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ABSTRACT

Queuing theory is examined in this paper in order to determine if the theory could be applied in educational settings. It is defined as a form of operations research that uses mathematical formulas and/or computer simulation to study wait and congestion in a system and, through the study of these visible phenomena, to discover malfunctions within the system that are otherwise transparent. Basic assumptions of the theory and structures and characteristics of queuing systems are outlined, and areas of application other than education are listed. The literature dealing with time-on-task, teacher burnout, student grouping, and classroom discipline is reviewed to demonstrate that queues are prevalent in educational systems. The methods used in the systematic study of queues--mathematical analysis and computer simulation--are also discussed. The following conclusions are drawn: (1) the basic assumptions of queuing theory can be met in educational systems; (2) education experiences the types of problems typically analyzed through the theory; (3) wait and congestion exist in education and contribute to other more serious problems in the field; and (4) the tools and techniques of queuing analysis are appropriate for educational research. Areas for further research are suggested, and 23 references are listed. (MES)

Queueing Theory: An Alternative Approach To Educational Research

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Running head: QUEUEING THEORY

Abstract

Queueing theory is used to study wait and congestion within a system and, through the study of these visible phenomena, to discover malfunctions within the system that are otherwise transparent. After reviewing the theory and its application in areas other than education, a cursory review of the litearture dealing with time-on-task, teacher burnout, student grouping, and classroom discipline was used to demonstrate that queues are prevelant in educational systems. It was concluded that queueing theory could be a viable tool of inquiry for the educational researcher.

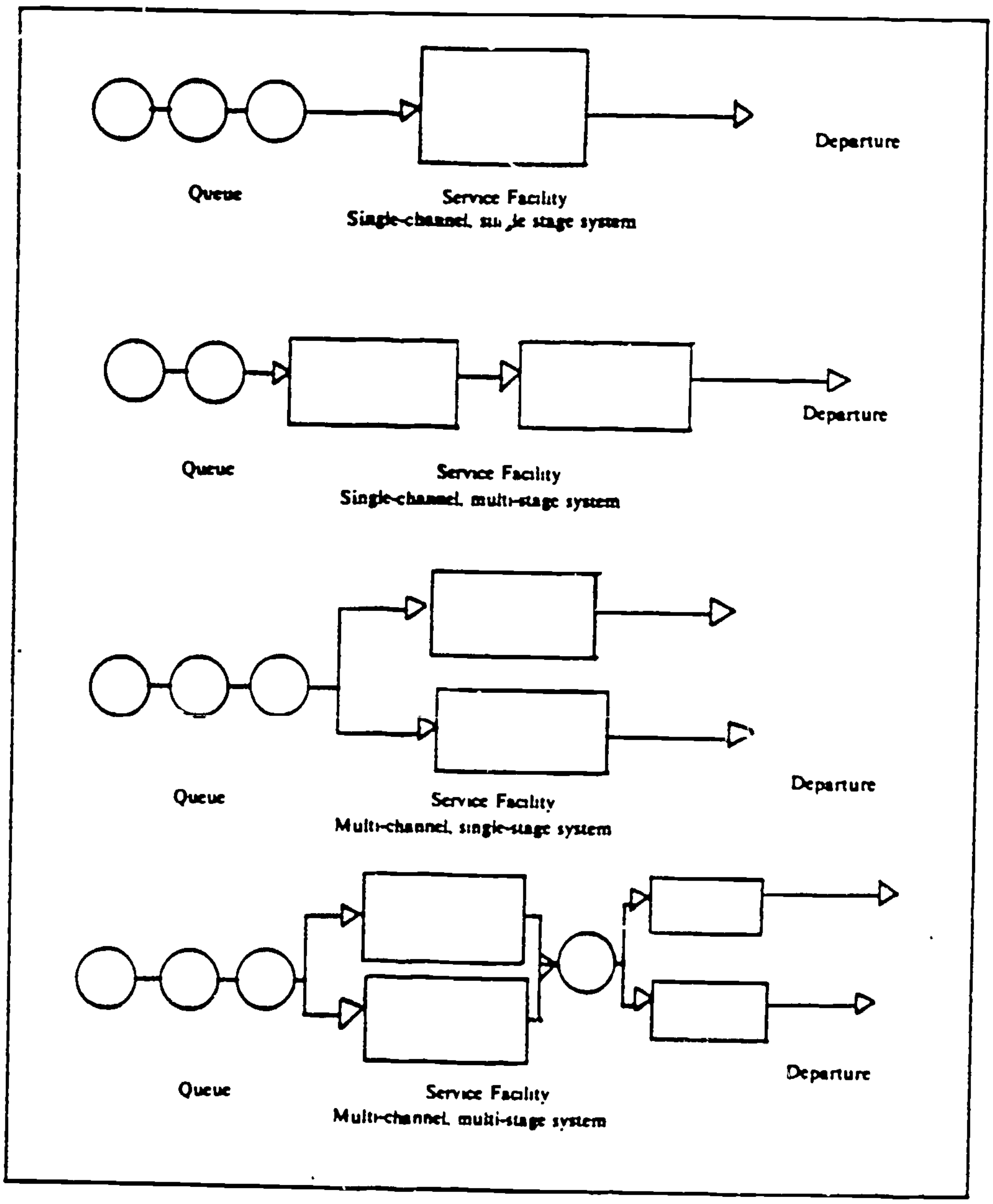
Queueing theory is a form of operations research that uses mathematical formulas and/or computer simulation to study wait and congestion within a system. The purpose of the theory is to study the queues that result from such congestion and, through the study of these visible phenomena, discover malfunctions within the system that are transparent to the decision maker. Although queueing theory was originally applied to telephone trafficking problems, today it is being adopted by many different fields and adapted to their needs. Queueing theory has been proven to be effective in almost all areas of business and formal courses on the subject are being taught in most Colleges of Business. Computer science and industrial engineering apply queueing theory daily and case studies have been conducted in music, library science, social psychology, and in the health fields (Giffin, 1978; Gross & Harris, 1974; Murdoch, 1978; Newell, 1971; Panico, 1969 and Saaty, 1961).

