Developing a set of terminals for users who had no computer experience and whose normal jobs could not be subject to interference involved human factors. Most of the design work focused on the keyboard and display interfaces of the terminals. Studies were made, alternative designs were considered, and tests were performed to ensure that the equipment was easy to use and provided acceptable speed and accuracy.

Human factors in the development of a family of plant data communication terminals

by M. Ominsky

Human Factors Engineering adapts and optimizes things for human use. Different projects require varying amounts of human factors effort, depending on such considerations as system complexity, expected user skill level, and environmental requirements. For that reason, work by human factors personnel on a given project can range from designing the layout of the controls and displays on an operator's console to measuring the total performance of a system with a human included as part of the system.

The IBM 3640 Terminal Family provides an excellent illustration of most of the types of work that can be done by human factors personnel during the development of an integrated system. This paper describes our participation in the many phases of the design of that system, and by means of the example conveys some idea of the importance and relevance of human factors to product design.

We first describe the system development process and the role the Human Factors group had in it and next introduce the 3640 Terminal Family. Each of the development stages is then related to work performed by Human Factors in connection with this system.

The system development process

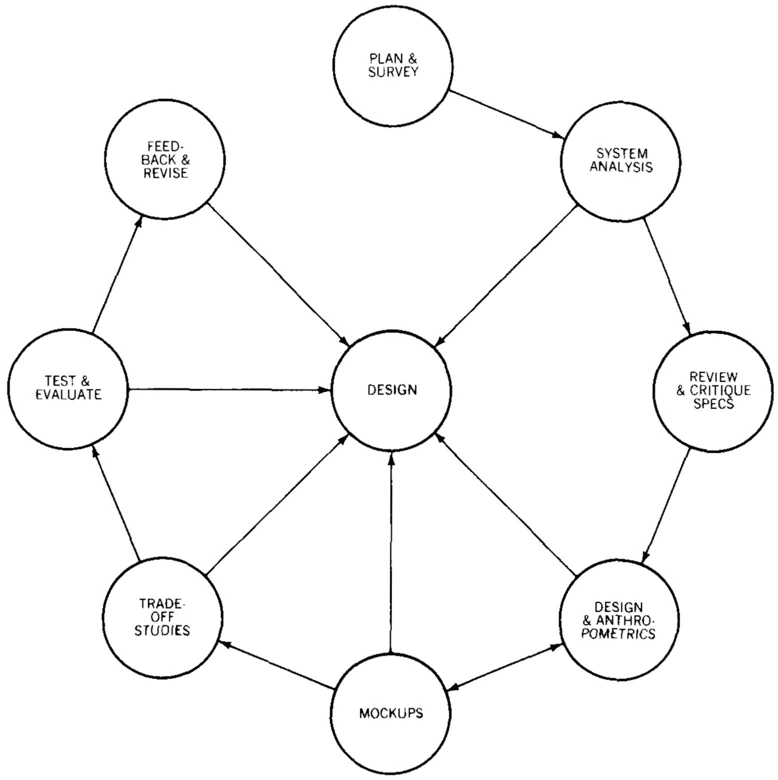
The system development process can be viewed from many perspectives. To a system manager the first stage consists of reviewing the *objectives* and then the *requirements* set forth by marketing and planning groups. In response to these requirements, the system manager produces a set of system *specifications* that should satisfy the requirements. *Designs* are *formulated*, *built*, and *tested* against those specifications. If the system successfully passes its tests and is still deemed marketable, it is then *announced*, *manufactured*, and *shipped* to customers.

Although that characterization is a gross oversimplification and does not necessarily hold true for the development of all systems, it can be used as a model to indicate where and how human factors can contribute to the system development process (Figure 1). Early in the planning and survey stage, human factors personnel work with requirements planning groups to determine customer needs, which can then be used to generate or verify requirements. Observations, interviews, questionnaires, and photographs at customer sites often bring the most critical needs to the forefront. These needs are further clarified and detailed during the system analysis stage. As a part of system analysis, human factors personnel study data from the field or from existing systems to quantify various aspects of system performance. Those data are also often incorporated into system specifications.

Next, the Human Factors group reviews and critiques system specifications and other system-related internal documentation to clarify and sometimes modify design requirements. In the design phase, anthropometric studies are performed, i.e., designing for the ranges of relevant body characteristics such as size, as well as the selection and layout of controls and displays.

The construction of mockups and the conduct of tradeoff studies, tests, and evaluations are all used in making design decisions. Mockups, lifelike models made from materials that range from

Figure 1 Human factors in the system development process



foamcore to metal, are important evaluative tools that can be used before actual working machines are available. Tradeoff studies typically result in decisions to select more of one variable in a particular situation at the expense of one or more other variables. These studies differ from other tests and evaluations of the product itself in that the latter determine at a later stage whether design criteria have been met. If the product successfully passes these tests, Human Factors is able to provide assurance to system management and ultimately to the end user that the announced product will be usable and will meet its performance goals. After a product has been shipped to customers, human factors personnel often perform field follow-ups to find solutions for problems that had not been anticipated earlier in the design process.

The 3640 Terminal Family

The IBM 3640 terminals attach to the IBM 3630 System, the 8100 computer, or the 4331 computer to provide a data communication system primarily, but not exclusively, for industrial plants. Spe-

Figure 2 Reporting terminal with scanner

cifically, it provides for the recording of production data, interactive access to local or remote data files, and dissemination of control documents directly on the production floor.

