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ABSTRACT

A method was developed for doing a computer simulation of elementary school activities for different school organizations, with traditional and multiunit schools being observed for significant factors relating to the use of space. Analysis of the collected data showed that group size varied significantly as a function of school program and activity. Design modules were then created describing activities for a school program in terms of the individualization of activities and the potential for an activity to distract other ongoing activities. Square feet per student were computed using optimal dimensions and collected observational data relevant to the actual space used during activities. A system of computer programs was designed and partially implemented that would accept as input a school program designation, a planned enrollment, and a proposed school floorplan and would apply the appropriate model to a schedule of activities to determine the adequacy of the proposed design in terms of projected space needs. (Author)

Final Report

Grant No. OEG-5-72-0015-(509)

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IMPROVEMENT OF ELEMENTARY SCHOOL DESIGNS THROUGH SIMULATION OF EDUCATIONAL ACTIVITIES

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

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U.S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE

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GENERAL INTRODUCTION

This report will describe a systematic procedure for determining those characteristics of a school program which affect or are affected by the physical constraints of a school building and the development of a computer simulation model which will provide school designers access to information from the model as applied to their own specific design proposals.

In the past two decades a variety of new schemes for organizing elementary and middle school education have been introduced in the United States, including team teaching, continuous progress or nongraded schools, individually prescribed instruction, and the multi-unit school.* The degree of success of an innovative school program can depend on the physical school structure into which it is introduced. According to a report by the Educational Facilities Laboratories (Gross, 1968), "Many a school administrator has felt thwarted 'because the building wouldn't get out of the way'" to allow for educational innovations to be put into effect.

The adequacy of a building for a given educational program can be described for the purposes of this report as a function of the amount and configuration of space available for carrying on educational activities under that program. That there is disparity among experts as to the allocation of space for educational activities is well documented (Engelhardt, 1970 or Castaldi, 1969). A comparison of award winning elementary schools in Nation's Schools (1968) showed a range of space allocation of from 54.2 to 112.3 square feet per student with costs ranging from $10.80 to $33.84 per square foot. Instructional space ranged from 40% to 80% of the total area of the facility.

Many American communities show an increasing desire to build school buildings which will accommodate a variety of instructional organizations but are unwilling to tolerate extravagant or inefficient structures.

Objectives

The study described herein was done with the intention of providing a link between educators and architects, enabling them to

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*The multiunit school concept was developed at the University of Wisconsin Research and Development Center. It is based on dividing a school into a number of separate independent units each administered by a team of teachers. There is strong emphasis on independent work and individually determined pace through the curriculum.

develop and test school designs under simulated conditions. Specifically there were three major objectives:

1. Development of a procedure for modeling the educational activities in two kinds of schools - traditional and multiunit.

2. Development of a computer simulation capability for applying the model to existing or planned structures.

3. Execution of the simulation procedure on selected test cases.

Objective (1) was accomplished through the design and test of a method for collecting data about elementary school activities by direct classroom observation. The subsequent analysis of the collected data determined those factors which would go into the proposed model. The collection of data and the analysis are described in sections II and III respectively.

To satisfy objective 2 a set of computer programs has been designed and partially implemented to incorporate the derived model and provide various outputs concerning space usage for the school designer. This system of programs is described in section V.

Appendix D describes the execution of the simulation on a hypothetical school employing one of the models derived from the data which was collected.

Review of Related Research

The evolution of teaching methodology has historically been accompanied by changing school structures to accommodate them. The one room schoolhouse of the 19th century has been transformed to the egg-crate construction of the first half of the twentieth century and finally to the open-plan schoolhouses of the past decade (Leu, 1965). The egg-crate design came about as the response to the requirement of absolute independence between grade levels; the open-plan in response to the attempt to abolish grade level differences and open lines of communication among teachers and students (e.g. non-graded or continuous progress schools). "The design of the school must be consistent with the type of instruction system carried on" (Engelhardt, 1970).

Current educational methodology still ranges from the traditional approach to the continuous progress school. One feature of any such methodology is the grouping of students in pursuing instructional activities. Theoretically, different methodologies call for different ways of grouping students.

For example, the multiunit program of individually guided educational calls for the use of small, medium and large groups ranging in size from a single individual to 150 or more for instructional purposes. New and remodeled schools employing the multiunit concept are either built "pod" style or include special facilities for handling whole unit activities (Klausmeier et. al.).

Furthermore, the variance in grouping policies and the growing policies and the growing trend on the part of school systems to try new methodologies has increased the demand for more flexible structures by school administrators. "Often even new buildings make no concessions in their planning to newer concepts of teaching ...." (Pilkington, 1967).

For their part, architects are not unaware of the problems posed in the development of adaptable school structures. Paul (1967) cites the need for architects to be aware of school philosophies, activities and the functional relationships between them. The emphasis on the individual learner in modern methodologies is reflected in considering each student to be a "module" with various interrelated dimensions, among them space (Yamanski et. al., 1970). Focus on the individual results in an optimum situation in which a student spends most of his time in independent study with small amounts of time allotted for discussion and consultation. Space needs in such a situation are more on the order of individual carrols and small seminar rooms than under programs where more group interaction requires areas which will serve the needs of larger concentrations of students.

Existing computer applications in architecture range from bookkeeping applications to the description of complete design systems (which have yet to become implemented). Thomsen (1968) describes a computer system which calculates a building's cost given its floorplan and definitions of materials. Teage (1968) enters the components of a building along with their spatial and structural relationships into a program called BUILD, and generates summary information of surface areas, room dimensions, areas and volumes of spaces, and cost.

A class of programs which solve problems in the optimal arrangement of equipment and facilities is exemplified by CORELAP (Lee, 1967) which accepts a relationship chart for departments, area restrictions for the departments, size of the unit area to be manipulated, and maximum ratio of building length to width, and returns a feasible plant layout before the building configuration is defined. COMPROGRAPH II, a product of Design Systems Inc. deals with the space allocation problem by solving a matrix of constraints on the relationship between entities (spaces in a building, activities in a space, buildings in a complex) and projecting the results into 2-space or 3-space in such a way as to optimize the solution.

In recent years some efforts to design computer simulation programs for architectural design have emerged, several of which have been specifically written for the development of educational facilities. Bullock et. al. (1970) designed a simulation program to aid in campus planning. Built around assumptions about how people circulate through the campus and the surrounding area, and what their schedules are likely to be, the program generates "individuals" who attend to their various activities. Among the results is a graphic representation of population density at various times throughout the campus.

At Florida State University the Educational System and Planning Center has developed a simulation program to determine student station requirements at the secondary school level (Banghart, 1970). Using as its basic calculating unit the "student module" (the space and resources required to maintain a student in a given activity at a particular time), the program schedules students into activities. The program then computes space requirements per activity type based on the schedule and number of student modules required per activity.

Apker (1970) has simulated a high school with modular scheduling in order to make better decisions about space needs. The high school had not yet been built at the time of the simulation. Among the questions answered by the simulation were "Could better decisions be made regarding building needs when using simulation?" The results showed that for a school of 1500 students the architect overestimated classroom needs by 21 rooms and underestimated seating space for large group instruction. The scheduling for Apker's simulation was performed by the Generalized Academic Simulation Program (GASP). Using a computer to generate complex schedules for modular schools has in most cases proved to be superior to manual methods both in quality and cost (Murphy, 1964).

The future of the computer in the architectural design process is perhaps best expressed by Negroponte in his book <u>The Architecture Machine</u> (1970). He cites the benefits of automating certain procedures and the use of simulation for determining optimum environments for activities. He envisions the evolutionary design process being presented to an evolutionary machine where a mutual training, resilience, and growth can be developed.

THE COLLECTION OF DATA BY DIRECT OBSERVATION
OF ELEMENTARY SCHOOLS

Introduction

This section will describe the development and implementation of an observation procedure for collecting data about elementary school activities which would characterize their actual and potential impact on educational space. The objective in collecting data was to show that the implementations of different scholastic programs in an elementary school can result a schedule and configuration of activities which would lead to different architectural conceptions.

The primary architectural descriptor of interest is the requirement for and use of space by activities. Assuming that the major component of an activity which requires space is the student, the objective of observation was to determine what factors in an activity under a school program contribute to the number of students engaged in the activity, and how the configuration of students and equipment in the space affect the total amount of space used in the activity.

Procedure

The design of an observation procedure consisted of 1) determining what information items should be recorded and 2) developing observation forms appropriate to the task.

Two schemes were developed, field tested, and rejected (see Appendix A) before a final version of an observation procedure was adopted. The criterion for the observation forms was that they be suitable for recording information about several events occurring simultaneously and that they be readily transferrable to punched cards.

Since the data collection scheme was to be "activity" oriented, it first became necessary to define an elementary school activity as it pertained to this study, then to determine the characteristics of activities in which we were interested.

An activity is defined, herein, to be any of a set of events, instructional or otherwise, which may occur in an observed space. Activities have certain descriptive attributes, among which are that they involve a number of people, they up space, they take a certain amount of time, and they may generate noise.

Determination of Pertinent Information Items

The determination of those aspects of elementary school activities which were to be observed came about as the result of several school visitations and consultations with principals, teachers, school architects, and school administrators. Several schools in southern Wisconsin were visited with the emphasis placed on open-plan schools. Rooms and pods were observed at length, and careful attention was given to any characteristics of an activity which could conceivably be affected or have an effect upon the physical constraints of the space in which it occurred and the actual utilization of the space. Information items which were chosen for inclusion on the final observation forms were:

- School in which observation was being performed
- Identification of classroom or pod in which observer was situated
- Activity or event being observed
- Start and end time of the event
- Identification of location or subspace within the space in which the event occurred
- Identification of the group being observed
- Group type (e.g. an indication of whether the participants were acting as a group or as individuals)
- Number of students
- Number of supervisory personnel
- Physical configuration of group
- Distraction factor (a composite index of noise and physical activity)
- Amount and kinds of equipment used in the activity
- Dimensions and locations of all spaces and subspaces

Design of the Observation Forms

The observation forms were designed so that the data recorded could be directly transferrable to punched cards, yet be conveniently recorded with a minimum of decision making on the part of the observer.

