and the generality of the model suggests that the scheduling rule will apply in a wide variety of settings.

The activation time scheduling model can be used to conceptualize the appearance of pauses in the data of the continuous work study just reported on. There is a stream of three events (typing, reference offtime, and pause offtime) proceeding across time. Each event has its own activation time, to be calculated from the data, and the model uses these activation times to specify the organization of the stream of the events across a work session, thereby providing a description of the work activity. Such applications of the model deserve serious consideration in future research on the scheduling of events during continuous work.

Additional formal characteristics of fixed activation time scheduling are reported in Birch (1986a) in which a rigorous motivational basis for scheduling is developed and certain issues that arise from the classical independence-from-irrelevant-alternatives condition of psychological

measurement are resolved for the continuous stream of events. Further model extensions to include the consequences of combining classes of events in the context of stream data are introduced in Birch (1986b) and shown to yield a method whereby the model can be used to assist in identifying independent categories of environmental stimuli and behaviors. This result holds out promise that a new, theoretically based, taxonomy for complex behaviors may be achievable.

The analysis of stream of events data was generalized in a doctoral dissertation by Holtgrave (1987) to include a general strategy for single subject research. This strategy is based on the collection, exploration, and modeling of time and frequency information in a "stream protocol" (a complete record of the time and type of all behavioral changes during an interval of observation). A special technique for modeling time and frequency information in an individual stream is developed, a technique grounded in the proposition that both the time spent in a type of behavior and the frequency of that behavior are related to the attractiveness of the behavior. In this way observable time and frequency aspects of the data are related to each other via attractiveness. Several model variations are presented, one of which combines a semi-Markov model with the constraints imposed by Luce's choice axiom (Luce, 1959). This model appears particularly well suited for stream data and can be related to the fixed activation time scheduling model and to a Markov model. The general strategy that is developed is shown to be more comprehensive than conventional single subject research techniques, to allow for the assessment of a new treatment effects hypothesis, to provide an easy-to-use framework for model building, and to encompass presently available models for the stream of behavior.

Another direction of development of the scheduling rule research was taken by Iacobucci (1982) in her M.A. Thesis. She provides an example of the work scheduled environment of a supervisor who must take action based on many sources of incoming information. A specific scheduling model is described and shown to be capable of answering questions of interest to the supervisor in the given example. The determinism inherent in the model makes conventional statistics inappropriate for describing these scheduled systems. In the thesis Iacobucci begins work on the very important task of using the model to develop statistical methods that will be appropriate for testing

hypotheses concerning stream data.

Complex Motivational and Cognitive Processes under Continuous Task Requirements.

Cuqlock and Birch (1987) undertake to answer a fundamental question about single-task and dual-task tracking; namely, can the nature of a task be distinguished from the way in which it is carried out? In their study evidence is presented that single-task and dual-task tracking can be conceived of as "doing the same thing under different conditions" when it is the tracking activity that is to be characterized. But when viewed in terms of the structure of the movements that occur, single- and dual-task tracking exemplify "doing different things." Subjects carried out single- and dual-task tracking during repeating, 30-s cycles throughout 10-min trials. Cognitive tasks to be carried out concurrently with tracking in the dual-task condition were designed so that the physical environment was the same during the two tracking intervals. Consistent and reliable mean differences for the single- and dual-task tracking intervals were found for average integrated error (AIE) and for the spectral measures of phase, amplitude, and coherence. Tetrad differences analyses (Spearman, 1927) suggest that although one common factor may be responsible for the observed AIE differences, separate factors for single- and dual-task tracking seem to be called for by all three spectral measures. Discussion centers on the theoretical and empirical distinctions to be made among the concepts of action, activity, performance, and movement structures, and the way in which measures of each may be affected by the tasks presented to subjects.

The tracking study just reported relates both to the structure of working over time and to the motivational and cognitive processes that go on in such work. A second study by Cuqlock and Birch continues this line of investigation but with a different task and with different kinds of conditions; namely, one of the type where a supervisor is monitoring multiple inputs and consolidating them into a prediction about a system.

Supervisors are often called upon to determine the values of a variable on the basis of multiple input values and to do so repeatedly as the configuration of input values changes. Furthermore, the man-machine-environment-system contains many situations wherein information must be

differently weighted to make optimal system control decisions. Not only may it be necessary to weight some sources of information more than others to make an accurate prediction, but it may also be required that an individual weight the information on a particular display differently as a function of other system conditions. One example of this is the skilled pilot who assigns weights to the information from the flight instruments in accordance with their relevance to a particular maneuver, or in accordance with the environmental conditions. The validity of cues for the criterion value and the redundancy of information regarding the criterion are important to the predictions that supervisors must make.

In order that accurate determinations of criterion values be made, the most advantageous cues must be selected and utilized correctly. The Cuqlock and Birch study was an investigation of cue selection and utilization under conditions of differing cue validities and redundancies.

