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ABSTRACT

An effort was made to operate a computer simulation of individualized self-paced instruction concurrently and in parallel with an actual conventional course. The simulation was in effect a management information system for instructors and students, with modifications as they were made by participants. A pilot program was run at Catholic University in 1973. Ultimately a prevalidated simulation of a course should be possible. (SK)

The Use of A Concurrent Simulation in the Management of Individualized Instruction

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SUMMARY

This paper is a preliminary report of an attempt to run, concurrently, and in parallel with an actual course, a computer simulation of individualized and self-paced instruction. The simulation is, in effect, a management information system for the instructors and students who may use the information provided by the simulation to modify their behavior with respect to the course. The simulation is then modified to reflect changes when they are made by the participants. The ultimate, expected output is a pre-validated simulation of the course for resource planning and scheduling prior to its next presentation.

I. Individualized Instruction.

It is both intuitively attractive and generally borne out by experiment that greater individualization of the educational process leads to a faster learning rate when averaged over all students, as well as greater student satisfaction and less "wastage" of slower student learners. For these reasons, there has been in recent years a significant expansion in the individualization of instruction from the elementary school to the university, as well as in technical and industrial training. By individualized instruction in this context is meant:

1. Course activities are broken into short segments called "learning modules," which are largely self-instructional and through which learners can proceed at their own pace.

2. Achievement of learners is tested after completion of each learning module in the course.

3. Students are permitted at least some selection as to which modules they undertake.

Authorities differ widely on just what constitutes "individualized instruction", but all of them agree that student self-pacing is a basic and essential ingredient. Weisgerber states that: "Learning can be said to be individualized to the degree that the learner believes that his education is personalized to meet his needs and facilitates and encourages his independent progress." He then goes on to list ten criteria for individualized instruction, the first of which is self-pacing.(1) Johnson and Johnson give a three part definition of individualized instruction, the first part of which is that: "Course activities be broken into short segments through which learners can proceed at their own pace".(2) Edling repeatedly emphasizes that self-pacing is the basic ingredient. "In all individualized instruction, the pace of instruction is determined by the individual." "All individualized instruction requires, by definition, individual pacing." "Such instruction may or may not be efficient, but if each individual is allowed to set his own pace, then the instruction meets the essential criterion which differentiates it from group instruction".(3)

However, individualization and especially self-pacing is frequently found to be more efficient than group-paced, totally teacher controlled instruction. Matson says: "The results.... show the SPI [self-paced instruction] approach to require less faculty time than the conventional lecture approach. The student time required is approximately comparable by either method".(4) Chien's experience in handling large introductory courses by "decoupling" indicated greater work-load for faculty on the first trial operation while the material was still being produced and modified, but about the same as a normal course load thereafter.(5)

James A. Dunn and others at the American Institutes for Research in the Behavioral Sciences state that, generally, all individualized instruction systems have in common: a high materials consumption rate, short equipment life, high level of student activity (resulting in noise if conducted in a common area), and a modification of the teacher's role from instructor to manager and occasional tutor. They define the need for a "requisite information system" to keep track of students, teachers, materials, and equipment, and to allocate the last three among the first.(6) Simmer found that the operation of a self-imposed scheduling program in a large high school required the services of a full time coordinator.(7) The problem of the efficient allocation of typically scarce learning resources in a self-paced instructional situation shows up in the consistently documented inadequacies of facilities and need for coordination,(8) as well as the frequent recommendations for automatic data processing assistance.(9) As Ammentorp and others put it: "In short, individualized instruction systems tend to generate waiting lines."(10)

II. Management Problems In Individualized Instruction.

Attempts to introduce individualized instruction often have been blighted by the sudden emergence of a complex and time-constrained allocation-of-resources problem in an area where little or no management expertise was previously required.

