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A Laboratory to Facilitate Computer-Controlled Behavioral Experiments

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INTRODUCTION

The Management Science Laboratory was conceived by faculty in the Center for Research in Management Science at the University of California at Berkeley as a facility for behavioral research.[1] A facilities grant from the National Science Foundation was awarded to the Center, and an interest group was formed to design and construct a laboratory for experiments with human subjects in situations based on models from the behavioral disciplines.

Our thinking was guided by results from a prototype laboratory[2] and by the emerging literature in experimental gaming. Two principal considerations were that the environment should not detract from the experiments and, whenever possible, automatic control should be substituted for human control over experimental variables. The use of a digital computer as the heart of the experimental control system would achieve the generality which was required. The design of the laboratory was given over to architects who consulted with the faculty, while the computer control system was designed by technicians coordinated by one faculty member. These two activities have now been brought to fruition and the results are in use for both teaching and research.

PHYSICAL SYSTEM

The laboratory occupies some 3000 square feet of space in a rectangular layout below ground. A sketch of the floor plan is given in Figure 1. Two doors provide access for people, and there are two large equipment access doors on each end of the space. One end of the rectangle is reserved for the computer and control

[1] Many of the faculty associated with the Center for Research in Management Science have been involved at one time or another in the physical facilities' planning. Special mention should be made of Hector Anton, F. E. Balderston, C. West Churchman, Edward Feigenbaum, Julian Feldman, and the authors of this paper.

[2] Developed by Hoggatt during an appointment as Research Professor in the Miller Institute for Basic Research in Science, 1960 to 1961.

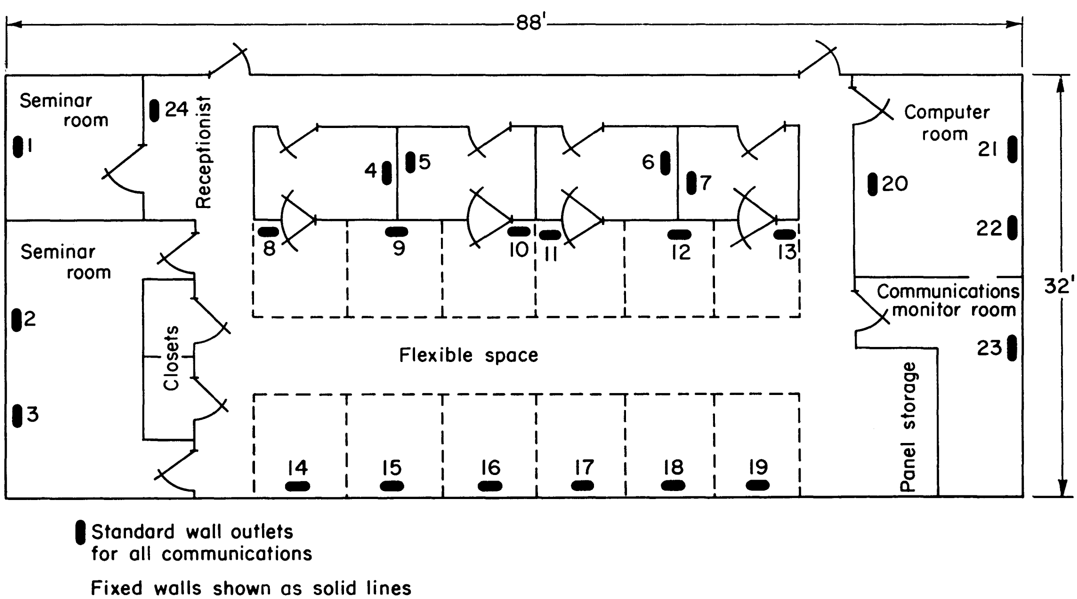

FIGURE 1. FLOOR PLAN OF THE MANAGEMENT SCIENCE LABORATORY.

panels. The rest of the space is given over to seven rooms with fixed walls and a large area which can be broken up into cubicles.

The architects were faced with two particularly interesting classes of problems. On the one hand was the technical problem—in fact an array of complicated interlocking subproblems—of providing environments that had reasonable visual and spatial neutrality, while being protected against contamination from outside influence (most particularly acoustic). Into these environments had to go all of the normal mechanical systems plus all of the special communications and computer linkages. To achieve this also required some reasonable prediction as to the kinds of spaces that particular experiments might demand over a future period of some years.

