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The Stanford School Scheduling System.

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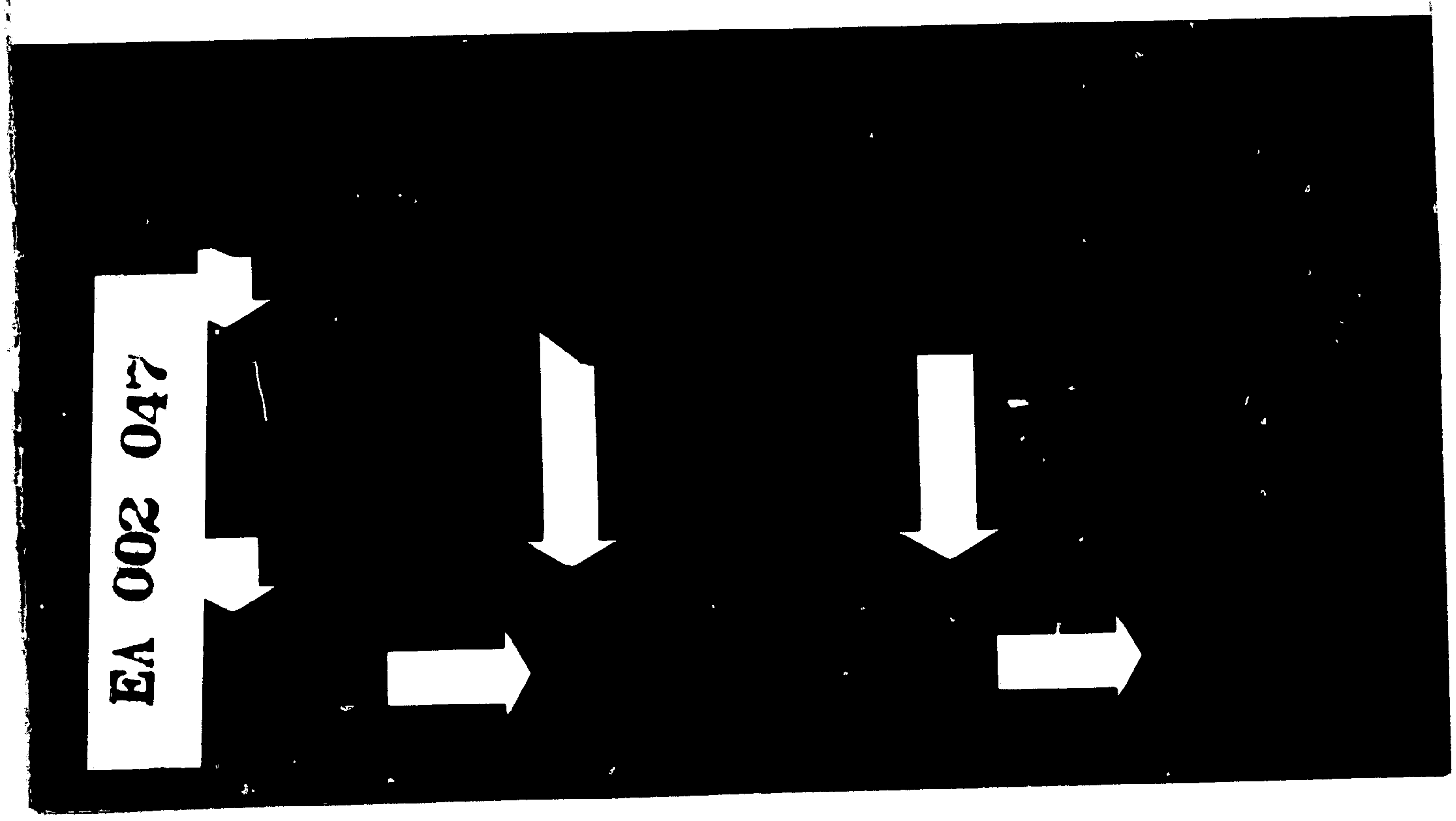
This booklet gives a general overview of the computerized Stanford School Scheduling System (SSSS) which is designed to make scheduling less difficult for individualized programs in secondary education. Topics covered include new flexible scheduling and variable course structure designs in secondary education, the school scheduling problem, schedule construction using the SSSS, field testing of the SSSS, SSSS parameter limits, and computer system requirements. Among the advantages of the SSSS are (1) it is a technology which enables the construction of complex flexible schedules; (2) it requires precise definition of the design of each course offered in the school program, as well as the overall program design; and (3) it encourages professional personnel to explore in detail the appropriateness of different arrangements of time, class size, pupil grouping, and use of staff and facilities. The availability of technical documents and the set of programs for the SSSS written in FORTRAN IV for IBM systems 360-40, 360-50, or 360-67 is described in the final section. (TT)

STANFORD UNIVERSITY SCHOOL OF EDUCATION
AND DEPARTMENT OF INDUSTRIAL ENGINEERING

THE STANFORD SCHOOL SCHEDULING SYSTEM



PREFACE

Secondary education in the United States is an exciting venture today, as it has been in the past. The once revolutionary goal of a secondary education is now taken for granted in the United States. The goal today is to individualize secondary education in order that the potential inherent in each person can be more fully realized. A New Design for High School Education, as conceived by Robert N. Bush and Dwight W. Allen, furnishes a framework that permits increased individualization within the secondary education process.

Implementation of a new design for high school education has become possible because computers can now be used to generate the entire school schedule, thanks to the original work of Robert V. Oakford of the Stanford Industrial Engineering faculty. The Stanford School Scheduling System is a set of computer programs that will perform the difficult and onerous task of computing a school schedule.

We are pleased to announce that after a five-year period of field testing, development, and refinement the Stanford School Scheduling System is now being released to the public domain. It gives us pleasure to be able to report that both flexible scheduling and the Stanford School Scheduling System have been well received during the past five years. The number of schools for which schedules were computed grew steadily: 4 in 1963, 23 in 1964, 35 in 1965, 50 in 1966, 93 in 1967 and over 100 in 1968.

In this document we present Bush and Allen's concept of "A Framework for High School Education." From this conception evolved the notion of flexible scheduling based on variable course structures. We formulate the school scheduling problem. We describe the Stanford School Scheduling System and its use in the construction of schedules. We outline selected statistics relevant to field testing of the Stanford School Scheduling System. We specify the school parameter limits and computer system requirements imposed by the Stanford School Scheduling System. This document is intended as a general rather than a technical description of the Stanford School Scheduling System. The availability of technical documents and of the set of programs is described in the last section of this booklet.

