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SIMULATION FIDELITY AND NUMEROSITY EFFECTS IN CDTI EXPERIMENTATION

The NASA-Ames agreement No. NCC 2-93 between NASA-ARC and Tufts University in effect from September 1980 to August 1981 and by extensions to December 1982 had as its major thrust veridical tests of Simulator Numerosity and Fidelity as affecting CDTI experimental results. This will be briefly commented on as several papers describing results have been presented in conference.

A. VERIDICAL TESTS OF SIMULATOR NUMEROSITY AND FIDELITY.

A series of protocols had been devised and discussed with ARC personnel as tests for determining the differences in experimental results attributable to the levels of numerosity and fidelity of CDTI simulators in a CDTI scenario.

Although extensive work had been completed on using the Boston-Logan area as the traffic setting, work based on interviews with pilots and controllers and tower personnel, an existing traffic configuration based on the San Jose area was used instead.

A series of 4 experimental comparisons were run at ARC during August 1981 testing various levels of simulator fidelity and CDTI numerosity. The conditions were:

H7 : 3 simulators with CDTI + 4 pseudopilots with CDTI
H2 : 2 simulators with CDTI + 1 simulator without CDTI and
4 pseudopilots without CDTI
H0 : 3 simulators without CDTI + 4 pseudopilots without CDTI
L2 : 2 simulators with CDTI + 5 keyboard targets without CDTI.

Each of the 4 conditions were run twice per group with 3 groups. Each group included an air traffic controller in addition to the required number of pilots (7).

The scenario required A/C scheduled into the San Jose area to be sequenced, merged and landed. At some point in the ongoing task, an emergency was declared and the runway was closed for approximately 5 minutes. A complete run including the emergency lasted 30 minutes. During each run complete data were taken on the individual A/C. In addition, all verbal messages were tape-recorded and post flight questionnaires were filled out by the participants.

The results of the experiment are extensive and a number have been reported previously [12,13]. These are summarized here with comparison to previously acquired CDTI simulation-experimental ones. A full description of the experimental set up, etc. can be found in (Chappell & Kreifeldt, 1982).

B. SIMULATOR FIDELITY

There were three levels of simulator fidelity, the "cabs" (air carriers) which were the most realistic as to control inputs, dynamics, etc.; "pseudos" (general aviation) which were joystick/throttle table top controls; and the least realistic "keyboard" which permitted one pilot to command multiple targets through simple keyboard inputs. There were a number of statistical differences attributed to the simulator fidelity. The general aviation targets were issued more speed, heading and altitude changes when these were individually piloted as "pseudos" than when they were all under control of a single pilot (keyboard). This, of course, infers that communications per target would be greater for the more faithful simulation, a fact supported by an analysis of the verbal data showing that the GA targets received about 10% more communications as "pseudos" than as "keyboards". Further and although confounded with target type (air carrier-most realistic or general aviation - less realistic), the cabs (air carrier) received about 40% more communications than the less realistic GA simulators. Thus, the controller's verbal workload, a primary measure of workload and capacity could be seriously underestimated with lower fidelity target. This could have potentially serious consequences on the safety of a system as estimated by using low fidelity simulators when verbal workload is taken as a safety measure.

Compared to the air carrier targets (most realistic simulators), the GA targets had the greater altitude and localized errors at the OM and the greater horizontal path length. The errors were probably greater because the GA simulator instrumentation was quite primitive compared to that of the air carriers. The longer GA horizontal path length was most likely attributable to the ATC prediliction for giving air carriers preference over GA.

The intercrossing times at the OM and MM were greatest for the keyboard targets and least for the air carriers with somewhat more tighter controlled (smaller variance) as well. The better instrumentation in the air carriers compared to the lower fidelity may account for their better delivery to the OM. The keyboard targets had the longest intercrossing times at both MM and OM. Thus if a low fidelity (keyboard) target facility such as at NAFEC is used to generate controllable targets for ATC capacity simulation studies, the capacity may again be seriously underestimated.