Three kinds of data were recorded; quantitative (e.g. group size), categorical (e.g. subject) in which items could be chosen from a list, and graphic (dimensions and locations of spaces and subspaces).

The quantitative and categorical items were designed to be entries on an 8½ × 11 observation sheet, one column for each entry.

Each observation of an event could thus be described on one line of the sheet. To conserve space on the sheet, lists of categorical items were drawn up and appropriate codes assigned to them for use by the observer. Codes were purposely made mnemonic so they would be meaningful and easy to learn, and the maximum number of written characters on each line was less than 80, facilitating the transfer to punched cards.

The graphic data consisted of a floorplan of the space at which an observer was to be stationed. On the floorplan, the observer would draw and name (keyed to the observation sheet) each subspace in which a recorded event took place. The space and subspace drawings were later transferred to punched cards through the use of a digitizer in the cartography department at the University of Wisconsin.

A complete guide and explanation of the items on the recording sheet is shown in Appendix B.

Selection of Sample Schools

Two types of elementary school programs were observed -- the traditional program where one teacher ran a self contained classroom of from 20-40 students, and the multiunit program where teams of 4-5 teachers worked with units of 150-200 students.

Three schools were selected for observation, two of which were multiunit (Schools A and B), the other, traditional (School C). Because of the recent trend in building open-plan or pod-type schools without walls, the two multiunit schools selected were of the open-plan type (see floorplans Figures 1 and 2). Classrooms in School C were rectangular with dimensions of 22' × 35' or 27' × 29'.

All of the spaces observed at Schools A, B, and C were instructional areas ranging from grades 1-6. In School A, the three units observed represented the equivalent of grades 1-3, 3-5, and 4-6 for units 2, 3, and 4 respectively. In School B, only the units representing grades 3-5 and 4-6 were observed. In the traditional school, C, classrooms were observed for grades 1-5. Two weeks of observation was done at School B (the first of which served to acclimate the observers, not all of whom were available each day) and one week of observation was made at each of Schools A and C. The actual time spent in each space at School C was dependent on the decision of the individual teacher as to how long her classroom could be observed.

The operation of the multiunit schools was based on individual unit schedules which allocated blocks of time for general subject areas. For example, the first 30 minutes of every morning at School A unit 4 was scheduled for language arts activities. At School C,

Figure 1

Floorplan of Observed Units

School A

1" = 36'

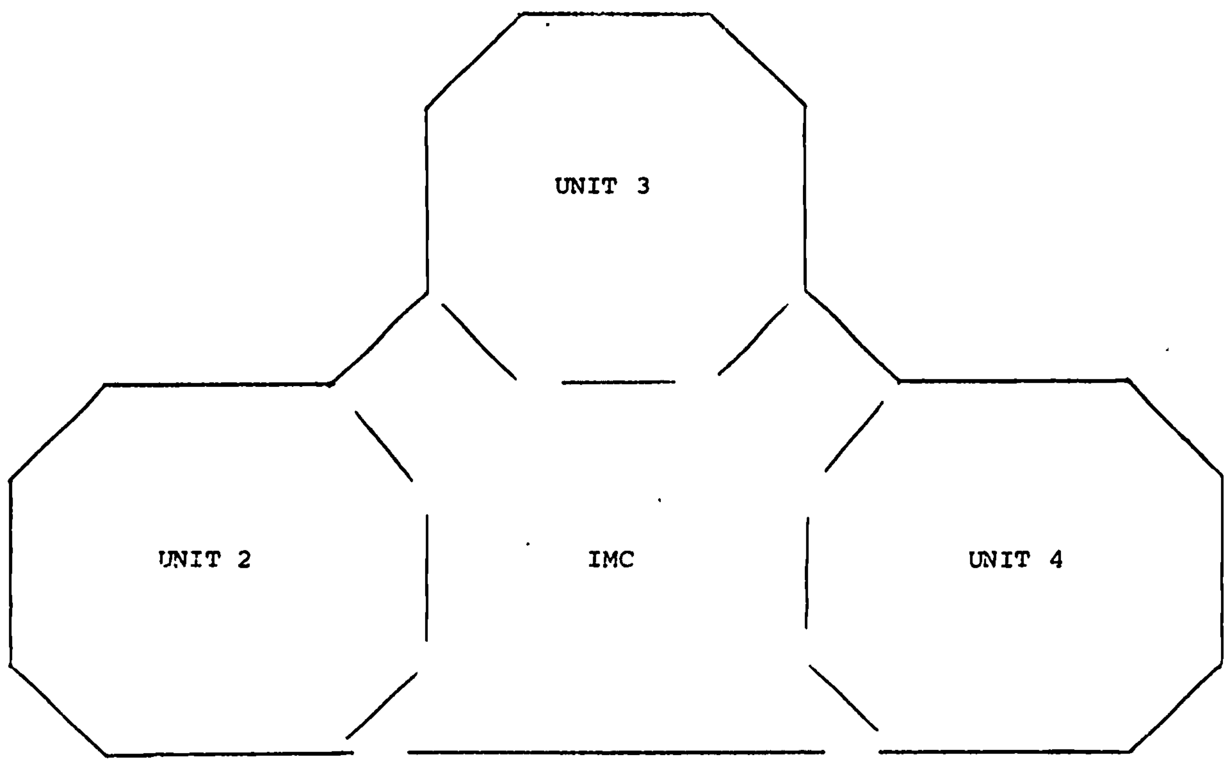
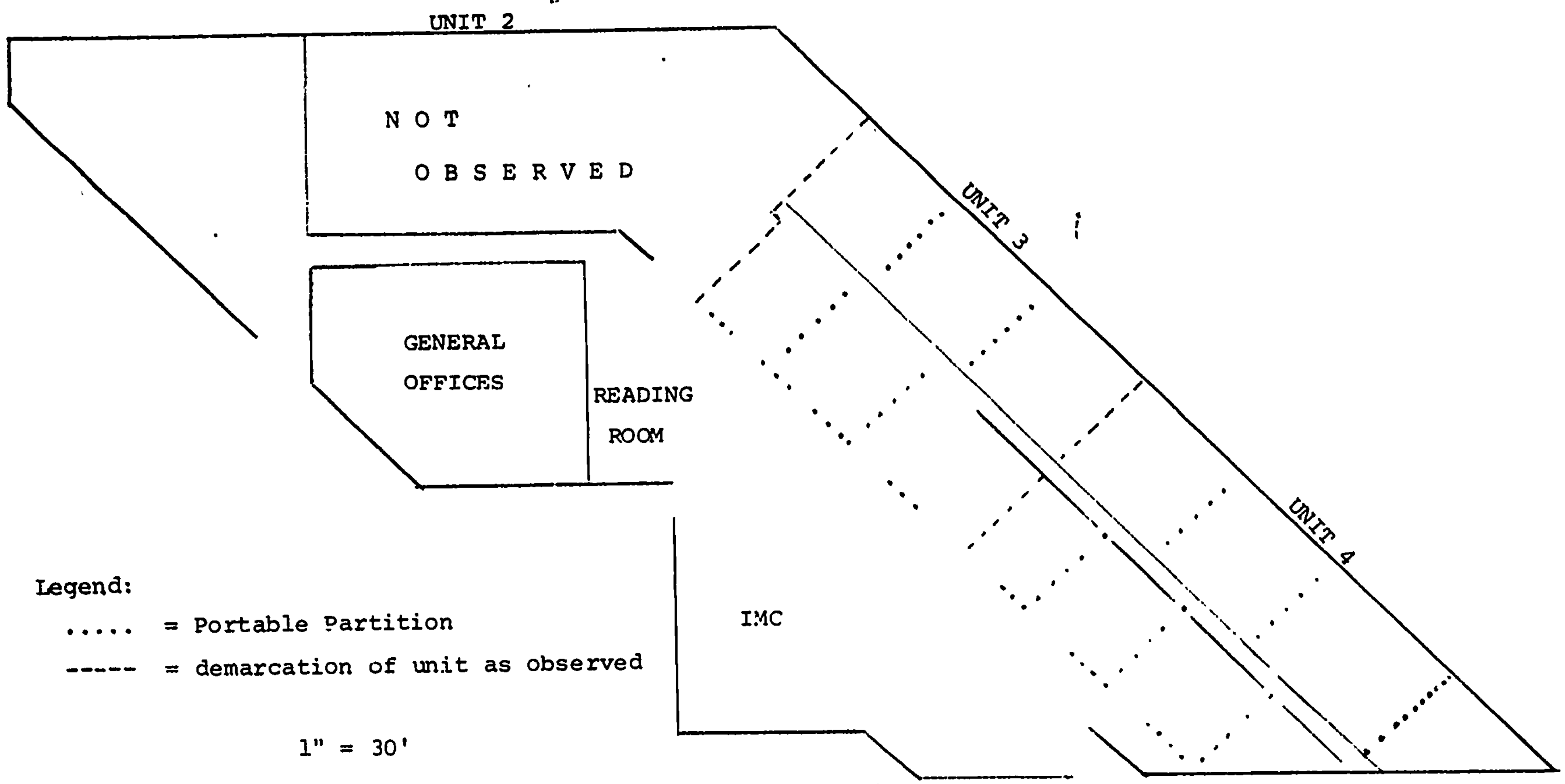


Figure 2

Floorplan of Observed Units

School B



Legend:

..... = Portable Partition

----- = demarcation of unit as observed

1" = 30'

the traditional school, the classrooms each operated on their own specific achedule with more specific activities designated at each time period. A sample schedule for School A, unit 4 is shown in Table 1. The length of the scheduling cycle at all three schools was one week, the only daily changes representing accommodations made for physical education, art, and music.

It should also be noted that School B was in a transition phase, from a traditionally operated school to a multiunit school. Hence, there was a tendency for organizing spaces and groups more on the order of the self-contained classroom than might otherwise have been expected.

Collection of the Data

The actual collection of data was performed at the three schools from April 10, 1972 to May 5, 1972 for the periods of time described earlier.