Many have contributed to the development of the Stanford School Scheduling System. The Fund for the Advancement of Education of the Ford Foundation contributed two substantial grants to the support of this effort. The support and encouragement of Lester W. Nelson, Edward J. Meade, Jr., and G. H. Griffiths of the Fund are appreciatively acknowledged. I. James Quillen and his successor, H. Thomas James, Dean of the School of Education, and Joseph M. Pettit, Dean of the School of Engineering at Stanford University, have provided a favorable environment for the activities of the Stanford School Scheduling project. Their support and encouragement have been greatly appreciated.

The development and use of the Stanford School Scheduling System was encouraged and supported by the Office of Education of the U.S. Department of Health, Education, and Welfare through Contract Number OE-2CAD-570-94 which funded a project entitled "Flexibility for Vocational Education Through Computer Scheduling."

Many members of the project staff have made important contributions to the development of the system. Without exhausting the list, the following names stand out: Lynne A. Chatterton, Verne Stevenson, and James W. Wilson programmed components of the system. Stephen C. Brophy, J. Roger Hamilton, John Hauser, and Arturo Salazar revised component programs and contributed to improvement of the system. James Smith, James Olivero, Arthur Coombs, Robert Kessler, Donald DeLay, and Ray Johnson played important roles in the use of the SSSS to construct schedules for schools that were experimenting with the new design. They, and many educators who have used the Stanford School Scheduling System, have contributed suggestions for improvement. Mrs. Dorothy Hurley, as secretary to the project, has contributed a great deal of patience and understanding during the many trying hours of the project.

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October 30, 1968

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A FRAMEWORK FOR HIGH SCHOOL EDUCATION*

The idea of secondary education that has developed in the United States has been one of this country's boldest thrusts on the frontier of human affairs. During the eighteenth and nineteenth centuries America forged the new concept that secondary schools should be freely available to all youth who wish to attend. Then, in the first half of the twentieth century the United States took another bold step by making education compulsory, not just through elementary school but also through the secondary school years. This revolutionary goal of a high school education for all has been almost achieved, and until recently, no other country ever envisioned, much less attempted, to realize such a goal. But events race onward as ideas flow quickly and forcefully around the modern world. Following World War I, countries in many parts of the world observed the unprecedented level of material well-being that the United States had achieved. Surmising that this well-being was not unrelated to the extensive provision for schools in the United States, these countries have been adopting for themselves the goal of compulsory secondary schooling and have been rapidly expanding and democratizing their schools.

A further unique feature of secondary education in the United States, in addition to its universal character, has been the comprehensive high school--that high school in each community which serves everyone irrespective of his status or aim in life. Here have mingled the bright and dull, the devout and heathen, and the children of the rich and of the poor. In place of the rigid test systems and separate schools developed in Europe, the United States offers its children the comprehensive high school.

Even though some recent criticisms have suggested that secondary schools in the United States should revert to the European pattern mentioned above, it now appears that this alternative is not acceptable and that the basic idea of a comprehensive secondary school remains sound for this country. But the extensive critical public discussion of the American high school has led to the conclusion that even though the high school was a pacesetter in the last century and has been a vital factor in helping to achieve a high standard of living, this is no time for complacency. Quite the opposite. Now is the time to move in new directions; to dream again a new American dream; and to conceive a new standard for ourselves and possibly for the world.

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*This section of the report is based on the first chapter of A New Design for High School Education, pp. 1-6, by R. N. Bush and D. W. Allen.

The new goal which is now beginning to emerge refers not to amount and numbers (i.e., everyone in school for a given number of years)--a quantitative standard of the past--but rather to a quality of excellence to be achieved in the education provided for everyone in high school. Though the debate over what shall constitute an education of the highest quality for each pupil has not been concluded, more than a suggestion emerges that the new goal evolving from public discussion of secondary education is this: All youth shall, by the end of compulsory schooling, be so launched in a broad, liberal education that they will continue such education as a lifelong pursuit. Further, each person's education will have been so planned that he will be encouraged to develop, as early as his talents are discovered, one or more lines of specialization which will represent the flowering of his own unique interests and abilities. In the past the plan has been to encourage a liberal education for those going to the university and into the professions and a specialized vocational training for those going immediately to work. In Europe those two educational streams have been diverted to separate schools; in the United States they are both in one school, the comprehensive high school. But the new concept holds that the level of education needed in the next half-century--adequate to meet the needs of the nation as well as the individual--requires that for everyone both a liberal and a specialized education shall have been well begun by the end of compulsory schooling.

Already overcrowded with pupils, with more to come, and confronted with the necessity for reaching higher levels of excellence than ever before regardless of severe shortages of teachers and finances, the American high school must develop new, more efficient and effective measures to its ends lest it fail in its new mission. Despite these formidable obstacles, there is reason to be optimistic, for already signs may be seen in secondary schools throughout the country that teachers and administrators are working to turn this crisis into new educational opportunities. For example, national commissions of scholars, teachers, and educationists are at work revising the high school curriculum. Experimentation with television, tape recorders, teaching machines, and other technological aids is opening new vistas for producing and enhancing learning. Although each of the many innovations appears promising, they cannot all be fitted into the high school program as it is now organized. Also, administrators concerned with the several subject-matter fields are convinced that they could provide better programs if they had more of the pupils for longer periods of time, and if they had greatly expanded and improved facilities. Obviously, not all that each group wants can be granted; time, money, staff, and space are limited.

In a concern with trying to organize secondary schools for everyone, the high school[1] has developed a standard system of units and credits, and all subjects meet for the same number of minutes per period and periods

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[1]"High school" as used here refers to grades 7-12.

per week for pupils of all levels of ability. Everyone, the present regulations commonly state, shall take five years of English before graduating, which means 55-minute daily periods for each of the thirty-six weeks of the two semesters. One chief shortcoming of such standardization has been that with physical education required each year, English for five of the six years, and social science for four years, pupils are shortchanged in their education in science, mathematics, foreign languages, and the arts--subject fields of profound and growing importance in these times.

Furthermore, the standard system of units and credits, based as it is on the length of time that students spend in the classroom, is beginning to reflect the adverse consequences of misplaced emphasis. The American high school exists, after all, in order for students to learn, not in order to help them pass away a certain amount of time. The focus of education, in the high school and elsewhere, is necessarily on the student--what he knows, what he can do, what he understands, and what he can create. And time as measured out in units or years or 55-minute class periods is simply not a good measure of what students can do.