Two air carriers were within 1 nm horizontal separation longer than any of the other 4 pairing of air carrier, pseudos and keyboard targets (pseudos and keyboard targets were never used at the same time) while two pseudos were within 2.5 nm and 3.0 nm horizontal separation longer than any of the other 4 pairings.

C. FACILITY SIMULATION LEVEL

There were two facility fidelity levels; a HIGH fidelity level of 3 aircarriers (cabs) and 4 GA pseudos or a LOW fidelity level of 2 air carriers and 5 GA keyboard targets. In either case there were 7 controllable targets in the problem at any time. The following statistical differences were attributed to the facility simulation level.

The GA targets received more altitude, heading and speed changes in the HIGH than in the LOW facility fidelity level which reiterates the previously stated results for individually piloted GA targets (pseudos) as opposed to the multiply commanded GA targets (keyboard). The LOW fidelity facility produced about 30% longer intercrossing times at the MM and OM than did the HIGH fidelity level. As the previous section indicated, this was attributable to the longer times with keyboard and GA targets than with the individually piloted GA targets (pseudos). Thus the lower the overall fidelity level of a facility the more seriously the runway capacity may be underestimated.

D. CDTI EFFECTS

Although the experiment was not strictly a CDTI one, there were several statistical differences attributable to CDTI/nonCDTI conditions without, however, distinguishing separately the simulator fidelity or facility fidelity variables.

Perhaps the most relevant finding is that as the number of CDTI equipped targets increased from zero to two (air carriers) to seven (3 air carriers and 4 pseudos), the number of communications per target increased as well. There was a 18% increase with two CDTI's compared to none and a 23% increase with seven compared to none. Thus there was a slight (4%) increase with 7 CDTI's compared to 2. This suggests that the controller verbal workload would be higher with CDTI. However, the communication with CDTI's must be of the advisory type. GA targets with CDTI made 70% more speed changes, 34% more altitude changes and had a 12% shorter horizontal path length with CDTI than without. The CDTI equipped targets also had 27% more communications than the nonCDTI equipped ones. Again, these communications must be of the advisory nature. A surprising finding was that the intercrossing times variance was about 8% greater for CDTI equipped targets. This is counter to a previous study(14) which showed that CDTI equipped simulator air carrier targets had a <u>smaller</u> intercrossing time variance than did nonCDTI targets.

There was no statistical difference between CDTI/nonCDTI targets in terms of spacing violations. Thus many CDTI's were no more unsafe than fewer or <u>no</u> CDTI targets.

E. DISCUSSION

The experiment has demonstrated that in fact results for various system measures important in ATC and CDTI studies may depend upon the level of the facility fidelity and the number of actual individually piloted CDTI targets used to simulate a multi-CDTI traffic environment. The magnitude of the difference will, of course, depend on the scenarios chosen. In particular, the use of a cluster of keyboard controlled targets commanded by one "pilot", a common way of simulating controllable traffic in a simple, economic fashion, produces results on a number of measures considerably different from those obtained using a one target-one pilot realization. The ATC method could be expected to differ in significant ways in a one target-one pilot (realistic) environment compared to a multiple target-one pilot one. This difference would thus cause the results obtained from a low fidelity, few CDTI simulations to be strongly suspect when attempting to transfer those results to a real world multi CDTI environment. While the experimental scenario used produced statistically significant differences ranging from a few percent to 70%, this one experiment can only demonstrate the fact that simulator fidelity and CDTI numerosity do effect both magnitude and direction of results. By itself it cannot set absolute correction factors to apply to the measures for different levels of fidelity and numerosity for any arbitrary scenario. However, in as much as the scenario and protocol of the experiment were quite realistic and open, the validity of the comparison results seems assured.

Other experiments using other scenarios would have to be run to establish solid correction factors for measures dependent on fidelity and numerosity.

Over the years since ATC-CDTI studies were begun at NASA-ARC under a NRC fellowship in 1972, the experimental scenarios have become more realistic in being less controlled and better simulated increasing at least the face validity of the results. As control over the experiment is loosened to permit more realistic behavior, the need for multivariate statistical methods of analysis and description increases. It is strongly suggested that these methods which include discriminant analysis, clustering, hierarchical techniques, multidimensional scaling, etc., be studied and applied. An example of the use of these techniques can be found in Kreifeldt, Parkin and Hart (1977) and Kreifeldt and Parkin (1975).

