SYSTEM RESPONSE TIME, OPERATOR PRODUCTIVITY AND JOB SATISFACTION

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ABSTRACT

This study examines the impact of on-line system response time on CRT operator productivity and job satisfaction. It was predicted that increase in response time would affect total transaction volume and total errors adversely, that is, total transaction volume would decrease with longer response times and total errors would increase. Total productive transactions, the difference between total transactions and total errors, was expected to decrease as response time increased. Operator job satisfaction was also expected to decrease.

The study confirmed the prediction with regard to total transactions and productive transactions: both decreased as response time increased. Total errors actually decreased as response time increased, up to times of 12 seconds. When response time exceeded 12 seconds, errors increased. The impact of response time on productivity suggests nearly all transactions should be completed in 12 seconds or less. Beyond this level, the organization in the study suffered severe penalties in lost productivity. A relationship was also found between increased response times and reduced job satisfaction.

INTRODUCTION

Over the past several years, many companies have implemented on-line computer-based information systems. With each such implementation, previous manual or computerized batch processing methods used to process the same data are discontinued. Once this occurs, it is generally not possible to revert to the old procedures. The result is increasing dependence upon on-line computer systems.

With such dependencies and a growing community of on-line system operators, user groups become increasingly sensitive to response time and system down time. Slow or unavailable systems interfere with a group's productivity - the ability to complete their work on a timely basis (Streeter, 1975). In addition, many user department managers strongly believe that poor response time has an adverse effect on the job satisfaction of operators.

The cost of user job dissatisfaction is potentially high, since greater turnover, lower moral and a lower willingness to pursue company objectives are believed to result (Strauss and Sayles, 1972). Absenteeism, tardiness, longer lunch hours and coffee breaks may also occur. There is also evidence that dissatisfaction with computer-based systems can lead to resistance to the system on the part of users or even deliberate sabotage (Lucas, 1978). Apparently, job satisfaction is also an important factor in both the physical and mental health of workers. (Locke, 1978).

PREVIOUS RESEARCH

Miller (1968) hypothesized that if system response time is delayed more than a few seconds beyond the time when the operator is ready to begin the next transaction, operator performance will deteriorate. That is, total transactions submitted will decrease faster than the rate suggested by the longer response time. At the same time, errors will increase.

A number of articles address this topic but only a few are based upon empirical evidence (Carbonell, 1968; Didner, 1970; Nickerson et al, 1968; Shackel, 1969; Parsons, 1970; Boies and Gould, 1971). Morfield, et al (1969) reported that operator response time increased with system response time, supporting Miller's hypothesis and Boies (1974) and Williams (1975) confirmed this conclusion.

Williams (1973) determined that mean response times of two and four seconds were "tolerated" by subjects. When subjected to mean delays of eight seconds, most individuals used a pre-empt feature that resulted in an immediate system response. He concluded that "some type of operator criteria" was exceeded by the eight second response time.

Miller (1976) varied the output baud rate (1200 or 2400) and the variability of output in an experimental setting. He reports that the baud rate made no difference in problem performance measured by time to complete a task; however, increasing the variability of the output display rate resulted in decreased performance and poor user attitudes.

Goodman and Spence (1981) found that variability in response time did not affect students in a problem-solving experiment. However, the task required fitting a line on an interactive, graphics terminal and these results may not generalize to the commercial environment.

Williges and Williges (1982) found that increased system response time adversely affected performance in an experiment with subjects updating and entering personnel records.

Most of these studies suggest that at some point, response time interferes with the ability of operators to work at their own pace. Thus, when response time is excessive, both productivity and job satisfaction are affected adversely.

Unfortunately, most of the articles cited have shortcomings. The only subjects used in the Morfield study were Morfield and his three associates. Both C.M. Williams and J.D. Williams used typists as subjects; none worked as on-line system operators on a regular basis. Slow speed (300 baud) terminals were used in some of the research.

Most operators in industrial situations encountered by the authors use high speed (1200 to 9600 baud) Cathode Ray Tube (CRT) terminals. CRT terminals are silent and generally display an entire screen of information (up to 1920 characters) in one short burst. It is not clear that results derived from the use of slow-speed mechanical terminals are necessarily applicable to systems using CRT terminals (Prokop and Brooks, 1970).

One study that utilized CRT terminals concluded that response time had no impact on operator performance (Williams, et al. 1976). Unfortunately, non-typists who were unfamiliar with the use of on-line systems were used as subjects. Operators of most on-line systems both type well and develop significant skills in the use of their system. In addition, they utilize the system on a daily basis for extended periods of time. Being the major tool for performing their jobs, it would appear that the system, its design, performance and ease of use would have some impact on the way operators feel about their jobs.

Considerable research has been conducted on the relationships between productivity and job satisfaction. The classical "human relations" viewpoint suggests that the satisfied worker was a productive worker (Wanous, 1974). More recent research, however, indicates that there are significant difficulties in simultaneously achieving high levels of job satisfaction and productivity (Katzell and Yankelovich, 1975).

The current view that generally prevails is that job productivity and job satisfaction have a reciprocal relationship, with one resulting in the other. The stronger relationship, however, is believed to be between productivity and job satisfaction (Wanous, 1974). In addition, there is evidence that errors and job attitudes are inversely related (Walther and O'Neil, 1974).

RESEARCH MODEL AND HYPOTHESES

Research Model

In order to study the impact that response time has on operator productivity and job satisfaction, the research model shown in Figure 1 was developed. Each box in the model represents a measurable variable. "System Response Time" is the average response time experienced by on-line system users. "Total Transactions" is the number of transactions processed per terminal per day and "Total Errors" is the number of transactions rejected per terminal per day. "Operator Productivity" is the total number of useful transactions, that is, the difference between total transactions and total errors. "Job Satisfaction" is measured using the results of a modified Job Descriptive Index (JDI) questionnaire. (Smith, et al. 1969)

The solid lines indicate the relationships investigated by this study. The hypotheses test for the existence of these relationships and the direction of any resulting change. The broken lines indicate relationships that may also be present, as suggested by the literature on productivity and job satisfaction. Such relationships, however, are beyond the scope of this study.

The discussion below describes the approach taken to test the model in Figure 1. For the first three hypotheses it is possible to place restrictions on the form an equation must take to satisfy the actual conditions under which operators work. There are, however, several possible functional forms for the relationships predicted in the model. The researchers have chosen the most parsimonious equations that fit the conditions under which the system operates.

Hypotheses

Previous research and interviews with on-line system operators suggest that increasing response time affects the dependent variables of the model unfavorably.

1.) <u>Total Transaction Volume</u>. If response time was instantaneous operators would require less time to complete each transaction and more time would be available for processing other transactions. If response time increases, less time is available for processing other transactions.

HYPOTHESIS 1 - Total transaction volume varies inversely with system response time.

There are several requirements for an equation to test Hypothesis 1:

1) No transactions will be processed from a terminal if the terminal is not used.

2) If the system is "down," no transactions can be processed.