With mounting knowledge and increased sophistication about children, their educational needs, and how they learn, it becomes difficult to ignore the fact that not all children need the same amount of time to learn specific things. Nor do all children come to school with equal backgrounds and talents. Some pupils entering high school are already more advanced in a subject than others will be upon graduation. Some will be able to communicate in a second language after two or three years' study; others will take five or six years to develop this same communication skill. Some pupils with excellent achievement and background in one subject would be better off if they were to spend their time in studying another subject rather than in serving time to meet a requirement. The present lockstep of six years to graduate and a rigid set of course requirements makes little sense. Hard and fast rules that will fit all pupils are difficult if at all possible to find. Thus, though the curriculum as a whole must be designed, that portion of it in which each individual is scheduled to enroll should result from an objective, highly personalized diagnosis of his needs.

The difficulty with the standard, time-bound curriculum is not so much that it fails to give students an opportunity to learn, but rather that it fails to take advantage of, or even conceive of, the imaginative range of alternatives which could be made available to help them learn more. So long as the high school begins with the assumption that everything must somehow fit into the standard schedule, there is no room for asking the kinds of questions and getting the kinds of answers which could truly revolutionize education in the last third of the twentieth century. As long as the standard schedule rules, educators will not be able to ask and functionally answer such questions as: How can requirements be arrived at and stated more flexibly so that important differences in pupils are taken into account? How can class periods of different lengths and classes of different sizes be employed to provide maximum learning for different students in different subject areas? Such questions can neither be answered nor asked within the confines of a high school schedule that has room for only one class size and one class period length. And yet it may well be that the significant improvement, and even the survival, of the comprehensive high school depends on the achievement of practical answers to such pressing questions.

The promising results of many experiments now in progress will depend for their wide application upon arranging the schedule of the high school so that new and different courses and curricula can be accommodated. To make possible the fitting together of separate facets of the problem, a new design for high school education must be formulated. This design should strike a balance between curricular requirements and electives; it should not only guarantee the absence of significant gaps in the education of any pupil but also take adequate account of that pupil's individuality. This new design should provide flexible arrangements for the conducting of classes, arrangements which consider not only the pupils' differences, but also the unique talents and specialized competences of teachers, as well as the relevant differences in subject matter areas.

With the advent of electronic data-processing procedures and high-speed computers, the possibility of developing a flexible high school schedule, capable of providing an atmosphere wherein educators can conceive of and implement educational alternatives to serve the educational needs of pupils, has become a reality. These machines have been used in a variety of complex industrial, governmental, and military applications. They mark a new industrial revolution--freeing men from mental labors more prodigious than the physical labors eliminated by the power revolutions of the past two centuries. As a school schedule becomes more varied to provide for new levels of individualization, the number of schedule alternatives increases geometrically. What is an odious task under current practice, without mechanical assistance becomes an impossible task. The magnitude is incredible--if an 80-period week is used for 1,800 students, it would take a computer capable of a million operations a second about twenty-five years to consider systematically all alternatives possible for a single schedule. The use of computers, however, demands a much more thorough analysis of the problems and decisions involved than has been necessary under more straightforward manual systems of scheduling.

And it is in this respect--its continuing demand for careful analysis and decision-making--that computer scheduling may well make its most important contribution to American education. In sometimes painful contrast to the traditional schedule which allows a multitude of decisions regarding class length, size, and content to be made by sheer default, the computer schedule demands that educators actively decide on all such issues. It is in the process of decision-making, of designing and choosing among alternatives, that the greatest hope of computer scheduling lies. For insofar as educators can begin actively to design instructional programs which live and die on the basis of their effects on students rather than their convenience within arbitrary time constraints, the entire process of education in America can gain a much-needed chance for increased relevance and effectiveness.

The proposals presented in A New Design for High School Education are offered in the hope that, as they are further developed and tested, they may help to remove the fetters which now encumber many attempts to experiment in education. The motto of those building this framework is: Take away the limitations. Those working in each subject-matter field, as well as those who have responsibility relating to the organization and administration of the school enterprise, those who teach there, those charged with interpreting its responsibilities to reflect public policy, and those who prepare its practitioners, are invited to consider these questions: If, in high school, you could provide all pupils with an ideal program of study in each subject, how would you arrange the instruction? What would be your aims? For which different groups of pupils would you provide? Would each group take the same curriculum, but at a slower or faster pace? Or would you have different aims, different materials, and different amounts of time for the teaching of pupils of different abilities and interests? What kind of a staff would you provide? What size classes would be most desirable? What content would be most useful? How would you evaluate the results? These are the demands, and the computer schedule must be seen as a tool both for allowing such questions to be asked and for enabling the tentative answers to be implemented, revised on the basis of their value to students, and re-implemented.

The challenge to education has always been to provide instruction which is relevant to the future world of its students. In an America which enters the last third of the twentieth century, that task means far more and presents far greater challenges than it has ever before. It means, for example, that educators must supply experiences for their students which are relevant to a future which no one can hope to predict. It means that a wide range of educational alternatives must be tried in the hope that some of them may prove relevant to that unpredictable future. The following educational tools have been developed to meet these challenges, and to devise constructive alternatives for achieving excellence in education.

A FORMAL DESCRIPTION OF THE SCHOOL SCHEDULING PROBLEM

Variability in course structures is a fundamental factor of the flexible high school schedule. The concept of variable course structure and its effect on schedule construction is described in some detail next.

The term course refers to a body of subject matter that is to be studied by a student. For example, Algebra I, General Math, English Literature, Typing I, and Spanish I all could be names of different courses. The term course structure refers to the organization of students, faculty, and facilities into meetings for purposes of studying the subject matter of the course.

Essential Elements of Course Structure

The following are among the essential elements of course structure:

A. The instructional phases that are to be scheduled separately.

For example, a course would require one or more of the following course phases:

1. A lecture phase that could be attended by all students enrolled in the course meeting as one class.
2. A discussion or problem-solving phase in which the total enrollment would typically be sectioned into small groups for class meetings.
3. A laboratory phase that typically requires special facilities and may therefore necessitate the sectioning of the total enrollment into small groups for class meetings.
4. An independent study phase that typically would include and extend the kinds of study that is referred to now as "homework." The independent study phase is not scheduled. Instead, the student would be free during part of the school day while laboratories and resource centers are open for him to use as he requires them in his independent study phase.