The hardware consists of a family of factory floor terminals and auxiliary supporting units. A key feature of the system is the magnetic entry of information by a scanner attached to the *reporting terminal*. Magnetic data entry is a significant improvement over the slow and error-prone method of keying (Figure 2). This terminal provides the system with the main source of data for tracking parts and materials. Another terminal contains punched card and badge readers to serve in the transition from punched data input to magnetics.

To allow several operators to attach to the same control unit, the *scanner control unit* accommodates up to four port connections to magnetic scanners or slot readers. The system produces its own media using the *encoder/printer*, which encodes and prints magnetic labels or cards. Workers' arrivals and departures are recorded by the *time and attendance terminal*. An *automatic data unit* monitors and controls factory equipment. Other devices are a *display terminal* to provide managerial control and a *printer* to produce routings or other factory outputs.

The system was designed for the operational or execution level systems characterized by:

1. Recordings of workers' attendance and arrival and departure times
2. Dispensing of jobs by the foreman
3. Tracking of jobs or parts through the system
4. Recording and reporting of test results
5. Monitoring and maintaining product quality
6. Controlling product records at both the loading and unloading docks

Human Factors involvement in developing the terminals

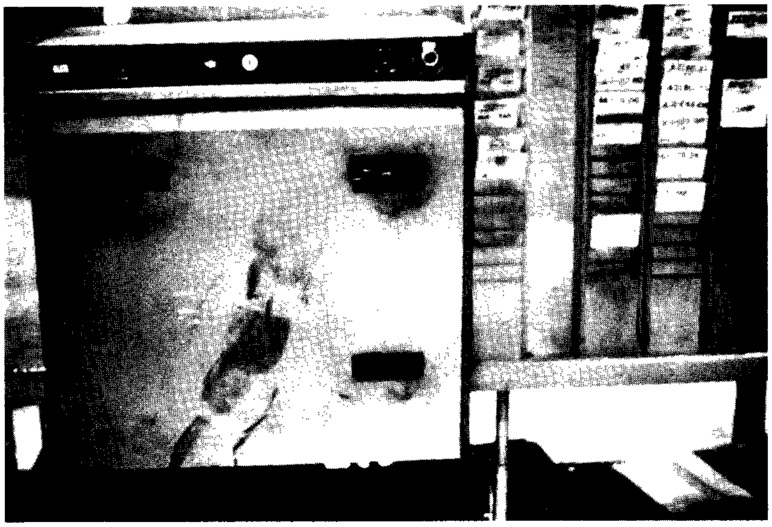
The contributions of Human Factors to the development of the 3640 Terminal Family can be conveniently grouped under five separate headings: planning and survey, design, mockups, tradeoff studies, and testing and evaluation.

Planning and survey

Our involvement began in the planning stage with a field survey. In cooperation with Product Requirements Planning we visited several customer sites to determine the environments in which the products would be placed, how they would be used, and whether existing products were adequate. The field study data eventually included questionnaire results, pictures, and recorded interviews taken during visits to a small but representative sample of factory operations.

The results of these studies showed clearly that the system would have to work in an extremely wide variety of factory environments. Some were as clean as a normal office environment; others were extremely dirty. Moreover, dirt and contaminants were not all in the form of black soil. For example, flour processing creates white dust that covers everything in a baking factory. In other factories corrosive vapors can eat away the internal parts of unprotected machines. Airborne oil in some factories can wreak havoc with terminals designed for traditional office use. Our studies showed further that horizontally oriented keyboards and printers were especially susceptible to contamination and that openings which expose the internal workings of a machine should be avoided in such environments.

Figure 3 Terminal with footprint



Lights and displays have to contend with extremely variable ambient lighting conditions—from mixtures of dark and light areas to extremely bright areas that can wash out many displays. Hoods and barriers have sometimes been tried to protect terminals from harsh environments. Figure 3, entitled "Terminal with Footprint," however, is an eloquent testimonial to the difficulty of protecting terminals from human abuse. Indeed, one company went so far as to encase an existing CRT (cathode ray tube) in steel wire mesh to protect it from wayward wrenches.

In summary, the field studies pointed to five major kinds of problems with existing systems that needed to be avoided in the new terminal family:

1. Generally poor environmental protection
2. Top openings that allow contaminants to enter into the internal parts of the machines
3. Designs that were not easy for operators to learn or use
4. Slow input techniques that impacted the mainstream jobs (production) and that did not readily accept variable input information
5. Inadequate feedback and prompting

Design

After identifying current problems and initial requirements, we proceeded into the design stage. Although human factors design work touched all the devices in the system, most of our work was focused on the magnetic devices and the reporting terminal. The