Five observers were hired, only three of whom worked at any one time. Each day observers were assigned a space and given their materials. The materials consisted of observation sheets, instructions (including lists of categorical items with their codes) and a floorplan. Assignments were rotated daily to reduce bias. Prior to the first live observation, a training session was held with each observer and their part in the project was explained in detail.

Discussion

Since the study was interested in the physical aspects of activities, attention was focused on those events which could be considered instructional entities or those which represented the dynamics of groups. The group dynamics data included descriptors of formation of a group and subsequent coalescing into a larger group or the splitting into subgroups. Furthermore, items denoting circulation within spaces and between spaces were recorded in an attempt to discover patterns of circulation, especially for open plan schools.

The data collection phase yielded about 3000 lines of observations. The data, however was not as readily adaptable to computer analysis as had originally been thought. Some of the difficulties were due to the constraints of the observation form itself; some to the transformations which had to be performed on the data before it was acceptable, and some to the lattitude given to the observers which resulted in either inconsistent or uninterpretable data.

The instructional data items were discovered to be the most accurately recorded and more manageable than the circulation and group dynamics information. Furthermore, the instructional activities were recorded as a set of sequential states from which it is possible

TABLE 1

Sample Schedule for Unit 4 School A

UNIT FOUR	
8:30	Language Arts Block (Ind. Reading and Conferences) Spelling-Creative Writing
9:00	Physical Education Group 1
9:30	Physical Education Group 2
10:00	Phonetic Skill Groups
10:30	Math
11:30	Noon Hour
12:30	Study Hall-Music-Physical Education-Art
1:00	Math
2:00	Recess
2:15	Reading Groups
3:15	Dismissal
3:15	Unit Meeting Time

to infer some of the other information types. Thus, the final data set as prepared for analysis, consisted of about 940 observations of instructional activities at the three schools, and the digitized floorplans and subspaces of the schools and spaces observed.

Recommendations

With a few alterations, the forms described are adequate for recording observations of elementary school instructional activities. A different approach will be necessary to observe and record circulation and group dynamics directly. The precise approach would depend on the inferences which could be drawn from the instructional activities about circulation and group dynamics in the observed elementary schools.

Alterations to the observation forms would include:

- Pre-assignment of names to all spaces and subspaces observed (the observers were allowed to generate their own names)
- Delete the density codes since they can be computed
- Eliminate group names (the observers cannot keep track of the content of groups)
- Create a more rigid format for the observation sheet by dividing each entry column into n spaces where n is the maximum number of alphanumeric characters which can be recorded in the entry, and declaring whether the item should be left or right adjusted in the column. This would considerably ease the problem of keypunching errors.

DATA ANALYSIS AND RESULTS

Introduction

This section will describe the analytical procedures which were applied to the collected data and summarize the results. The objectives were:

1. To develop a predictive model of group size in a given activity for a particular school program.
2. To generate a file of design modules pertaining to the use of space by activities.

The concept of design modules is introduced in objective 2 as a vehicle for describing an activity in terms of the physical configuration of students within the space, square feet of space required per student, furniture and special equipment used, the type of group pursuing the activity, and the distraction factor.

From the design module and the group size chosen, the amount of space for an activity can be computed. Furthermore, a relationship between activities can be determined as a function of the distraction factor and can be used in determining the actual placement of activities in a space.

It should be noted that as an exploratory study, most of the results described herein are directed toward identification and verification of the variables which determine the relationship between an activity and its space requirements under a particular school program.

Developing a Predictive Model of Group Size

Objective 1 was to develop a predictive model of group size. An analysis of variance was performed to discover from which other variables there were significant effects. A conservative level of significance ($p < .001$) was chosen to reduce the chances of a TYPE 1 error.

The hypothesis tested was whether for a particular school program, an instructional activity under that program, and an age based grouping of students, there were significant effects on the size of groups. Once it was ascertained which of these factors contributed significantly to group size, tables of group size would be generated as a function of those factors in order to determine its distribution for each set of factor values.

Because the major focus of the study centered on the multiunit school and the most reliable data was recorded at School A, the decision was made to run a complete analysis of this school from which to derive a usable simulation model. Comparisons were made and are reported on all three schools, however, where the quality of the data allowed such an analysis to be done.

The analysis of variance was performed on School × Activity × Pod for the dependent variable Group Size. Although School B was designated as a multiunit school, it was still operating as a traditional school with some amount of teaming. It was thus decided to consider Schools B and C as operating under a "traditional" program and School A as the multiunit school. Activities were to have been broken down into Language Arts, Math, Science, Art, Music, Social Science and other (consisting mainly of independent work). However, Art and Music were generally carried on in special rooms and there were not observations of Social Science in conjunction with all levels of the other factors. Therefore, Art and Music were not included in the analysis and the small number of Social Science observations were included in the "other" category. The variable "Pod" corresponded to a unit in a multiunit school and served to bracket grade and age levels. The three levels in terms of school grade were 1-2, 2-4, and 4-6. There was an obvious difficulty in attempting to compare these "units" with the more rigidly defined grade level in the traditional school. It was decided that the best comparison could be made by breaking the traditional school into 3 units consisting of grade 1, grades 2 and 3, and grades 4 and 5.

An $F(\infty,1)$ of 33.07 showed school program to have a significant effect upon group size and an $F(\infty,3)$ of 13.41 for Activity was also significant, both at the .001 level. Also significant at the .001 level was the interaction of School × Activity with an $F(\infty,3) = 6.32$ (Table 2).

The interaction effect stipulated that group size could only be predicted as a function of the values of the School and Activity factors, as opposed to just school alone.

Over all schools, a histogram (Figure 3) showed that the percent of frequency of occurrence decreased, in general, with respect to group size. Furthermore, a reasonable categorization of group sizes into "small", "medium", "large", and "very large" could be made for groups ranging in size from 1-6, 7-16, 17-35, and 35+.

For the particular model of School A, the observed group sizes were categorized into the four levels and a frequency table for each Activity was tabulated (See Table 3). The categories were further justified upon an examination of the mean group size at each level which fell nearly in the center of each grouping. In addition, the distributions of group size within the category limits, were relatively flat (save for the peaks at multiples of 5).

TABLE 2

SUMMARY OF VARIANCE ESTIMATES, ERROR TERMS, AND F-RATIOS FOR SIGNIFICANT SOURCES IN THE ANALYSIS OF VARIANCE OF GROUP SIZE

Source	df	MS	F-Ratio
School	1	19856.16	33.07
Activity	3	8053.09	13.41
Pod	2	4115.09	6.85
School × Activity	3	3796.12	6.32
School × Pod	2	1545.77	2.57
Activity × Pod	6	922.47	1.54
School × Activity × Pod	6	1448.57	2.41
Within Cells	898	600.4056	

Figure 3

Percent of Observed Frequency of Group Sizes

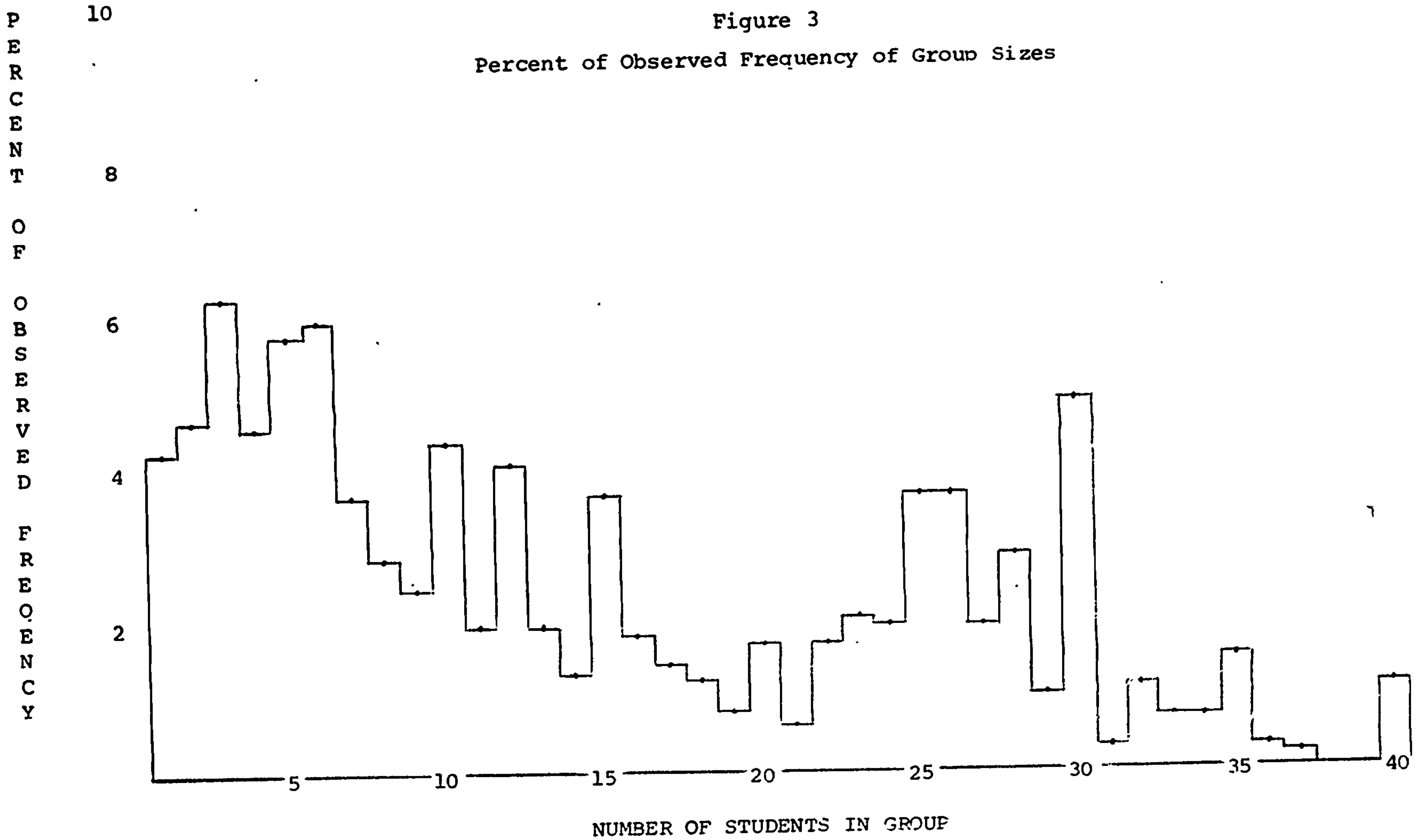


TABLE 3

OBSERVED FREQUENCIES OF GROUP SIZE/ACTIVITY FOR SCHOOL A

GROUP SIZE		ART	ACTIVITY* LANGUAGE ARTS	MATH	SCIENCE	OTHER
1-6	Count	11	82	13	3	11
	% Col	25.00	40.00	33.33	5.26	13.25
	Mean Groupsize	3.6	3.2	4.1	3.6	3.75
7-16	Count	8	70	8	14	17
	% Col	18.18	34.15	20.51	24.56	20.48
	Mean Groupsize	12.5	11.4	11.3	10.3	10.7
17-35	Count	15	43	12	33	22
	% Col	34.09	20.98	30.77	57.89	26.51
	Mean Groupsize	28.4	25.2	24.1	25.8	24.0
35+	Count	10	10	6	7	33
	% Col	22.73	4.88	15.38	12.28	39.76
	Mean Groupsize	52.9	96.2	46.0	106.3	96.4