To design a facility adaptable to new generations of experiments, the exact nature and requirements of which were as yet unknown, a relatively simple line of inquiry was pursued. Experimenters were asked to describe experiments they had done, were doing, and wanted

FIGURE 2. THE EXPERIMENTAL AREA PARTITIONED INTO 7′ × 7′ EXPERIMENTAL CUBICLES. SOUND-BAFFLED AIR CONDITIONING OUTLETS, T.V. MOUNTING RACKS, AND TRACKS FOR THE PANELS ARE VISIBLE IN THE CEILING.

to do. They were also asked to describe experiments they thought someone else ought to do, including "far out" experiments that should be done "sometime by someone." Analyzing these descriptions and roughly designing prototypical spaces showed that infinite flexibility was not required, there being far more stability in the requirements than had been suspected. When small seminar (dividable) space was set aside on an essentially permanent basis, the remaining changeable space was reduced to reasonable limits.

Once the architects knew the spatial divisions required, design became a straightforward question of solving the technical problems of movable systems-cum-services. The movable partition system used in the final design had a wall structure well designed acoustically, but the means for moving the panels was entirely overhead. This did not cut up the floor with tracks but did require a costly overhead supporting system.

Both types of movable panels (those with doors and the plain one) are finished with a vinyl fabric and some incorporate a chalkboard. Panels can be used interchangeably throughout the space. One basic cornerpost intersection is used: for a straight-through wall; for a 90-degree intersecting wall; or as a tee-type unit with three walls intersecting at one point. The overhead track system is laid out so that the entire space may be divided into cubicles approximately two panels wide in each dimension; about 7 feet by 7 feet, as shown in Figure 2. The total space can therefore be divided in half, divided into four rooms; or divided into medium-sized rooms on one side and small cubicles on the other side of a central corridor. Numerous other corridor-cubicle arrangements are also possible (Figure 3).

FIGURE 3. MODIFICATION OF THE SPATIAL ARRANGEMENT IS QUICK AND EASY. Here, the experimental area shown in figure 1 is depicted with one row of cubicles broken down, thus creating a large area adaptable to conferences or debriefing sessions.

Panel storage occupies an area of about 10 feet by 11 feet at one end of the large laboratory space. Panels may be moved out of storage and set into place by one man in about five minutes.

The panels are about 4″ thick, made of heavy steel plates enclosing an acoustical fill. Each panel is supported from the ceiling track by two ball-bearing trolleys while the cornerposts are supported using a single trolley.

Coaxial cable is run from a patch panel in the computer room to numerous locations in the lab space to provide any possible cubicle setup with video communication. An independent intercom system is run to each space from the receptionist area so that a separate means of communication is provided and yet under supervisory control if needed.

As already outlined, much care was taken to design for acoustic isolation of each outlet, whatever supply is concerned, so that no space configuration can ever cause acoustic contamination of any other space. Dr. Walter W. Soroka, the acoustic consultant, conducted sound transmission loss tests in the laboratory space upon completion of the building work. He found three weak areas in the cubicle setup with movable panels two of which could be eliminated and the third guarded against in specially sensitive experiments. Sound level tests were also conducted with the ventilating system on and off. With the ventilating system off, sound levels were just above the threshold of hearing. With the system operating, sound levels were like those of a good broadcasting studio or concert hall. It was suggested that the ambient sound level be increased to override outside noises leaking into the space. This could be done by increasing the air velocity in the ventilating system or by transmitting a "pink" sound through the intercom system.

The laboratory space has been in limited use for two years; no major weaknesses have been discovered in the facilities, and there has been no demand for facilities which could not be adequately met by the design as it was finally implemented.