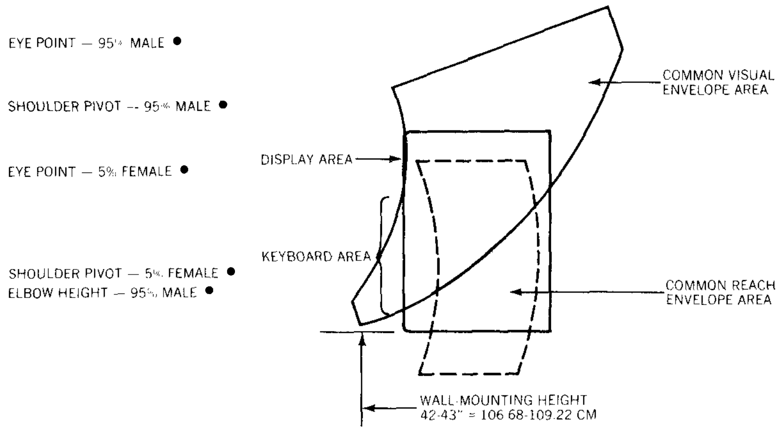
Figure 4 Scanning a magnetic card

major innovative component of this system is the magnetic hand scanner. With it, an operator can enter data more easily than can be done using the relatively slow and error-prone method of keying. In normal use, the scanner is passed across a magnetic stripe on cards, badges, or labels which might be carried on the person, attached to paperwork routings, or stuck on boxes or other materials (Figure 4).

Early design focused on the shape of the device and on the way it would normally be grasped or held. Tests allowed us to reject such alternatives as a pencil shape in favor of the current hand grip design (Figure 4). Our tests also showed that gimbaling the head of the device (allowing it to rotate), widening the magnetic stripe, providing bidirectional scanning, and double-encoding the data would increase significantly the number of successful scans. The gimbaled head allowed users to tilt their hands and still maintain full scanner contact with the magnetic stripe. The wider stripe made it easier for users to stay within the magnetic area.

Since poor feedback to the operator had previously been identified as a significant problem in many existing systems, a considerable amount of attention was directed toward providing a useful alternative. A dual feedback system of lights and a buzzer was recommended and incorporated to provide feedback to the user about the success or failure of each scanned input. A green light and a short (0.4 second) buzzer sound indicate a successful scan; a red light and a longer (1.1 seconds) buzzer sound indicate an

Figure 5 Visual and reach envelopes of the wall-mounted reporting terminal for 5th percentile female and 95th percentile male standing operators



unsuccessful scan. Not only do these signals provide unambiguous feedback to the naive user, but their duality (audio and visual) ensures some feedback under the extremes of either high ambient lighting or high noise levels. However, the short buzzer can be disabled for certain office areas in which noise may be a problem.

The size and orientation of the keyboard reporting terminal were fixed early. To provide environmental protection for the keyboard and entrance slots, the unit is designed to be mounted vertically on a wall or to sit on a tabletop.

Various components of the keyboard terminal were carefully specified. A 22-character gas panel was selected to provide prompting messages that would be visible under high ambient light conditions. The display is mounted so that it can easily be kept clean with routine maintenance. Color-coded incandescent indicators were chosen instead of LEDs (light-emitting diodes) to provide a clear indication of the system status even to operators who may be working up to 50 feet away. To provide proper feedback at all times, the design allows bulbs that fail to be replaced by the customer. Anthropometric data were applied to ensure that the unit could be seen and reached by the full range of sizes of people who might use it. Anthropometric data also allowed us to specify recommended mounting heights (Figure 5).

Tests showed that the actuator mechanisms of the keyboard technology originally selected for this factory terminal did not provide tactile feedback that was good enough. The keys felt mushy and nonuniform. Accordingly, new key actuators were designed with a greater keying distance, a better "snapping" feel, and even some auditory feedback. The modified keyboard with the newly designed key actuators provided greater positive tactile and auditory feedback than the original keyboard. Additional function and flexibility are obtained through the use of a flexible overlay that allows customers to change labels on the function key area of the keyboard.

Other design decisions led to the rear mounting of the on-off switch to prevent accidental activation and to discourage deliberate tampering. Furthermore, easy access for maintenance was provided by a five-sided cover design.

Mockups

Since working models are usually not available until very late in the development process, mockups are extremely valuable tools for trying out new design concepts. For example, they also allowed us to study early designs in various settings and to determine how and where they might be used. These models were brought to our own manufacturing areas, placed in different locations, and examined and photographed. In addition, personnel who would be using these devices were asked for their opinions and evaluations of the size and accessibility of the units. Wooden models of scanners were built in the initial stages of design to try out different grips and head configurations.

From simple mockups and models we eventually moved to those having much greater detail. In the absence of a working prototype, a test system was built with an actual working keyboard, display, punched card and badge readers, magnetic hand scanner, and magnetic slot reader. This model had only enough electronics to interface with a computer in a simulation of the actual working terminal. Although only a simulation, the combination of real operator interfaces and programmed software allowed us to conduct detailed testing at an early stage of development that would not have been possible otherwise. Such testing, to be described in detail in the section on testing and evaluation, provided assurance that the system was usable by typical manufacturing personnel.