Although many of the problems that have been analyzed through the use of the theory are analogous to problems in education, the field of education is conspicuous by its absence from the list of applications. In addition, most educational systems are so complicated that in-depth understanding of how they operate can only be accomplished through formal system analysis procedures such as queueing theory.

The purpose of this study, therefore, was to examine queueing theory to determine if the theory could be applied in an educational setting. It was determined at the onset of the study that the theory would be untenable in education if: (1) the basic assumptions of the theory can not be met in an educational setting; (2) the theory is designed to analyze a particular class of queues and these queues are non-existent in education; (3) queueing problems in education are so insignificant as to warrant no formal investigation; or (4) the tools and techniques used in the theory are inappropriate for educational research.

Significance of the Study

This study should be of special interest to the educational technologist who seeks to find solutions to practical problems and thereby improve the practice of education because "anyone who hopes to improve an organization needs first to understand it, and understanding is the chief legacy of inquiry (Willower, 1977 p. 79). Therefore, the significance of the study lies not in the mere creation of a model or the testing of a theory, but rather in the prospect that a new tool of inquiry, queueing theory, may be introduced to the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educational community. For, as noted by Getzel, (1977) "new instruments and techniques of observation and analysis play a role not only in the solving of problems but also in raising questions which might otherwise never have been thought of" (p. 18). As new questions are raised, and the answers to the questions are sought, new insight into, and an understanding of, the problems will be gained.

Introduction to Queueing Theory

Queueing theory is used to study wait and congestion within a system. Wait occurs whenever a unit must wait for service and if more than one unit is forced to wait congestion results. The problem of congestion increases proportionally with the randomness of arrivals and the variation of service times. The queues that result from this congestion are often symptomatic of other, more severe, system problems including problems with staffing, scheduling, and/or material allocation.

Queueing Structures

The basic structure of a queueing system is defined in terms of the number of service channels and the number of service stages. Although queueing diagrams almost always depict queues in a linear fashion, it is not necessary that the units "line-up" for service. Anytime a unit is waiting for service, it is in a queue. Figure 1 presents the four most common queueing structures.