*Enough observations of art were made at School A to be included in the table.

Thus, a group size g for a scheduled activity can be chosen by the following method. Let C_i, $i = 1,4$ designate the four categories of group size with category limits L_i and U_i for the lower and upper limits respectively. Let p_i stand for the observed percentage of observations for which the group size fell into C_i. An activity is first assigned a group size category with probability $P(C_i) = p_i$. Within the category, the distribution of group sizes is assumed to be even, hence an evenly distributed random number between L_i and U_i is chosen to be g, the group size.

Discussion

A method has been presented for deriving an estimate of the group size for an activity under a particular elementary school program.

The method consists of determining the factors which affect group size by an analysis of the variance of group size as a function of the school program, activity, and grade range in which the observed group size occurred, and developing frequency distributions for group size as a function of the significant factors.

For the schools observed, the school programs and activity were found to have had a significant effect on group size. The interaction effect of school program and activity was also found to be significant. Group size did not appear to vary significantly in different grade ranges.

These results must be interpreted cautiously as the sample size of schools observed was much too small for any confidence to be ascribed to the statistical analysis. It would appear that observation of schools on a larger scale would be warranted on the basis of the data collected, and the elements of the simulation model be developed on stronger premises.

Creating the Design Module

The second objective of the data analysis was to generate a file of design modules pertaining to the particular use of a space by an activity under a given school program. A design module provides information about three major characteristics of an activity*:

*Only the data for School A was completely analyzed for the purpose of exemplifying the method of building design modules. Hence, this is the data which would be applied to a simulation of the multiunit educational program.

TABLE 4

ACTIVITY DESCRIPTERS

1. Configuration (CONF) -- A description of the physical arrangement of students and furniture in the observed space. Five configuration types were recorded - frontal minimal (FMI), frontal optimal (FOP), circular (CIR), radial (RAD), and clustered (CLU). A detailed description and diagram of these categories is shown in Table 5.

2. Furniture (FURN) -- The major furniture items in use during an activity. These items were recorded as chairs (C), desks (D), tables (T) and none (.).

3. Square feet per student (SQFTPER) -- This item is used to describe the density of students in a space. SQFTPER was computed by dividing the area of the space in which the activity occurred by the number of students observed.

4. Group Type (GRPTYPE) -- A description of the nature of the activity in terms of whether it was being pursued independently (I), or by the group as a whole (G).

5. Number of Teaching Personnel (NT) -- Used to differentiate supervised activities (1)* from unsupervised activities (0).

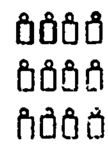
6. Distraction Factor (DF) -- A number ranging from 1-4 which characterized the potential of the observed activity to distract another activity occurring simultaneously and adjacent to the observed activity with no intervening walls.

*The total number of teaching personnel was recorded for each observation, but only the knowledge that the activity was or was not supervised has been necessary to the implementation of the simulation.

TABLE 5

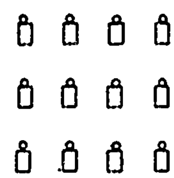
CONFIGURATION CATEGORIES

1. Frontal Minimal (FMI) - Students arranged rectangularly, in rows with aisles between rows.



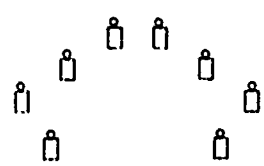
Frontal minimal configuration

2. Frontal Optimal (FOP) - Students arranged rectangularly, in rows with aisle space on all sides of each student.



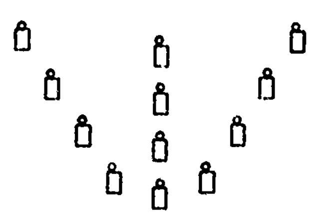
Frontal optimal configuration

3. Circular (CIR) - Students arranged in a circle or arc.



Circular configuration

4. Radial (RAD) - Students grouped in lines radiating from a common center.

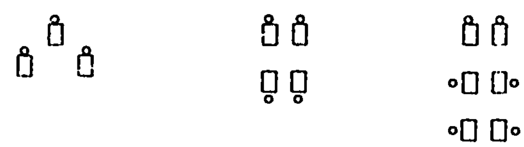


Radial configuration

TABLE 5

(continued)

5. Clustered (CLU) - Students scattered in small groups.



Clustered configuration

1. The amount of space needed per student for an activity

2. The nature of the activity (group or independent, supervised or unsupervised)

3. The distraction potential of the activity upon other activities.

The simulation program uses this information to decide the type and amount of space needed for the activity, and where to place an activity with relation to other ongoing activities.

To determine space per student needs, the relationship between observed configuration, furniture and square feet per student was examined. The group type and numbers of teaching personnel recorded by observers yielded the information desired about the nature of activities, and the distraction factor observed was tabulated to determine the third characteristic. Tables 4 and 5 define the activity descriptors analyzed to build the design modules.

Two approaches to the calculation of space per student were employed to provide the simulation program with the capability of evaluating space utilization under theoretically optimum conditions and to test designs in situations reflecting the observed management of instructional space. The first utilized estimated dimensions of furniture and necessary aisle space for different configurations to determine square feet per student. The dimensions used and results are shown in Tables 6 and 7. The observed use of instructional space is displayed in Table 8. Square feet per student was divided into 5 categories and cross tabulated with each of the 5 observed configurations. Frequencies across categories are also shown. Because frontal optimal represented only 0.5% of over 400 observations in School A, this configuration was not included in the design modules for multi-unit schools.

In the optimal mode of operation, the selection of a value of square feet per student for an activity is made by choosing a configuration C_i with probability

$$p_i = \frac{\text{number of times configuration } C_i \text{ observed}}{\text{total number of observations}}$$

(see Table 9), and a furniture item at random and entering Table 7 to obtain the computed figure. To simulate observed conditions, a configuration C_i is chosen as above and a range of square feet per student is chosen with probability

$$p\ (\text{range}) = \frac{\text{observed frequency of range for configuration } C_i}{\text{total observations for configuration } C_i}$$

TABLE 6

OPTIMUM DIMENSIONS

Dimensions of Furniture Items used on Per Student Basis

		Length	Width
1.	Desk (including chair)	3 ft.	2 ft.
2.	Chair only	2 ft.	2 ft.
3.	Table (including chairs)	2 ft.	4 ft.
4.	No furniture	2 ft.	1.5 ft.

Aisle Space or Circulation Space Per Configuration Per Student

		Front	Side	Square Feet Estimate
1.	Frontal Minimal	2 ft.	--	
2.	Frontal Optimal	2 ft.	2 ft.	
3.	Radial	--	--	18 sq. ft.*
4.	Circular	--	--	16 sq. ft.*
5.	Clustered (assuming 4 desks per cluster)	4 ft.	4 ft.	

TABLE 7

COMPUTED OPTIMAL SQUARE FEET PER STUDENT

	Configuration	FMI	FOP	RAD	CIR	CLU
Furniture	Desk	10	20	24	22	42
	Chair	8	16	22	20	36
	Table	16	32	26	24	48
	No Furniture	6.0	14.0	20.25	18.25	30.25

*These are rough estimates derived from plotting each of these configurations to scale for groups of 20 students using desks, computing the total area and dividing by 20 to yield an average per student space allocation.

TABLE 8

PERCENTAGES OF FREQUENCY OF OBSERVED INSTRUCTIONAL SPACE PER STUDENT PER CONFIGURATION - SCHOOL A

			Configuration					
Square feet per student	4-10	Count	15	0	16	0	45	76
		% Col	40.5	-	17.2	-	18.1	18.7
		Mean Sq.Ft./Stud	6.6	-	6.9	-	6.0	6.3
	11-25	Count	10	0	33	0	37	82
		% Col	27.0	-	35.5	8.0	14.9	20.2
		Mean Sq.Ft./Stud	17.5	-	17.6	16.0	15.1	16.5
	26-50	Count	10	2	17	13	62	104
		% Col	27.0	100.0	18.3	52.0	24.9	25.6
		Mean Sq.Ft./Stud	33.4	37.5	37.3	43.8	36.3	37.1
	51-100	Count	2	0	12	4	32	50
		% Col	5.4	-	12.9	16.0	12.8	12.3
		Mean Sq.Ft./Stud	51.7	-	67.9	79.7	69.2	69.0
	100+	Count	0	0	15	6	73	94
		% Col	-	-	16.1	24.0	29.3	23.2
		Mean Sq.Ft./Stud	-	-	322.7	194.8	239.1	249.6
	TOTAL		37	2	93	25	249	406
			100.00	100.00	100.00	100.00	100.00	100.00
			19.2	37.5	75.1	83.5	91.4	80.3

TABLE 9

FREQUENCIES AND PERCENTAGES OF OBSERVED CONFIGURATIONS - SCHOOL A

Configurations	Frequency	Percent of Observed Frequency
FMI	37	9.1
FOP	2	.49
CIR	93	22.9
RAD	25	6.6
CLU	249	61.3

(see Table 8). An evenly distributed random number (values within the range are assumed to be evenly distributed) is generated bounded by the limits of the range and becomes the figure for square feet per student.