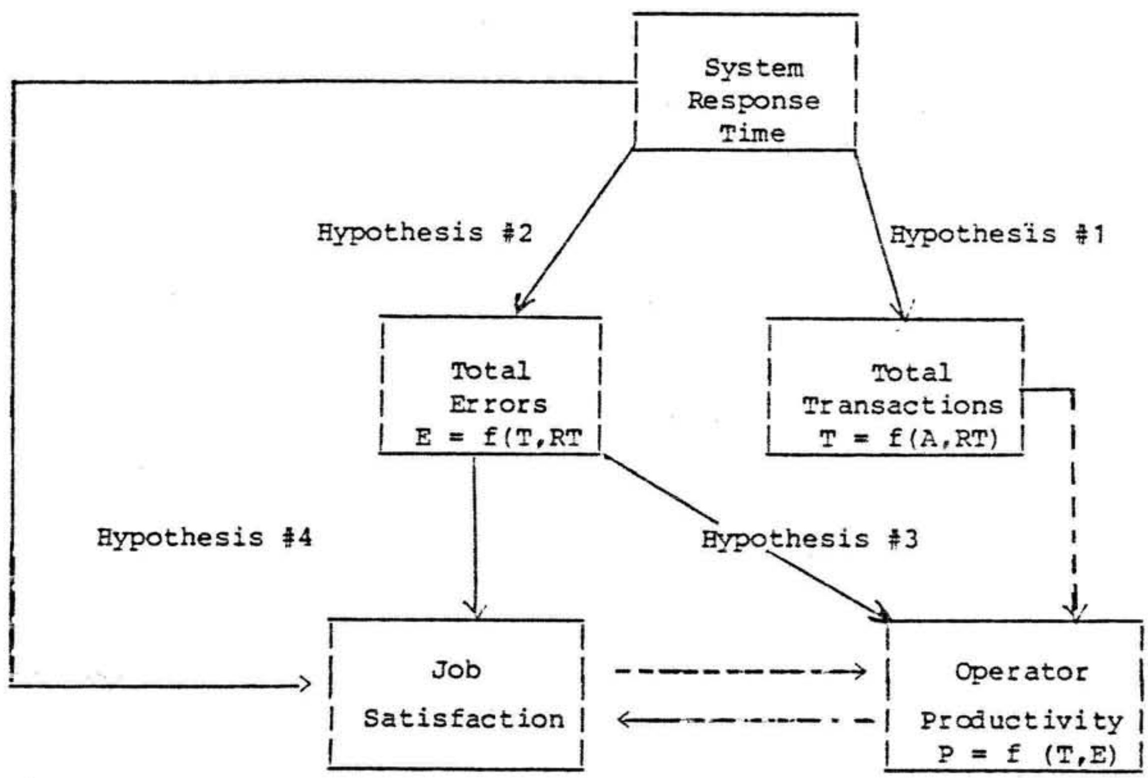

Figure 1 - Research Model

3) Response time reduces the time available to process other transactions.

4) Total transactions are limited by the total time available to process transactions during the measurement period.

Equation (1) satisfies these four requirements:

(1) $$T = \alpha A^{\beta} \exp^{-\gamma RT}$$

Where: T = total number of transactions per day
α = average number of transactions processed per minute when response time = 0
A = active daily terminal time in minutes
β = fatigue factor
exp = base "e" = 2.7183
γ = time rate of change in number of transactions per day due to response time
RT = response time

(The unit of measurement is transactions per day)

In order to submit a transaction to the computer, an individual must spend time at a terminal entering the necessary information. If no time is spent at the terminal, no transactions will be processed. The slope of transaction volume versus active time must be greater than zero.

$T = 0$ when $A = 0$ (no transactions are processed when active time is zero)

$\frac{dT}{dA} > 0$ (transactions increase when active time increases)

Total available time is controlled by the number of hours per day available to process transactions. Since the total number of hours is finite, the total transaction volume must be finite. Thus:

$T = \infty$ when $A = \infty$ (transaction volume is infinite only when active time is infinite)

Operator activities are those action such as "think" time and typing time required to complete a transaction. The maximum speed of these activities depends upon the design of the system (i.e., how many fields must be completed, how much research must be done by the operator to complete each field, the availability of information, etc.) and the typing skills and intelligence of the operator. Such factors determine the value of ", the maximum number of transactions that can normally be processed per minute by the work force using the system.

As the workday progresses, the effectiveness of operators is generally reduced due to fatigue, lowering the rate that they process transactions. This means that the slope of transaction volume versus active time is not constant but must decrease as total active time increases.

$\frac{d^2T}{dA2} < 0$ As active time increases, it causes a smaller and smaller increase in total transactions)

If an on-line system is "down" (i.e., not available), no transactions can be processed and response time can be considered to be infinite.

$T = 0$ when $RT = \infty$ (When response time is infinite, no transactions are processed)

Response time represents time spent at the terminal waiting for "something to happen." Generally, an operator accomplishes nothing during this interval. So the longer the interval, the less time will be available to process additional transactions and vice versa. Thus, transaction volume decreases as response time increases as proposed by Hypothesis 1.

$\frac{dT}{dRT} < 0$ (Transactions decrease when response time increases)

Transaction volume is zero when response time is infinite (i.e., the system is "down"), assuming someone spends time at the terminal attempting to process transactions. Knowing this, one can conclude that the relationship between transaction volume and response time cannot be linear. If it were linear, transaction volume would have to equal zero at a value of response time much less than infinity. From observing on-line system operation, some transactions are processed even when response time exceeds one minute or more. In order to approach zero asymptotically, increases in response time must cause less and less of a reduction in transaction volume. This means that the slope of the function cannot be constant, but must increase (i.e., approach zero) as response time increases.

$\frac{d^2T}{dRT2} > 0$ (As response time increases, its impact on transaction volume decreases)

2) <u>Errors</u>. When response time becomes lengthy, operators are likely to lose their place in required sequences, become distracted, or lose their train of thought. When this occurs, it is anticipated that errors will increase. Thus, the longer the response time, the greater the number of errors and vice versa.

HYPOTHESIS 2: Errors or error rates vary directly with system response time.

This hypothesis is based upon the research of Williams (1975) who found that errors were essentially constant when response time was less than 15 seconds. Between 15 and 30 seconds, however, they increased sharply. Equation (2) can be used to test Hypothesis 2:

(2) $E = \lambda T^{\mu} \exp^{\psi RT}$

where:
- E = total number of errors per day
- λ = base error rate per transaction
- T = total transaction volume
- μ = learning or experience factor

exp = base "e" = 2.7183
Ψ' = rate of change in errors per day due to response time
RT = response time

This model states that errors are equal to zero when no transactions are processed. The constant factor "λ" says that individuals make more errors as they process more transactions. At the same time, the exponent "μ" suggests that as operators process more transactions, they become more proficient and tend to make errors at a decreasing rate.

E = 0 when T = 0 (no errors occur when no transactions are processed)

$\frac{dE}{dT} > 0$ (errors increase as transactions volume increases)

$\frac{d^2E}{dT^2} < 0$ (errors increase more slowly as transaction volume increases)

The exponential term allows minimum errors to occur when response time is equal to zero. In addition, it enables errors to increase at an increasing rate as response time increases.

$\frac{dE}{dRT} = 0$ when RT = 0 (Errors are at a minimum when RT = 0)

$\frac{dE}{dRT} > 0$ when RT > 0 (Errors increase as response time increases)

$\frac{d^2E}{dRT^2} > 0$ when RT > 0 (Errors increase more quickly as response time increases)

where:

$\frac{dE}{dRT} =$ first derivative or slope of errors with respect to response time

$\frac{d^2E}{dRT^2} =$ second derivative or rate of change of the slope or errors with respect to response time

3) Productivity. A productive transaction is one that does not contain errors. When a transaction is rejected by the system, it must be corrected and resubmitted. Total productivity is the difference between the total transaction volume and total errors.

HYPOTHESIS 3: Operator productivity varies inversely with system response time.

Operator productivity is the difference between total transactions and total errors:

(3) $P = T - E$

Where: P = total productive transactions
T = total transaction volume
E = errors

This expression is estimated by a direct substitution of the expressions for total transactions and total errors. Thus, Hypothesis 3 is dependent upon the results of testing Hypothesis 1 and Hypothesis 2.

Job satisfaction. When response time is slow, operators become concerned about the cause of the poor response time, apparently affecting their actions in and feelings about their jobs. When response time is adequate, system performance is taken for granted and is not a factor. Thus:

HYPOTHESIS 4: Feelings of job satisfaction are affected adversely by longer system response time.

As explained in detail below, the fourth hypothesis was tested through the administration of the JDI at three points in times.

RESEARCH DESIGN

Environment

The research was conducted in the Circuit Layout (CL) organization of a large midwestern utility. CL has over one hundred clerks who utilize five on-line systems with a total transaction volume exceeding 70,000 per day. The purpose of the organization is to issue circuit orders, actually instructions to make specific connections, disconnections or modifications to interstate telephone circuits.

Operator preparation of transactions is somewhat complex. First, the operator must determine the requirements for a circuit from a printout that is provided. Typical requirements are add, change, discontinue, redesignate, cancel and modify. If the circuit is to be added, the operator must enter one transaction to determine if the offices, or locations, the circuit is to run between are defined and valid. If one or more of the offices are not defined, the operator must conduct research and complete the definition.

Once the definitions are verified, the operator enters a second transaction to determine if a route (or routes) between intermediate telephone offices is defined. If it is and has spare capacity, the route is selected. If a route is not defined or the route has no available capacity, the operator must consult with various engineers to establish a route, determine an appropriate route with capacity or determine if equipment will be released on the desired route in time to meet due dates.