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insert figure 1 about here

The first structure in Figure 1 (single-channel, single stage), is the simplest of all queueing systems. In such a system, there is only one server and consequently only one line is formed. The second structure (single-channel, multi-stage) is one in which there is only one line, but the unit must pass through several stages before service is complete. In the next queueing structure (multi-channel, single-stage), there are several lines but the unit must pass through only one stage. The final diagram represents a system in which there is more than one stage and there are several servers at each stage (multi-channel, multi-stage).

Characteristics of Queueing Systems

According to queueing theory, there are six major components of a queueing system that may determine the way in which a queue is formed:

1. Arrival_pattern: average number of arrivals per unit of time (e.g., the average number of students that need the teacher's individual attention during one class period).

2. Service_pattern: average time required to service a unit (e.g., the average amount of time it takes to complete an instructional packet).

3. Queue_discipline: manner by which units are selected for service;

FIFO -- first in, first out
LIFO -- last in, first out
SIRO -- service in random order
PRIO -- service by priority

4. Number_of_service_channels: number of parallel service stations that can service units simultaneously (e.g., number of IBM computers in an instructional lab).

5. Number_of_service_stages: number of stages a unit must proceed through before the service procedure is completed (e.g., checking in with lab attendant, doing work at computer, checking out with lab attendant).

6. System_capacity: The number of units allowed in the system at any one time (e.g., number of students allowed to enroll in a graduate class).

Basic_Assumptions_of_the_Theory

Queueing theory can only be applied to systems in which the following assumptions are met:

1. both arrival rates and/or service rates involve a degree of uncertainty or randomness - if this were not true, each event could be scheduled to the exact moment and there would never be a queue;
2. average service rate is greater than average arrival rate - if this assumption is not met, then there would always be a queue;
3. the probability distribution of both arrival and service rates can be determined.

These assumptions can be met in instructional settings. Assumptions one and two can be proven by simple observational data. For instence, it is easily observable that students complete assignments at varying rates and even the best of instructors cannot predict with 100% accuracy the exact moment when the students will complete their assignment. Observational data will also support assumption number two. For example, if the server is a learning lab and that lab is idle at least some portion of the day, then assumption two has been met. Assumption three is not as easily verifiable because the appropriate database currently does not exist in education. It is, however, reasonable to assume that such data can be collected because much of the current work being done in educational research is based on similar statistical data.

Application of Queueing Theory

Table 1 displays the number of queueing theory application abstracts that were published by OR/MS from January, 1961 through January, 1985. OR/MS is a publication of Executive Science, Inc. which each month abstracts articles that have appeared in current publications.

Insert Table 1 about here

Table 2 presents an array of the type of system problems that have been studied through the use of queueing theory and provides examples of corresponding problems in educational systems. The table is in no way comprehensive but is intended to portray the wide variety of problems that can be studied through the use of the theory.

Insert Table 2 about here

Educational Issues

None of the 214 studies presented in Table 1 addressed an educational problem and a search of the ERIC database failed to uncover any queueing studies that were conducted in education. However, many of the problems that have been addressed through the use of the theory (Table 2) are analogous to problems in education. Is it possible that queueing problems in education ar so insignificant as to warrant no formal analysis? In order to answer this question, current educational issues were examined to determine if some of the recursive problems in the field can be defined more precisely through the use of queueing analysis.

Time-on-Task

Over the last several decades, researchers increasingly have directed their attention toward the use of time in education. (For a review of this literature see for example, Anderson, 1984; Karweit, 1983; Walberg & Frederick, 1983; Wiley & Harnischfeger, 1974). From

Area of Study	1961-65	1966-70	1971-75	1976-80	1981-85	TOTALS
Inventory Management	7	1	2		1	11
Personnel Selection	1	1				2
Quality Control		1	1			2
Production Scheduling	12	6	5	4	2	29
Plant Layout	1	1				2
Procurement of Raw Materials	1		1			2
Maintenance	1	2	3	5	5	16
Service Trades				1	1	2
Government Service			2	4	4	10
Office Management	1	4	2	3	4	14
Transportation	17	10	21	6	2	56
Communication	5	3	1	3	2	14
Facilities Replacement	2					2
Public Health	4	1	3	8	6	22
Research and Development	1		1	1		3
Manufacturing	3					3
Materials Handling	1	4				5
Miscellaneous	10	3		5	1	19
TOTALS	67	37	42	40	28	214

