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Human Factors and Behavioral Science:

Performance in Locating Terminals on a High-Density Connector

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In two experiments thirty participants located terminals on variations of a new main distributing frame connector. Abutting individual connectors in mirror image led to a higher termination density. Location times and errors were evaluated using deadline procedures. Experiment 1 results showed a high incidence of parallax, counting, and left-right reversal errors. Design modifications aimed at reducing these errors led to improved performance in Experiment 2. Parallax, counting errors, and location times were significantly reduced. The continued occurrence of left-right reversal errors is discussed.

I. INTRODUCTION

Main distributing frame (MDF) connectors provide termination points for outside plant cable and protect central office personnel and equipment from harm due to foreign electrical potentials. Some connectors also have provision for making cross-connections. Over the years connector design has responded to increased space demands on main frames. A new 309-type protected connector achieves a higher density of terminations by putting two independent connectors to-

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gether in mirror image. Although the physical arrangement of the two abutted connectors differs, functionally they are equivalent.

Figure 1 shows prototypes of the original 309-type connector and a modified version with designation labels to identify terminal numbers. The modified connector incorporates features based on recommendations from the human factors studies described below. The direct spatial correspondence between cross-connect and protector fields and the familiar grouping by fives or tens found on previous connectors is missing in the new composite. Because each connector row consists of two cross-connect pairs and five protector units, it was important that the designation labels reflect users' expectations of direction of count and facilitate their making the appropriate associations.

The aim of a preliminary pencil and paper experiment (unpublished) was to choose the most natural numbering scheme. For both connectors, results showed consistent but independent horizontal left-to-right counting patterns associated with cross-connect and protector locations. Concern was generated from the preliminary study about potentially high error rates within connectors and possible confusions between connectors. The loss of spatial correspondence with the new design and the above results led to the hypothesis that shading connector backgrounds would help users to localize specific cross-connect and protector terminals. In the first experiment, two shading schemes were compared with the unshaded connector version in both slow and fast deadline conditions. It was anticipated that any differences in performance between the shaded and unshaded connector versions would be more evident with the rigorous work pace of the fast deadline.

II. EXPERIMENT 1

2.1 Method

2.1.1 Subjects

The participants in Experiment 1 were 18 male Bell System employees, several of whom had relevant experience as craftspeople.

2.1.2 Design and Materials

The experiment can be characterized as a within-subjects design in which each participant located cross-connect pairs and protector units on each of the three connector versions in both deadline conditions. As schematically illustrated in Fig. 2, the version 1 connector represents the original prototype 309 connector with the preferred labeling; in addition versions 2 and 3 include cross-connect field background patterns grouping cross-connect pairs by fives and tens, respectively. The layout of each connector version is a mirror image, but the

