A CASE STUDY IN PERCEPTION AND OPERATIONS MANAGEMENT: AUTOMATIC TELLER LOBBY DESIGN

By

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ABSTRACT

The application of technology to improve productivity in the growing U.S. service sector has had significant impact on the traditional concept of customer service, as functions which have traditionally been performed by people are now being carried out by machines. The elimination of face-to-face transactions severs a key feedback mechanism used by service providers to assess the quality of their service as it is perceived by customers.

As a result, service companies must increasingly rely on theoretical and analytical tools to evaluate the quality of their operations. While operations research methods can provide a number of valuable insights, quantitative techniques are often insufficient to account for the psychological experiences of customers. An approach to recognizing and overcoming these psychological factors is emerging under the name perception management.

This thesis studies a design of a new automatic teller lobby in a bank, and uses the tools of both perception management and operations management to develop approaches for reducing the impact of overcrowding and high queuing levels. To anticipate the perceptual experiences of customers using the facility, the author proposes a psychological profile of ATM customers using some findings of Environmental Psychology. To understand the operational aspects of the lobby design, the author compiled automatic teller transaction data and created a simulation model of the service system.

Thesis Supervisor: Dr. Richard C. Larson

Title: Professor of Electrical Engineering

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First, I acknowledge my advisor, Professor Dick Larson, who provided enthusiastic, insightful guidance for this project as it followed its sometimes crooked path to completion. I am also grateful to Professor Amadeo Odoni, for giving me the idea to build a simulation model of the ATM facility, and to Professor John Sterman and his Teaching Assistant, Bent Bakken, for their help in designing the Stella model. Finally, I thank the other members of Dr. Larson's thesis group, "The Sloan Seven", who provided references, ideas, and encouragement which strengthened this thesis.

I could not have undertaken this project without the cooperation of some friendly and helpful contacts at the "client" bank. I am sorry to only be able to acknowledge them anonymously. They know who they are.

I. INTRODUCTION

The application of technology to improve productivity in the growing service sector is a key goal for the health of the U.S. economy. This phenomenon has had significant impact on the traditional concept of customer service, as functions which have traditionally been performed by people are now being carried out by machines. The loss of human interaction between the service provider and the customer severs a principal feedback mechanism for assessing quality of service as it is perceived by customers. In some cases, no human server is even present to observe the experience of the customer, and customers no longer have an obvious outlet for voicing complaints or compliments.

As a result of this increasing reliance on technology, and the resulting lack of direct interaction with customers, service companies must rely on theoretical and analytical tools to evaluate the quality of their service. While traditional operations research methods offer some insights, quantitative techniques are often insufficient to account for the psychological experiences of customers. There have been numerous examples of service delivery systems which were perfectly adequate "on paper", or "by the numbers", but which failed to meet customer expectations in practice, due to subtle psychological factors which eluded the managers or designers of the system.

An approach to recognizing and overcoming these psychological factors is emerging under the name "Perception Management" (Martin). The techniques of perception management have been particularly successful in the area of queuing. For example, in a queuing environment which is performing optimally from an operational standpoint, but is still providing substandard service, perceptions management offers methods to alter the customers' perception of the queuing experience to affect a more positive (or less negative) impression. Approaches to queuing have also been addressed under the headings "Psychology of Queuing" (Maister), and "A Multiattributed Approach to Queuing

Theory" (Larson). All of these emerging areas of study and practice are loosely built on the scientific foundations of environmental psychology, and liberally supported with anecdotes of successful applications.

As competition in the service industries becomes increasingly technology-intensive, and the feedback provided by face-to-face contact with customers disappears, companies will have to take the burden on themselves for assessing their levels of service, or lose their customers to more service-conscious competitors. Successful service organizations will blend the traditional tools of operations management with the newer, less conventional tools of perception management, to provide consistent high-quality service (or at least the appearance of high-quality service) to their customers.

II. A CASE FROM THE BANKING INDUSTRY: ATM QUEUING

The service delivery problem addressed in this paper was brought to my attention by Professor Richard Larson, of the M.I.T. Operations Research Department, who had been contacted by a local Commercial Bank. This problem provided a perfect case study for the application of the two-pronged approach to service system evaluation and management presented in the introduction.

The bank was undertaking an expansion of a key local branch (Branch X, for the purpose of this paper), and as part of the expansion, the Automatic Teller Machine (ATM) lobby had been redesigned. As this was a complex and heavily-used ATM facility, and the current installation had been plagued by severe overcrowding at peak hours, the bank was interested in maximizing the benefits, and minimizing the liabilities, of the reconfigured lobby.