"Student-paced instruction provides an opportunity for considerable savings in training time, since each student can spend exactly the amount of time he needs to spend in order to master each topic. However, student-paced courses may lose all or part of this potential savings as a result of students' spending more time than they actually need to spend in order to master certain topics."(11)

Procrastination has been a constant problem with all forms of self-paced instruction. It is mentioned by nearly every researcher. The reasons suggested are many. Edling reports: "It is very difficult for some teachers to keep track of all students when they are working in different places in the same materials."(12) Matson points out that the requirement to actually master each segment of the course before going on to the next is a major hurdle for the perennial "C" student who has learned to accept from himself a constant low level of performance.(13) In any case it is clear that some students do not readily adapt to self-pacing and few students are able to diagnose their own difficulties well enough to seek appropriate assistance immediately.(14) Early and accurate prediction of individual student progress would permit timely intervention through counseling or remedial instruction of such slow or "stalled" students.

At the introduction of a new, or extensively revised, self-paced course, despite numerous individual try-outs, during, and even after field tests, it is common to find instances of instruction inadequate for the stated objectives.(15) It is then extremely important to detect early and correct any points at which many students are encountering difficulty. If an artificial time constraint (such as a school semester) is imposed on the course, it also becomes important to detect early whether an unacceptably large number of students are unlikely to complete the course in the alloted time.

III. The Operational Analysis of Individualized Instruction.

An attempt has been made to develop a mathematical model of individualized instruction. Representations of the instructional process as a flow graph and as a state-space have been worked out in some detail. Serious questions regarding the stationarity of the process arise from attempts to handle statistically the "free" choice of individual human beings.

The process of individualized instruction resembles in its operational structure the process of manufacturing in a multi-product machine shop where the workers operate at their own pace on individual machines and the materials are routed through them to produce a variety of final products. This arrangement may be contrasted to the assembly line where a single product is produced by the carefully scheduled confluence of its component parts. The multi-product machine shop has been studied as a network and mathematically modeled by operations analysts for many years.(16) Its scheduling problems are similiar to those in self-paced and individualized instruction. Indeed, similiar problems arise in any project type operation in which multiple people or machines are doing various different tasks which must be brought together to form some final product.

What makes the process of individualized instruction formally different, is its dependence on a series of relatively unconstrained decisions made by the students. Such events may be modeled as a stochastic (random) process but one which is non-stationary in the statistical sense. The statistical measures of its probabilistic character (for instance its mean and variance) change with time.(17) This lack of stationarity makes difficult the prediction of a single student's future performance based solely on his past performance.

There are two aspects of the operation of a human decision maker which tend to make his output a non-stationary process. First, the human decision maker tends to adapt his behavior to the changing conditions. To the extent that he has information about his progress and that of his fellow students, he may modify his choice of modules and even the length of time he takes to complete them in a way not predicted by past performance. Secondly, his behavior is subject to unknown and uncontrolled influences from outside the system being modeled.

Furthermore, since the primary objective of individualized instruction is to maximize student learning within the resource constraints, any attempt to optimize such a system must take into account each student's view of the course and the effect of that view on his individual progress. In making his choices from among the options available, he must compromise between mutually incompatible objectives: for instance;

1. A longer waiting time to use self-selected learning modules versus an uninterrupted progress via an externally assigned series of modules.

2. The effort involved in learning (the difficulty and number of modules) versus the perceived importance of what is being learned (the grade received or the occupational advancement resulting).

Smallwood, for instance, developed a mathematical model for computer based instructional systems which viewed the teaching as a branching network of blocks of instruction through which the student progresses at his own pace and by his own selection among alternative routes resulting from his performance on past blocks of instruction. He described performance measures based on conditional probabilities, and defined the probability of a student, with a known response history on preceding blocks, making a particular multiple choice response, as the fraction of students out of an infinite population with identical response, histories who will select the same alternatives. He discussed the difficulty of estimating these probabilities in practical cases but did not provide any general approach for so doing.(18)

Belgard and Min used a sequential linear programming model. They assumed the teaching-learning process to be piece-wise linear, took the probability of success as a negative cost coefficient, and by local optimization of each stage, produced global optimization of the whole process. Their sequence of stages is predetermined, but each stage has alternate activities available. "The Optimization Loop selects the tasks within a stage and assures the highest probability of passing the achievement criteria in the shortest amount of time for a particular student."(19) The probabilities of passing each task for each student (conditional upon his being ready for that task) seem to be crucial for the success of this method also. But the authors appear to obtain them a priori from the opinions of "psychologists and teachers".