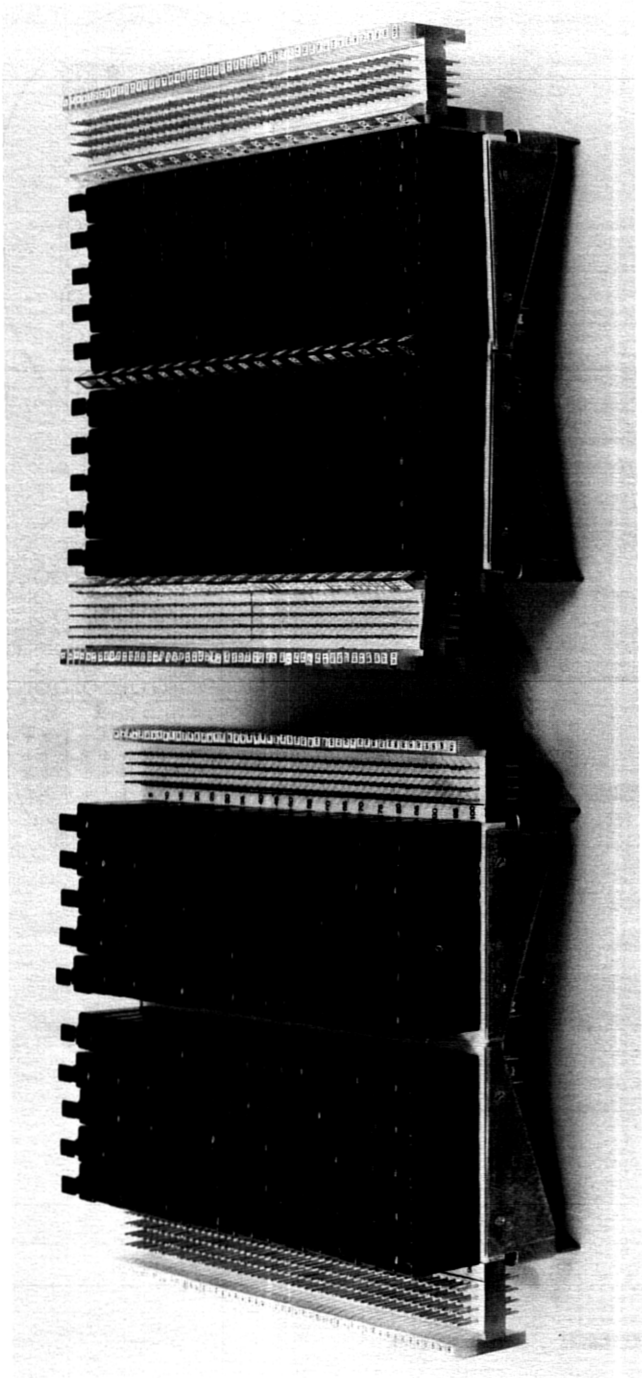

Fig. 1—Originally proposed (left) and modified (right) 309-type protected connector.

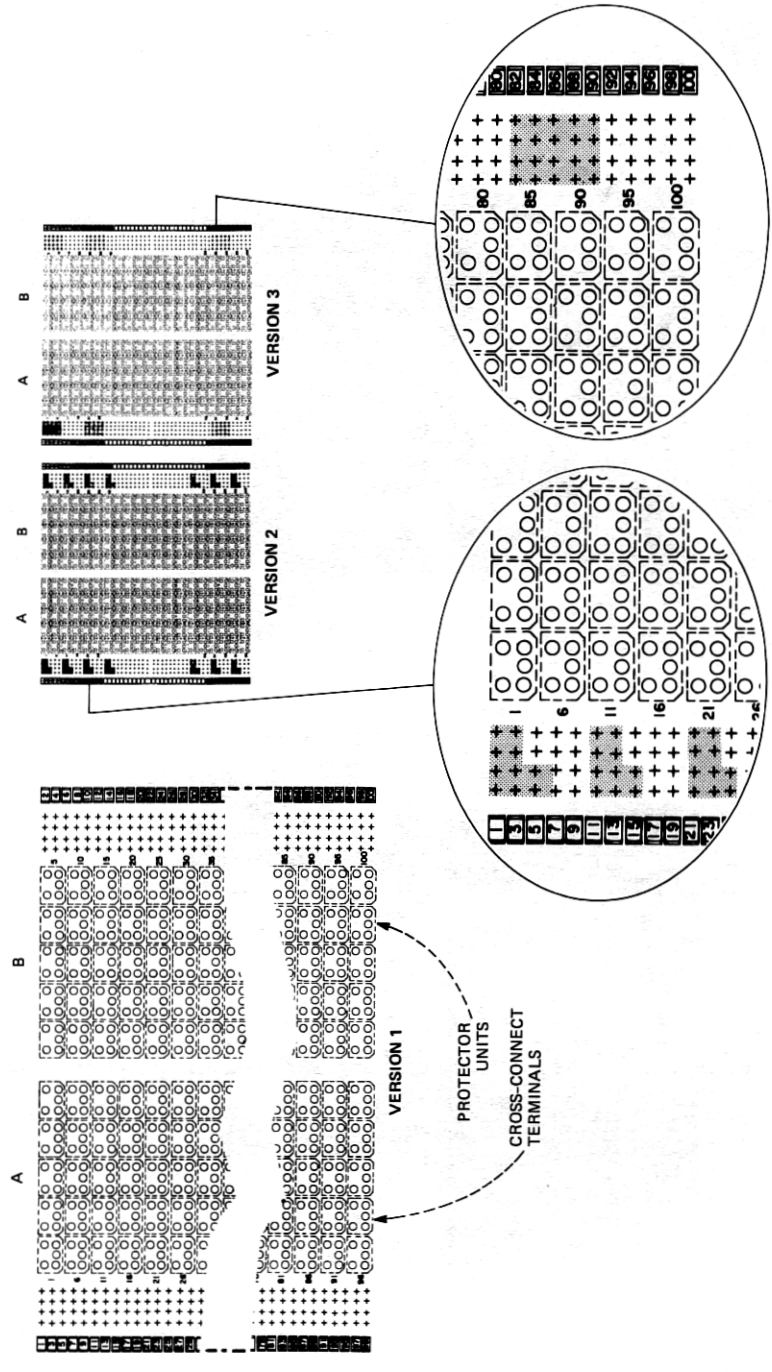

Fig. 2—Schematic illustrations of connectors (Experiment 1).

numbering scheme is not. The option of carrying the cross-connect field background patterns up to the designation strips was rejected as too costly. For purposes of these studies, the independent mirror image connectors of each version are labeled A and B.