Table 1: Number of Abstracts Published on Queueing Theory Application in OR/MS -1/61 to 1/85

Author	Purpose of Study	Analogous Problems in Education
S unty & Hare (1960)	to compute to number of spare parts to keep on hand at each field station	computing the number of consumable books needed in an individualized lab
Maxwell (1965)	to study problems of best inventory size and the best production sequence	determining the number of learning stations needed and the best sequence of learning stations
Nelson (1967)	to study production systems that are constrained by limited labor resources and limited machine resources	individualizing a program that is constrained by a limited number of learning resources
King (1970)	to determine the optimum crew size required to reduce wait-time	determining the optimum number of aids or volunteer tutors needed to reduce student wait-time
Graff (1971)	to apply queueing theory in the decision for investment in additional resources	determining the need for investing in additional Audio/visual equipment
Gaver Strinvansan (1972)	to optimize corporate research and capabilities in the production of new products	optimizing formative evaluation and development capabilities in the production of new products
Leigh (1974)	to explore relationships between available resources and workloads	exploring relationships between number of free computers in a lab and the workload of the students

Table 2: Summary of Queueing Theory Applications

Author	Purpose of Study	Analogous Problems in Education
Rosseau & LaPorte (1977)	to minimize the patients' total queueing time at an outpatient clinic where patients require a variety of services	minimizing students' time off-task that is caused by wait-time
Styles & Cox (1977)	to assist management in attaining a balance between different activities in pharmaceutical research	attaining a balance between different instructional design and development activities
Gross & Pinkus (1979)	to design a support system for items	developing a support system for repairable AV equipment using outside resources
Albright (1980)	to describe optimal control of operation and repair of a fleet	obtaining control of operation and repair of AV equipment
Ament (1980)	to classify customers and tellers according to degree of difficulty in transactions and set up two queues accordingly	classifying students by the type of problems and the amount of time they require for help
Elsayed (1981)	to compare two repair policies, one with priority for a particular mode of failure and the other without	comparing different types of help sessions in which students with certain kinds of problems receive priority in obtaining help
Scott & Hailey (1981)	to study the utilization of cardiac telemetry units in a hospital; to analyze the costs and benefits of adding units	utilizing resources in a learning lab and determining when new units should be added

Table 2a: Summary of Queueing Theory Applications

Carroll's Model of School Learning (1963), to the Beginning Teacher Evaluation Study (BTES) work done in the mid-1970's, and on through the effective school research of today, it has been shown repeatedly that there is a positive relationship between time-on-task and learning. One of the major findings from the tim -on-task research was that a surprisingly large amount of time during the school day is spent in non-instructional activities. Rossmiller (1983) has calculated the amount of time that the average student spends on task during a school year of 1080 hours to be approximately 364 hours. Burns (1984) found that, on the average, only 75% of the elementary school day is actually spent in the classroom and 37% of that time is spent on non-instructional activities. Karweit and Slavin (1981) have observed that:

> To increase achievement from a score of 3.4 grade equivalent to 3.8 would require a daily increase of 13 minutes of active learning time. This increase, from 37 to 50 minutes, would require either a sizeable increase in scheduled time or tremendous improvements in classroom efficiency....realizing significant gains in learning time would have to come from recovering lost minutes due to interruptions, waiting, and classroom transitions. (p. 171)

Previous time-on-task studies have focused on such variables as day length, the amount of time that is allocated to each subject, how time is actually spent in the classroom, and how much time students spend on-task (Stallings, 1980). These studies have been successful in showing a relationship between time and learning, but they have shed little light on how to improve educational practice. The researchers have been able to identify some of the ways that non-instructional time is used. Among these are time that is spent in: waiting for help from the instructor; making a transition from one activity to another; and, acquiring and returning instructional materials. Such activities usurp as much as 25% of the instructional time (Thurlow, Graden, Ysseldyke & Algozzine, 1984; Anderson, 1984; Karweit, 1984).