IV. Management Information Systems.

Management information systems have been developed over the years to assist the control of such projects and to plan, allocate, and schedule resources. By a "management information system" is meant the entire collection of procedures, operations, and functions devoted to the generation, collection, evaluation, storage, retrieval, and dissemination of data and information about an activity or a combination of activities. Such systems should be designed to assist the decision-making of those persons concerned with an activity's management at one or more levels. In individualized or self-paced instruction, those individuals include both the instructors, or "course managers", and the students. If both the students and the staff have information, at all times, as to the rate of progress of each individual student now pursuing the course, and predictions concerning their future progress based on the historical rates of progress of past students in the course, they can all take action to optimize the allocation of learning resources and the processing of students through the course.

Any management information system should at least provide record keeping and information retrieval on past and current events, but to make such an automated system cost-effective, it should perform more than these functions. It should also be capable of exploring future effects of present management decisions, and the sensitivity of future outcomes to the uncertainty of present information. In the case of the management of individualized instruction, this requires the reliable prediction of, at least, the pace of individual student's progress. It may also require the prediction of their choice among alternative parts of a course.

This problem is similar to that of estimating unconstrained arrival or departure rates for transportation, communication, and other "service systems"; but the "queuing theory" developed to handle these, deals mostly with aggregates rather than individuals and generally assumes a Poisson distribution of arrivals.(20) Only recently have there been any successful attempts to deal with the (presumed random) behavior of individual human beings in situations at all similar to the operation of individualized instruction. These have involved computer simulation using a Monte Carlo technique where the underlying distribution has been derived empirically. Murray-Lasso and Akle generated their random numbers (for calls to a community information service) directly from the experimentally obtained histograms.(21) Brewerton, Gober, and Howe reduced their data to a series of triangular distributions (based on the best, worst, and most likely cases) and combined them in a simulation to predict physician manpower requirements.(22) Globerson and Nagarvala simulated the unexplained absenteeism of workers in industry by drawing from an empirically developed weekly probability profile and the conditional probability of absence an any day given an absence on the previous day.(23)

One instance in which the researchers were able to demonstrate close agreement between experimental data and a theoretically derived, closed form expression for the frequency distribution of events heavily influenced by human decisions, was in the case of traffic flow on a multiple-lane highway. The complexity of the distribution is worth noting. It involves three different processes described by the authors as relaxation, interaction, and adjustment. Morever, the expression used, includes a delta function, thus requiring statistical validation to be performed on the cumulative distribution of vehicle speeds. Finally, they report observing "the dominating effect of the 'adaptive' behavior of the drivers. This pattern of behavior illustrates the essential non-linearity of human behavior involving the continuous interplay between 'program' and 'realization'".(24)

V. A Concurrent Simulation.

In order to allow for the effects of student value structures and the vagaries of human decision making, it is proposed to use a participative simulation, run concurrently with an actual course, in which, both the course and the simulation can be modified by the decisions of the students as well as by those of the course manager and the instructors.

This paper reports the preliminary attempts to run what amounts to an interactive management information system concurrently with an individualized course, thus providing a means of directly modifying the operation of the simulation by the actions and decisions of the human participants. The computer program for this concurrent, participative simulation interacts with the students and instructors through a three-level decision process.