To determine the model for characteristics describing the nature of an activity for School A, Group Type (students working as a group or students working individually) was cross tabulated with whether or not there were supervisory personnel present. More then half of the observed activities were pursued as a supervised group and almost 30% of the observed activities involved students working individually (Table 10).

The distraction potential of an activity was assumed to be school independent, thus was calculated across schools (Table 11). For the class of activities observed, the results showed an expected concentration of low distraction potential values.

Discussion

A method for modeling three characteristics of an elementary school activity has been presented. The latter two, nature of the activity and distraction potential, are modeled by selecting factors with a probability reflecting the frequency those factors were actually observed.

Two models were proposed for determining square feet per student. In simulating an activity against a proposed design the question must be posed on to whether space allocation should be assigned under optimal conditions or whether it should reflect observed space use.

The answer depends on the use to which the simulation will be put. The optimal figures could be used in determining basic space needs and thus establish lower bounds on the design of classrooms or open-style pods. It must be remembered, however that the actual space utilized and the space necessary to carry on an activity may be substantially different. In a spatial environment such as that of School A an activity may be perceived as occupying 7400 feet of space even though only 20 students are involved. Thus, a model employing space allocation figures as they reflect observed utilization would put the proposed design to a more rigorous test.

Finally, it would not be unrealistic to hypothesize that the amount of space used for an activity expands to fit the space available. In the three schools observed in this study, the mean observed square feet per student for Schools A, B, and C was 80.3, 44.3, and 17.8 respectively. This may be interpreted as an architectural effect incurred from a structure such as School A with large open pods as

TABLE 10

Joint Frequency Percentages of Group Type and Presence of Supervisory Personnel

Group Type	Supervisory Personnel	Percent of Observed Frequency
Group	Yes	55.9
Group	No	14.2
Independent	Yes	15.1
Independent	No	14.7

TABLE 11

Frequency and Percentage of Observed Distraction Factor by Activity

A C T I V I T Y

Distraction factor		ART	LARTS	MATH	SCI	OTHER
1	Count	28	279	62	53	98
	% Col	52.83	61.97	44.93	54.64	52.13
2	Count	14	125	44	30	48
	% Col	26.42	27.96	31.88	30.93	25.53
3	Count	11	40	27	12	41
	% Col	20.75	8.95	19.57	12.37	21.81
4	Count	0	5	5	2	1
	% Col	0.0	1.12	3.62	2.06	.53
	Total Count	53	447	138	97	188

compared to the more restricted self-contained classrooms of School C. The observation and data analysis scheme described in this report would be readily adaptable for the collection and interpretation of data to formally test this effect.

SIMULATION TECHNIQUE

Introduction

A computer simulation system which has been designed and partially implemented will be described in this section. The three major components of the system are (1) the assignment of students to a set of scheduled activities, (2) the assignment of activities to a set of available spaces and (3) the analysis of space use. The model which the simulation program utilizes is derived from the data collected by the direct observation of elementary schools operating under particular school programs.

The simulation programs mentioned previously (Banghart, Apker) utilize essentially the same strategy to determine space requirements. Apker focuses on the high school environment, which with more rigid scheduling and apparently less flexibility in grouping differs substantially from the elementary school environment. The Florida State University simulation develops space requirements but does not attempt to schedule activities into either pre-assigned spaces or fit the activities into a pod or open space.

The assignment of activities into an open space can be considered to be a member of the class of design problems which involve fitting a set of objects into a space. The general problem remains unsolved, practically speaking, by computer technology. Restricted versions of the problem have been researched by Grason (1970) and Pfefferkorn (1972). Grason develops a solution to the problem of placing rooms on a floor of a building. The rooms and the building must be rectangular. Constraints which can be accommodated include adjacency of, communication between and physical dimensions of spaces.

Pfefferkorn approaches a less restricted problem -- that of placing a set of well-defined objects into a 2-dimensional space of any shape. He further allows constraints such as the requirement for an object to be in view from any point in the space. Objects can be placed into the space and then moved and rotated until the desired set of constraints is satisfied.

The representation of the space and objects are a major factor in the success of these programs. However, they also require great amounts of memory storage and the complex programs which must manipulate them require a relatively long time to reach a solution which is not necessarily an optimal one.

A method is currently being researched which will assign scheduled activities into a space in an open plan school and satisfy constraints on the relationship between activities and the requirement that for certain activities the line of sight must be open to all points in the space where the activity is assigned.

Functional Description

The simulation system called EDUSIM consists of a main program and a set of subroutines as depicted in Figure 4. A controlling program reads the input parameters "school program type", "number of students", and "mode" (specifying optimal or observed square feet per student area requirements). Based on the school program type, the program reads the set of activity descriptors used to model that program. A proposed floorplan or list of spaces and areas for a school is then read. The coordinates of each space on the floorplan must be digitized in the same form as the drawings of the observed spaces described previously. If a floorplan has been input, the subroutine PAREA is called to compute the areas of all the spaces described on the plan. (See Appendix C). The compiled list of spaces and areas is then sorted by area into ascending order for use later by the routine ASGSPC for assigning activities to spaces.

A schedule of activities for a scheduling cycle of length ND is then read along with the starting time for each day, ST, and the length of a scheduling module M.

The major logical components of the system focus on the assignment of students to activities and the assignment of activities to spaces. The subroutine SCHACT controls the flow of activities to which students are assigned and from which students are becoming available as well as monitoring the assignment of activities to spaces. Figure 5 shows the interaction between SCHACT, ASGNST (a subroutine which assigns students to activities) and ASGSPC, the assignment of activities to spaces. As shown, SCHACT scans the schedule for activities which are beginning, ending, or in process at the end of each time period and compiles those activities into lists for use by ASGNST and ASGSPC.

The routine ASGNST assigns students to activities. In assigning students to activities the assumption is that the selection of any given student for an activity is a random process. For each activity in the list ACTNT, the number of students to be assigned is determined by choosing a group size according to the model described in section III. Once the number of students to be assigned to each activity is determined, a pool of "eligible to be assigned" students is created. The pool initially consists of all the students in the school and is divided into appropriate independent units. Any students not assigned during a time period are scheduled for independent work. At any subsequent time period the students available consist of the conjunction of previously unassigned students and the students compiled from the list of activities being completed at the time period. Students are