Waiting for help is, by definition, a queueing problem and queueing theory certainly can provide the structured, systematic approach that is needed. In addition, by examining studies that have been done outside of the field of education, it can be seen that queueing theory can likewise be employed to analyze wait and congestion problems that result from transitions from one activity to another or from the acquisition of materials. The solutions to such problems may well rest in alternative approaches to resource allocation, staffing, scheduling, and/or instructional methods and queueing theory can provide valuable insight into the study of these alternative approaches.

Student Grouping Patterns

It is possible that the amount of time that students in a particular classroom spend in waiting or in transistion from one activity to another is influenced by the characteristics of the individuals within the class. Everston (1982), in comparing classrooms composed of high-ability students with those composed of lower-ability students, found that the lower-ability classes required a great deal more individualized help from the teacher than did the higher-ability group. According to Everston, "multiple individual demands for help from the teacher meant that more students had to wait a considerable time before getting help" (p. 342). While the students were waiting for that help, they were essentially placed in a queue.

Beckerman and Good (1981) conducted a similar study that compared favorable classrooms (less than 1/3 of students were lower-ability students) with unfavorable classrooms (more than 1/3 of the students were lower-ability). They found that "teachers in a more favorable classroom have more time to provide individual help to low-ability students, because there are fewer demands on teachers" (p. 324). At the same time, Everston, Sanford and Emmer (1981) found that students in extremely heterogeneous classes spent more time off task than students in other classroom organizational patterns.

Although these findings are not surprising, they do reinforce the idea that the way children are grouped in a classroom affects the amount of the time that individual children spend waiting for help and this in turn could affect their level of academic achievement. Unfortunately, little research has been done on how student grouping affects such outcomes (Beckerman and Good, 1981). Queueing theory can be used to compare how different classroom organizational patterns influence the amount of time that a student will spend waiting.

Teacher Burn Out

The literature on teacher burnout often focuses on helping the teacher cope with stressors that exist within the educational setting (Bardo, 1979; Hendrickson, 1979; Kyriacoua & Sutcliffe, 1979). The most frequently mentioned solutions for burnout are concerned with helping teachers deal with their own emotions, rather than being concerned with the elimination of the source of the problem. McNeely (1983) has noted that the literature on burnout "often treats as a constant the organizational environment within which the burned out are employed. In short, remedies consistent with this level of conceptualization obviously favor attention on the individual as the agent of personal change" (p. 84). The same literature that emphasizes coping strategies also identifies lack of time to grade papers, lack of time for individual student needs, and lack of adequate books, materials and equipment as being the major causes of stress in the teaching profession (Cook & Leffingwell, 1982; Needle, Griffin, Svendsen, & Berney, 1980; Weiskopf, 1980). Each of these stress causes results in queues forming - queues of papers waiting to be graded and queues of students waiting for books, materials and/or equipment. Given the current database, it is difficult, if not impossible, to determine if the shortage of teacher time is due to poor organization or due to over-utilization of the teacher as a resource and yet it is necessary to identify the source of the problem before viable solutions can be found. Queueing theory certainly can help in this process because the theory is used to analyze both resource utilization and queueing problems that result from poor system organization.

Classroom Discipline

There are many causes of discipline problems within a classroom but student wait-time is one of the leading contributors to the problem (Doyle, 1985; Everston, 1982; Kounin, 1970). Wait-time often results in behavioral problems as described by Everston (1982):

> At one point, five students were at the teacher's desk, and most of them were waiting for help ... Having so many students in such close proximity to each other frequently created problems and led to the misbehavior. (p. 349)

The phrase "waiting for help" indicates that a queue has formed and strongly suggests that the situation would be especially amenable to queueing analysis. The diminution of discipline problems is especially important in light of the findings from the time-on-task research for as Seifert and Beck (1984) have noted:

> Each incident of discipline reduces the number of minutes of engaged learning time from two to four minutes, depending upon the seriousness of the discipline problem. Each time the teacher stops the

engaged learning process to discipline a student the entire class is placed in an off-task mode. (p. 30)