F. PREVIOUS CDTI RESEARCH UNDER NASA-ARC FUNDING

The author began ATC-CDTI studies at NASA-ARC in 1973 under a NRC Fellowship and subsequently under a series of consortium fundings and grants. The major experiments are summarized in Kreifeldt (1980). Considerable prototyping work was also conducted at Tufts University on development of a minicomputer based low cost, multi-simulator facility the outlines of which are summarized in Kreifeldt (1981).

A full listing of all the papers, presentations and reports produced under the grants on the grant matters are given in the Bibliography.

MINICOMPUTER BASED MULTIMAN SIMULATOR FACILITY

In addition to the above work, the contents of the minicomputer multicab prototyping facility have been shipped to Dr. Diane Damos at Arizona State University on October 1982. This included two desk top simulators, two computer systems, specially developed hardware/software and various manuals and drawings. The work at Tufts on this prototype facility as presented in various papers and reports had produced a prototype facility that could support simultaneously up to eight minicomputer based flight simulators of fairly high fidelity. The advantage of the facility would be its flexibility, low cost and reliability as well as its ability to stand alone for many types of experiments.

As no further development support was obtained for this facility under the NCC 2-93 agreement, progress stopped in September of 1980. However, a brief progress report by Mr. Gary MacDonald was prepared on September 2, 1980. This report is enclosed and supplements the series of technical reports and papers given earlier and listed in the Bibliography.

This bibliography lists various papers and reports describing work done under NASA grant NSG 2056 to prototype a minicomputer based simulation facility at Tufts.

Kreifeldt, J.G.,Gallagher, O.,"Design Outline for a New Multiman ATC Simulation Facility at NASA-Ames Research Center," Proc. 13th Annual Conference on Manual Control, MIT, Cambridge, Massachusetts June 1977.

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MacDonald G., "Multiman Flight Simulator System." Progress report for the period Oct. 1979-Sept. 1980, Tufts University, Department of Engineering Design, Sept. 2, 1980.

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7. Kreifeldt, J. G., Hart, S.G., Parkin, L., "ATC by Distributed Management in a MLS Environment." 13th Annual Conference on Manual Control, MIT, Cambridge, Massachusetts, June 1977.

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9. Kreifeldt, J.G., "Redesign of the Air Traffic Control System - Moving People Through Distributed Management", 22nd Annual Meeting of the Human Factors Society, Detroit, Michigan, October 1978.

10. Kreifeldt, J. G., "Effects of Distributed Management on ATC System Workloads", 14th Annual Conference on Manual Control, Los Angeles, April 1978.

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NOTE: Items 15-21 also appear on the separate bibliography TUFTS MINICOMPUTER BASED SIMULATOR PROTOTYPE FACILITY.

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16. Abstract
A comparison of twenty pilot workload assessment techniques was performed using a simulated flying task in which three levels of psychomotor workload were imposed. The experiment was conducted in a three-degree of freedom motion-base simulator. The twenty techniques evaluated included opinion measures, spare mental capacity measures, physiological measures, eye movement behaviour and primary task performance measures. The primary task was an instrument landing system (ILS) approach and landing. All measures were recorded between the outer and middle markers on the approach. Three levels of psychomotor load were obtained by the combined manipulation of wind gust disturbance level and simulated aircraft pitch stability. Six instrument-rated general aviation pilots participated in the experiment.

Two opinion measures, one spare mental capacity measure, one physiological measure, and one primary task measure demonstrated sensitivity to psychomotor load in this experiment. These measures were: Cooper-Harper ratings, WCI/TE ratings, time estimation standard deviation, pulse rate mean, and control movements per unit time. No intrusion into primary task performance was found for the physiological spare mental capacity measures. The results of this experiment demonstrate that the sensitivities of workload estimation techniques vary widely, and that only a few techniques appear to be sensitive to psychomotor load.

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