Figure 4

Functional Flowchart of EDUSIM System

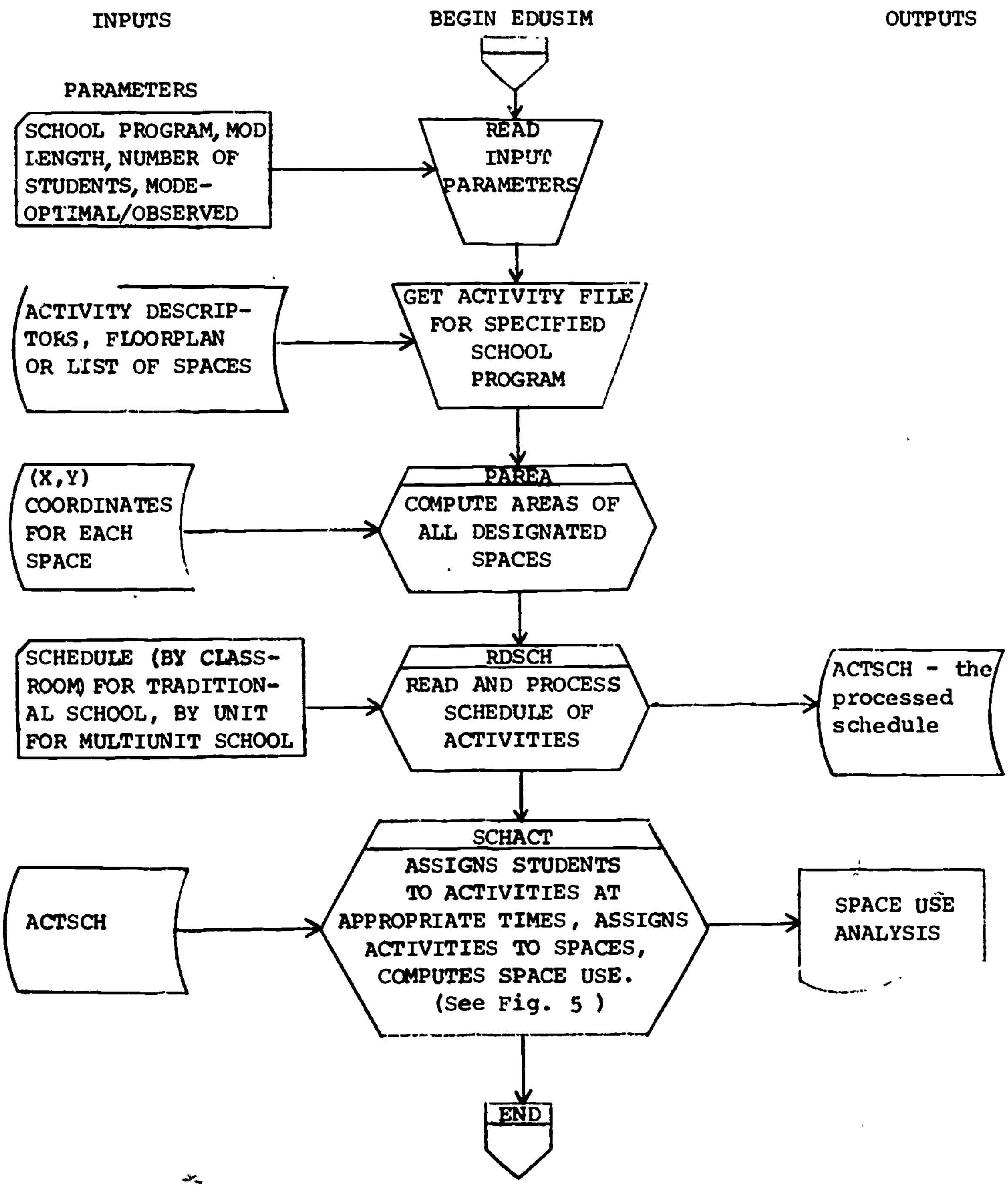
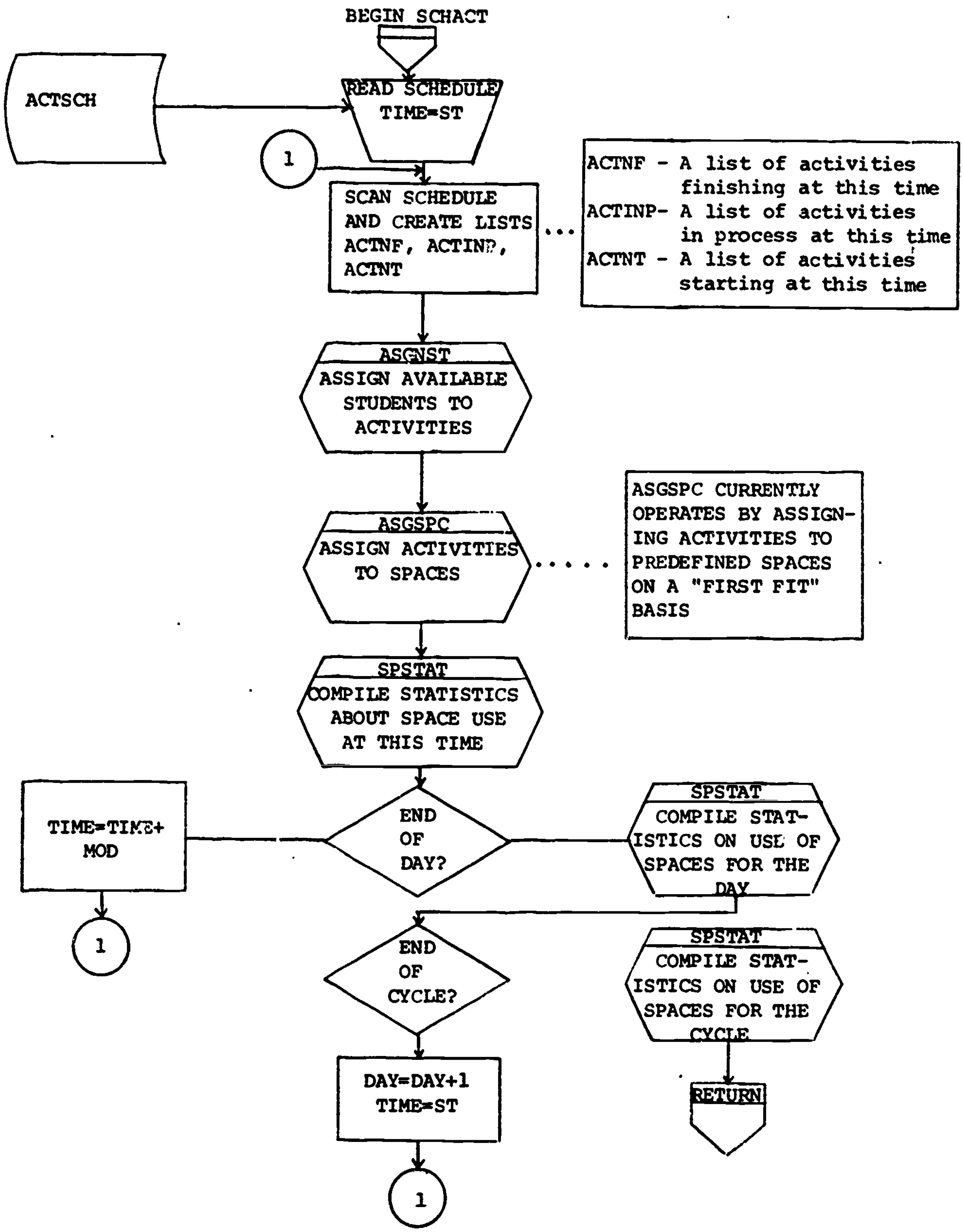


Figure 5

Functional Flowchart of SCHACT - Scheduler of Activities for the Simulation



then randomly assigned from the pool into the next scheduled activities in appropriate numbers.

The computation of space requirements for each activity is performed using either optimal or observed square feet requirements as described in section III, and multiplying by the number of students assigned to the activity.

Assignment of activities to spaces takes place upon invoking subroutine ASGSPC. In its present form ASGSPC is constrained to assigning activities into available spaces of fixed dimensions using a modified "first fit" algorithm. Spaces available are maintained on a list in ascending order. Requests for space are serviced in descending order, unless other priorities call for a modification of the space request list. Each request is assigned to the first space on the space available list whose area equals or exceeds the area of the request. All spaces of which the assigned space is a subspace become unavailable for further assignment during the current time period. At each time period, terminating activities relinquish their space to the available space list.

Space utilization is computed as a percentage of available space and from the standpoint of the frequency of use made of a space. For each space assigned during a time period the percentage of its area used by its activity is calculated as

$$\frac{\text{area required by activity}}{\text{area of space}} .$$

For each time period the total space used is divided by the total space available to yield an overall space utilization figure. At the end of each day, the number of modules of time each space was in use is divided by the total number of time modules in the scheduled day to show the percentage of time the space was actually in use.

Outputs from the program include:

- The parameters for the simulation
- A list of spaces for the proposed design and their areas
- The schedule used
- Listings of students assigned to activities (optional)
- Listing of spaces to which activities assigned
- % area utilization of each space at each time period
- % of total available area used at each time period
- % of time each space in use over day.

Another optional output capability allows the tracing of individual students through the schedule to allow analysis of optimal scheduling techniques and circulation patterns. Time constraints have prevented full development and implementation of the program system, however, a fascimile example of the output from a simulation is shown in Appendix D.

SUMMARY AND IMPLICATIONS

A system for simulating a class of elementary school activities for two kinds of elementary school programs has been described. A method for collecting data and analyzing it for the purpose of building the model of a school program for use by the simulation system is introduced, and a functional description of the existing system is presented.

The collection and analysis of data gave evidence that existing differences in school programs can affect methods of grouping students for a set of instructional activities. Design modules were created to characterize the space requirements of an activity for different configurations of students and furniture, and to establish constraints on the relationships between ongoing activities by which to establish the criterion for placing activities in the large open spaces being designed for modern schools.

The simulation program accepts as input a school program, an enrollment figure, a mode parameter designating an optimal or observation based spatial requirement, a proposed school design, and a school schedule. It then reads the appropriate model for the school program and traverses the schedule, assigning students to activities and activities to spaces. Computed output includes the completed schedule and various space utilization information.

The observation technique is oriented toward the identification and characterization of activities, their use of space, and their relationship to one another. The specific case to which the observation scheme was applied was an elementary school. Such a scheme need not be limited to schools, however. New building designs are being proposed which attempt to be more responsive to the "activities" to take place in them. An analysis of these activities and the subsequent simulation of them on a new design could certainly help to avoid costly mistakes. The information from a data collection can be applied to the structure in which the observation took place to analyze space utilization and the adequacy of the building as it exists.

Further research is being carried out in two areas:

1. Design and implementation of a program to automate the construction of elementary school schedules based on observed data.

2. Implementation of a program to assign activities into "pods" or open spaces with no predetermined dedicated subspaces.

The existing observation data provides information concerning the probable starting times and durations of activities and the relative frequency of activities for a school program. Schedules can be built which would reflect these observed data.

Research on the implementation of a method for assigning activities into open spaces, has resulted in the development of a specialized data structure to represent such spaces and allow programmed operators to search the available space for subspaces which will satisfy the area requirements and relation constraints imposed by the activity to be assigned.

APPENDIX A

Development of an Observer Recording Sheet

DEVELOPMENT OF AN OBSERVER RECORDING SHEET

Two different kinds of recording methods were tested before the final procedure was adopted. First, a narrative type recording sheet was developed. The observer was expected to record in narrative form all of the events he saw taking place in the space. The observer was given a floorplan for his space, a sheet of observation procedures (page 39) and several observation forms (page 40). For each event that occurred the observer would note the time and write a description of what he saw.

A test of narrative-type observation sheet was made at an open-plan school with three volunteer observers. Results were similar to those shown on page 41. Translation of the recorded data to a format which could be keypunched and read by a computer was quite difficult because of the volume and ambiguity of the recording.

A second observation sheet was designed on which an entire event could be described on one line. Descriptors were assigned to specific columns on the sheet and consisted of quantitative and categorical items. The start time of each activity was recorded and activities were codified and broken down into three phases -- onset, instructional, and code. (See pages 42-44).

A field test of the revised form revealed several inadequacies. Because only the start time of an event was being recorded, it was difficult to compute its duration. (An activity was assumed to have terminated when a new one started in the same location.) The phases of an activity were often indiscernible or too brief to be of note.

Revisions made to the observation form included adding a column for the end time of an activity, and dropping the phase codes of activities. The final version of the form is described in section II.

OBSERVATION PROCEDURES

1. Fill in heading information on observer sheet.

2. Write items and numbers of pieces of equipment in the area to be observed in margin at left of sheet.

3. As an event occurs, record the starting time and begin the detailed commentary of what is taking place. Use location codes as indicated on the floor plan. Essentially, an event is a change in status of something in the observed space. This can mean things like a change in the activity or subject being pursued, the entrance and exiting of groups or individuals, a change in the physical configuration in the room etc. Any change of status in any of the following items can be considered to be an event. Pay close attention to them and record their status frequently.