Summary of Educational Issues

Many currrent educational problems that have been identified in the literature do contain queueing elements and four of the more general educational issues were chosen for examination in this paper. In each of the four cases it was shown that traditional research methods have added to the educational knowledge base but have done little to suggest how the practitioner can implement the findings. The research methods that were used in many of the studies were designed to aid in conclusion-oriented research, not in decision-oriented research. In addition, each study was designed to examine only one aspect of the system. Through the use of queueing theory, it is possible to examine several areas simultaneously. For instance, the phenomenon of discipline, or misbehavior, manifests itself in all four areas that were examined, but it manifests itself in different ways. In the area of time-on-task, discipline problems can detract from the total engagement time of the entire class and thus reduce the time-on-task. At the same time, students vary in the amount of individual help they require from the teacher and because of this, the ratio of high-ability students to low-ability students will affect the amount of time that students must wait for help. Wait-time in turn is directly proportional to the number of discipline problems and the more discipline problems, the more time the students will spend-off task. In addition, excessive discipline problems can, and do, add to teacher stress and hence indirectly to teacher burnout.

The intertwining that is apparent between each of these areas can be traced to elements of wait or congestion within the syst . Because all educational systems are complex systems, such intertwining and interrelatedness are not surprising. Changes that ameliorate malfunctions in one area of the system often will result in undesirable changes in other areas of the system. A research method that is versatile enough to examine each component independently or to examine all the components simultaneously could add valuable insight into the functioning of the system and could aid in system related decision-making. Queueing theory is just such a method.

Tools and Techniques

The properties that are common to all queues were outlined earlier and even though the identification of the properties is an important first step in the understanding of a queuing problem, a more in-depth understanding can only result from a systematic examination of the queue. The two methods that are used in the systematic study of queues are mathematical analysis and computer simulation. Both methods involve the construction of queueing models - models that are designed to replicate both the system and the interaction of the major components within the system. The use of models: (1) facilitates the description and comprehension of a system; (2) reveals hidden relationships between various components of the system; (3) helps to determine the kinds of data that need to be collected; (4) allows the system to be viewed in its entirety by examining all of the variables simultaneously; and (5) makes it possible to enlarge the system of interest in a step-wise fashion (Vazsonyi, 1963).

One of the major advantages of using models is that they allow the decision maker to experiment on a replica of the system rather than on the system itself. This is especially important in education where: (1) the manipulation of the variables to be studied may prove to be disruptive to the system; (2) it is often difficult to deal with all of the possible alternative solutions in one experiment; and, (3) it is often difficult to isolate the effect of one variable from the effects of other variables.

Mathematical Models

Mathematical, or analytical, models use mathematical formulas and equations to show the relationships among various elements in the system. In a queueing model, the parameters are defined in terms of average arrival rate and average service rate or in terms of average time between arrivals and average service time. The variables include queue length, time spent in the queue, and server utilization. The constants can include such things as the number of parallel servers and/or the number of service stages.

The selection of the proper mathematical formulas to be used in the solution of an analytical model is based on the characteristics of the queueing system. Figure 2 gives the formulas for the simplest of all queues - queues with only one channel and with little fluctuation in either service or arrival patterns.

Figure 2: Queueing Formulas (Adapted from Tersine, 1978)

		$\lambda/M/1$	$\lambda/M/5$
Mean arrival rate		λ	λ
Mean interarrival time		$1/\lambda$	$1/\lambda$
Mean service rate		μ	$M\mu$
Mean service time		$1/\mu$	$1/M\mu$
Expected number in system	(L)	$\frac{p}{1-p}$	$\frac{\lambda}{\mu} + \frac{(\frac{\lambda}{\mu})^M \lambda\mu Po}{(M-1)!\ (\mu M-\lambda)^2}$
Expected number in cueue	(-0)	$\frac{p^2}{1-p}$	$\frac{(\frac{\lambda}{\mu})^M \lambda\mu Po}{(M-1)!\ (\mu M-\lambda)^2}$
Mean time in system	(W)	$\frac{L}{\lambda}$	$\frac{1}{\mu} + \frac{(\frac{\lambda}{\mu})^M \mu Po}{(M-1)!\ (\mu M-\lambda)^2}$
Mean time in cueue	(wo)	$\frac{Lo}{\lambda}$	$\frac{\lambda^2}{\mu(\mu-\lambda)}$
Server utilization	p	λ/μ	$\lambda/M\mu$
Probability of cueue	P_o	p^2	
Probability of no units in system	P_o	$1-o$	$\frac{1}{\sum_{n=0}^{M-1} \frac{1}{n!}(\frac{\lambda}{\mu})^n + (\frac{\lambda}{\mu})^M \frac{1}{M!\ (1-p_m)}}$

insert_Figure_2_about_here

The purpose of the hypothetical problem that follows is to show how queueing theory might be used in the investigation of one fairly common educational problem.