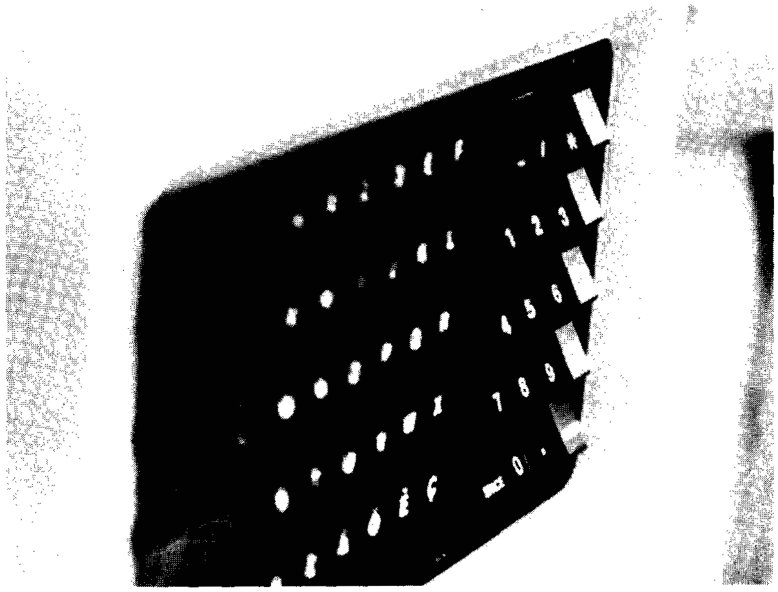
Tradeoff studies

Tradeoff studies involve either research of existing data or testing of alternative concepts to find optimum solutions. In the case of this system, tradeoff studies focused on keyboard selection and design, the selection of a data recording device for the time and attendance application, and the design of the display character font.

keyboard selection and design

The selection of a keyboard technology was made after a team study examined a large number of alternatives that were rated for a combination of factors such as cost, technology, environment,

Figure 6 Experimental large key shingle overlay



and usability. Human Factors focused on the force, displacement, feedback, and size of keys, on labeling, and on performance. Engineering emphasized product cost, development cost, and technical specifications. The final choice of a keyboard with newly designed keytop actuators to provide better tactile and auditory feedback was the solution that best met our cost and human performance objectives.

Efforts were also made to improve suspected deficiencies due to the size of the keyboard and its vertical orientation by a proposal that would angle the keyboard and use a large key overlay. Angling the keyboard, we thought, would provide a more natural orientation, easier keying, and better visibility. A type of shingle overlay would provide a natural angle and a larger target for keying, and allow bigger lettering (Figure 6).

With the foregoing in mind, a study was performed to determine the effectiveness of the proposed keyboard alternatives (Figure 7) using 14 factory-experienced personnel to key randomly selected numerics. Subjective questionnaire data indicated high user preference for an angled shingled keyboard. Yet performance results showed no statistically significant differences in either throughput or error rates for either the shingle overlay or angled keyboard. Since our tests showed no clear-cut performance advantages for any of the experimental variations, cost and development considerations resulted in a decision to remain with the conventional keyboard.

Figure 7 Side view of the six keyboard conditions tested

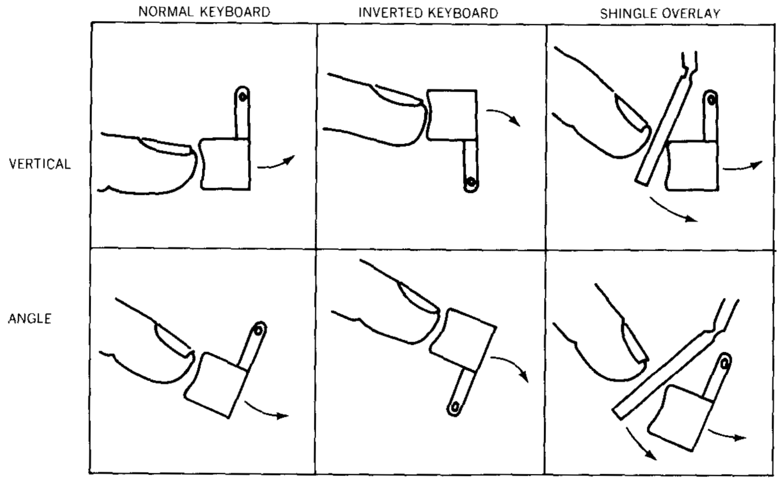
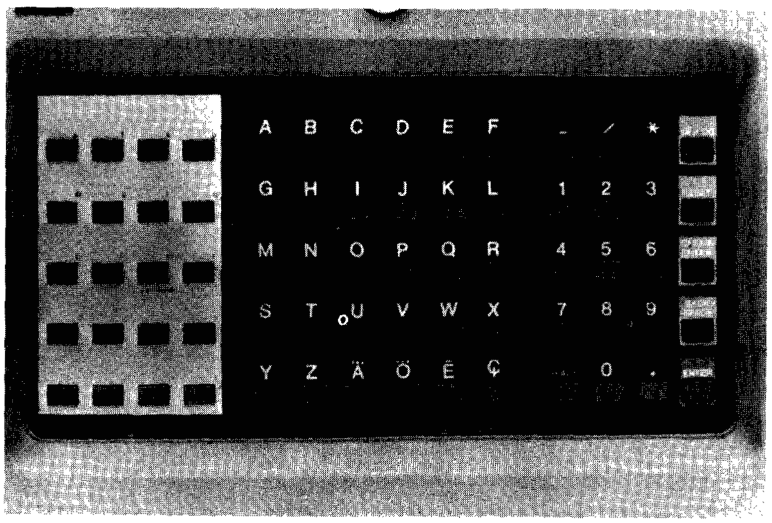
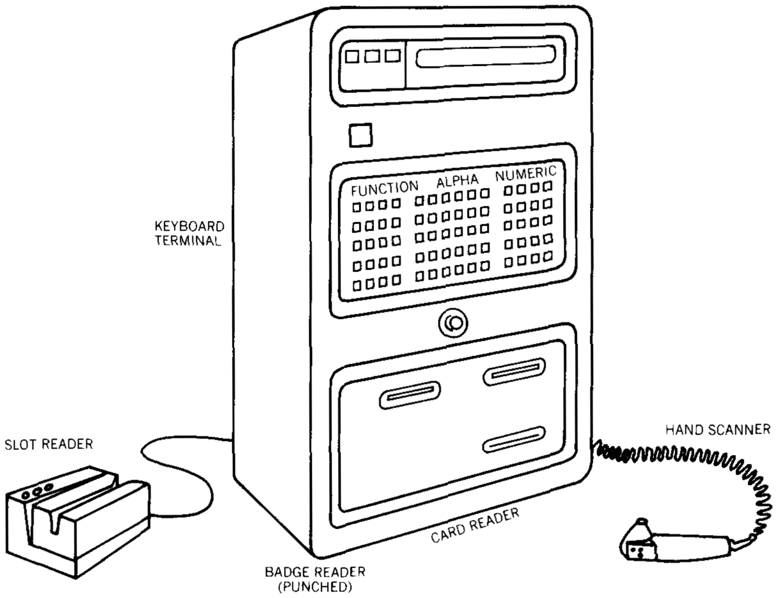


