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13. ABSTRACT (Maximum 200 words) Large and complex organizations, in general, face the same continuous challenge of allocating common shared resources efficiently and effectively. The allocation problem is complicated when these shared resources are scarce and rationing becomes necessary. This project proposes to test experimentally rationing mechanisms that can be constructed by using the serial cost sharing rule. Such rationing protocol will be compared with more common alternative rules, such as priority protocols as FiFO (First in, first out) and FiLO (First in, last out), which are based on average cost sharing. A natural comparison is in terms of total number of agents served or in terms of welfare performance and distributive consequences of each rule (such as failure rate, or surplus collected).			
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## FINAL TECHNICAL REPORT

GRANT #: N00014-00-10769

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INSTITUTION: University of Mississippi

GRANT TITLE: An Experimental Study of Rationing Mechanisms

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OBJECTIVE: In this project we propose to analyze possible rules to ration a service or a shared resource, and to allocate its costs among the users. Some cost sharing rules, such as the Serial Rule or the Average Cost Mechanism, must be evaluated experimentally to verify if they are implementable. Rationing mechanisms, or queuing protocols as FiFO or FiLO based on these two cost sharing rules need also to be considered. None of these mechanisms have been validated experimentally. Comparisons of all these mechanisms in terms of welfare and fairness will be performed.

APPROACH: In this study we have combined economic theory with experimental economics. Contributions to the theory have been to generalize probabilistic rationing mechanisms. We have then brought subjects into the laboratory to study their response to these and other rationing rules. The subjects' choices and decisions have been compared with predictions from the theoretical models.

ACCOMPLISHMENTS (throughout award period): We have used all of the PI's previous work on cost sharing to deal with the issue of rationing. Whenever demand exceeds supply and we have to ration the demanders of a service, the subjects will face a specific cost; that is, they will have to wait. Such a cost for waiting will have to be divided among the users of the service. All our previous studies of cost sharing mechanisms will be applicable at this point. For example, if the total waiting cost is divided among the demanders proportionately to the size of their demand, that is we are using the *average cost sharing mechanism*, this is equivalent to dividing the total waiting time among the demanders in proportion to the size of their demand. A typical problem of the AC rule is that it tends to favor high demanders and, therefore, it could induce over demand. Alternatively, we could divide the total waiting cost according to the *serial cost sharing mechanism*. This rule induces truthful revelation of needs and it is fair. Our previous studies, funded by ONR and NSF grants, have proven that this rule is implementable. Finally, making every unit wait the amount of time by which each incrementally increases the total waiting time in the queue corresponds to using the *marginal cost pricing mechanism*. The latter induces an allocation of the shared resources which leads to the highest net utility level.

In a first treatment we have run several experiments in which subjects were asked to choose strategically output demand, given that the cost was allocated according to one of the three cost sharing rules. The experimental design is such that each subject is called to share the good with (or plays against) three computerized players. The subjects were told that the computerized players always play the dominant strategy choice: i.e., always choose the quantity that earns the highest possible return. About ninety subjects participated in the experiments. This was a very

controlled environment. The fact that each human subject played against three computerized players made the experimental design relatively easy. In each of the 30 periods, the players, both computerized and human, were assigned a different preference parameter value. We considered two different sets of possible values for the preference parameter to test the sensitivity of the cost sharing rules with respect to subjects demanding small versus large quantities.

The following results can be stated:

- 1) The preference parameters drawn from the Second Set of Values lead, in general, to the choice of higher Nash equilibrium quantities. If values are drawn from the Second Set, the overall performance of all the cost sharing rules is decreased.
- 2) Comparing the behavior of inexperienced and experienced subjects, we see that in general their choices did not converge to the dominant strategy choice immediately. Even though the game induced by the serial cost sharing rule is dominance solvable, the players took several iterations of the game to converge to dominant strategy.
- 3) The serial cost sharing rule performed relatively better than the other two cost sharing rules, both in terms of efficiency and of equilibrium play.