Up to now, the operator has simply verified information relevant to the circuit. From this point on, transactions generate changes to databases and instructions to field personnel to make changes to physical circuits.

The third transaction is an inquiry to locate spare transmission equipment to which the circuit can be assigned. If no spare equipment exists, consultations with others is again required. The fourth transaction reserves the appropriate equipment for this circuit. The fifth transaction is an inquiry to locate spare office equipment for the circuit. Additional transactions may be required if the first transaction fails to identify the required spare equipment. Once located, an additional transaction is required to reserve the equipment.

At this point, a transaction is entered that generates a telegram to the telephone engineer who is located in another city, and the operator proceeds with the remaining steps of the circuit order. The first transaction in this process involves the entry of administrative data, including the circuit order number, due date, mileage, reason for adding the circuit, and various technical information. All of this data is either included on the source documents or is derived by the operator using decision tables or other aids.

Next, circuit layout data is defined, describing the equipment reserved and routes defined earlier. This task could require numerous transactions, but is usually five or less. A single transaction is then entered to include notes or any special information relevant to the circuit, completing entry for that circuit.

The CL operation is totally dependent upon on-line systems. When the systems are "down", work functions cannot be completed. Manual methods were discontinued and forgotten several years ago. In the past, when response time became slow,[1] users maintained that system performance was interfering with their ability to complete their jobs on schedule. A significant amount of overtime was required in some cases to complete necessary work functions.

Experimental Design

Over 100 CRT terminals are located on the third floor of CL's main building. Of these terminals, 19 are isolated and these terminals and their operators constituted an experimental group. The remaining terminals and operators formed a control group.

The JDI questionnaire was administered to both groups in a conference room in sessions of fifteen to twenty individuals before the experiment began. On the twelfth calendar day following the first session, response time for the experimental group was degraded from an average of about six seconds to 14 seconds where it remained for four days. Neither the operators nor their supervisors were aware of the change. The control group's average response time was maintained at the six second level.

During the morning of the day that response time returned to normal, the JDI questionnaires were repeated. The subjects were instructed to indicate how they currently felt and not to try to remember what their previous answers may have been. About eight weeks after the second session, a third questionnaire session was held.

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[1]At one point in the past, average response time varied between 15 and 20 seconds.

Data Collection

Data on transactions volumes, active time and response time were monitored by the system. The unit of analysis in this study is the person-day; there were 1174 person-days worth of observation. Each person-day provides one value for active time, total number of transactions, average response time (for all of the operator's transactions that day) and total errors.

The Job Descriptive Index (JDI) questionnaire completed by the operators asks respondents to put a "Y" beside an item if it describes that aspect of their jobs using on-line computer systems. If the item does not describe that aspect of their job, they put an "N" beside the item. If they cannot decide, they place a "?" beside the item. The scoring of the JDI results in a score of 3 if someone is satisfied with a specific aspect of a job and a score of 0 if someone is dissatisfied. Response time, transactions volume, error rates and other data were gathered from on-line system log tapes. This information was collected for the three days prior to each questionnaire session.

DATA ANALYSIS AND RESULTS

Total Transaction Volume

To test Hypothesis 1, a linearized form of Equation 1 was estimated using regression analysis with the response time and transaction volume data collected before each questionnaire session. See Equation (4)[1] and its graph, Figures 2a and 2b.

(4) $T = 2.53\, A^{.917} \exp^{-.032RT}$

T = total number of transactions per day

A = Active time in minutes

RT = response time

[1] $R^2 = .81$ SEE = .3024 F = 2531.7 P .001

$T_{RT} = 10.5$ P .001 $T_A = 70.0$ P .001

Linearized Form $\ln T = \ln \alpha + \beta \ln A - \gamma RT$

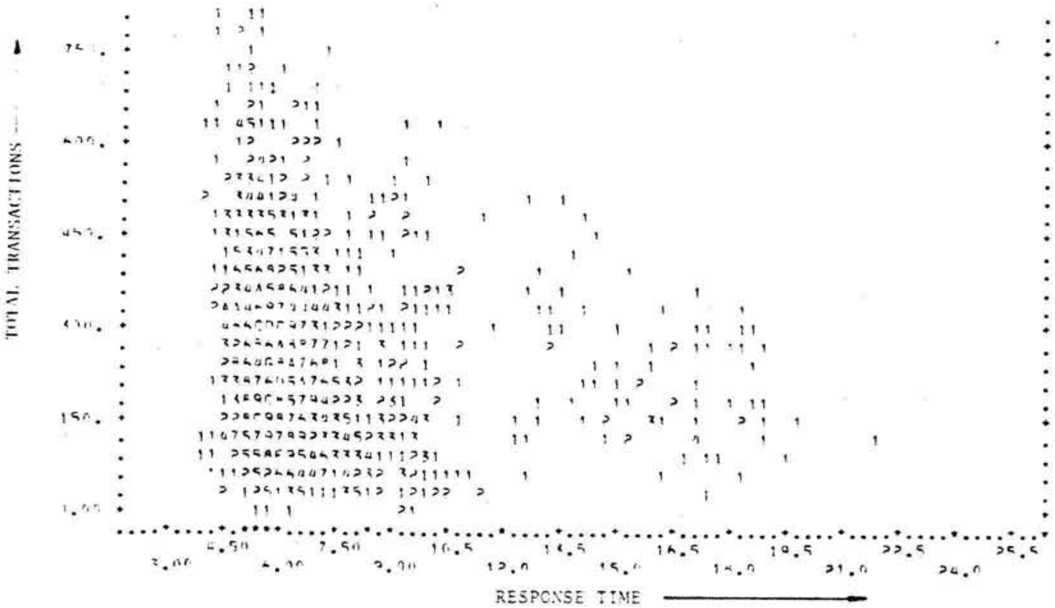

Figure 2a - Scatter Plot - Total Transaction Volume vs. Response Time

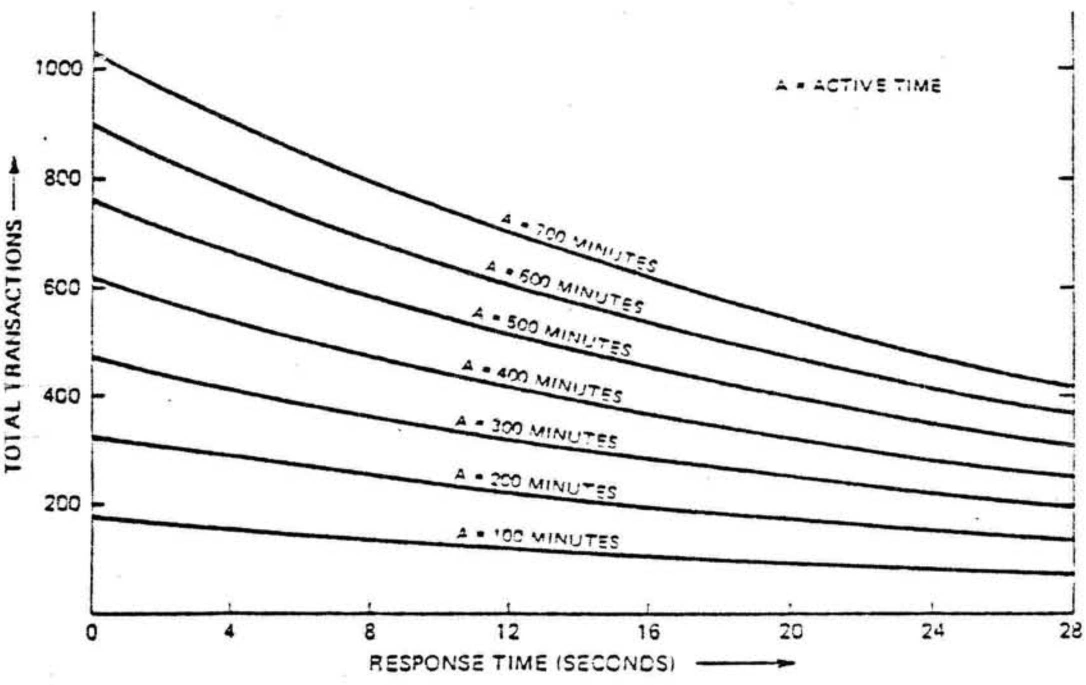

Figure 2b

The negative exponential in this equation indicates that total transactions decline for each additional second of response time. The results strongly support Hypothesis 1: transaction volume is inversely related to response time.