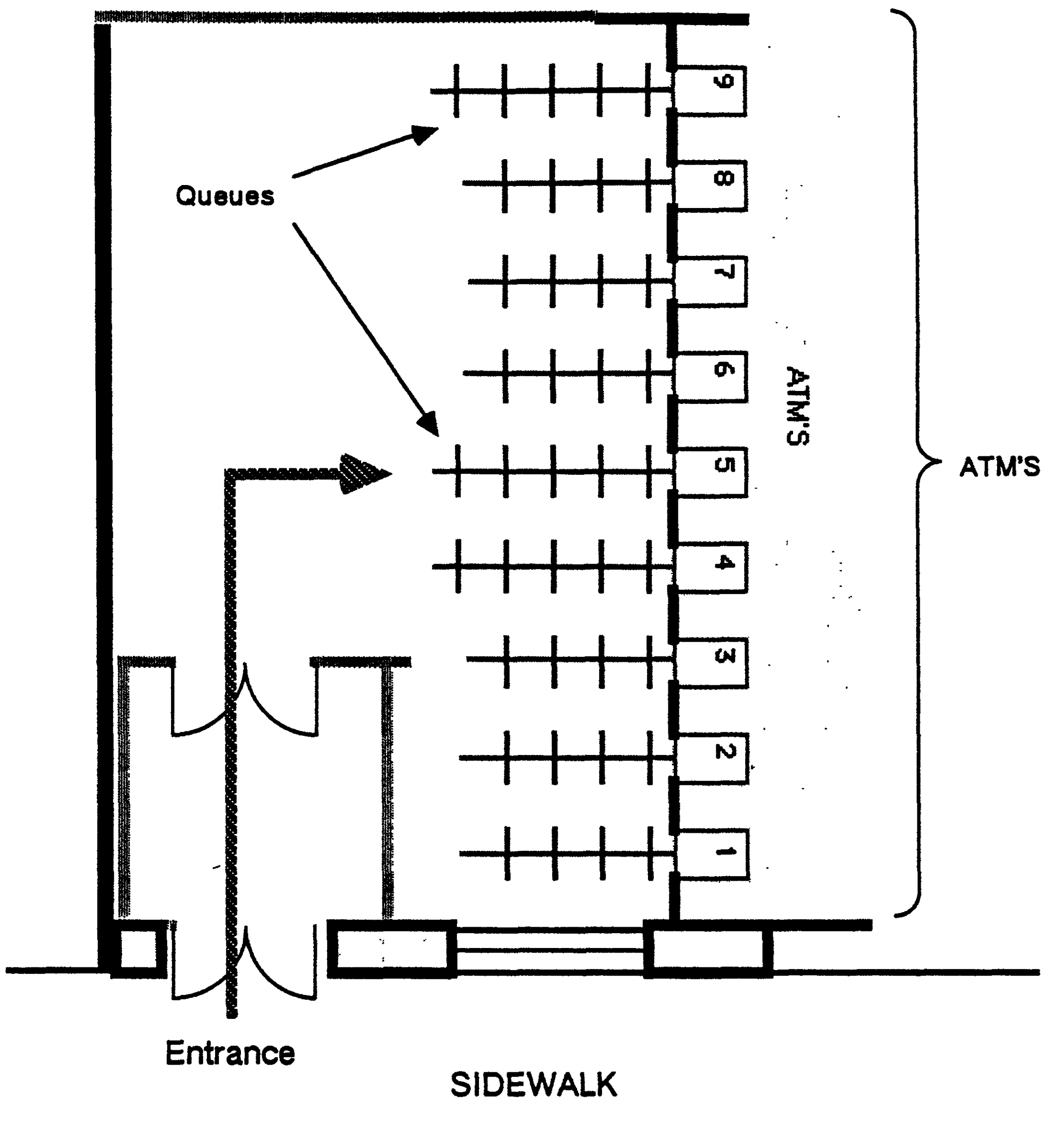
Since the branch expansion had already been designed and the contracts for construction signed, the bank was primariliy interested in how they could optimize some of the operational characteristics of the new ATM lobby. Upon reviewing the situation, I agreed that some operational fine tuning might improve the level of service provided by the new system, but felt that it still might not accommodate peak hour traffic adequately. With this in mind, I decided to also try to anticipate how customers would perceive the new service delivery system, and then offer some methods to improve these perceptions, within the operational constraints of the system.