B. The meeting pattern for each phase of a course.

A meeting pattern is specified in terms of meetings per week and periods per meeting. For example, a lecture phase class might meet once a week for two periods; a discussion phase class might meet twice for three periods; and a laboratory phase class might meet once for four periods.

C. The sections (separate classes) that are to be scheduled at each phase:

Pertinent factors are as follows:

1. The number of sections to be offered at each phase of a course depends upon the total course enrollment and the class size limitations for that phase of the course.
2. The teaching assignments for each section are normally specified in advance.
3. The room assignment for a section is specified in advance if a special purpose facility is required. Scheduling of sections into general purpose rooms is normally deferred until after class meetings have been scheduled.
4. Restrictions, if any, on the time that a section can be scheduled.

D. Course enrollment list.

A list of the students that have requested that the course be included in their program.

E. Interphase dependencies to be observed.

The interphase dependency concepts described below are illustrated in Table I. In that table and in the discussion that follows, it is assumed that the phases of a course are numbered I, II, III, and the like, where the number I is assigned to the phase with the fewest sections, and so on.

Table I

An Illustrative Course Structure

Data Specified	Phase and Section						
	I-1	II-1	II-2	III-1	III-2	III-3	III-4
Teaching Assignments	A,B,C,D	A,B	C,D	A	B	C	D
Room Assignments	LR	LAB	LAB	Not Specified			
Course Enrollment	W,X,Y,Z	X,Z*	W,Y*	X*	Z*	W*	Y*
Meeting Pattern							
Meetings per Week	1	2	2	1	1	1	1
Periods per Meeting	3	2	2	3	3	3	3

*Scheduling of students to sections is part of the scheduling process and is not part of the course structure specification. These section assignments are shown to illustrate the notion of interphase student grouping dependency.

1. Teaching assignment dependency. A course structure may require that the teaching assignments at phase III may be dependent upon the teaching assignments at phase II, which in turn are dependent upon those at phase I. This notion is illustrated in Table I, in which the team of teachers A, B, C, D are assigned to the single section of phase I; the teacher teams A,B and C,D are assigned to sections 1 and 2 of phase II, respectively, and separately to sections 1 through 4 of phase III.
2. Room assignment dependency. It has not been common, but it is anticipated that room assignment dependencies analogous to teacher assignment dependencies might arise when school facilities are designed with multiphase course structures in mind.
3. Student grouping dependency. It is quite common for a course structure to require both teacher and student grouping interphase dependencies. The latter notion is illustrated in Table I by the sectioning of the students W, X, Y, and Z at phase II and phase III The students scheduled into sections III-1 and III-2 must be drawn from those scheduled into section II-1, and the students scheduled into sections III-3 and III-4 must be drawn from the students scheduled into section II-2.

The combination of teacher and student grouping dependencies permits a student-teacher relationship to be maintained through all phases of the course, and it further provides (in theory) that all students in a particular phase III section have been commonly exposed to the subject matter of the course.

Scheduling of students into sections takes place as the schedule is computed, not a priori. The scheduling algorithm must provide for maintaining student grouping dependencies between phases as the schedule is computed.

If a student is to be scheduled into a course, he must be scheduled into exactly one section of each phase of that course. For the course defined in Table I, the seven sections distributed among the three phases could be defined symbolically as follows:

Phase No.	Sections
I	S_{100}
II	S_{010}, S_{020}
III	S_{001}, S_{002}, S_{003}, S_{004}

Note the correspondence between the phase numbers and the nonzero subscript positions. Subscript positions 1, 2, and 3 (from left to right) are associated respectively with phases I, II, and III.

With the student grouping dependency indicated in Table I, there are just four composite sections (composed of exactly one section from each phase) into which students can be scheduled. These four sections are defined symbolically to be S_{111}, S_{112}, S_{123}, S_{124} where combination of subscripts identifies the course-phase sections from which a course section is composed. A student enrolled in composite section S_{112} must be enrolled in section S_{100} (section one of phase I), section S_{010} (section one of phase II) and section S_{002} (section two of phase III). If there were no student grouping dependencies, four more composite sections--S_{113}, S_{114}, S_{121}, S_{122}--could be defined for the course set up in Table I.

4. Meeting sequence cycle. From the student's point of view, the meeting sequence cycle for a course is the order in which he attends the class meetings of the composite section into which he is scheduled. For some courses it may be deemed necessary that all students in the course will have the same prespecified meeting sequence cycle. This concept will be illustrated by reference to the course described in Table I, where the number of meetings per week are one, two, and one, respectively, for phases I, II, and III. For that course, a prescribed meeting sequence cycle might be 1232--which indicates that each student in the course must be scheduled so that his phase I section meeting should precede his first phase II section meeting, which should precede his phase III section meeting, which should precede his second phase II section meeting. This pattern would be repeated cyclically throughout the school year.

   A limited capability for specifying meeting sequence cycle is provided in the SSSS.

5. Time lapse between successive meetings in a composite section. The educator may require for a particular course that a prespecified time should elapse between successive class meetings in a student's meeting sequence cycle. In traditional course structures each class meets once each day, and a time lapse of one day between meetings is inherent in a sequence cycle. When multiphase course structures are introduced, a student may be scheduled into consecutive meetings from two or more phases of a given course unless a time lapse restriction is specified.

F. Dependencies between courses.

Sometimes the educator finds it desirable to specify dependencies between courses. For example, it may be required that all the students in two or more courses shall meet together for the lecture phase but that otherwise the courses be scheduled as though they were a single course in order that the students can be transferred from one course to the other at the end of the semester.

G. Restrictions on availability of resources.

To provide for part-time teachers and part-time students, restrictions may be placed on the times at which individual teachers or students are available for scheduling. Similar restrictions can be specified for rooms.

The School Scheduling Problem

A school schedule specifies the places and times that each class will meet, the students who constitute the class, and the teacher or teachers that are to meet with the class. The first step in the construction of a school schedule involves a set of policy decisions by the school's faculty, administrators, and students--decisions in which the faculty and administrators determine the content and structure of the courses to be offered and in which each student, in consultation with his counselor, identifies the courses in which he wants to be scheduled.

The problem, then, is to schedule class meetings in time and space--observing the restrictions imposed by the course structure specified and satisfying as many of the students' requests for course enrollment as possible.