A work assignment consisted of twenty trials of locating and marking cross-connect pairs and corresponding protectors. Cardboard trays with 20 plastic cups provided work assignment information. Each cup contained the material for one trial, a cross-connect cap and protector unit each marked with an A or B to designate which connector, and a specific number from 1 to 100 for position within the connector. Time to locate and install each set of cross-connect caps and protector units was recorded on a *Datamyte** Data Collector. If the participant did not complete a trial and press the response button by the imposed deadline, a brief beep occurred. The 34-second slow and 16-second fast deadline times were chosen from the results of a pilot study. In that study, response times measured in an unpaced task showed that 34 seconds was ample time to complete a trial and that a 16-second deadline would be inadequate about 50 percent of the time. Search time was measured as the interval between response button presses. In addition to time data, the position of each cross-connect cap and protector unit was recorded for identification of type as well as number of errors.

2.1.3 Procedure

Each participant completed a practice work assignment of ten trials followed by one work assignment on each of the three connector versions at each of the two deadlines. Order of presentation of connectors within as well as between deadlines was counterbalanced across participants, and the six work assignments were completely rotated through the six connectors every six participants.

Each participant was read instructions describing the physical arrangement of the A and B connectors and the procedure to be followed. For each trial, the procedure was to find the terminal marked on the cross-connect cap and protector unit, place the cap over the cross-connect pair, replace the corresponding protector with the labeled one, and then press the response button to denote completion of the trial. The experimenter emphasized that a clock which was reset by depressing the response button would be running; the goal was to complete each trial before the buzzer sounded.

2.2 Results

Mean time to locate cross-connect and protector unit sets was used

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* Trademark of Data Acquisition Equipment, Electro/General Corporation.

in an Analysis of Variance (ANOVA) computed with subjects (18) and connectors (3) with both slow and fast deadline conditions (2) as variables.[1] No significant differences in search times were found for the three connector versions, nor were there deadline x connector interactions.

In determining errors each cross-connect cap member and protector unit was considered separately. The overall error rate was 4.5 percent. Results of the data analysis showed error rates were not affected significantly by the connector background or by the pace of the work (slow versus fast deadline). Percent and types of errors are summarized in Table I.

Three main error categories were found: parallax, left-right reversals, and counting errors. Parallax errors were responses incorrectly displaced vertically by some number of rows. If a terminal was marked on the wrong connector but in the correctly numbered position, e.g., A3 instead of B3, it was called an L-R reversal error. Counting errors were mistakes in locating terminals in any row within a correct connector that did not fit any obvious pattern.

2.3 Discussion

The addition of background patterns to cross-connect fields did not aid in locating connector terminals. Errors were useful in pinpointing areas for design modifications. Parallax, a problem associated with high-density connectors, is likely to be accentuated because cross-connect and protector fields, as well as numbers referring to them, are in different planes. With the 309-type composite connector, additional difficulties may be related to the abutment of two independent connectors. The large number of L-R reversal errors suggested the need

Table I—Errors in locating terminals

Cross-Connect and Protector-Unit Errors	Experiment 1 ($N = 18$)	Experiment 2 ($N = 12$)	
Type	Average for All Connectors	Original Connector	Modified Connector
Left-right reversals	1.4% of all responses (31% of errors)	1.88% of all responses (20.2% of errors)	1.25% of all responses (46% of errors)
Parallax	1.5% of all responses (34% of errors)	5.1% of all responses (55% of errors)	0.5% of all responses (19.2% of errors)
Counting	1.25% of all responses (27% of errors)	1.5% of all responses (15.7% of errors)	0.3% of all responses (11.5% of errors)
Other	0.7% of all responses (8% of errors)	0.8% of all responses (9% of errors)	0.6% of all responses (23.3% of errors)

for a clearer demarcation between the two connectors, and counting errors pointed to difficulties in locating terminal positions.