Educational Example: A study conducted by a local school district revealed that the district owned more educational films per student than did any other district within the state. At the same time, teachers within the district used proportionally fewer films than did teachers in the surrounding districts. An analysis of the situation revealed that six teachers shared in the use of one projector, that it was used on the average of 12 times a week, and that it was often unavailable when teachers wanted to use it. The teachers picked up the projector at the beginning of a period and returned it during their break which meant that the teachers would hold the machine for an average of two hours. It takes 30 minutes, on the average, to show a film and the machine remains idle for the remaining 1 1/2 hours.

Following the preliminary analysis, two alternative solutions to the problem were suggested. The curriculum council recommended the purchase of six additional projectors. The media director, whose budget would be affected most directly by the purchase, suggested that, in lieu of buying new machines, the school could use a student to deliver the machines to the classroom when needed and to retrieve them after each viewing session. Everyone agreed that this would be the less expensive of the two alternatives, not everyone agreed that the teachers' needs would be met by such a solution.

A queueing analysis would begin by examining each of the alternatives and extracting the pertinent data about each as shown in the chart below.

	Plan_1 Status Quo	Plan_2 With Additional Machines	Plan_3 With Student Attendant
Number of teachers	6	3	6
Number of films shown	12	6	12
Length of film	30	30	30
Number of minutes machine held	120	120	

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After the data have been extracted, a mathematical model of each of the plans would be designed. Data from Plan I will be used to demonstrate how the analyst would compute the basic queueing statistics that would be used to compare the alternatives.

The average arrival rate is 12 - the average number of films shown in a one-week period. Although it takes only 30 minutes to show a film, it is necessary to model the entire time the teacher retains the projector - 120 minutes. Because the school week is 30 hours long (5 days x 6 hours), the service rate is equal to 15 units per week. Based on this information, all other queueing statistics for Plan I are calculated as follows:

p = Percent of time the projectors are busy
= 12/15 = .80 utilization rate

P_q = Probability that teachers are waiting
= $.80^2$ = .64

L_q = Expected number of teachers waiting
= .64/.20 = 3.2 teachers waiting

W_q = Average time a teacher must wait before receiving a projector
= 3.2/12 = .266 x 30 hours = 7.98 hours

P_0 = Probability of no waiting
= 1-.80 = .20

Similar calculations were performed for each of the alternative approaches and the resulting statistics are presented below.

			p	L_q	P_0	W_q
Plan 1	12	15	0.8	3.2	0.2	0.266 (7.98 hrs)
Plan 2	6	15	0.4	0.266	0.6	0.044 (1.32 hrs)
Plan 3	12	30	0.4	0.266	0.6	0.022 (0.66 hrs)

An examination of these data from the queueing analysis reveals that plans 2 and 3 are almost identical and that both plans are superior to the status quo. Surprisingly, plans 2 and 3 vary in only one area -- expected wait-time. The amount of time a teacher can expect to wait for a projector is twice as long in plan 2 than in plan 3 and this demonstrates the complexity of queueing situations. The service rate is accountable for this difference and because this rate is used to calculate several of the intervening statistics, it has a compounding effect on both the formation of the queue and upon the corresponding amount of time spent in waiting.

Although this situation is hypothetical, it is not an uncommon one in education. In many cases where similar decisions must be made, the decisions are based on purely financial considerations or on the power base of the groups presenting the alternatives. An immediate benefit that derives from a queueing analysis is that the frame of reference for the decision maker can be shifted from a subjective one of "I think" or "I feel" to a much more objective one of "I can show" or "I can demonstrate".