1. At entry: students select paths; equipment and instructors are assigned.

2. At each transition: time estimates are revised, students revise their paths, and resources are reassigned.

3. At each resource move: time estimates are revised and made known, and students again revise their paths.

Even this highly adaptive procedure requires the prior establishment of some rules governing its operation. For instance, the computer program assigns equipment and instructors in accordance with the following priorities, in order:

1. Student preferences.

2. Minimum waiting time totaled over all students.

3. Minimum non-utilization of the equipment and instructor resources.

This concurrent simulation operates simultaneously and in parallel with the real events being simulated. Information flows both ways between the simulation and the actual course or training activity. Events occuring in the actual course are used to modify the simulation to make it more realistic, information and predictions from the simulation are used by those managing or taking the course to modify their behavior in a presumably rational way.

VI. Operational Procedure.

At the beginning of the course, the manager gives the students either a flow chart showing the alternative choices available to them (for an example, see Fig. 1), or else a list of optional tasks and their point count or value toward the completion of the course. For each task or learning module in the flow chart, the student is also given a time estimate for completion obtained either from previous operation of the course or from the designer's best guess. The student is also given a "bottleneck measure" for each item which indicates the degree of difficulty he can expect in obtaining the required equipment, material, or personnel for completion of that module. Figure 2 indicates how queues may form for entry or exit from a learning module. Each student is then required to fill out and return a form within some reasonable time to indicate his particular path through the course flow chart, or the particular set of optional tasks he expects to perform, as well as the times at which he expects to complete each one. It is emphasized to him that he may at any time change his options and that the completion dates are in no way binding, but merely a set of self-imposed goals. Students failing to turn in the form are entered into the flow, nevertheless, in accordance with the second of the two priorities listed above: i.e., to minimize the waiting time of all students and maximize resource utilization.

The computer simulation is initialized with the same data provided to the students. This includes, besides the material mentioned above, those restrictions imposed by the association of certain equipment with certain learning modules and the assignment of specific instructors to monitor only certain modules. During the operation of the course the computer program may be modified by deleting or adding to any of this initial data, but the primary information periodically presented to it is an event or transition report. This may take four forms: (a) one student completes a test on one module; (b) one student uses one equipment for studying one module and joins the queue, if any, waiting to take the test; (c) one student joins the queue waiting for the equipment or material required to study one module. (d) one student begins using equipment to study one module. When the students have filled out their planning forms, this data is also provided to the simulation, and it is modified whenever students modify their plans. Throughout the course, output data is periodically (weekly, daily, or on demand) provided to the instructor and students by the computer simulation. This data normally consists of the following five items: (1) the expected waiting time for every possible queue based on all student plans and either past performance or the time estimate made by the course designer; (2) the progress of each student compared with the rest of the class, and with all past classes; (3) the likelihood of each student to finish, either by the arbitrary end of the course or by the time specified as his self-imposed goal; (4) the class progress as a whole in terms of the average number of modules completed so far and the expected time until completion for various percentages of the class; (5) the utilization rates of equipment and instructors, both their frequency of use and the length of time used. The final set of data from a course then provides the initialization data for the next time the same course is presented.

VII: Results of a Pilot Study.

A pilot project of this sort was run at the Catholic University of America in 1973. It used a "Kellerized" or self-paced one semester course in Behavioral Psychology, consisting of eleven modules and a project. All modules were required. Twenty students took the course. At the time each student felt competent to conclude a particular module, he/she was tested orally by an interview using prescribed questions. The student either passed (and progressed to the next module) or failed (and was required to restudy and try again). Five different methods of prediction were used in the simulation of the course.

Prediction Method (1)

Straight line extrapolation based on average time per module obtained by considering last event only.

Update by slipping predicted completion some percentage of the time since last event.

Prediction Method (2)

Establish student pattern based on average of "event ratios" defined as time since last event divided by number of modules completed this event, for each event. Update by adding largest multiple of this average less than elapsed time since last event.

Prediction Method (3)

Derive student behavior pattern by separate extrapolation of time between events and number of modules completed in an event. Update by selecting that aspect of student's past performance which best "explains" the delay.

Prediction Method (4)

Weighted average of student's performance so far with the performance required to complete the course "on time". Update by recalculating prediction based on "today" rather than last event day.

Prediction Method (5)

Step forward module by module using weighted average of student's past performance with performance of other students who have advanced further. Update by including any new information about other students' performance.