Total Errors

To test Hypothesis 2, data were used to estimate a linearized version of Equation (2). Examining the residuals (the difference between the actual and estimated values of total errors) from the regression on a problem was apparent. Almost all residuals above the 10 to 13 second range were positive, indicating total errors is this region were greater than estimated by the equation. The scatter plot indicated that errors do appear to increase beyond this level. Therefore, the relationship of total errors to response time must be "U" shaped and an appropriate model is:

$$(5)\quad E = \lambda T^{\mu} \exp^{(-\phi(RT-K)D_1 + \delta(RT-K)D_2)}$$

Where: E = total errors
λ = base error rate per transaction
T = total transactions
μ = learning or experience factor
exp = base "e" = 2.7183
K = response time where minimum errors occur
ϕ = rate of change when response time less than "K" seconds
δ = rate of change when response time greater than "K" seconds
RT = response time

The new model has the same relationships with respect to total transactions as before. Total errors decrease at response times less than "K", the breakpoint between decreasing and increasing errors. They increase at response times greater than "K".

$$\frac{dE}{dRT} < 0 \quad \text{when } RT < K \text{ seconds}$$

$$\frac{dE}{dRT} > 0 \quad \text{when } RT > K \text{ seconds}$$

$$\frac{dE}{dRT} = 0 \quad \text{when } RT = K \text{ seconds}$$

In order for errors to be minimized when response time is equal to some finite, non-zero value, the rate of decrease in errors must decrease as response time approaches the breakpoint K. When response time is greater than K, increasing response time would cause the rate of increase in errors to increase. This means that the following must be true:

$\frac{d^2E}{dRT2} > 0$ when $RT \neq K$ (Errors decrease at a decreasing rate below RT = K; Errors increase at an increasing rate above RT = K

A regression analysis on a linearized form of Equation 5 using the error and response time data collected before each questionnaire session and the fitted values[2] of total transaction volume from Equation (4) produces Equation (6)[3]:

$$(6)\quad E = .1757T_f^{.836} \exp(-.112(RT-12)D_1 + .15(RT-12)D_2)$$

Where: E = total errors
T_f = fitted values for total transactions for Equation (4)
RT = response time
D_1 = 1 when response time is less than 12 seconds
0 otherwise
D_2 = 1 when response time is greater than 12 seconds
0 otherwise

[2]This is commonly called "Two stage least squares". It is necessary to eliminate the impact of random errors from the first equation on the second.

[3]$R^2 = .38$ F = 243 SEE = .7335 $T_{TF} = 24.2$ ($p < .001$)
$T_{RT_1} = -8.1$ ($p < .001$) $T_{RT_2} = 6.2$ ($p < .001$)
Linearized Form: $\ln E = \lambda \ln + \mu \ln T_f + \phi(RT-K)D_1 + \delta(RT-K)D_2$

The function is graphed in Figure 3; twelve seconds was determined to be the point of minimum errors by minimizing the sum of squared residuals at various response time levels.

This equation partially supports Hypothesis 2 which was based upon the conjecture of previous authors and a study by Bell Laboratories (Miller, 1968; Williams, 1975). Beyond 12 seconds for the CL system, the short-term memory of operators apparently begins to be exceeded, resulting in loss of place in required sequences, forgotten codes required for the next entry, etc.

As response time increases, operators apparently work more slowly. Perhaps they double-check entries, look up codes, etc., because they know the response time will be non-trivial. If they submit an incorrect entry, they must correct and re-enter it, incurring the response delay twice for a single transaction.

Operator Productivity

Equation (1) for total transactions and Equation (6) for total errors form a set of two simultaneous equations which were to evaluate Equation (3) on productivity. First, the value for "T" was estimated and the result substituted into the error equation. The difference was then computed to arrive at the number of productive transactions. Results are shown in Figure 4.

Figure 4 supports Hypothesis 3 for the systems in the research: total productivity is inversely related to response time.

Job Satisfaction

Methodology. To explore the relationship between response time and job satisfaction data, matched t-tests, F-tests and cross-lagged correlations[6] were used. First, a principle components factor analysis using varimax rotation was performed on questionnaire data from the first session for both the control and experimental group.

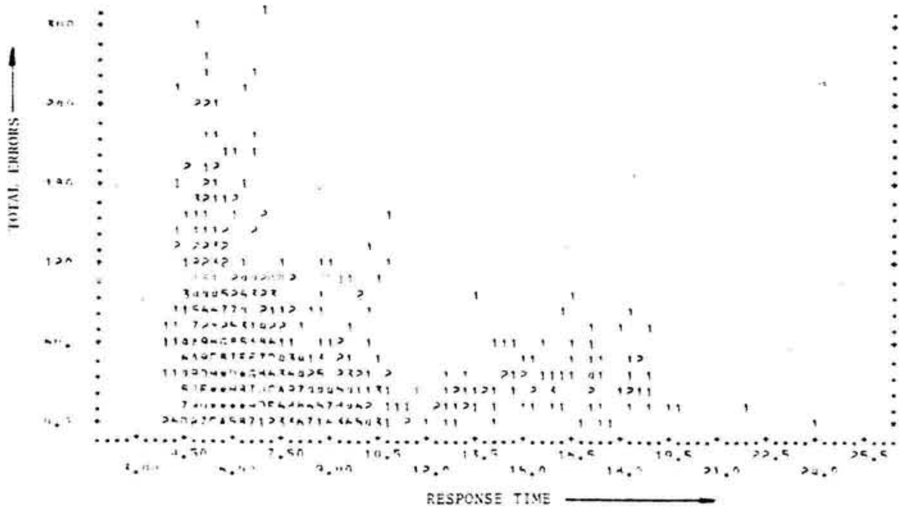

Figure 3a - Scatter Plot-Total Errors vs. Response Time

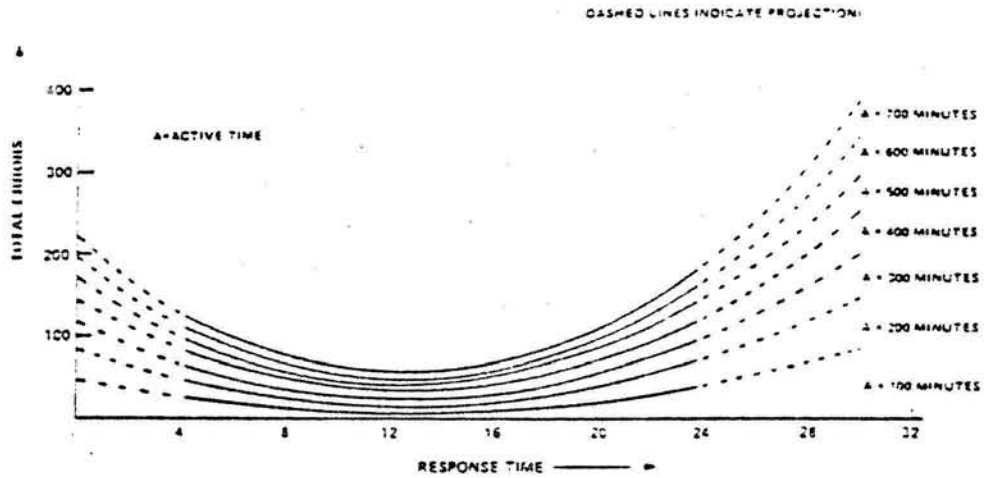

Figure 3b - Total Errors vs. Response Time
(From Equation 6)

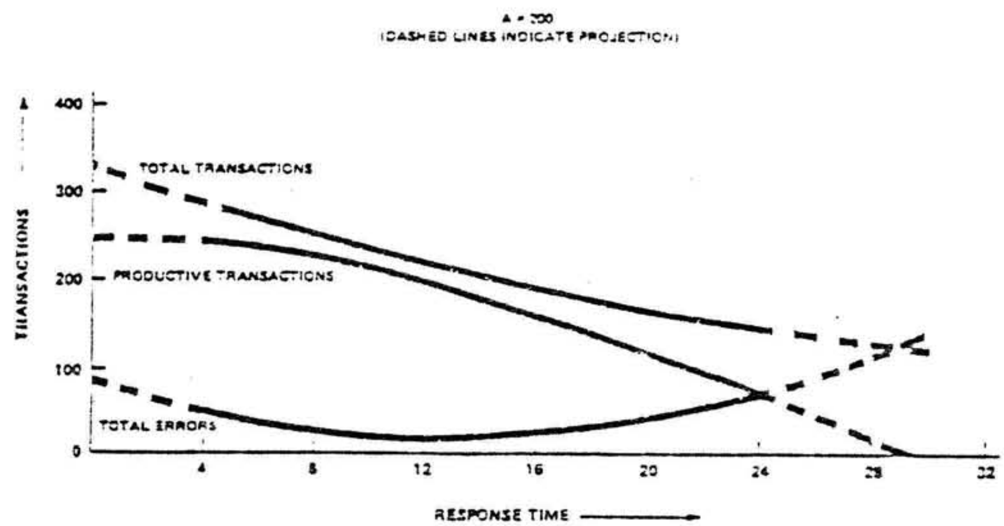

Figure 4 - Transactions, Errors, Productivity

The purpose of factor analysis is to identify variables that cluster together, an indication they are measuring closely related items. These items are grouped together by averaging the response to each of the questions in the group for each individual. The results of the factor analysis suggested the grouping of variables into factors shown on Table 1.