   - Subject being studied
   - Groups and size of groups (if a group divides, give the new groups names like G1, G2 etc. and record their activities
   - Number and types of supervisory personnel
   - Center of attention of the group (e.g. teacher, device, etc.)
   - Equipment in use
   - Physical configuration of people and equipment in the space
   - Noise level
   - Level of physical activity

4. Feel free to make evaluations, but enclose all evaluations in brackets [--]. Try to make the evaluations reflect architecturally significant observations such as: "activity needs more space" or "lighting is inadequate".

Observer			Location B
School			
Date			
List of Equipment		Time	Description of Events
Item	Total		

Observer	Location B
School	
Date	

List of Equipment		Time	Description of Events
Item	Total	9:00	32 S enter space, Noise High, sit at desks, frontal
DEsks	42	9:04	T walks in hands out exercise sheets. (Kids pull out stationery from desks) desks ar-
CHairs	55		ranged in rows, 6 rows 7 desks each facing
Tables	2		Black Boards (see plan)
Teach Desk	1		
Bookcase H	3	9:06	Quiz begins, Noise Low, Subject--Math
Bookcase L	2	9:18	Quiz ends--sheets handed in.
Black Board	2	9:21	Projector brought in, chairs moved to Location
SCreen	1		B_2, facing screen hanging from BB2.
TV			[small children have trouble moving chairs]
Movie Project			9 S and 1 T join the group, shades pulled over windows, lights out.
COnstruction		9:31	Movie starts--subject social studies
Tools		9:51	Movie ends, lights on.
		9:56	Discussion starts--(social studies) seating arrangement--no change.
		10:04	Change configuration into groups 5 and 6 each (G2-G6) 1 of 5 (G7) 6 S & 1 T leave the space.
		10:06	individual work starts: 1 group works with teacher on math problems around table location B_3
			3 Groups work at desks on math, noise level medium.
			1 Group playing game on floor near BB1.
			1 Group of 5 building hut location B_4. [groups working well, group building hut disturbs G2]
		10:21	Another teacher enters works with group at B_1 on math.
		10:25	First teacher stops with group, supervises 3 groups at desks plus original group.

SAMPLE COMMENTARY SHEET

SAMPLE RECORDING SHEET

OBSERVER

SCHOOL

DATE

SCHOOL TYPE

SPACE LOCATION

Time	Activity Phase	Group Name	Group Size	Loc.	Subj.	Supervision	Attention	Configuration	Equipment in Use	Noise	Phys. Activ.	Comments

KEY TO RECORDING SHEET

1. Time - start time of an event.

2. Activity phase - the activity observed can be said to have distinct phases, the onset, the instructional or main phase and the code, or end. Within each phase the activity is further broken down as shown in Figure 1.

3. Group size - number of pupils in group being observed.

4. Location - name assigned to a location as described on observer's floor plan.

5. Subject - a 3 or 4 letter code naming the subject to be studied.

6. Supervision - number and type of supervisory personnel (teachers, aides, etc.).

7. Attention - a code describing the group's focus of attention.

8. Configuration - a code describing the physical configuration of

9. Equipment in use - a list of codes describing each piece of equipment in the room which is actively in use.

10. Noise - an estimate of the level of noise being generated by the group being observed (Low(L), Medium(M), High(H)).

11. Physical activity - an estimate of the level of physical activity of the group being observed (Low(L), Medium(M), High(H)).

12. Comments - appropriate comments by the observer. Such comments should be of the form: "Too much space", "too little space", "interference from noise", "lighting adequate", etc.

ACTIVITY PHASES AND CODES

I. Onset

- OW - Students walk into space
- OF - Movement of furniture
- OM - Exchange of materials (turning in papers, passing out equipment, etc.)
- OE - Setting up equipment
- OO - Organizational activity
- OC - Change of configuration
- ON - No movement of people or equipment

II. Instructional or main

- IL - Lecture
- ID - Demonstration
- IQ - Question and answer session
- IS - Individual student presentation
- IC - Class discussion
- II - Independent work
- IG - Group work
- IT - Test
- IM - Movie
- IP - Playing

III. Coda

- CW - Students walk out of space
- CF - Movement of furniture
- CM - Exchange of materials
- CE - Removal of equipment
- CT - Transitional event (people moving in and out of room)

APPENDIX B

Final Version of the Observer Recording Sheet

Observer: ______________ School: ______________

Page ______ Date: ______________ Space: ______________

LINE	TIME START	TIME END	LOC	GRP	GT	#S	#T	EVENT	BASIC CONFIG.	DF	#CH	#DE	#TA	#TD	OTHER EQUIPMENT							
01																						
02																						
03																						
04																						
05																						
06																						
07																						
08																						
09																						
10																						
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23																						
24																						
25																						

RECORDING SHEET INFORMATION

1. PAGE - Letter the pages consecutively starting with "A".

2. LINE - The line number is filled in.

3. TIME - Record the time of day running from 0000 (12:00 midnight) to 2400 (11:00 PM) as each event starts and ends.

4. LOC - Name of the subspace being observed consisting of the letter name assigned to the main space (Space blank in recording sheet heading) and a two digit number from 01 to 99.

5. GRP - Name of the group being observed consisting of a letter (preferably "G") and a two digit number from 01 to 99.

6. GT - Group Type. If the people in the group are ding individual work record "I". If they are acting as a group, record a "G".

7. #S, #T - Record the number of students and teaching personnel, respectively.

8. EVENT - See EVENT CODES

9. BASIC CONFIG. - See CONFIGURATION CODES

10. DF - Distraction Factor. An estimate of how much this activity would affect other activities occurring immediately adjacent to it without separating materials. Record a "1" for no distraction, "2" for little distraction, "3" for moderate distraction, and "4" for high distraction.

11. #CH, #DE, #TA, #TD - Record the number of CHairs, DEsks, TAbles, and Teacher's Desks respectively.

12. Other equipment - See accompanying list.

13. The last column under OTHER EQUIPMENT will be used as follows: If an asterisk is placed rightmost in the column, all the information on the line will be considered as commentary. Feel free to comment often and on any subject but with special emphasis on the use of space.

    If a page letter and line number appear left-adjusted in the column, the line will be assumed to be a continuation of the line designated.

EVENT CODES

I. Subject Events

A. Language arts

1. Communicative activities............ COMM
2. Listening........................... LISTEN
3. Speech.............................. SPCH
4. Reading............................. READ
5. Writing............................. WRITE
6. Spelling............................ SPELL
7. Grammar............................. GRMR

B. Mathematics

1. Addition............................ ADD
2. Subtraction......................... SUB
3. Multiplication...................... MULT
4. Division............................ DIV
5. Set theory.......................... SETS

C. Social studies

1. Current events...................... CURR
2. Geography........................... GEOG
3. History............................. HIST
4. Political science................... POL

D. Science

1. Physical science.................... PHYSCI
2. Biology............................. BIOL
3. Experiments......................... EXPER
4. Process activities.................. PROC*

E. Art

1. Drawing, painting, etc. .... DRAW
2. Construction........................ CONST
3. Art appreciation.................... ARTA
4. Art history......................... ARTH

F. Music

1. Playing instruments................. PLAYIN
2. Singing............................. SING
3. Dancing............................. DANCE
4. Music appreciation.................. MUSA
5. Music theory........................ MUST
6. Music history....................... MUSH

---

*Process activities include inquiry, observation, and classification.

EVENT CODES (continued)

G. Other events

1. Increase in group size.................. INC
2. Decrease in group size.................. DEC
3. Break into smaller groups................ BRK
4. Combine groups.......................... COMB
5. Change of group type.................... CHTYP
6. Arrange equipment....................... ARREQ
7. Circulation within space................. CIRCI
8. Circulation in and out of space.......... CIRCW
9. Recess.................................. RECESS
10. General homeroom activities.............. GEN
11. Space unused............................. EMPTY

CONFIGURATION CODES**

I. Basic configurations

A. Rectangular

1. Frontal minimal with desks .... FMIND
2. Frontal optimal with desks .... FOPTD
3. Frontal minimal with tables .... FMINT
4. Frontal optimal with tables .... FOPTT
5. Frontal minimal with chairs .... FMINC
6. Frontal optimal with chairs .... FOPTC
7. Frontal minimal - no furniture .... FMIN.
8. Frontal optimal - no furniture .... FOPT.

B. Circular

1. Circular with desks .... CIRCD
2. Circular with tables .... CIRCT
3. Circular with chairs .... CIRCC
4. Circular without furniture .... CIRC.

C. Radial

1. Radial with desks .... RADD
2. Radial with tables .... RADT
3. Radial with chairs .... RADC
4. Radial without furniture .... RAD.

D. Clustered

1. Clustered with desks .... CLUDn*
2. Clustered with tables .... CLUTn
3. Clustered with chairs .... CLUCn
4. Clustered without furniture .... CLU-n

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*Record the average number of items in the cluster for "n". Items means furniture in 1, 2, and 3, and students in 4.

**Configurations should be recorded as one of the codes above followed by a space density indicator. The space density indicators are:

1. Sparse ..... S
2. Moderate ... M
3. Heavy ...... H

OTHER EQUIPMENT

Equipment should be recorded as a two digit number from 01 to 99 followed by a two character equipment code. Record only the equipment used actively by the people in the subspace.

I. Equipment codes

A. Blackboard (permanent) ..... BB
B. Blackboard (portable) ..... BP
C. Partitions .... PA
D. Carrels .... CA
E. Television set .... TV
F. Television stand .... TS
G. Radio .... RA
H. Record player .... RP
I. Movie projector .... MP
J. Movie screen .... MS
K. Film strip projector .... FP
L. Tape recorder .... TR

If there is not enough space to record all of the equipment used in an activity, use additional lines on the recording sheet. Record the additional equipment under the OTHER EQUIPMENT columns except for the last column on the page. Write the page letter and line number (left-adjusted) for which the current line is a continuation in this column.