Figure 8 Front view of the keyboard layout for the reporting terminal



Several studies in the literature show the telephone numeric arrangement of keys with 1 2 3 across the top to be slightly better than the calculator arrangement with 1 2 3 at the bottom, particularly for low-skilled operators.[1,2] Those findings led to the selection of the telephone arrangement for our terminal. A block alpha arrangement was selected (Figure 8) partly to avoid an office typewriter look in a factory setting and partly because the standard typewriter design could not fit with the internal arrangement of the hardware. Besides, tests have shown only a negligible difference in performance between the block alpha and typewriter arrangements for persons who do not type.[3,4] Customer-program-

Figure 9 Alternative time and attendance devices tested (for illustration only; not all devices can be used together)



mable function keys were clustered together on the left side of the terminal and labeled with lower-case alpha characters which corresponded to the characters displayed on the gas panel when the keys were struck. For example, if transaction "a" (e.g., JOB START) is initiated by an operator, the character "a" will be displayed along with prompting messages until all steps are completed. In this way users can always identify what task is currently being processed. This method proved to be an acceptable alternative to the more desirable but expensive backlighted function keys that were initially proposed.

selection of time and attendance input media

Since time and attendance recording (T & A) is a central application for this system, we examined the suitability of a number of existing T & A devices. No existing device could meet our requirements for feedback, ruggedness, and response time. Accordingly, we designed a laboratory experiment to evaluate the magnetic hand scanner (MHS), the magnetic slot reader (MSR), the punched card reader (PCR), the punched badge reader (PBR), and the keyboard (KB) as potential candidates for our system (Figure 9). All the devices were instrumented and used by 16 factory workers who entered their identification numbers as they repeatedly passed each terminal. These tests showed that the magnetic slot reader was by far the best device for the application. Users passed by the MSR at a rate of more than one every two seconds with a misread rate of less than one percent. By contrast, only one third that rate was achieved with either the MHS or PCR.

Table 1 Time and attendance application study throughput: the number of people recorded per minute by each of five devices under three system delay conditions. The delays of 0.3 and 1.5 seconds are averages of distributions of delays.

Device	*System delay* (sec)		
	0	*0.3*	*1.5*
Magnetic slot reader	34.6	29.2	17.3
Punched badge reader	22.3	20.7	13.7
Keyboard only	13.8	13.3	10.6
Magnetic hand scanner	10.9	10.0	10.0
Punched card reader	9.4		

Table 1, however, shows that response time feedback delays are much more critical for devices with faster walk-by rates. In other words, the relative superiority of the magnetic slot reader is reduced dramatically as system response time delays increase. Even with the longest response time, however, the MSR still gave the highest throughput.

Questionnaire data generally agreed well with the objective performance measures. Fifteen out of the sixteen test subjects selected the MSR as the device they would prefer to use daily as a time and attendance recorder. User comments indicated that the MSR was "faster," "more reliable," "a lot easier to operate," "more efficient," and "less error prone" than the other devices tested. They also felt that the horizontal orientation of the MSR on a horizontal surface was the best mounting position, thereby agreeing with the objective data on this matter.