Below, I describe the environmental and technical problems faced by the bank in the new lobby, and then offer an approach to their solution based a balanced blend of perception management and operations management.

A. The Environmental Context

In order to understand the operational and perceptual strengths and weaknesses of the current lobby, and to anticipate improvements or detractions in service quality offered by the new lobby design, I will describe the critical physical characteristics of each.

1. Diagram 1:
CURRENT ATM LOBBY AT BRANCH X



a) The Current ATM Lobby

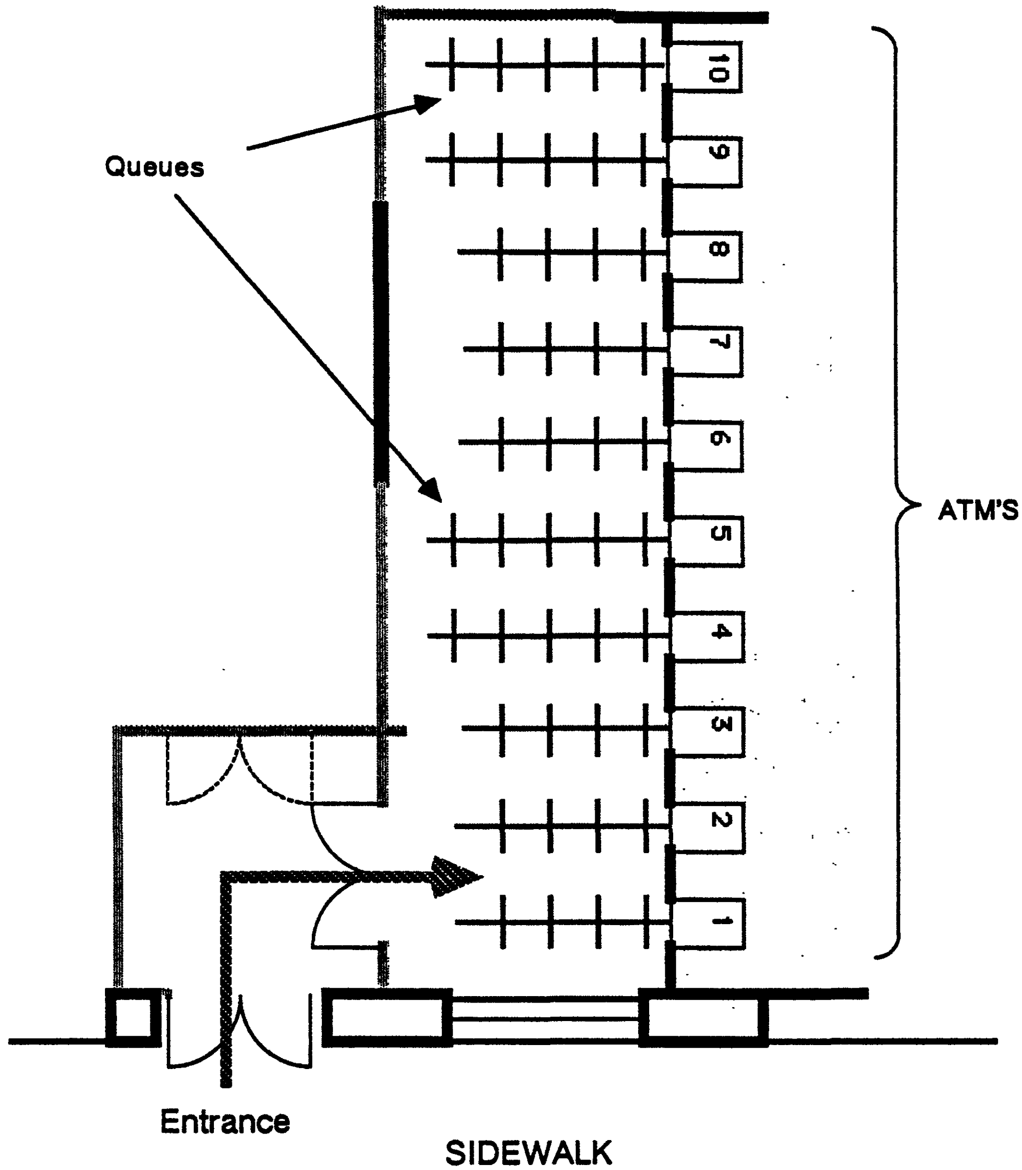
The current lobby is square, more or less, with nine ATM's lined up on one wall perpendicular to the street. (See Diagram 1). Two of the machines are inside the main bank lobby, and thus are only available during banking hours.