Traditionally all courses have been structured almost identically. Each course has had just one phase, and the meeting pattern has been the same for all classes, i.e., one period each day in the school week. Great emphasis has been placed on holding class size below some specified limit, e.g., 30 students. Within this structure, the teacher would allocate time to the various instructional phases as he saw fit. Bush and Allen conceived the multiphase course structure previously described as necessary to the achievement of educational objectives that are deemed important. The introduction of multiphase course structures does not change, but it does greatly increase the complexity of the scheduling problem. The increase in complexity is apparent to an educator experienced in school scheduling.

High school administrators were able to construct usuable high school schedules when virtually all classes conformed to the traditional meeting pattern of one period per day, five days per week. It was the elimination of this obstacle to important educational objectives that motivated the authors to study the school scheduling problem and to develop the Stanford School Scheduling System.

A secondary benefit from the mechanization of school scheduling is the transfer--from the professional school administrator to the computer--of the onerous computation required in the construction of a school schedule. Each year professional school administrators devote an aggregate of several millions of hours to the construction of school schedules.

A school schedule typically comprises the following documents:

A. The master schedule, which contains an entry for each class that is scheduled. Each entry identifies the class by name or number, e.g., General Math, section 1; the meeting time, e.g., MWF periods 3 to 5; the name of the teacher who will conduct the class; and the number of students scheduled into the class.

B. For each student, a schedule that specifies for each period in the school week the class and the room to which that student is scheduled at that period.

C. For each teacher, a schedule that specifies the class and room to which that teacher is scheduled for each period in the school week.

D. For each room, a schedule that specifies the class and teacher that are scheduled to that room for each period in the week.

E. For each class, a list of the individual students who are scheduled into the class.

Some conception of the volume of data contained in these documents is indicated by the fact that as much as 120,000 lines may be required to print a complete set of documents for a school with 2,600 students.

The construction of a school schedule necessitates the construction of a master schedule, i.e., a determination of the times at which classes will meet, as well as student, room, and teacher schedules. A distinction should be made between school scheduling and the scheduling or assigning of students to classes after the master schedule has been determined. The latter is an important, but not the major, part of the school scheduling problem. Very effective computer-based systems for assigning students to classes have been reported by Blakesley (1963), Akin ("7070/74 and 1401 Class Scheduling"), and Anderson (1964). It appears that this problem has been effectively solved.

The major problem is to schedule classes to meet at such times that most if not all of the student requests for course enrollment can be satisfied. Appreciable work has been devoted to the larger problem of constructing a school schedule that tends to maximize the number of student requests for course enrollment that are satisfied. The works of Appleby, et al. (1961), Holz (1963), and Holzman and Turkes (1964) have been reported.

The Stanford School Scheduling System described herein and the GASP system developed by Holz have demonstrated a practical capability of coping with the scheduling problems presented by the educational objectives of Trump and Bush and Allen. Hereafter the Stanford School Scheduling System will be referred to frequently as the SSSS.

THE STANFORD SCHOOL SCHEDULING SYSTEM

The SSSS comprises nine major computer programs and several supplementary programs written in FORTRAN IV for use on the IBM 360-40 or larger computer. The following are sketches of the major components of the system:

1. Data Collection. The data collection component of the system, defined in detail in the School Manual, Stanford School Scheduling System (1968), provides forms for recording a school's policy decisions as they are reflected by course structure specifications and the students' course requests. The data from these forms are punched in IBM cards which serve as input to the SSSS system.

2. INCA, "INput Card Audit". The INCA program reads the punched cards and records the card image in a magnetic file. The program checks the card records for detectable errors and logical inconsistencies. A message is written for each error or inconsistency detected. The program can update the data set to reflect insertions, deletions, or changes in the file. Such corrections would be specified via punched cards after the error messages have been studied.

When the detectable errors and inconsistencies have been eliminated from the data, the INCA program prepares a file that serves as input to the SSP (School Scheduling Program). The INCA program assigns a code number to each course, course-phase, section, teacher, room, and student. Within SSSS these entities are identified by code number only.

The file prepared by the INCA for the SSP contains a sequence of data packets. For each course-phase there is one data packet containing the essential elements that describe the structure of that course-phase and its interphase dependencies. The packets are ordered basically according to the potential value of scheduling a section of the course-phase, where the value of scheduling a section is defined in terms of the total student periods of class time per section. There are exceptions that are observed in ordering the data packets. For example, all course-phases for which meeting times are prespecified in the data are placed at the head of the sequence. Furthermore, the educator can arbitrarily specify changes in the ordering.

3. SSP, "School Scheduling Program." The SSP actually constructs the schedule of class meetings by processing the sequence of course-phase data packets prepared in INCA. The objective of the SSP is to schedule classes so as to maximize the number of student course requests that are accommodated.

When a section of a course-phase is scheduled, the following events occur:

a. The teaching assignments for the course-phase are observed, and a teacher (or teaching team) is selected.

b. The meetings-per-week and periods-per-meeting specifications for the course-phase are observed. A time pattern is generated at which the teacher (or teaching team) is available. The time pattern is a combination of periods that satisfies the meetings-per-week and the periods-per-meeting specifications and further provides that no two meetings of this section will fall on the same day.

c. If a room assignment is specified, a test is made to determine whether or not the assigned room is available. If not, a new time pattern is generated at event (b).

d. The list of students eligible to be scheduled into this section is observed, and the students from this list who are available at this time pattern are identified. To be on the list, a student must have requested the course to which the current course-phase belongs. However, the list may be further restricted by an interphase student grouping restriction. If an adequate number of students is available, a section is scheduled, and the teacher and room availability records are updated to reflect this action. Otherwise, a new time pattern is generated at event (b).

e. The number of sections to which the teacher (team) is assignable is observed. When the teacher has been assigned the specified number of sections or when all time patterns at which the teacher is available have been considered, the next teacher (team) in the assignment list is identified at event (a), and the foregoing process is repeated.

f. When all sections of the course-phase have been scheduled, or when it becomes apparent that no more can be scheduled, the students are assigned to sections in a way that balances section sizes insofar as student availability permits. The student availability records are updated to reflect the scheduling of students to sections.

The foregoing process is repeated for successive course-phases. In the scheduling of individual sections, exhaustive searching will be performed to find a time pattern at which the teacher and room assignments can be honored and at which an adequate number of students are available. Furthermore, extensive but not exhaustive searching is performed in an attempt to schedule as many eligible students as possible, given the scheduling decisions that have been made previously. To this extent the SSP tends to satisfy as many student requests as it is possible to satisfy. However, the SSP does not provide for descheduling and rescheduling of sections, nor does it provide for descheduling or rescheduling of students. In this respect it departs from the scheduling theory.