APPENDIX C

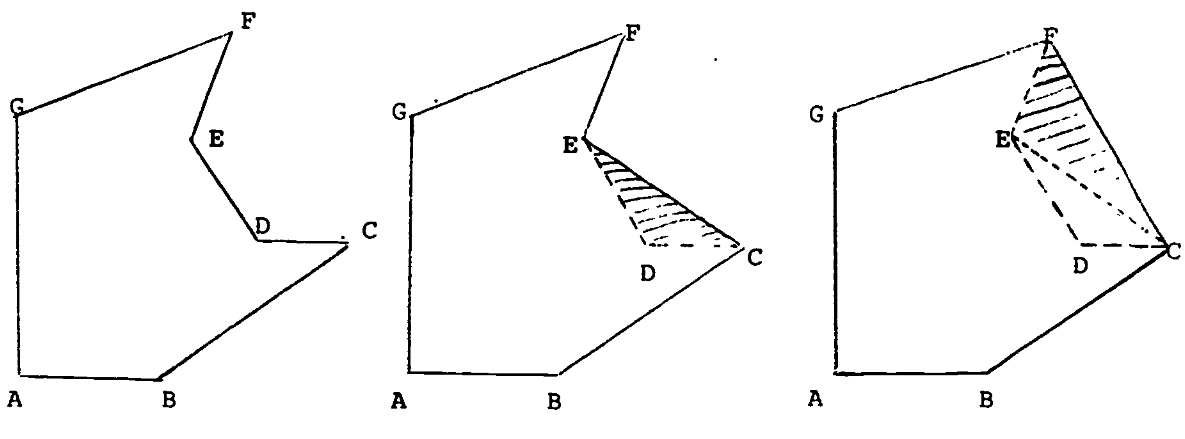
The Computation of Floor Space in Subroutine PAREA

The computation of school floor space is made in the program PAREA. PAREA can compute the area of any n-sided polygon, concave or convex, given an ordered list of the (X,Y) coordinates of its vertices. The computation of area takes place in two stages;

(1) PAREA traverses the polygon eliminating concave points, summing the areas of exterior triangles including these points and creates a convex polygon;

(2) PAREA computes the area of the convex polygon by summing the areas of a set of its interior triangles and subtracts the total area of external triangles to yield the correct area.

An example follows to clarify the above description. Figure 4 shows a concave polygon ABCDEFG. PAREA examines each point in relation to its preceeding and succeeding points to determine whether or not the point represents a concavity of the polygon. PAREA starts



with the points A, B, and C and examines B to determine if it falls to the "left" of the directed line segment AC. This would imply that B is a concave point. As shown, B is a convex point, however, and PAREA continues by looking at B, C, and D. Looking at C, D, and E PAREA encounters a concavity at D. D is eliminated and the area of the external triangle CDE is computed. Since D has been eliminated, PAREA continues traversing the polygon by looking at E, F, and G and on around to F, G, and A. Note that in the case of two or more consecutive concave points they will not all be eliminated in one pass around the polygon. PAREA continues traversing the figure until it makes a pass in which no concavities are eliminated. Thus on the second pass, E is discovered to be a concave point and the area of CEF is computed. At this time PAREA constructs all the interior triangles of the new convex polygon ABCFG containing point A and not both of its adjacent points. Thus triangles ABC, ACF, and AFG are constructed and their areas are computed. The sum of the areas of these three triangles is the area of ABCFG. Subtracting the sum of the areas of triangles CDE and CEF, PAREA thus computes the area of ABCDEFG.

The algorithm PAREA uses to determine of a point falls to the left of a line and thus represents a concavity can be shown in a decision table. Given the coordinates of three points (X_1,Y_1), (X_2,Y_2), and (X_3,Y_3) we wish to determine if (X_2,Y_2) falls to the left of the directed line segment whose end points are (X_1,Y_1) and (X_3,Y_3). The decision table is the completed extension of the following reasoning. The slope M of the line from (X_1,Y_1) to (X_3,Y_3) is $(Y_3-Y_1)/(X_3-X_1)$ and its Y intercept B can be given as $B = Y_1 - MX_1$. If the quantities (Y_3-Y_1) and (X_3-X_1) are both positive and $Y_2 - MX_1 - B$ (substituting (X_2,Y_2) in the equation of the line segment being analyzed) is positive then (X_2,Y_2) can be said to fall to the left of the line and is therefore a concave point in a polygon. If the quantity $Y_2 - MX_2 - B$ is 0 then (X_2,Y_2) is colinear with (X_1,Y_1) and (X_3,Y_3) and if it is negative, (X_2,Y_2) falls to the right of the line segment. Analyzing by cases yields the following decision table:

$Y_3 - Y_1$	$X_3 - X_1$	$Y_2 - MX_2 - B$	(X_2,Y_2)
+	+	+	concave
+	+	-	convex
+	-	+	convex
+	-	-	concave
-	+	+	concave
-	+	-	convex
-	-	+	convex
-	-	-	concave

In case $(X_3 - X_1) = 0$ which would yield an infinite slope (a vertical line) and cause a divide fault in the computer, PAREA examines the direction of the line and the relationship of the X_2 coordinate to either X_3 or X_1 to determine if (X_2,Y_2) is a concave vertex of a polygon.

APPENDIX D

Facsimile Sample of Output from the Simulation Program

PARAMETERS TO THE SIMULATION

SCHOOL PROGRAM TYPE ..... MULTIUNIT
NUMBER OF STUDENTS 100
MODE .... OPTIMAL

SPACE LIST

SPACE	AREA (SQUARE FEET)
A00	5000.0
A10	1000.0
A30	225.0
A31	400.0
A32	150.0
A11	1000.0
A33	330.0
A34	170.0
A35	250.0
A36	75.0
A12	1000.0
A37	210.0
A38	190.0
A39	600.0
A13	2000.0
A40	475.0
A41	260.0
A42	130.0
A43	350.0
A44	850.0

NOTE: A00 IS THE NAME OF THE ENTIRE SPACE. A10, A11, A12, AND A13 ARE SUBSPACES OF A00 AND ARE FOLLOWED BY THE SUBSPACES THEY CONTAIN.

SCHEDULE OF ACTIVITIES FOR SPACE A00

TIME MODULE = 5 MINUTES   TOTAL AVAILABLE MODULES = 66

TIME	ACTIVITY	# SECTIONS
0830 0845	*GEN*[1]	1
0845 0930	MATH	7
0930 1030	LARTS	4
1030 1130	SCI	5
1130 1230	LUNCH	
1230 1310	OTHER	3
1310 1400	LARTS	2
1400 1415	*GEN*	1
1415 1500	ART	4
1500	END DAY	

[1] THE MULTIUNIT SCHOOL SCHEDULE OFTEN INCLUDES WHOLE UNIT ACTIVITIES. FOR THE PURPOSES OF THIS EXAMPLE SUCH ACTIVITIES ARE DESIGNATED AS *GEN*.

SUMMARY OF STUDENT ASSIGNMENTS AND SPACE USE (CONT.)

TIME	ACTIVITY	SECTION	NUMBER OF STUDENTS	SPACE/ STUDENT	AREA REQ'D	SPACE	PERCENT OF SPACE USED	PERCENT OF AVAIL-ABLE SPACE USED
1130	LUNCH	***ALL SPACES ASSUMED EMPTY***						
1230	OTHER	1	35	48.0	1680.0	A13	84.0	
		2	40	24.0	960.0	A	96.0	
		3	10	24.0	240.0	A31	60.0	
		TOTALS	85		2880.0			57.6
1310	LARTS	1	5	42.0	210.0	A37	100.0	
		2	3	48.0	144.0	A32	96.0	
		TOTALS	8		354.0			7.08
1400	*GEN*	1	100	42.0	4200.0	A00	84.0	
		TOTALS	100		4200.0			84.0
1415	ART	1	5	32.0	160.0	A38	84.2	
		2	39	22.0	858.0	A11	85.8	
		3	27	20.0	540.0	A39	90.0	
		4	15	24.0	360.0	A31	90.0	
		TOTALS	86		1918.0			38.36
1500	END DAY							

SUMMARY OF STUDENT ASSIGNMENTS AND SPACE USE

TIME	ACTIVITY	SECTION	NUMBER OF STUDENTS	SPACE/ STUDENT	AREA REQ'D	SPACE	PERCENT OF SPACE USED	PERCENT OF AVAIL-ABLE SPACE* USED
0830	*GEN*	1	100	42.0	4200.0	A00	84.0	
		TOTALS	100		4200.0			84.0
0845	MATH	1	4	24.0	96.0	A42	74.6	
		2	8	24.0	192.0	A37	91.4	
		3	6	10.0	60.0	A36	80.0	
		4	17	22.0	374.0	A31	93.5	
		5	20	8.0	160.0	A34	94.1	
		6	3	42.0	126.0	A32	84.0	
		7	31	20.0	620.0	A44	72.4	
		TOTALS	89		1628.0			32.56
0930	LARTS	1	9	10.0	90.0	A42	69.2	
		2	40	18.25	730.0	A44	84.7	
		3	12	42.0	504.0	A39	84.0	
		4	4	16.0	64.0	A36	85.3	
		TOTALS	65		1388.0			27.76
1030	SCI	1	24	16.0	384.0	A31	90.6	
		2	28	10.0	280.0	A33	84.8	
		3	35	16.0	560.0	A39	90.3	
		4	11	14.0	154.0	A34	90.6	
		5	2	26.0	52.0	A36	69.3	
		TOTALS	100		1430.0			28.60

*TOTAL AVAILABLE SPACE IS 5000 SQUARE FEET.

PERCENTAGE OF TIME MODULES SPACE IN USE

SPACE	NUMBER OF MODULES IN USE	PER-CENT
A00	6	9.1
A10	6	9.1
A30	6	9.1
A31	44	66.7
A32	25	37.9
A11	35	53.0
A33	23	34.8
A34	44	66.7
A35	23	34.8
A36	56	84.4
A12	6	9.1
A37	25	37.9
A38	15	22.6
A39	37	56.1
A13	14	21.2
A40	14	21.2
A42	35	53.0
A43	14	21.2
A44	35	53.0

NOTE: ALL THE SUBSPACES OF A SPACE ARE CONSIDERED TO BE IN USE WHENEVER THE SPACE ITSELF IS IN USE.

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