A between groups design was used to measure the effect of redundant information on cue usage. Redundancy was manipulated by varying the magnitude of the correlation between the two most valid cues ( $X_1$  and  $X_2$ ) of the five cues employed in the task. There were three groups used. One group was presented with cue/criterion values which had a .5 correlation between  $X_1$  and  $X_2$ , the second group had a .7 correlation, and the third group a .9 correlation. The validities for cues  $X_1$  through  $X_5$  were .9, .7, .5, .3, and 0, respectively, and the multiple correlation between the criterion and the five cues was approximately .95 for all three redundancy groups. Two measures of task performance were taken: (1) frequency of selection of each of the five cues (either one out of the two presented or one, two, three, four, or five out of the five presented) and (2) the correlation between the subject's predicted criterion value and the feedback value given, referred to as prediction accuracy.

Cue selection was not required of the three groups when presented with all five cues from which they were to make their predictions; a situation that allows a test of the effects of the degree of redundancy between the  $X_1$  and  $X_2$  cues on prediction accuracy. The correlation between the predicted and the feedback values for the 5-cue trials was calculated for each individual and subjected to Fisher's  $r$ - $z$  transformation. These measures, referred to as  $Z_r(5)$  for convenience, translated into average prediction

accuracy correlations of .75, .53 and .47 for the .5, .7, and .9 redundancy groups, respectively. Statistical analyses indicate that prediction accuracy is significantly better for .5 redundancy than either .7 or .9 and that the latter two conditions are not distinguishable.

Prediction accuracy for the three groups was evaluated in similar fashion when a single cue had to be selected and used in prediction. The resulting  $Z_r(1)$  values gave average prediction-feedback correlations of .68, .49, and .40 for the .5, .7, and .9 redundancy groups, respectively, and statistical analyses showed again that accuracy was best for the .5 redundancy condition and that the .7 and .9 conditions are not distinguishable.

It appears, therefore, that the groups make different selections of single cues, a conjecture supported by analyses of the Pick 1 of 5 selection data where it is found that the .5 group selects  $X_1$  70% of the time whereas the .7 and .9 groups do so only 38% and 31% of the time, respectively. This difference among the groups disappears when selections of either  $X_1$  or  $X_2$  are analyzed. Thus, not only is redundancy a factor in prediction accuracy but in selection as well, leaving the .7 and .9 groups less able to make use of the most valid  $X_1$  cue consistently in their predictions. The overall better prediction accuracy for all three redundancy groups when 5 cues are available than when a single cue must be selected for use in prediction does mean that the higher redundancy groups make use of the additional cue values but not as well as does the .5 group.

Tetrad differences analyses, (Spearman, 1927) designed to allow evidence for separate selection and prediction factors to appear, fail to suggest other than a single factor underlying the complete prediction performance. This is the case for each redundancy group, for  $X_1$  and  $X_2$  selection as well as for only  $X_1$  selection, and for 1-cue and 5-cue predictions. All subjects apparently are doing the same thing, and doing it differentially skillfully, even though task structures differ because of redundancy and the groups differ in prediction accuracy.

In still another kind of study, one of judgments of similarity of a set of simple geometric figures, data collection was carried out in extended work sessions. The task was complex and demanded that images of the figures be formed and judged for similarity. The stimuli were ten L-shaped figures

clearly located physically in two dimensions. This structure was recovered very well by multidimensional scaling using both direct ratings of similarities and pair comparison judgments.

Of most interest in this study was the question of whether subjects could use symbolic inputs to construct images of the figures which would then be judged for similarity. This task is analogous to that faced by a supervisor who receives information by symbols (e.g. words, letters, numerals) but must process this information cognitively to make visual comparisons.

Subjects received associative training of one of two types relating letters to the L-shaped figures. The "elements" training required that letters be individually associated with the vertical and horizontal segments of the L-figures; the "configural" training provided for associations between letter pairs and the complete figures. During training subjects were instructed to form the appropriate image to the letter but their capability for doing this was tested in the opposite direction; that is, they had to report the proper letters to the visual stimuli.

Similarity judgments were collected for stimuli that were all symbols and for mixed sets of symbolic and visual stimuli and the resulting multidimensional scaling structures were compared to those found for the purely visual stimuli. All structures are remarkably close to that defined by the physical characteristics of the L-figures indicating great accuracy of imaging and a high level of cognitive processing during comparisons. These results suggest that good performance can be expected from supervisors and monitors of complex systems who must make judgments of this kind under mixed input conditions over extended periods of time.

### C. List of All Publications

- Birch, D. (1984). A model of fixed activation time scheduling. Journal of Mathematical Psychology, 28, 121-59.
- Birch, D. (1986). From the dynamics of action to measuring the stream of behavior. In J. Kuhl and J. W. Atkinson (Eds.), Motivation, Thought, and Action. New York: Praeger Publishers.
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### D. Participating Scientific Personnel

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- 1 - Ph.D. dissertation was supported by contract funds
- 2 - Earned Ph.D. degree during contract period
- 3 - M.A. thesis was supported by contract funds
- 4 - Earned M.A. degree during contract period

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