The results of the SSP consist of class lists for individual sections. Each class list specifies the teacher (team), the room (if any), the students scheduled in the section, and the times at which the class is to meet. The class lists are recorded in a magnetic file.

4. UDL/PTWS, "UpDate Lists/Program To Write Schedules." The PTWS section of UDL performs a large-scale sorting operation to convert the class lists prepared by SSP into teacher, room, and student schedules. A schedule as prepared by PTWS is actually a list of the code numbers of the sections into which the resource has been scheduled as reflected by its appearance on the class list of that section. The results of the PTWS program are recorded in a magnetic file.

Any student whose course requests have not been completely satisfied by the SSP scheduling is identified as a status 1 student.

5. UDAMC, "UpDate After Manual Changes." We have found that the school administrator may want to specify certain changes in a schedule generated by SSP even though he regards the schedule as acceptable. Sometimes these changes do not affect the schedule of classes or the schedules of resources. For example, it may be necessary to correct the spelling of, or change the name of, a teacher or a room. Frequently the changes may affect the schedule of classes and/or the schedules of resources. For example, changes in teacher assignments or room assignments occur. Sometimes the administrator may even reschedule or modify the scheduled meeting time of one or more sections.

6. UDCREQ, "UpDate Course REQuests." We have found that changes in course requests are inevitable. The plans of returning students sometimes change; new students register in the school after the schedule is fixed; some students do not return to school. The UDCREQ program provides for modification of SSSS records to reflect these changes. Whenever a student's course-request

list is modified, his existing schedule is automatically invalidated and he becomes a status 1 student.

7. SAP, "Student Assignment Program." The SAP is used after the class schedule has been fixed for scheduling a status 1 student into sections of courses that he has requested. It provides for consideration of alternative courses specified by the student in his course-request form in the event he cannot be scheduled satisfactorily into all the courses requested. In making substitutions, the SAP considers the preference of the individual as indicated by his course-request list and tries to avoid substitutions for those courses for which the student has indicated a high preference.

8. RAP, "Room Assignment Program." We have learned from experience that better schedules result when *a priori* room assignments are restricted to classes requiring special-purpose rooms. We have also learned that there is not general agreement among school administrators as to the preferences that should be observed in assigning rooms. Some administrators prefer to make the room assignments manually after the schedule is fixed because they can, thereby, best satisfy the individual preferences and needs of that school's faculty.

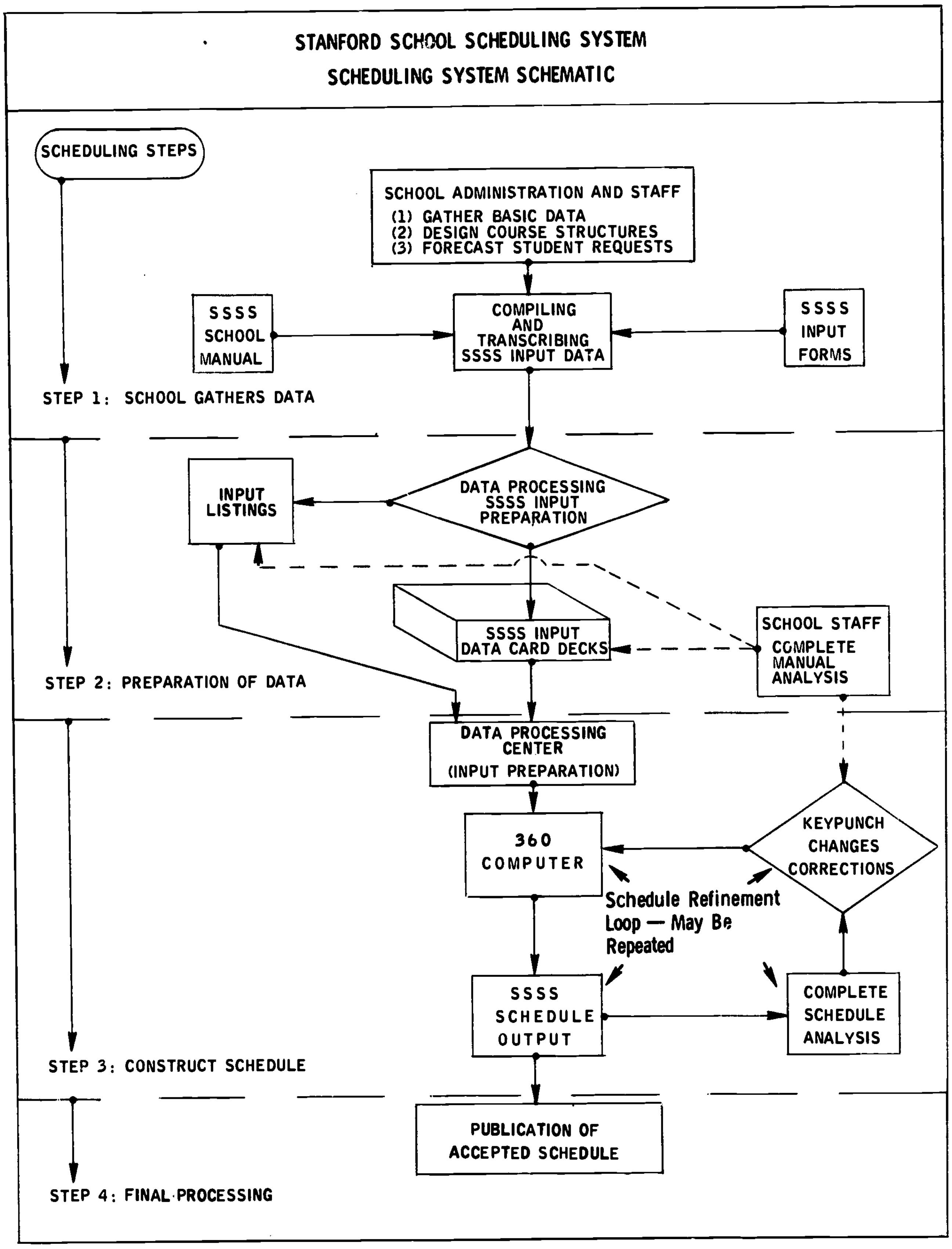
The RAP provides for automatic assignment of rooms after the schedule is fixed. It requires the school to work out a classification of rooms; the class of room (or the classified room) required by each course phase must be identified; the room preferences for each teacher must be specified; and, finally, the faculty must be ranked to indicate the individual teacher priority for having his preferences observed in making room assignments. The net effect is that teachers with high priority will have their preferences honored, whereas those with low priority may not do so well.