The results were used to compute difference scores for each individual between the various questionnaire sessions (i.e., time 1 minus time 2; time 2 minus time 3; time 1 minus time 3). These difference scores were used to perform tests to determine if statistically significant changes between the control and experimental groups had occurred.

Figure 5 illustrates the approach used in cross-lagged correlation analysis. The purpose is to isolate the cause and direction of a change in the value of a variable. It involves measuring two variables at two points in time. Six correlations are computed, one for each pair of variables.

The correlations r_1 and r_3 are called synchronous correlations, r_2 and r_4 are autocorrelations (correlation of a variable on itself at a later point in time), r_5 and r_6 are called cross-lagged correlations.

If the cross-lagged correlation that has the greatest magnitude is positive:

$$r_6 > r_1 = r_3 > r_5$$

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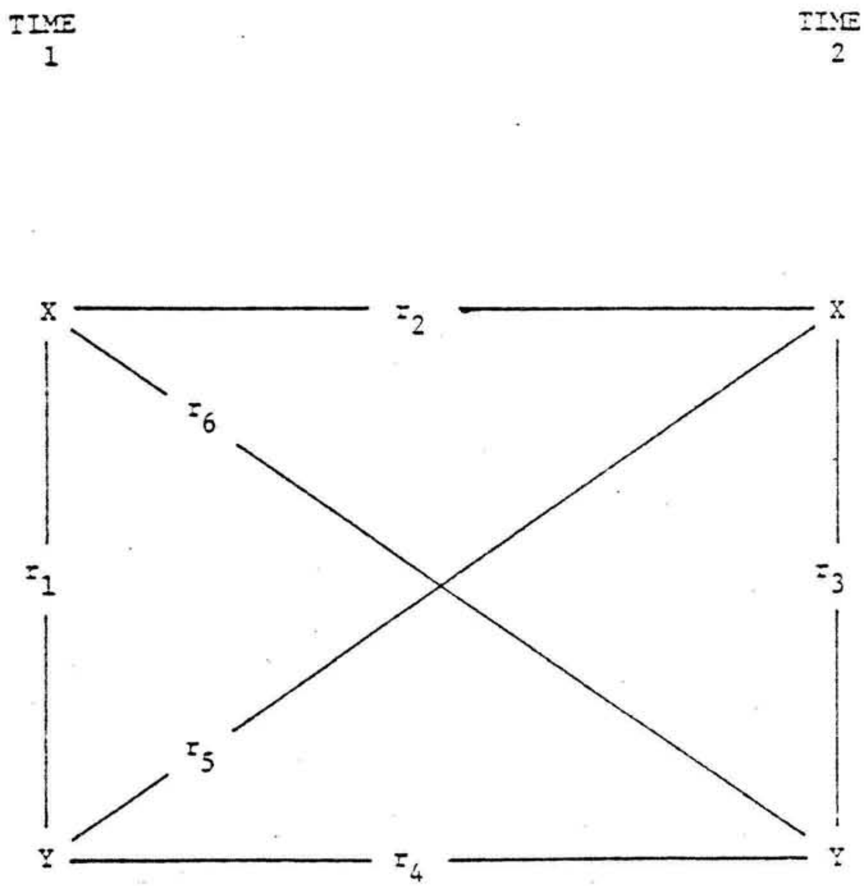
[6]David A. Kenny, "Cross-Lagged Panel Correlation: A Test for Spuriousness", Psychological Bulletin, Vol. 82, No. 6, 1975, p. 887-903.

FIGURE 5 - Cross Lagged Correlations



r_1 & r_3 - synchronous correlations

r_2 & r_4 - autocorrelations

r_5 & r_6 - cross-lagged correlations it would be possible to conclude one of the following:

1) Y causes a decrease in X

2) X causes an increase in Y.

If, on the other hand:

$$r_6 < r_1 = r_3 < r_5$$

we could conclude either:

1) Y causes an increase in X

2 X causes a decrease in Y.

Table 1 - Definition of Factors

Factor Name	Variable Names
Co-Worker Traits	Stimulating, Boring, Slow, Ambitious, Stupid, Fast, Intelligent, Easy To Make Enemies, Smart, Lazy, Unpleasant, Active, Loyal.
Response Time	Response Time Too Slow, The Response Time Lately Slows Me Down.
Income	Income adequate for normal expenses, underpaid, bad.
Supervisor Abilities	Influential, Up To Date, Knows Job Well, Intelligent, Around When Needed.
Supervisor - Shortcomings	Hard To Please, Impolite, Doesn't Supervise Enough, Hard To Meet.
Supervisor - Relationships	Praises Good Work, Tells Me Where I Stand.
Satisfaction	Fascinating, Routine, Challenging.
Job - Environment	Creative, Healthful.
On-Line System Use	I Enjoy Using On-Line Systems, I Like The Terminal I Use Most Often.
System Down Too Much	System Down Too Much.
System Performance and Design	Sum of system questions
Supervision	Sum of supervision questions

If the cross-lagged correlation that has the greatest magnitude is negative, the conclusions are reversed.

In the present situation, Y is response time. Since response time is controlled by the computer, response time can only affect satisfaction scores; satisfaction scores cannot affect response time.

Using the grouping of variables to factors shown on Table 1, both matched "t" tests and "F" tests were performed on difference scores to determine if a change in satisfaction had occurred. Table 2 shows the factors that demonstrated statistically significant changes. The matched "t" tests, as shown in the table, indicate the presence of change in the average responses of individuals between the control and experimental groups. Changes, however, can occur in both directions simultaneously, canceling any effect on the average. Therefore, the "F" test was computed to determine the presence of high variability in the responses.

The statistically significant cross-lagged correlations are shown on Figure 6. These results partially support Hypothesis 4: feelings of job satisfaction are adversely affected by poor response time. The direction of change summarized below indicates an increase or decrease in satisfaction, based upon the difference scores in the experimental group as compared to the control group. Except as noted, changes occurred in the experimental group while the control group remained stable.

COWORKER TRAITS - Showed a mild improvement with poor response time. It decreased when response time returned to normal.

TABLE 2 - Significance Tests

FACTOR	Difference Scores Session 1 - Session 2: Experimental Group N = 16 AVG.	VARIANCE	Control Group N = 70 AVG.	VARIANCE	T	F
Coworker Traits	- .09	.19	- .01	.18	NS	NS
Response Time	.78	1.37	.34	1.85	1.31^{a}	NS
Income	- .04	.58	[illegible]	.48	NS	NS
Supervisor Abilities	- .11	.79	- .04	.30	NS	[illegible]
Supervisor Shortcomings	- .32	.92	.03	.29	-1.41^{a}	[illegible]
Frustrating	.30	.29	.17	1.10	NS	3.78^{d}
Satisfaction	.22	.76	- .10	.44	1.38^{a}	1.74^{a}
Supervisor Relations	- .27	.92	.05	1.02	-1.19←	NS
Job Environment	.40	.44	.12	.66	1.43^{a}	NS
On-Line System Use	.31	.49	.10	.34	1.12←	NS
Luxuries	.05	.25	.11	.49	NS	1.96^{a}
System Down Too Much	- .38	.98	.16	2.59	-1.72^{b}	2.64^{c}
System Performance & Design	3.13	15.21	.94	30.58	1.86^{d}	2.01^{b}