Figure 3 shows a summary of the analysis used to evaluate these five prediction methods used in the pilot study. Figure 4 shows how, for the more adaptive method five, the prediction accuracy rapidly improved during the first one third to one half of the course.

VIII. Future Plans.

The relatively unsophisticated statistical methods used were clearly inadequate, but the basic concept nevertheless shows considerable promise. Current efforts are being directed toward development and evaluation of a more adaptive prediction technique using unsupervised cluster analysis to categorize student behavior and provide a prior data base of archtypical pattern clusters. The concurrent simulation would then predict each student's future progress by successive conditional estimation through the following operations carried out at each time step:

1. Add the recorded progress (up to this simulated time) of the additional students to the data base and use it to adjust the relative probabilities for each pattern cluster.

2. Place each student whose progress is to be predicted into one of the hierarchical performance pattern clusters based on his past record thus far.

3. Use the stored histories of the other students which fall into that same pattern cluster to generate a histogram of the frequency of their levels of progress for each future time step.

4. Using the expected value of each histogram, predict the future progress of the student in question.

ONE REPRESENTATIVE EVENT IN THE FLOW CHART

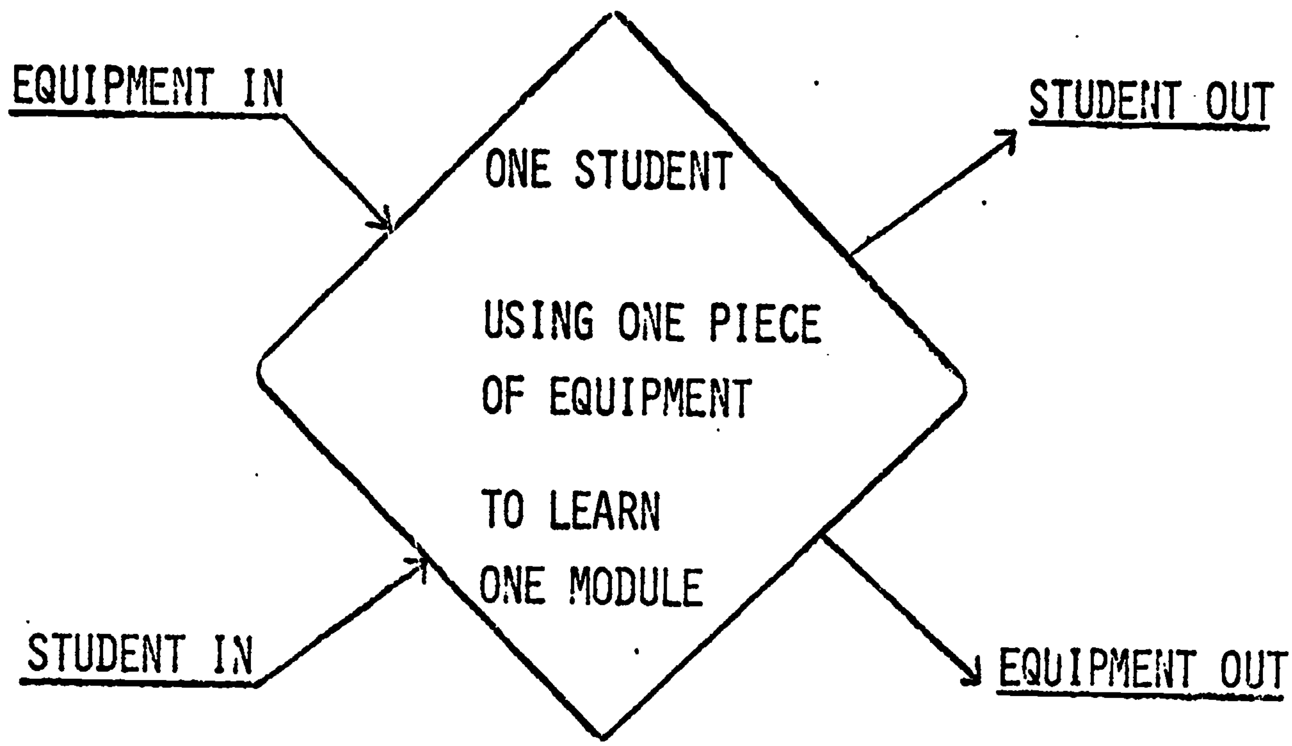

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FIGURE: 1

POSSIBLE BOTTLENECKS

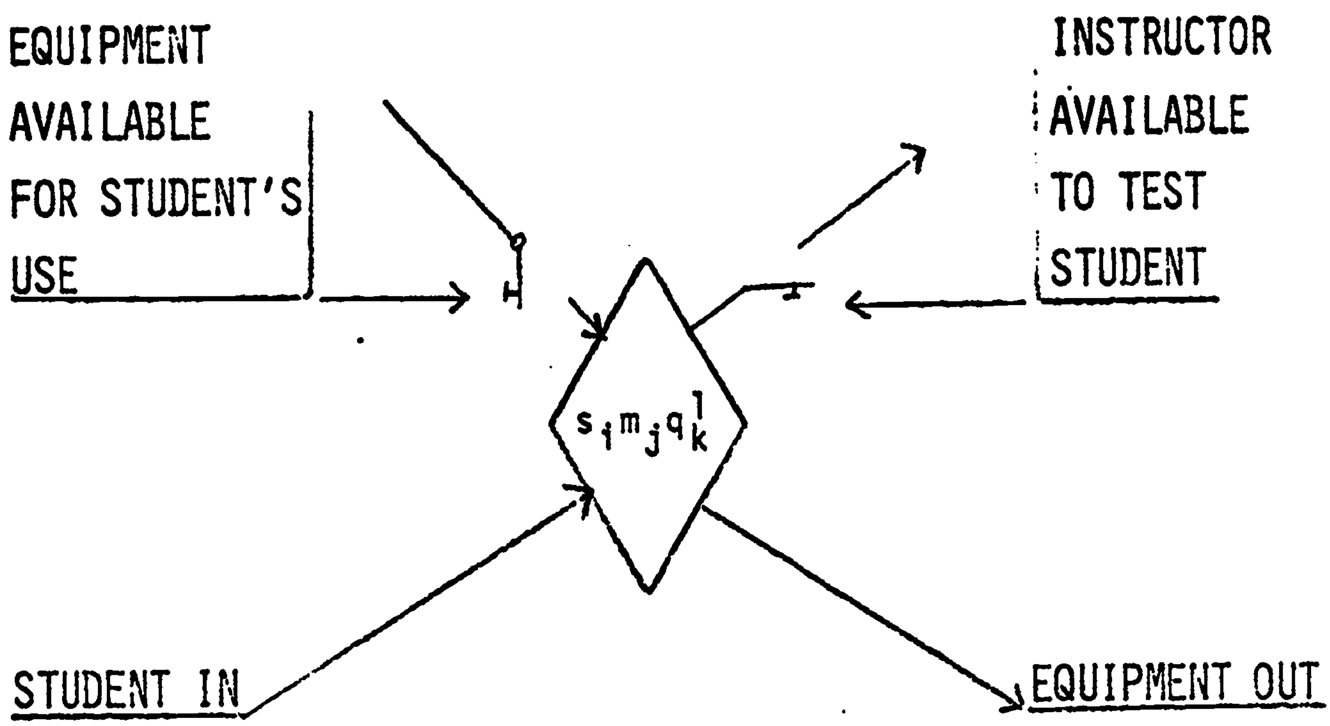

FIGURE: 2

PREDICTIONS OF WHEN 50% OF THE CLASS WOULD BE FINISHED

PREDICTION FROM DAY:	DAY PREDICTED:
15	250
20	220
25	138
30	110
45	99
60	94
75	92
90	99
105	116

(ACTUAL 50% COMPLETION DAY WAS THE 106'TH)