In a second treatment, we have designed an experiment to evaluate the serial and the average cost pricing mechanism in a more challenging environment, both with complete and limited information. In this environment we had twelve players of four different types, sharing a common resource by requesting quantities and being charged a corresponding cost. Thus, the environment is more complex than the earlier studies. The goal was to assess the performance of the two mechanisms in various settings, to study how human subjects learn in these different settings, and whether and how the learning dynamics leads to convergence to stage game Nash equilibrium.

We have implemented three different sets of experiments. In the a baseline experiment, we conducted 10 sessions of the serial and average cost sharing mechanisms under complete information with twelve players randomly matched with each other in each of the 50 rounds. Each player is given complete information about the payoff matrix, the structure of the game, the quantity chosen and the corresponding payoffs of all players.

Often, however, players have extremely limited information, and they do not know the payoff functions, nor how their payoffs depend on the actions of others. In one limited information experiment, we conducted 10 sessions with 12 players, who were randomly re-matched into pairs in each of the fifty rounds. In another treatment, the players were matched into fixed pairs at the beginning of each session, and play the same partners for fifty. In both experiments, the only information players have was their own action and the resulting own payoffs. We conducted computerized experiments at the MERL Laboratory at the University of Mississippi and at the RCGD Laboratory at the University of Michigan in July and August 2001.

The following results can be stated:

- 1) The efficiency of the serial mechanism is significantly higher than that of the Average cost pricing mechanism under both the complete information treatment and the limited information treatment.
- 2) For both the serial and the Average cost pricing mechanisms, the efficiency under complete information is significantly higher than that under limited information.
- 3) For both the mechanisms, the equilibrium hit rate under complete information is significantly higher than that under limited information. Under limited information, the

frequency of Nash equilibrium play under serial is weakly higher than that under Average cost pricing.

CONCLUSIONS: In the case of Navy Training Programs, multiple agents share a same service, each demanding a certain number of seats in the program. If total demand is greater than the total capacity, then congestion appears and the different units experience delays. A common way of ration demanders is to use a FIFO packet scheduling algorithm, where all demands are serviced on a first-come-first-serve basis. The FIFO algorithm corresponds to the average cost pricing mechanism, where an agent's cost share is proportional to her own demand. One agent's usage can affect the quality of service of other agents and aggressive users can get more than an equal share of these shared facilities. In contrast, there is the possibility of allocating congestion on the basis of the serial cost sharing mechanism. This scheduling algorithm would leads to congestion allocation such that an agent's average queue is independent of demands higher than her own. This problem of congestion belongs to the more general class of cost sharing problems. In a wide variety of real world situations a group of agents share a common resource, such as computing facilities, secretarial support and lab facilities within an organization. A cost-sharing mechanism distributes the service and allocates the corresponding costs to each agent.

In this project we have studied the performance of the two cost sharing mechanisms in various settings, to study how human subjects learn in these different settings, and whether and how the learning dynamics leads to convergence to stage game Nash equilibrium. In general, our experimental results have shown that the serial mechanism performs significantly better than the average cost pricing mechanism in all treatments both in terms of efficiency and predictability measured as frequency of equilibrium play.

SIGNIFICANCE: This research will assist the Navy in providing a more efficient and equitable allocation of personnel to training programs whenever rationing or queuing occur. This study is consistent with the objectives of the ongoing 6.2 Training Management research. This ongoing research is attempting to address the persistent problems of course scheduling and booking of training seats by using heuristic algorithms to solve computationally difficult allocation problems. This proposal offers a different approach in that it proposes market type mechanisms to achieve an optimal allocation.

PATENT INFORMATION: N/A

AWARD INFORMATION: P.I. on leave at the National Science Foundation.

REFEREED PUBLICATIONS (for total award period):

1. "Centralized versus Decentralized Decision Making in a County Government Setting," (2001). Forthcoming *Economics and Governance*.

BOOK CHAPTERS, SUBMISSIONS, ABSTRACTS AND OTHER PUBLICATIONS (for total award period)

1. “An Experimental Evaluation of the Serial Cost Sharing Rule,” (2001). Under revision at the *Journal of Public Economics*.
2. “An Experimental Study of Congestion and Cost Allocation Mechanisms for Distributed Networks,” (2001). Mimeo