FACTOR	Difference Scores Session 2 - Session 3: Experimental Group N = 16 AVG.	VARIANCE	Control Group N = 57 AVG.	VARIANCE	T	F
Coworker Traits	- .05	.08	- .16	.34	1.01^{a}	4.29^{d}
Response Time	- .58	1.14	.03	1.54	-1.82^{b}	NS
Income	- .13	.18	.07	.40	-1.34^{a}	2.15^{b}
Supervisor Abilities	- .02	.81	.07	.74	NS	NS
Supervisor Shortcomings	- .17	.38	.06	.90	-1.08←	2.35^{b}
Frustrating	- .21	.77	- .08	.79	NS	NS
Satisfaction	- .22	.81	- .02	.50	NS	NS
Supervisor Relations	.49	1.42	- .15	1.37	1.76^{b}	NS
Job Environment	.19	.56	- .10	.83	1.21←	NS
On-Line System Use	- .27	.25	0.00	.48	-1.63^{a}	1.90^{a}
Luxuries	.08	1.23	.06	.30	NS	4.07^{d}
System Down Too Much	- .08	1.46	- .35	2.79	NS	1.90^{a}
System Performance & Design	-3.85	19.18	- .06	35.28	-2.25^{d}	1.84^{a}

FACTOR	Difference Scores Session 1 - Session 3: Experimental Group N = 16 AVG.	VARIANCE	Control Group N = 60 AVG.	VARIANCE	T	F
Coworker Traits	- .14	.30	- .18	.67	NS	NS
Response Time	.23	2.59	.28	2.50	NS	NS
Income	- .05	.66	.24	.49	-1.32^{a}	NS
Supervisor Abilities	- .15	.45	.06	.79	NS	1.76^{a}
Supervisor Shortcomings	- .43	1.06	.11	1.02	-1.32^{b}	NS
Frustrating	.16	1.00	.02	.98	NS	NS
Satisfaction	- .10	.83	- .10	.72	NS	NS
Supervisor Relations	.03	2.37	0	1.23	NS	1.92^{a}
Job Environment	.53	.92	- .01	.88	2.01^{c}	NS
On-Line System Use	- .07	.49	.06	.72	NS	NS
Luxuries	.07	1.27	.22	.32	NS	2.25^{b}
System Down Too Much	- .47	1.04	- .33	3.57	NS	3.43^{d}
System Performance & Design	-1.00	30.58	.17	36.00	NS	NS

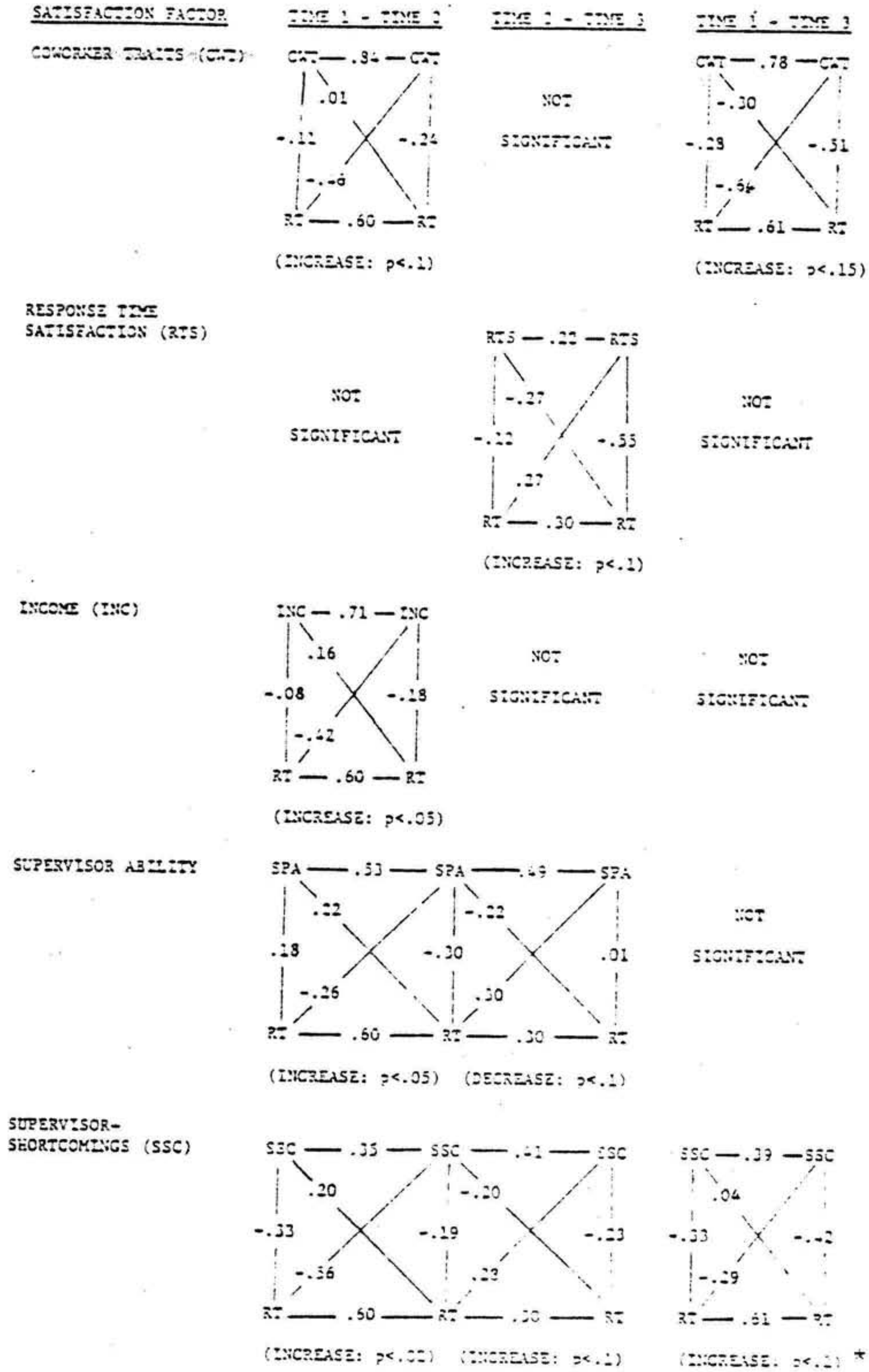
SYMBOLS INDICATE FOLLOWING PROBABILITY OF ERROR:

a $p < .10$
b $p < .05$
c $p < .025$
d $p < .01$

NS Not Significant
← $p < .15$

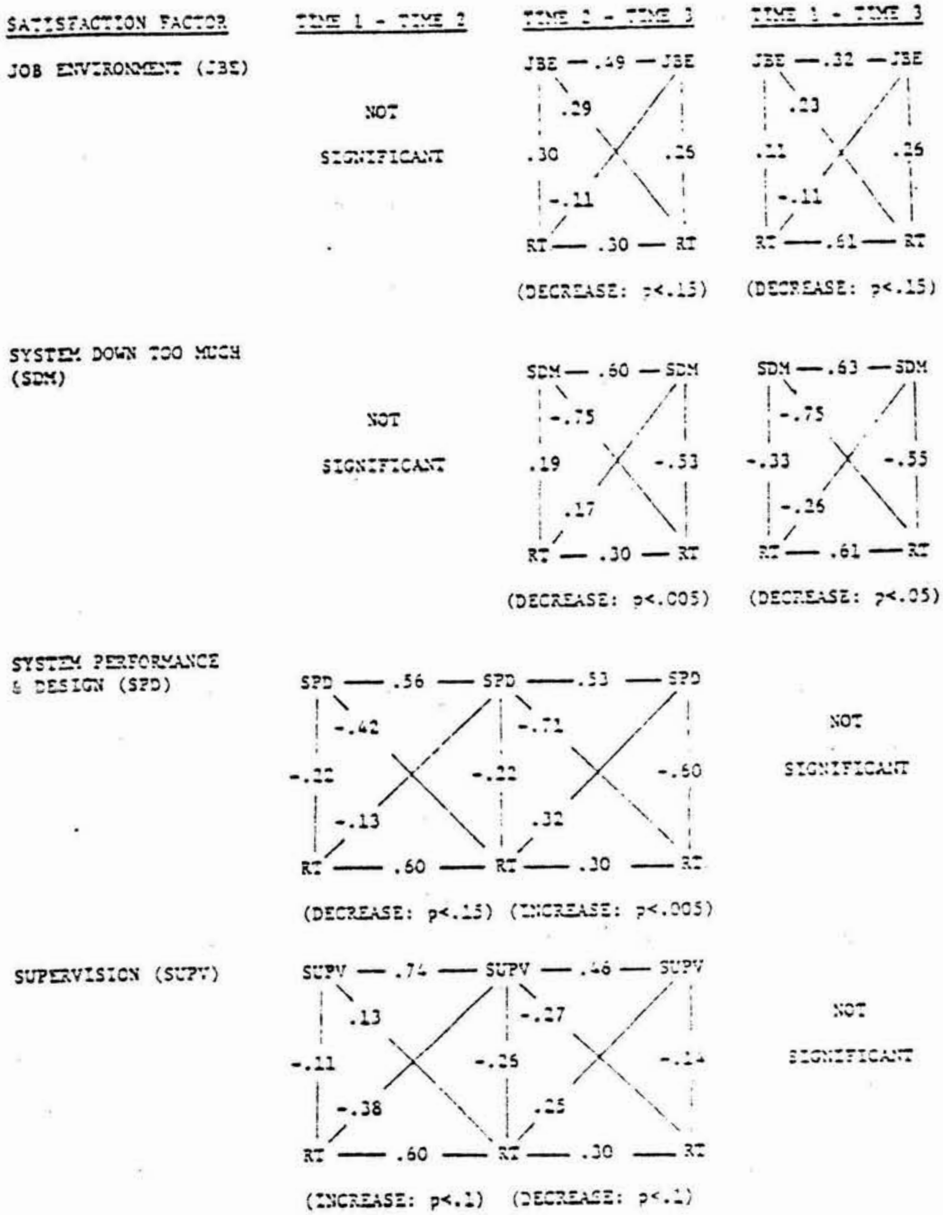
Note: Positive difference score indicates decrease in satisfaction. Negative difference score indicates increase in satisfaction.