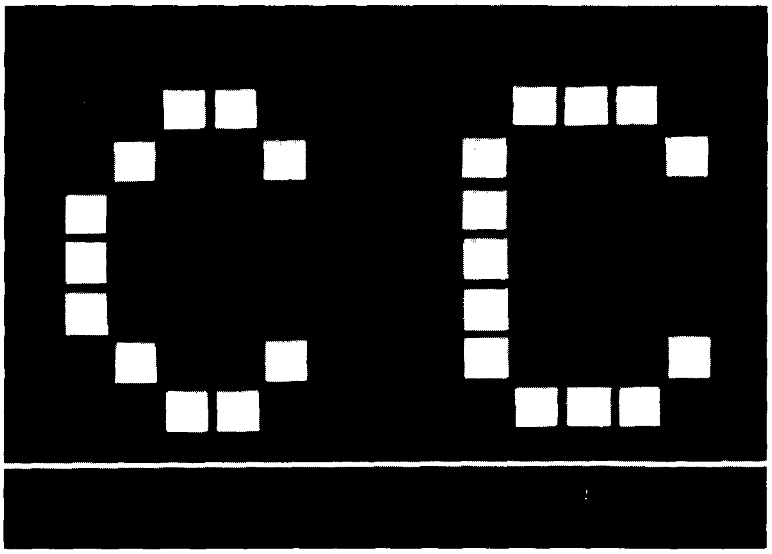
design of display characters

The final tradeoff study was done with the display characters. The conventional design of the characters from small-font displays looked odd when they were generated with the square-dot matrix pattern on the 22-character gas panel. In a small study six subjects were shown two to ten proposed designs of each character and told to select the one that seemed best to them. Alternative designs were drawn on paper grids as in Figure 10, and the selections receiving the highest ratings were put into a full alphanumeric set. Typical system messages were created and revisions were made to the character set based on the appearance and distinctiveness of individual characters.

Testing and evaluation

Tradeoff studies are used to select from among alternatives during the early phases of design. Evaluations, however, measure the performance of a system or its components after design has been completed. Their purpose is to determine whether the system or its components work as they are supposed to work. In the case of the terminal family, evaluations ran the gamut from evaluations of displays under bright ambient lighting, through trials of

Figure 10 Example of two square-dot matrix character designs



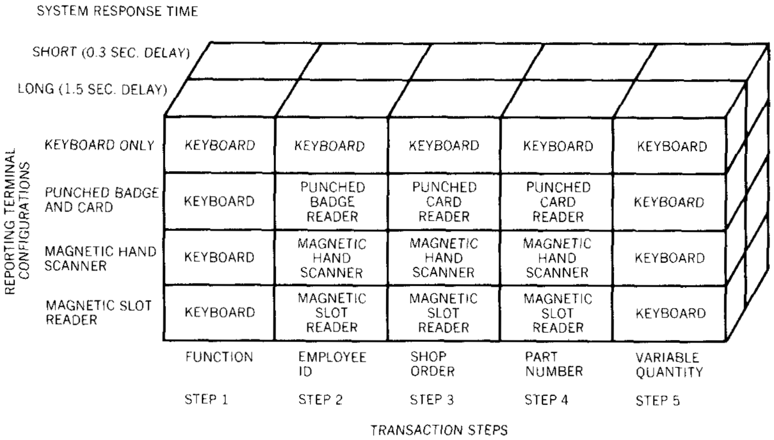
procedures and documentation, to formal tests of the hardware and system characteristics.

The most extensive testing was done in a configuration/applications study during which over 30 000 transactions were entered by 16 persons experienced in the manufacturing industry using variations of the reporting terminal. The purpose of the study was fourfold:

1. To compare various configurations and combinations of hardware by the performance of operators carrying out transactions on them.
2. To determine the effect of the system response time delays on user performance and attitudes.
3. To establish baselines for field user performance and programming simulations.
4. To verify the existing design and to validate the normal transaction procedures.

This study had two independent variables: system delay time and hardware configurations. We tested two system delay times (short and long)[5] and four hardware configurations or primary methods of data entry (keyboard only, punched card and badge readers, magnetic hand scanner, and magnetic slot reader). Each of the 16 operators was given eight ten-minute test sessions for all eight combinations of response time and configurations. Order effects were counterbalanced using a Latin square. Each of the eight combinations of hardware and response time was tested with the same five-step simulated transaction consisting of the

Figure 11 Configuration/application test design consisting of four reporting terminal configurations, two system response time delays, and five transaction steps



entry of a function start, employee identification, shop order number, part number, and variable quantity (Figure 11).

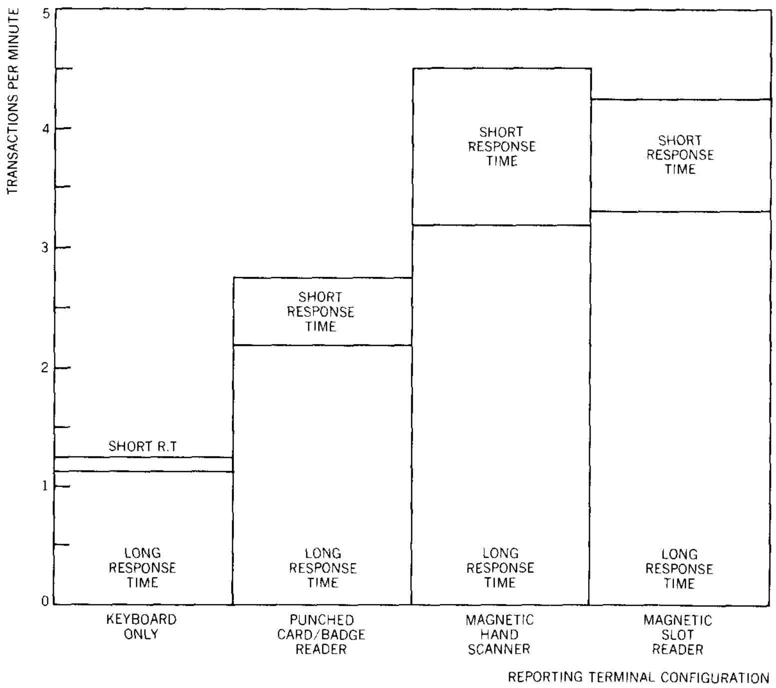
Since prototype hardware and software were not available at the time, Human Factors put together its own system simulation by building computer interfaces that would match those specified for the actual system. Furthermore, software was designed to allow the experimenter to specify and change such variables as system configurations, transaction steps, messages, and response time curves. An automatic data collection and scoring system was modified from previous project testing. All tests were done in our own laboratory.

throughput

Figure 12 shows that when the system response time is short, almost four times as many transactions can be entered with the magnetic devices and media as with a keyboard. Although that throughput differential is reduced somewhat at the longer response time, transactions with magnetic devices are still about three times faster than with key entry. Another way of looking at the data shows that reducing the system response time from 1.5 seconds to 0.3 second increases the throughput by 24 to 30 percent for the faster magnetic transactions but only by 6.5 percent for the relatively slow keyed transactions. Response times as short as 0.3 second require a buffered input.