THE PROCESS CONTROL SYSTEM[3]

Figure 4 is the schematic of the computer system. At the center is a time-shared PDP-5 with DECTAPES, IBM compatible tape, full-duplex teletype multiplexor, analog-digital digital-analog conversion, micro clock, voltage out (one shot) and sense channels and a memory-to-memory link to a PDP-8 computer. The PDP-5 is quiescent responding to a 100 millisecond interrupt to update its clock or to a demand for service from one of the devices which it serves. On demand the PDP-5 slavishly responds or transmits to a peripheral device or stores data. The PDP-8, which has extended arithmetic, operates on a variable quantum break of 10 milliseconds up to 100 milliseconds and can be tuned to match the environmental characteristics of any given experiment. Control over the experiment resides in the PDP-8 which can issue commands to the PDP-5 to send character strings or operate external devices. For example, in creating a log of the experiment the PDP-8 may select characters from the input string of a teletype, add control characters and the real clock time to the string and have the PDP-5 write this information on the DECTAPE. Since the IBM compatible tape is not time-shared, data may be put on IBM compatible tape and punched into cards elsewhere at another time.

Programming Systems[4]

Library and text editor. A library, text editor and assembler have been combined to produce a DECTAPE-oriented library system, which operates on the two machines. The programmer has tapes which contain his programs and the operating systems so that he may quickly control the system by mounting a tape and accessing the library. A program may be stored in character mode, edited from console, assembled into binary code, incorporated with other machine language programs, and stored under a name which can be used to load it into core. Integrity of the information is provided by physical possession of the tapes.

Time-sharing systems. Each computer has its own time-sharing system which operates independently of the other. They provide for up

[3] Engineering design and implementation of this integrated system was the work of Don Fanshier, President of Neoteric Systems, Inc. Special mention should be made of the design and implementation of the multiplexor by Jack Andresen.

[4] Programming developments have been made by many persons, including Sipko Andrea, Robert Fitzhugh, John Meng, Jeff Moore, Joe Schlesinger, Robert Stubenitski, David Steingart.