FIGURE 6 - CROSS-LAGGED CORRELATIONS - RESULTS



* shown for completeness

FIGURE 6 - CROSS-LAGGED CORRELATIONS - RESULTS (cont.)



NOTE: Test/retest reliabilities (autocorrelation of results on each Satisfaction Factor) for the control group ranged between 0.6 to 0.9 in all categories.

SATISFACTION WITH RESPONSE TIME - Dropped with poor response time and improved when response time returned to normal.

SUPERVISOR ABILITIES - Satisfaction showed an increase with more variation with poor response time. The cross-lagged correlations indicate that it decreased when response time returned to normal, but there was no long-term impact.

SUPERVISOR SHORTCOMINGS - Satisfaction improved with more variability with poor response time. When response time returned to normal it remained at higher levels.

SUPERVISOR RELATIONS - Increased with poor response time and moved lower when response time returned to normal; showed more variation over the long term.

SATISFACTION - This category decreased with more variation with poor response time; no long-term impact was apparent.

JOB ENVIRONMENT - With poor response time, both an immediate and long-term decrease in satisfaction with the job environment resulted.

ON-LINE SYSTEM USE - Satisfaction with on-line systems decreased with poor response time. When response time returned to normal, mixed results were indicated. No long-term impacts are apparent.

SYSTEM DOWN TOO MUCH - Higher satisfaction and less variation with poor response time. The lower variation continued when response time returned to normal and for the long-term.

IMPLICATIONS

The greatest strength of the study is that it included experienced operators in a "live" production situation. The information processed during the study represented serious transactions that were a portion of the user organization's normal business. Operators in the study had a major personal investment in the on-line systems, as they used them on a day-to-day basis. Also, the entry task is relatively complex when this system is compared to other on-line applications like a reservations system.

It was not possible in this study to vary response time to the degree feasible in a laboratory environment. Therefore, it was necessary to project the trends for cases where response time was less than four seconds and greater than 24 seconds. It was necessary to limit changes in response time to increases rather than decreases since response time was already reasonably fast.

Projections beyond the range of data must always be made with caution. In this case, however, the projections required below four seconds and in the 24 to 29 second range are not large. It is believed that these ranges are indicative of on-line system behavior. Beyond 29 seconds, when, according to the models, errors exceed transactions, it is clear that the models are not appropriate in their present form.

Total Transactions

From the research model, it was predicted that total transactions would vary inversely with system response time. This prediction received strong support from the equation for total transactions, derived above. Utilizing this model, one can examine the degree of impact that response time has on total transaction volume for the system in the research:

$$\triangle T\% = \frac{T_2 - T_1}{T_1} \times 100\% = (\exp^{-.032(RT_2 - RT_1)} - 1) \times 1$$

Where: T_1 = Initial transaction volume
T_2 = Final transaction volume
RT_1 = Initial response time
RT_2 = Final response time

Changes in transaction volumes for specific response time levels can be computed from this equation. Note that the percent change in transaction volume is dependent only on response time. Table 3 provides an illustration of the impact of specific response time changes on transaction volume.

Assume one would like to improve average response time from six seconds to four seconds, and has determined a modification to the teleprocessing network that should allow this degree of improvement. If each terminal is active for an average of 200 minutes per day (the CL average rounded to the nearest five minutes) an increase in transaction volume of 6.6% (from 269 to 286) will result.

RT	T%	RT	T%
+1	- 3.15%	- 1	+ 3.25%
+2	- 6.2 %	- 2	+ 6.6 %
+3	- 9.2 %	- 3	+10.1 %
+4	-12.0 %	- 4	+13.7 %
+5	-14.8 %	- 5	+17.4 %
+6	-17.5 %	- 6	+21.2 %
+7	-20.1 %	- 7	+25.1 %
+8	-22.6 %	- 8	+29.2 %

Table 3 - Percent Change in Transactions Volume vs. Response Time in Seconds

Errors

Originally it was predicted that increased response times would cause errors to increase. Apparently, as response time increases, operators initially use extra care in entering a transaction so they will not incur the lengthy response delay twice for the same activity.

The time required for verification depends upon the complexity of the transaction and the skill level of the operator. Below some response time level, it is faster (hence more productive to the organization) to let the computer do the verification, rather than double checking entries. Certainly, if individual error rates are low, response time must be high to justify spending the time to double check an entry.

At some point (12 seconds in the current study) operators do apparently begin to lose their place in required sequences, become distracted or lose their train of thought. The more response time increases, the greater the problem it poses for operators. Errors increase faster than the increase in response time. For this system, errors are minimized at the breakpoint of 12 seconds.

The change in errors due to a change in response time for this system can be computed as:

$$(8)\quad \Delta E\% = \frac{E_2 - E_1}{E_1} \times 100\%$$

where: E_1 = errors at initial response time
E_2 = errors at final response time

Substituting the error model into this equation, one derives a detailed equation for the percent change in errors due to a change in response time:

$$(9)\quad \Delta E\% = \left(1 + \frac{T\%}{100}\right)^{.836} \exp^{(-.112B_1 + .15B_2)} \times 100\%$$

where: $T\%$ = percent change in transaction volume due to a change in response time

$B_1 = RT_2D_{12} - RT_1D_{11} - 12(D_{12} - D_{11})$
$B_2 = RT_2D_{22} - RT_1D_{21} - 12(D_{22} - D_{21})$
RT_1 = initial response time
RT_2 = final response time
D_{11} = value of D_1 at initial response time
D_{12} = value of D_1 at final response time
D_{21} = value of D_2 at initial response time
D_{22} = value of D_2 at final response time

If the initial and final response times are both less than 12 seconds or both greater than 12 seconds, the equation is greatly simplified.

Substituting the appropriate values for the dummy variables, the form for response times under 12 seconds becomes:

$$(10)\ \Delta E\% = (1 + \frac{\Delta T\%}{100})^{.836} \exp^{-.112B_1} \times 100\% = (1 + \frac{\Delta T\%}{100})^{.836} \exp^{-.112(RT_2 - RT_1)} \times 100\%$$

If both response times are greater than 12 seconds:

$$(11)\ E\% = 1 + (\frac{\Delta T\%}{100})^{.836} \exp^{.15B_2} \times 100\% = (1 + \frac{\Delta T\%}{100})^{.836} \exp^{.15(RT_2 - RT_1)} \times 100\%$$

Table 4 shows typical changes in errors caused by changes in response time when both response times are less than 12 seconds. Table 5 shows changes when both response times are greater than 12 seconds. When initial and final response times are on opposite sides of the breakpoint, the full equation must be used.