An analysis of variance on the throughput data showed that the differences for the two main effects, response time and configuration, were highly significant ($p < 0.001$). Throughput was significantly better for short response times than for the long response times. Statistical tests of the differences between individual configurations show a highly significant ($p < 0.001$) difference between the throughputs achieved with the keyed and the punched

Figure 12 Transactions per minute as a function of terminal configuration and system response time



card/badge transactions and between both of these and the two forms of magnetic transaction. There was no significant difference between the hand scanner and slot reader conditions.

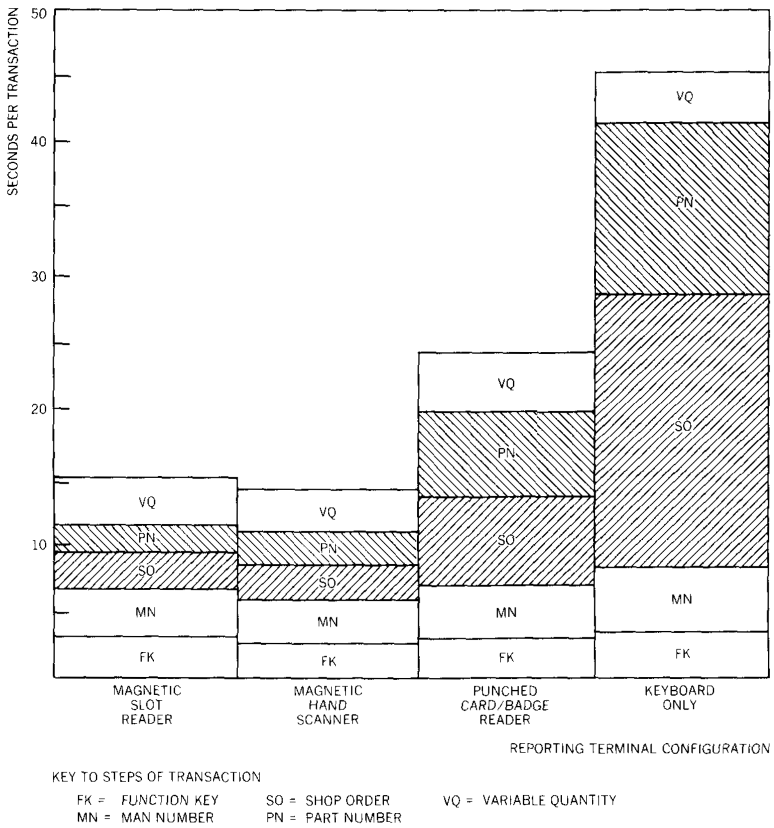
A more detailed analysis of total throughput times reveals dramatically the inefficiency of the keying in of large numbers by inexperienced keyers (Figure 13). Shop order numbers are composed of 12 digits. On the average it took 20.3 seconds to key in a shop number and only 2.6 seconds to scan it magnetically. The variable-quantity field, however, contained three digits. These three digits could be keyed almost as fast as a magnetic stripe could be scanned (3 to 4 seconds versus 2.6 seconds).

errors

Throughput is only part of the story. If errors are made, the data base on which people are relying becomes increasingly contaminated and thus less trustworthy. Because of the checking procedures built into the scanner coding system, there were no undetected errors made with the magnetic device. Procedural errors, however, did occur for the following reasons:

- An operator entered a piece of data while the IN PROCESS light was on.
- An operator entered the wrong step at the wrong time.
- An operator entered the same transaction twice.
- An operator skipped over a transaction.

Figure 13 Total time per transaction and component transaction step times as a function of terminal configuration and transaction step



Although these errors were recorded, proper programming checks could eliminate many of them in our operating system. Keyed transactions were most prone to procedural errors (six percent). Since it took so long to key in a transaction, operators sometimes apparently forgot which step or transaction was next. Yet, fewer than one percent of the short-duration scanned transactions (MHS and MSR) contained procedural errors. The longer system delays were associated with twice as many procedural errors (three percent) as the short delays.

Approximately three errors per 1000 entries of three-digit variable quantities or one error per 1000 keystrokes were keyed but not corrected by the operators. The uncorrected error rate for longer numbers was higher (five errors per 1000 entries for ten-digit entries), although the rate per keystroke was less (0.5 error per 1000 keystrokes). If operators take more care and time when they enter the longer strings of characters, the number of errors per thousand keystrokes should be less with the longer entries.

Table 2 Mean percentage of total accepted entries into the system via punched or magnetic media for short and long response times. The percentages are averaged across the last two days of testing and for all 16 subjects.