Based on the results of Experiment 1, the design of the 309-type connector was modified and a second experiment was conducted. A modified 309-type connector included an angled center designation strip with a vertical black line over the ridge for more distinct separation between connectors, and angled designation strips between cross-connect and protector fields for labeling rows on both sides. Angled rather than flat strips were used to minimize any change in connector dimensions and confusion between adjacent labels. To help further, cross-connect and protector fields were placed in more nearly the same plane by raising the cross-connect field and shortening the cross-connect terminal pins slightly so that the ends of the pins were in the same plane as the corresponding designation strip (see Fig. 1).

A similar experimental design was used in a second experiment to compare performance on the modified connector version and the original unpatterned connector of Experiment 1. Neither connector was patterned on the cross-connect field since patterning did not prove to be effective in Experiment 1. Only the fast deadline was used.

III. EXPERIMENT 2

3.1 Method

Twelve new Bell System participants with comparable experience to those of Experiment 1 took part in the study.

Designation strips on the modified connector were angled back 62 degrees from the vertical plane. The original connector was labeled as before. Four of the six work assignment trays and the practice assignment were used. After the practice assignment, the participant completed a 20-set assignment on each of the two connectors, followed by a break and a repeated measure on the two connectors. The order of connector presentation was counterbalanced and work assignments were rotated as before.

3.2 Results

As in Experiment 1, search time and error rate were the dependent measures. Subjects (12), connectors (2), and the repeated measure, trials (2), were the variables for the ANOVAs. Mean times to find and complete a connection on the original connector were 13.6 and 11.9 seconds for the first and second trials, respectively; these were 12.4 and 11.3 seconds on the modified connector. The modified connector version resulted in a modest but significant savings in search time ($F = 9.11$, $df = 1,11$, $p < 0.05$). The improvement in speed from the first to second trials on both connectors led to a significant practice effect ($F = 34.5$, $df = 1{,}11$, $p < 0.001$).

The overall mean error rate was 9.25 percent on the original connector and 2.70 percent on the modified version; an ANOVA showed that errors were significantly lower on the modified connector ($F = 10.36$, $df = 1{,}11$, $p < 0.01$), and improved with practice ($F = 7.31$, $df = 1{,}11$, $p < 0.05$). Interactions were not significant. Of greatest interest is the marked reduction in errors on the modified 309-type connector. As shown in Table I, using the same error categories, numbers of parallax and counting errors decreased substantially. Unfortunately, L-R reversals did not decrease.

3.3 Discussion

From a human factors standpoint, the lack of a one-to-one correspondence between cross-connect and protector fields and the abutment of two connectors in mirror image are not ideal. On the other hand, there is a real and immediate need for additional space on the MDF.

It is not clear whether the L-R reversal errors were due to difficulties associated with the left-right nature of the task, the mirror image arrangement, or even the proximity of the composite connectors. Although the two sides of each composite connector were called A and B, in all likelihood they were recognized in terms of their relative positions as left and right. People have difficulty discriminating left from right.[2] Despite the random assignment of work order pairs to the A and B connectors, 69 percent of the reversal errors in Experiment 1 and 73 percent in Experiment 2 were preceded by a correct response on the same side, as if participants were not paying attention to which of the connectors they had just worked on, and so continued to work on the same connector.

The terminal location task was chosen as it was assumed it would be sensitive to the spatial arrangement of the connectors. Time-consuming wiring operations were not included in the task as they should be constant. On the main frame, however, these and many other operations would interrupt the left-to-right scan. The search would also necessarily extend over a much wider area since a main frame consists of large arrays of connectors. The identification of main frame connectors at the top of vertical frame modules should also result in vertical top-to-bottom search. Thus, the predominant left-to-right orientation of the task may have been somewhat artificial. It is likely that L-R reversal errors would be reduced on the main frame where the inclusion of other operations should make the craftperson's job more sensitive to a connector's specific position.

While eliminating the one-to-one correspondence between cross-connect and protector fields results in higher density terminations on the MDF, craftspeople, like the experimental participants, may locate associated elements on the two fields independently. The potentially small difference in time should not affect productivity. In reality, a work assignment would not necessarily require work on both cross-connect and associated protector units. More important for the craftsperson's job may be the advantage of the front-facing work surface. There is some assurance that the craftsperson will keep his/her gaze nearly perpendicular to the angled designation strips on the modified 309-type connector, since numeral positions on the sides of the wedge-shaped strips preclude reading both sides from the same point. Besides providing clear labels and end points for rows, then, the angled designation strips may lead to more concentration that results in greater accuracy in terminal location.

In summary, the number and consistency in errors on the initially proposed 309-type connector were unacceptably high. Performance on a modified version was improved with significant reductions in parallax and counting errors. The resultant 309-type connector represents the integration of design and human factors efforts.

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