The tables and equations demonstrate that errors in this system increase when response time increases or decreases from 12 seconds. There is, however, a major difference in source of the error. When response time is less than 12 seconds, errors increase because operators are apparently less careful making entries and spend less time checking codes for corrections.* When response time is over 12 seconds, operators make errors because they become confused, distracted, or lose their place. Thus, when response time is less than 12 seconds, errors are an integral part of normal on-line system operation. When response time is greater than 12 seconds, errors indicate that normal system operation is breaking down.

*A referee suggested a slightly different explanation: operators are paced by the system. When it is fast, operators work quickly and make errors. When the system is slow, they work more slowly and carefully.

RT	E%	RT	E%
+1	- 13.0%	- 1	+ 14.9%
+2	- 24.2%	- 2	+ 32.0%
+3	- 34.0%	- 3	+ 51.6%
+4	- 42.6%	- 4	+ 74.2%
+5	- 50.0%	- 5	+100.1%
+6	- 56.5%	- 6	+129.9%
+7	- 62.1%	- 7	+164.1%
+8	- 67.0%	- 8	+203.4%

Table 4 - Percent Change Errors vs. Response Time
(Initial & Final Response Times Under 12 Seconds

RT	E%	RT	E%
+1	- 13.1%	- 1	+ 11.6%
+2	- 28.0%	- 2	+ 21.8%
+3	- 44.7%	- 3	+ 30.9%
+4	- 63.7%	- 4	+ 38.9%
+5	- 85.2%	- 5	+ 46.0%
+6	-109.5%	- 6	+ 52.3%
+7	-137.0%	- 7	+ 57.8%
+8	-168.0%	- 8	+ 62.7%

Table 5 - Percent Change: Errors vs. Response Time
(Initial & Final Response Times Over 12 Seconds)

Operator Productivity

Operator productivity is the difference between total transactions and total errors. The number of productive transactions per day should be a major concern of user department managers, since only productive transactions represent useful work. Unfortunately, most on-line systems totally ignore errors in reports summarizing system operation. Assuming active time is equal to 200 minutes per day, total transactions, errors and productivity for various response time computed from the previous results are shown on Table 6 and Figure 7.

	Response Time	Total Transactions	Total Errors	Productive Transactions	% of 4 Second Level
Range of Actual Response Times	4	287	49	238	100 %
	5	278	43	235	98.7
	6	269	37	232	97.5
	7	260	32	228	95.8
	8	252	28	224	94.1
	10	237	21	216	90.8
	12	222	16	206	86.6
	14	208	20	188	79.0
	16	195	26	169	71.0
	18	183	33	150	63.0
	20	171	43	128	53.8
	22	161	55	106	44.5
	24	151	70	81	34.0
Projection	26	141	90	51	21.4
	27	137	102	35	14.7
	28	133	116	17	7.1
	29	128	129	***	-
	30	124	147	***	-

Table 6 - Productivity vs. Response Time (A = 200)

*** - Errors exceed total transactions

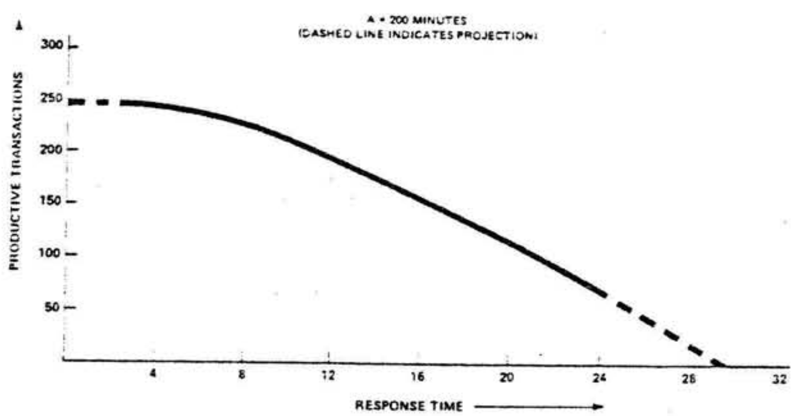


Figure 7 - Productive Transactions vs. Response Time

Productivity appears relatively flat below six seconds.[3] Transactions at such levels are rising but errors are increasing more quickly. Therefore, from a productivity standpoint, differences among four, five, or six second response time are relatively minor for this system.

Once the 12 second level is passed, transaction volume is decreasing but errors are increasing and productivity begins to fall drastically. In order to maintain productivity at reasonable levels, the vast majority (e.g., 98% of all transactions should be completed in 12 seconds or less for this system.)

Job Satisfaction

Based upon the results discussed above, response time apparently did affect job satisfaction. As noted, some of the categories, particularly those dealing with interpersonal and supervisory relations, showed improvements. Most indications returned to normal when response time returned to original levels. Categories related to tasks or tools, such as "Response Time Satisfaction", "Satisfaction", and "On-Line System Use" and demonstrated lower satisfaction with poor response time, as predicted and improved when response time returned to normal.

[3]Optimum productivity can be determined by finding the maximum of the productivity function. This occurs at 1.15 seconds for this system, a level that is not physically achievable due to technological constraints.

In interpreting these results, it is important to consider the observed actions of many of the operators who experienced slow response time. Immediately, they began to report troubles on the system to their supervisor. The supervisors, in turn, generally verified that a problem did exist and referred it both to the data processing staff in their own organization and directly to the computer center. The operators also complained to each other about the system's poor performance, suggested possible causes of and solutions to the problem to their supervisors, inquired if the problem had been located and asked when response time would return to normal. The supervisors made similar communications to the staff group and the computer center.

It has been noted elsewhere that as task uncertainty increases, the proportion of vertical communications increase while horizontal communications ecrease (Randolph and Finch, 1977). At the same time, the frequency of both types of communications increase.

The observed behavior of operators was consistent with this premise. That is, faced with poor response time, communications were directed vertically in an attempt to reduce uncertainty. The results point out the crucial role of supervisory management in helping workers cope with problems of this type.

In the current study, poor response time detracted from the task at hand. An increase in interpersonal interactions apparently accompanied the poor response time. Such an increase in affiliation is probably responsible for the improvement in satisfaction scores observed in categories dealing with interpersonal relations.

Reductions in task satisfaction could be explained by loss of autonomy caused by poor response time (Hackman and Oldham, 1975). Workers experience less control over the flow of work resulting in lower internal motivation. An alternate explanation is that lower satisfaction results from the lower productivity possible under degraded response time conditions, following the "productivity causes satisfaction" hypothesis of Locke (1970), Porter and Lawler (1968) and others.

CONCLUSION

The system in this study is characterized by rather complex tasks. The specific results, especially the point at which errors begin to rise as response time increases, would be different for other systems. However, it is possible to offer some conclusions based on the overall results of the research.

Response time is not easy to maintain at a specific level, since it is influenced by many factors including computer hardware, software, dataset placement, other jobs being processed, differences in transaction types processed from one day to the next, transaction volume, transmission line utilization, line errors and the like. When response time problems develop, even the most skilled technician sometimes is faced with a confusing array of interrelationships between the various system components. Frequently, there is not a single cause of the problem, but various factors working together to cause a degradation.

As supported by this study, response time is important to user groups who are dependent upon on-line systems. It is difficult to visualize any other factor normally encountered in business that has the potential to affect an organization's productivity to the degree possible with on-line systems.

Unfortunately, such impacts can strike instantly, as the system may go down or response time may degrade without warning. This study provides evidence that a degradation in response times reduces job satisfaction for operators as well as productivity when response time is excessive.

System performance, both response time and downtime, should be carefully managed. Performance results should be reviewed daily or weekly. Statistical quality control procedures should be used to maintain response time within control limits. As soon as response time goes out of statistical control, corrective action should be taken. Such efforts should not wait until response time has deteriorated from an average of five seconds to an average of ten seconds and caused satisfaction changes on the part of operators, significant productivity losses and dysfunctional interdepartmental relations.

Organizations are implementing on-line systems in large numbers. Many individuals operate these systems, and little work has been done to identify the impact of such systems on human operators. Hopefully, more research will be forthcoming, as the productive power of organizations and the job satisfaction of many individuals may depend on the results. If the profession understands how on-line systems behave and affect people, it should be possible to build systems that are both productive for organizations and satisfying for human operators.

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