Device/media	*System response time*		
	Short (0.3 sec)	*Long* (1.5 sec)	*Average of short and long*
Punch badge reader/punched badges	94.9	95.7	95.3
Punch card reader/punched cards	99.8	99.7	99.8
Magnetic hand scanner (MHS)/ magnetic cards	94.8	95.5	95.2
Magnetic hand scanner (MHS)/ magnetic labels	92.8	93.6	93.2
Magnetic slot reader (MSR)/ magnetic badges	96.6	97.6	97.1
Magnetic slot reader (MSR)/ magnetic cards	99.6	99.3	99.5

Errors per entry go up because the number of errors per keystroke does not drop enough to compensate for the increased opportunity for errors to occur in the longer entries.

In summary, two percent of the keyed transactions contained a keying error and six percent contained a procedural error. The magnetically entered transactions contained no undetected entry errors and fewer than two percent procedural errors.

Detected errors provide some measure of how well the several devices performed, although they are not as critical a factor as the previously discussed undetected errors. Forcing operators to make multiple attempts to get an accepted entry is not only time-consuming but frustrating. On the average, between 92.8 and 99.8 percent of total entries were accepted (Table 2). An analysis of variance showed that there were statistically significant differences among the percentages of accepted entries made with the four devices. Both the magnetic slot reader and punched card reader gave significantly higher percentages of accepted entries (98.5 percent and 99.6 percent) than did the magnetic hand scanner and punched badge reader (93.4 percent and 93.8 percent). The MSR did not differ significantly from the PCR, nor did the MHS differ significantly from the PBR. Variations in response time had no effect on the percentage of accepted entries.

questionnaire data

In general, users had quite favorable views of the devices included in the test. Almost all averaged responses were in either the good or very good categories.

Subjects were asked to order by rank their preference for the eight operations they performed. These ranks were then summed for all operators. Subjective results were consistent with the objective performance data. Scanning data with the magnetic slot reader was the most preferred method of entry, while keying long digit entries was the most disliked.

To summarize, the study measured and compared the performance of a typical factory floor transaction using various subsystem hardware configurations. The results showed that a system based on magnetic media and devices was faster and more accurate than a key entry system or a transitional punched entry system. Longer response times decreased throughput, increased procedural errors, and were generally disliked by users.

In addition to these important performance measurements, the study turned up a number of incidental findings that resulted in still further improvements. For example, the coiled cable on the hand scanner kept snagging on the corner of the terminal and tended to pull too much when the operators were scanning. Incorporation of straight sections at both ends and a reduction of tension on the coil solved that problem. The necessity for improving the reliability of the scanner magnetic head was demonstrated after we found that human use (and abuse) of the scanner produced more hardware failures than had been previously found with mechanical bench testers.

An important positive outcome was the finding that untrained operators could successfully perform a simulated product tracking operation with a wide variety of new devices. Moreover, they accomplished the task easily, accurately, and immediately.

A subsequent evaluation was done on the time and attendance device after the initial tradeoff study had shown the slot reader to be the best method for entry. Based on the recommendations of that study and of Marketing, the reader was designed with a double entry slot and with wider throat openings at each end for easier access. Tests with this design showed, however, that response times even as short as 0.5 second or less could result in workers "piggybacking" on one another, causing the loss of data. "Piggybacking" occurs when the second of two entries is made before the first entry has been completely processed, especially during the rush to leave work. Satisfactory performance was achieved for this condition by modifying the response time characteristics of the buffered terminal and subsequently verifying its impact through testing.

Other devices were also evaluated in separate studies. For example, problems found in testing the autofeed design of the encoder/printer led to a recommended redesign that resulted in fewer jams and easier and faster access to and clearing of jams when they occurred. In conjunction with this printer, special large-size print graphics were made available to improve the visibility of printed label information at a distance.

Finally, installation guides and problem-determination procedures were evaluated for the keyboard terminal and scanners. As a result of these studies, the procedures and documentation were extensively revised by, among other things, the incorporation of a more pictorial format to make the guides more understandable and easier to use.

Summary

This paper has described some of the human factors work done in the development of the IBM 3640 Terminal Family. Early survey work on data collection problems in existing installations helped to establish the design requirements of environmental protection and good feedback. Comprehensive iterative design made it possible to meet the goals set forth in the requirements. Tradeoff studies resulted in the selection of a pattern or set of optimal components such as the magnetic slot reader for time and attendance recording. Finally, extensive human factors testing provided the assurance that factory personnel could input data into the system easily and with acceptable speed and accuracy.

Did Human Factors help to produce a better product for the user? What if Human Factors had not participated at all? These are difficult questions to answer, since controlled studies of product development with and without Human Factors participation have, to our knowledge, not been done. We were, however, able to apply our skills at all levels of the development process for this product. Our participation was so interwoven in the fabric of the process that removing it would have resulted in a different product. One could speculate about the usability of differently shaped hand scanners, no auditory feedback, or still other design variations, but such musings do not provide the hard data needed for evaluating the bottom-line value of Human Factors. Human Factors contributions undoubtedly helped to make the final system much better than it would otherwise have been.

In conclusion, not every development effort allows as much involvement as this one. The success of the human factors work in the evolution of this system was due primarily to the mutual help and cooperation received from all product support groups and from the development groups of planning, engineering, and programming.

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CITED REFERENCES AND NOTE

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