9. UDL/UDCL, "UpDate Lists/UpDate Class Lists." As a consequence of the changes in student schedules that result from execution of the SAP program, the class lists prepared by SSP become obsolete. The UDCL section of the UDL program performs a sorting job that prepares new class lists based on the existing schedules of students.

10. TRANSLATE. The TRANSLATE program provides for decoding class lists and teacher, room, and student schedules and printing them in a form that is directly usable by the school. In the process of preparing a student's schedule, it makes lunch-period assignments for the individual student. It also prepares a master schedule for the school. For each section

offered, there is a line in the master schedule that identifies the course, the phase, the section, the teacher, the room, the meeting times, and the number of students enrolled.

There are nine more programs in the SSSS. Most of these are used primarily for diagnostic purposes and will not be discussed. The SHUFFLE program allows the user to specify the order in which course-phases will be processed for scheduling.


STANFORD SCHOOL SCHEDULING SYSTEM
SCHEDULING SYSTEM SCHEMATIC
SCHEDULING STEPS
SCHOOL ADMINISTRATION AND STAFF
(1) GATHER BASIC DATA
(2) DESIGN COURSE STRUCTURES
(3) FORECAST STUDENT REQUESTS
SSSS SCHOOL MANUAL
COMPILING AND TRANSCRIBING SSSS INPUT DATA
SSSS INPUT FORMS
STEP 1: SCHOOL GATHERS DATA
INPUT LISTINGS
DATA PROCESSING SSSS INPUT PREPARATION
SSSS INPUT DATA CARD DECKS
SCHOOL STAFF COMPLETE MANUAL ANALYSIS
STEP 2: PREPARATION OF DATA
DATA PROCESSING CENTER (INPUT PREPARATION)
360 COMPUTER
KEYPUNCH CHANGES CORRECTIONS
Schedule Refinement Loop — May Be Repeated
SSSS SCHEDULE OUTPUT
COMPLETE SCHEDULE ANALYSIS
STEP 3: CONSTRUCT SCHEDULE
PUBLICATION OF ACCEPTED SCHEDULE
STEP 4: FINAL PROCESSING

SCHEDULE CONSTRUCTION USING THE SSSS

Each school that was scheduled by SSSS was assigned a consultant from the Stanford School of Education. In this project, members of the staff functioned as schedule consultants. The consultant performed important functions: explaining to the educator the technical requirements of SSSS; helping the educator formulate course structures that will achieve desired educational objectives; and working out compromises that are necessary to achieve an acceptable schedule.

We found from experience that schedule construction using the SSSS usually fits into four steps, which are described graphically in Figure 1. A brief verbal description follows:

1. Data Preparation. The SSSS consultant played the very important role of explaining to the faculty of the school the capabilities of SSSS. Typically, he helped the teacher design course structures directed toward the achievement of the teacher's particular educational objectives. He guided the school in the collection of data and the preparation of the SSSS forms.

When the data were submitted to the SSSS project on punched cards, they were processed by the INCA program. The huge amount of data needed to describe a school's requirements inevitably contained some errors or logical inconsistencies. When necessary, the consultant assisted the school in defining corrections that eliminated the errors and inconsistencies found by the INCA program. The corrections were submitted for processing by INCA. If errors or inconsistencies recurred, further corrections were made and processed by INCA. When the errors were all eliminated, computation of a schedule was initiated.

2. Preparation and analysis of the schedule. Step 2 typically used the SSP, PTWS, and the TRANSLATE components of SSSS. A schedule of classes was generated by SSP. Teacher, room, and student schedules were prepared by PTWS. The master schedule and the teacher and room schedules were printed by TRANSLATE.

These data, together with summary statistics, were analyzed by the SSSS consultant and the school's faculty. The summary statistics included the fraction of total course requests satisfied, the number of students with incomplete schedules, and the number of unscheduled sections. In some cases the first schedule generated proved to be highly satisfactory to the faculty and satisfied over 99% of the total course requests. In many cases, particularly when the school was experimenting with new course structures, the first schedule was not satisfactory.

When a school decided that a schedule was not acceptable, it was necessary for the school faculty to state its objections specifically; then the SSSS consultant would try to suggest ways that the school's specifications could be revised to improve schedulability without seriously compromising the faculty's educational objectives. A revision in basic data would necessitate processing of the revisions by the INCA program; therefore, Step 1 of the schedule construction had to be re-entered. Steps 1 and 2 were repeated until an acceptable schedule was obtained.

3. <u>Modifications to an accepted schedule.</u> This step typically used the UDAMC, SAP, RAP, UDL, and TRANSLATE programs. Some schools elected to eliminate RAP, make room assignments manually, and introduce them to SSSS via the UDAMC program.

At the end of this step, a school typically requested a master schedule, a complete set of class lists, and complete sets of teachers, room, and student schedules. A school that anticipated an appreciable change in the composition of its student body because of withdrawals or new registration might wait until Step 4 was completed before requiring class lists and student schedules.

4. <u>Changes in course requests.</u> This step used the UDCREQ, SAP, UDL, and TRANSLATE programs, and it was executed on or about the opening day of school to provide for the changes in the students' course requests that accumulated after the completion of Step 3.

The UDCREQ program updated the SSSS records to reflect the specified changes in students' programs. Each student whose program was changed became a <u>status 1</u> student. The SAP program scheduled the <u>status 1</u> students into sections of the requested courses. The UDL program was used to update the class lists. The TRANSLATE program prepared the class lists and student schedules that were required by the school.

SSSS emphasizes throughout the priority of educational decisions over computer decisions. Wherever possible, choices between pupils in fulfillment of requests fall to the professional personnel rather than to the impersonal machinery of computer programs and the computer itself.

Again, SSSS serves three different functions. First, it is an enabling technology. Second, it requires precise definition of the design of each course offered in the school program, as well as the overall program design. Third, it encourages professional personnel to explore in detail the appropriateness of different arrangements of time, class size, pupil grouping, and use of staff and facilities. Experience with SSSS prompts the school staff to raise their sights about viable alternatives and to request expansion in variability of curriculums and courses.

FIELD TESTING OF THE SSSS

The SSSS has been subjected to a rather thorough test, which began in the summer of 1963 and is continuing through the present. In the past five years, some 315 schedules have been constructed for more than 100 different schools. Having once tried the system, most schools have continued its use.