Computer Simulation

Because of the complexity of many queueing systems, mathematical formulas often become unwieldy for all but the most sophisticated of mathematicians. As the number of interactions increases, the task of analyzing the effects of the interactions becomes more and more formidable and computer simulation becomes an indispensable tool.

Blake (1979) defines simulation as "the establishment of a mathematical-logical model of a system and the experimental manipulation of that model on a digital computer" (p. 3). Because simulation combines a logical model with a mathematical model, it tempers many of the constraints that are inherent in mathematical analysis and allows for more freedom in the construction of system models (Gordon, 1969). This easing of constraints makes it possible to study systems that were intractable with the use of mathematical analysis.

Model Formulation: In a computer simulation, a queueing system is defined in terms of entities, attributes, sets, and activities. Entities are the objects of interest within the system. The entities are used to model the progression of units through the system. Each entity has a number of characteristics that may or may not be unique to that entity. These characteristics, or attributes, guide a unit through the system. The attributes that an entity possesses are determined by the modeler and may include such characteristics as: the time that the entity entered the system; the type of service it is to receive; and the sequence in which it is to receive the service. A set is a group of entities that share the same attributes. It is not necessary, however, that the attributes for each member of the set contain the same value. For instance, one member of the set may enter the system at 1:10 and the next member enter the system at 1:29. Both members contain the attribute "time system was entered", but the value of the attribute is different for each one. Activities include all of the processes, or service stages, through which an entity must pass before leaving the system.

<u>Data Preparation</u>: There are basically three kinds of data that can be used in computer simulations: (1) real data, obtained from a total population; (.) sampling data that are obtained from a representational sample of the population; or (3) theoretical data, a combination of sampling-data and computer generated data.

<u>Programming Languages</u>: Although simulations can be run using general-purpose languages, the time required for program preparation generally can be reduced by using a special-purpose simulation language. Typically, such languages include: (1) a routine that schedules the events in simulated time; (2) random number generators; (3) routines that control the probability generator; (4) automatic calculation of statistical data; and (5) flexible report generators. (Davis & McKeown, 1984).

Access to a simulation language should pose no problem to the educational researcher. There are several languages that can be run on the more powerful microcomputers and most major universities have at least one mainframe version of a simulation language.

<u>Conclusion and Recommendations for Future Research</u>

As a result of this study it was found that: (1) the basic assumptions of queueing theory can be met in educational systems; (2) education does experience the types of problems that are typically analyzed through the use of the theory; (3) wait and congestion problems do exist in education and they contribute to other, more serious problems in the field; and, (4) the tools and techniques, including mathematical analysis and computer simulation, are appropriate for educational research.

Both the literature on queueing theory and the literature on educational issues suggests that there are an unlimited number of queueing problems in a service industry as large as the educational system. In addition, <u>every</u> educator with whom the author discussed the theory was able to identify queues within their own system. This leads to the conclusion that there is an unlimited number of educational areas that can benefit from queueing analysis. Listed below are examples of some specific areas that would lend themselves to queueing analysis:

... exploring relationships between the number of free computers in a lab and the workload of students;

... attaining a balance between different instructional design and development activities;

... optimizing formative evaluation and development capabilities in the production of new products;
... determining the need for investing in additional audio/visual equipment;
... determining the optimum number of volunteer tutors needed to reduce student wait-time;
... individualizing a program that is constrained by a limited number of learning resources;
... determining the number of learning stations needed and the best sequence of learning stations;
... computing the number of books resources needed in an individualized lab.

Before the theory can be applied, however, it must be tested in actual educational environments to determine if there is some hidden reason why the theory will not work. Naturalistic studies should be undertaken to add to the educator's basic understanding of where lines and bottlenecks actually occur. Techniques must be developed that will aid in the accurate collection of data. Only after the theory has been proven to be effective can it be used as a decision-oriented research tool in education. At every stage of theory adoption and adaption, a concerted effort should be made to see that queueing theory studies are published in leading educational journals. Even if the studies are site-specific, undertaken solely for the purpose of answering specific questions about specific systems, the findings must be published if the field of education is to make the most efficacious use of the theory.

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