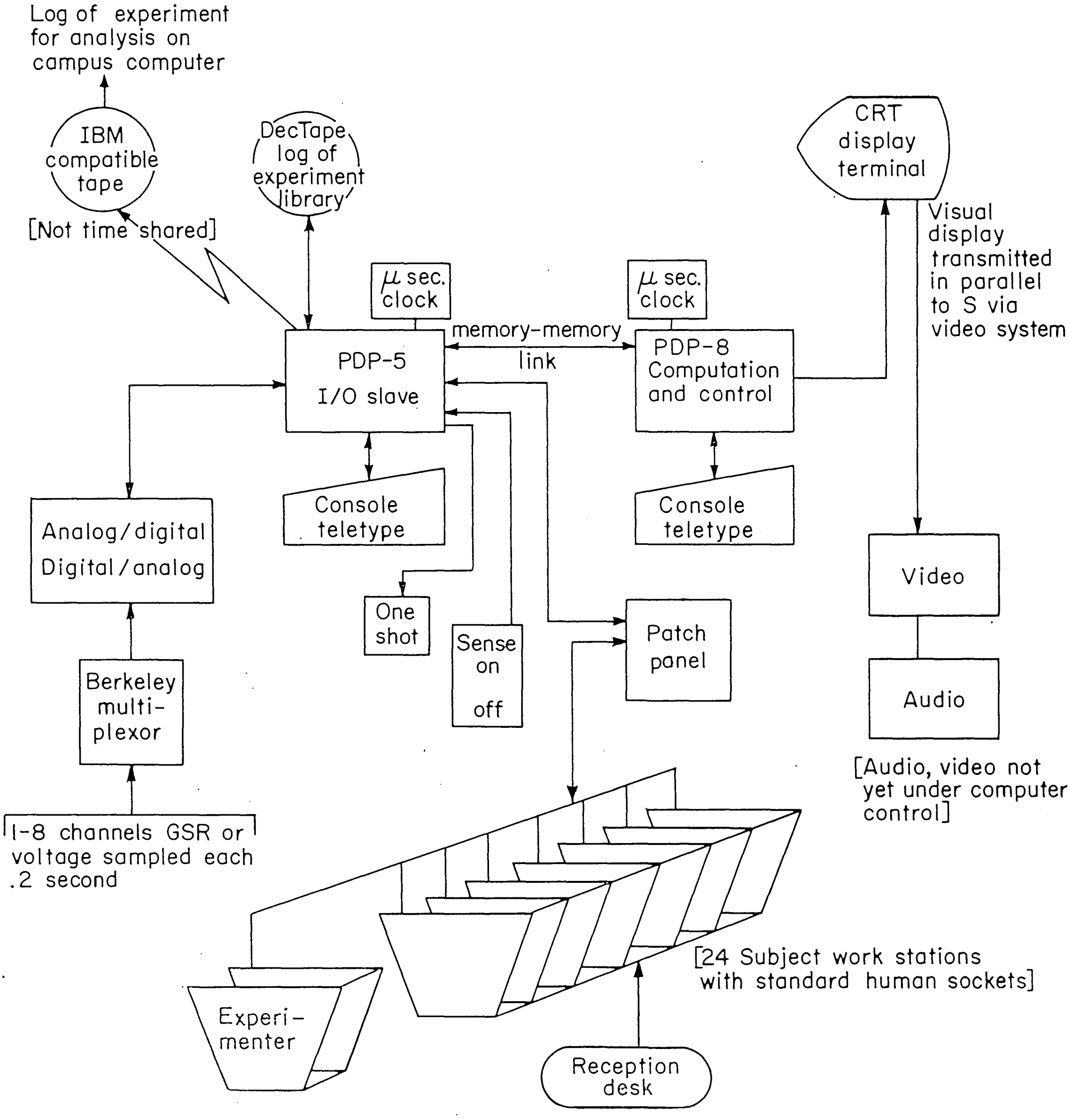

FIGURE 4. LOGICAL DESIGN OF COMPUTER CONTROL SYSTEM, CRMS LAB.

to 10 subjects or experimenters on consoles. Each user is given a list of variables which are swapped into working locations in the core and then swapped out to other core locations on the quantum break. It is possible to run on 10 teletypes with all I/O in operation without noticeable delay at the consoles.

Environmental control language. The very complicated system described would be of little utility to the academic community if it had to be approached on these terms. A language for specifying an experimental control program has therefore been invented and implemented, so that a user need not be a programmer to write in the language. It is therefore possible to debug programs from symptoms displayed in operation without ever having to descend to the level of machine language. We do this by simulating a machine which has instructions such as:

LOG	Write the current log buffer on tape.
STKSW	Go to the location x for next instruction.

x		
x	XLOAD5 104	Print the message whose name is at location 104 on the teletype.

Each of the pseudo instructions for this "machine" is coded in reentrant machine language with the variable stored in the user program work space. Thus they need exist in only one copy and several users may compute with the same routine asyncronously under the time-sharing system. This conserves space (a necessary consequence of trying to do so much with small machines) and the language becomes an operating self-documenting publication language for unambiguously specifying an experimental environment.

Limitations of the computer system. The present system is limited in several respects. Because we are using a small computer, we are restricted to situations with only a few variables and to response functions which do not require much computation. For the present, however, we shall exploit the present system rather than investing more resources in facilities' development. The reliability of this second generation hardware is also somewhat less than we would like and we are working to eliminate system failure by engineering and programming changes.

ECONOMICS OF THIS SYSTEM

Where fixed costs are concerned, this entire computer system could now be duplicated and surpassed in power for $80,000, and the space configuration might cost $200,000. The variable costs of operation are a few thousand dollars per year for maintenance and salaries for two professional employees (operator and system programmers); these are partially supported by a five-year grant to aid in the operation of the laboratory until it becomes self-supporting. The capacity of the system is very great—we could log 280 subject-hours in the laboratory in a single day and reduce the data overnight through the campus computer facility. We have run experiments in the morning and discussed results over the print-out at lunch on the same day. The experimenter finds himself in a situation with rapid feedback, which learning theory tells us is a very happy state of affairs. The lab is being used in classes, and students in computer courses are programming experiments for it.

Many elements—engineering, programming, architecture—have been combined to develop a facility, and we are now on the way toward its operational use. Whether or not this massive investment in facilities is worth its cost will become clearer over the next few years of operation as we shift our attention from development to substantive experiments.

The authors are affiliated with the University of California at Berkeley: Austin C. Hoggatt is professor of business administration and chairman of the advisory committee of the laboratory for management science, Joseph Esherick is professor of environmental design, and John T. Wheeler is associate dean for academic affairs and professor of business administration.

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