Schedules have been constructed for schools ranging in size from 113 students to 4,618 students and ranging in geographical location from Pennsylvania to Yamato, Japan. A few of these schedules have involved only traditional single-phase course structures, but most of them have involved multiphase course structures, incorporating many of the educational objectives suggested by Bush and Allen.

Although the SSSS was still in the experimental-developmental stage, it was used in the summer of 1963 to construct schedules for four high schools that were implementing many of the ideas suggested by Bush and Allen and thereby departing radically from the traditional course structures. The resulting schedules were accepted and implemented even though they were far from ideal. The SSSS project benefited from this experience, and the system was revised to provide for certain course structure requirements, particularly interphase dependencies, that had not been anticipated.

In 1964 schedules were constructed for 23 schools, including all of the schools scheduled in the previous year. Of this group, there was one school that decided at the last minute to go back to traditional course structures and therefore discarded the schedule that had been constructed by the SSSS. As in 1963 the SSSS project benefited from experience; the system was modified to improve its scheduling effectiveness and to reduce the computer time required.

In 1965 schedules were computed for 35 schools, with all but three of the schools from the preceding year repeating. In 1966 there were 50 schools scheduled, with five from the preceding year not repeating. In 1967 schedules were computed for 93 schools with eight from the preceding year not repeating. Of those eight, four schools had enrollments of less than 200 students.

The SSSS was originally written in SUBALGOL for operation on the IBM-7090. An obscure technical difficulty together with the obsolescence of the IBM-7090 made it impractical to release the SUBALGOL version of SSSS to the public domain. A decision was made in 1966 to translate the SSSS to a language that would permit widespread dissemination. The decision narrowed to a choice between FORTRAN IV and PL/1. For ease of translation PL/1 was favored. FORTRAN IV was eventually selected because the development of an efficient compiler for it seemed more certain than for PL/1.

The FORTRAN IV version of the SSSS, which included several refinements and improvements over the SUBALGOL version, was thoroughly tested in 1968 during the computation of schedules for well over 100 schools. Many "bugs" that had been introduced during the translation were isolated and corrected. Having been subjected to this amount of testing, the system should be well "debugged," but no guarantee can be given. There is the saying in the computer business that complicated programs are never completely "debugged;" instead they are used for long periods without a "bug" appearing.

Except for the first year, most of the schedules were computed on a contractual basis with the school paying a fee that was a function of the number of students scheduled. We are convinced that computer-based school scheduling is economically feasible. We visualize that the scheduling service will be performed variously by schools or school systems, by schools of education and by private companies that contract to perform the service.

The prospective user of the SSSS is urged to consider seriously the role of the educational consultant and to provide for such services either within his organization or by obtaining the services of a knowledgeable consultant.

There are several ways of assessing the effectiveness of the SSSS. One would be to compare its performance with a theoretical ideal. If this were done, the SSSS might come off rather poorly. Another would be to compare its performance with practicable alternative scheduling systems. When this is done, we believe the SSSS would usually compare rather favorably.

We find that the number of course requests (not) satisfied is a measure of scheduling effectiveness commonly understood by students, teachers, administrators and parents. In terms of this measure, our experience indicates that the SSSS would compare favorably with other practicable scheduling systems.

SSSS PARAMETER LIMITS

The SSSS was developed as a general purpose scheduling system that serves a wide variety of schools. The following is a list of parameters whose values may vary from school to school. One of the limiting values of these parameters shown below are dependent upon the number of bytes of core memory. This limiting value is marked with an asterisk.

Courses in a Student's Program	17
Course-Phases to be Scheduled	750
Days per Schedule Cycle	10
Modules or Periods Per Day	32
Modules or Periods per Schedule Cycle	160
Number of Sections in a Course-Phase	35
Number of Students in a Course	750
Number of Phases in a Course	5
Periods per Meeting of a Class	9
Rooms to be Scheduled	255
Rooms in a Room Team	5
Sections to be Scheduled	2,000
Students to be Scheduled	3,500*
Teachers to be Scheduled	300
Teachers in a Teaching Team	9

*This value should accommodate almost all schools. It can be increased to 6,400 students if a 275,000 byte core partition is provided by the computer system.

COMPUTER SYSTEM REQUIREMENTS

The SSSS has been operated on IBM systems 360-40, 360-50, and 360-67. The SSSS as released requires the following system features.

1. Central Processing Unit model 40, 50 or 65 with

   a. Standard Instruction Set.
   b. Decimal Feature Instructions.
   c. Floating Point Feature Instructions.
   d. Protection Feature Instruction.
   e. Clock (SVC 11).

2. Core Memory

   O.S. implementation with a partition of at least 200,000 bytes. In most instances, a 262,000 byte core with a small operating nucleus is sufficient.

3. I/O Devices

   a. Card read and punch (e.g., 1402).
   b. Line printer, 132 characters per line (e.g., 1403).
   c. Sequential Access Storage Devices.
      Each computer system on which the SSSS has been operated prior to release has had at least 2 Nine Track Magnetic Tape Drives (e.g., 2400).
      Disk Storage Drive (e.g., 2311 or 2314) 2 req.
   d. Direct Access Storage Device (e.g., 2311 or 2314).
      Resident on this device would be the OS Load Modules and the FORTRAN H direct access data sets.

4. If the SSSS programs are to be compiled, the FORTRAN IV level H compiler is required.

DOCUMENTATION AND AVAILABILITY OF THE SSSS

In addition to this brochure, the documentation of the SSSS consists of a School Manual, a Data Processor's Manual, and a set of Commented Source Programs.

The School Manual describes in detail the content and format of the data that must be prepared by the school in the data collection component of the Stanford School Scheduling System. A set of forms for recording data are described in detail and their use is illustrated by examples. These forms are designed to facilitate the transcription of the data to IBM cards for input to the SSSS programs. The format of these data cards is described in detail.

The Data Processor's Manual describes in detail the preparation and organization of job control and data cards for every job required in scheduling a school. This manual also describes the form and content of magnetic disk or tape files that are generated and used by the system.

The commented programs constitute the SSSS. The programs are written in FORTRAN IV and have been tested on IBM system 360-40, 360-50, and 360-67.

A complete set of the commented programs recorded on magnetic tape, together with a School Manual and a Data Processor's Manual can be obtained from

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A service charge will be made to cover secretarial, computer, and other costs incurred in continuing this service to the public.

The use of this system by anyone shall be entirely at the risk of the user. The Fund for the Advancement of Education, Stanford University, and Robert V. Oakford do not accept any responsibility for the effectiveness of the system.

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