PREDICTION OF INCOMPLETES

METHOD	MISS RATE	FALSE ALARM RATE
1	.06	.37
2	.15	.37
3	.30	.20
4	.06	.30
5	.13	.18

RELATIVE PERCENTAGES OF OVER- & UNDER-ESTIMATING

METHOD	OVER	UNDER
1	90%	10%
2	88%	12%
3	45%	55%
4	98%	2%
5	54%	46%

AVERAGE ERRORS:	BY METHOD:
37.7	1
43.9	2
42.9	3
24.6	4
16.8	5

FIGURE 3. Evaluation of Prediction's from Pilot Study.

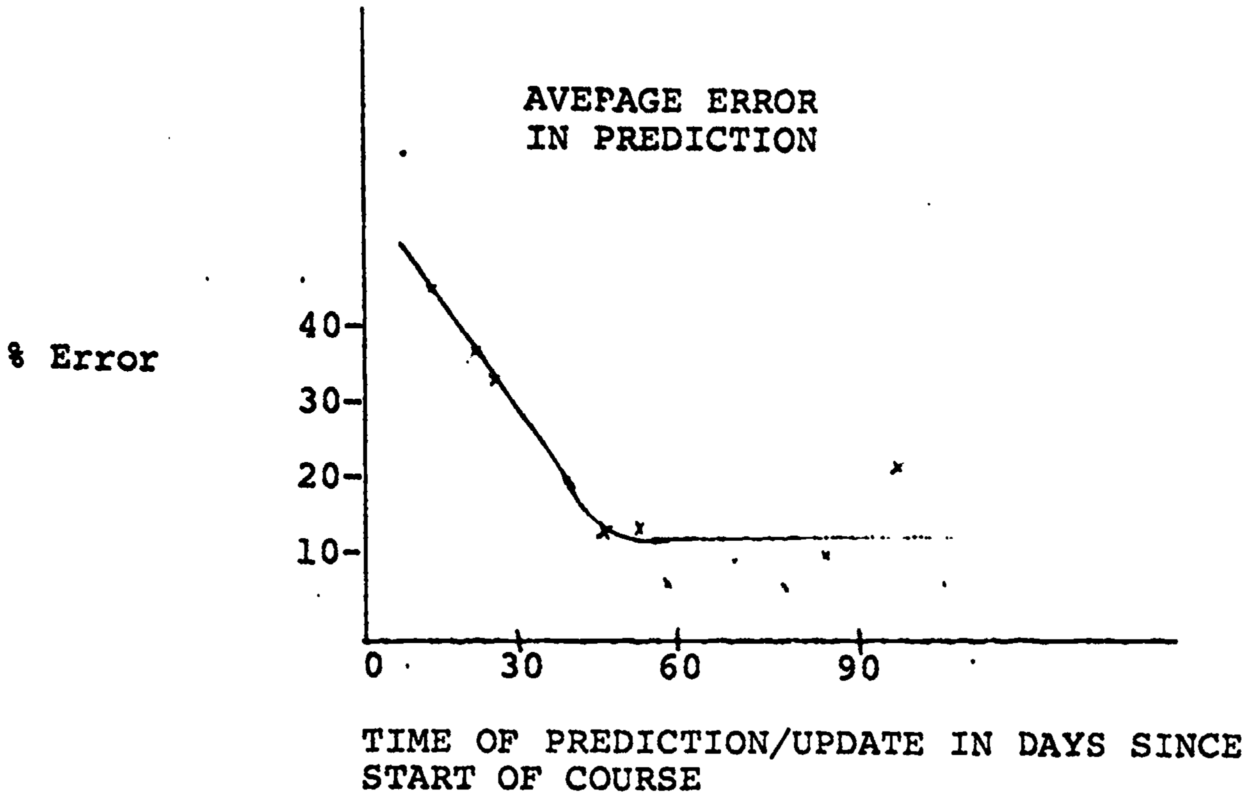

FIGURE 4: Error vs Time for Prediction Method Five.

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