Customers enter through a vestibule which places them near the middle of the lobby, opposite the fifth, or middle, ATM in the row of nine. From this point of entry, the queues for all of the machines are clearly visible, and it is relatively easy to judge which queues are shortest and therefore most attractive. The width of the space provices adequate space to accommodate queues of 10 or more customers in front of each machine; this condition has been witnessed at peak hours.

The current lobby has a dropped panel ceiling with flourescent panel lighting. Tables in the center of the current space provide space to set down parcels, to get out checks and bank cards, or to write deposit slips.

2. Diagram 2:

NEW ATM LOBBY AT BRANCH X



a) The New ATM Lobby

The new lobby will be deeper than the existing one, but also narrower, due to space constraints in the overall bank branch redesign. It will have ten ATM's along one long wall perpendicular to the street, all of which will be available twenty-four hours a day, seven days a week.

Access to the new lobby will vary depending on whether the main bank is open or closed. During banking hours, there will be three openings into the ATM lobby, at both ends and the center of the wall opposite the machines. After banking hours, however, access will be through a single entry vestibule which will place customers opposite the first two machines nearest the street. From this point, under crowded conditions, the relative lengths of the queues for the various machines will not be readily apparent, as customers standing in line for the near machines will obscure the queues at the opposite end of the lobby. The reduced width of the new lobby will provide an additional constraint in the new space: only five or six customers will be able to queue up behind each machine.

The ceiling of the new lobby will be a double-height barrel vault with indirect lighting. Two tables will be provided in the new lobby for customers to prepare transactions: one along the front wall, and the other halfway back the wall opposite the ATM's.

B. Technical Dimensions

In addition to the rather dramatic spatial differences between the current and the new lobbies, there will be technical differences between the old and new ATM's themselves. For a variety of reasons, the bank decided to install a number of limited-function ATM's in the new lobby. These machines will only offer cash withdrawal and a few other simple transactions. (It is important to note that these machines could get higher than average use from withdrawal customers, and could therefore require more frequent restocking with cash.)

A chief benefit offered by the cash dispensers from the bank's point of view is their low cost: while new full service ATM's cost $26,000 each, cash dispensers are available at little or no cost, as the bank has a fully-depreciated surplus of these machines in inventory.

The operational implications of using these machines were not so clearly understood. The bank suspected that they could get away with including some number of these machines without reducing the performance of the system, but didn't have the information or the resources to fully understand the problem. I suspected that these limited-function ATM's had the potential to provide more than just cost savings: I felt they might be used to actually improve the operational efficiency of the new system as well.

C. A Two-Pronged Approach

The new lobby poses some problems which cannot be resolved by an exclusive dependence on either perception management or operations management methods. Each discipline offers approaches to the problem, but any solution must balance the limited conclusions of both.

In the two following chapters, I will present both a perception management approach and an operations management approach to analysing the service environment of the new ATM lobby. These analyses are mutually dependent.

The psychological profile of customer experience, built on observation and theory, and presented in the next chapter, strengthens our quantitative analysis and allows more accurate accounting for customer behavior in the models described in the following chapter. But at the same time, the preparation and execution of these quantitative, data-driven, models reveals subtle customer behavior patterns, and feeds back to improve our understanding of customer psychology.

III. PERCEPTION MANEGEMENT: APPLIED ENVIRONMENTAL PSYCHOLOGY

The new ATM lobby represents an architect's best solution within some difficult design constraints, but it will not necessarily facilitate high-quality customer service. The key questions facing the bank regarding the environmental aspects of the design are the how the reshaped and reduced queuing environment might affect customer perceptions of queuing and crowding, and how some of these problems might be mitigated, using the techiques of perception management. I address these questions in this chapter.

In order to build a coherent mental model of the psychological experience of customers in an ATM lobby, I turned to some works in Environmental Psychology, itself an emerging discipline, which is one key scientific foundation of perception management. Environmental psychology is the study of how the physical environment affects human behavior. In the past, it has been successfully applied to the design of specialized environments, such as housing, offices, and institutions, but only recently have some studies appeared regarding retail and service delivery situations (Wener). I will use one recent model of retail crowding to develop a profile of an ATM customer's experience in the new lobby.

Once I have anticipated the psychological basis of the customers' experience, I will propose a number of potential methods for improving this experience, based on the tenets of perception management.

A. Insights Offered by Environmental Psychology

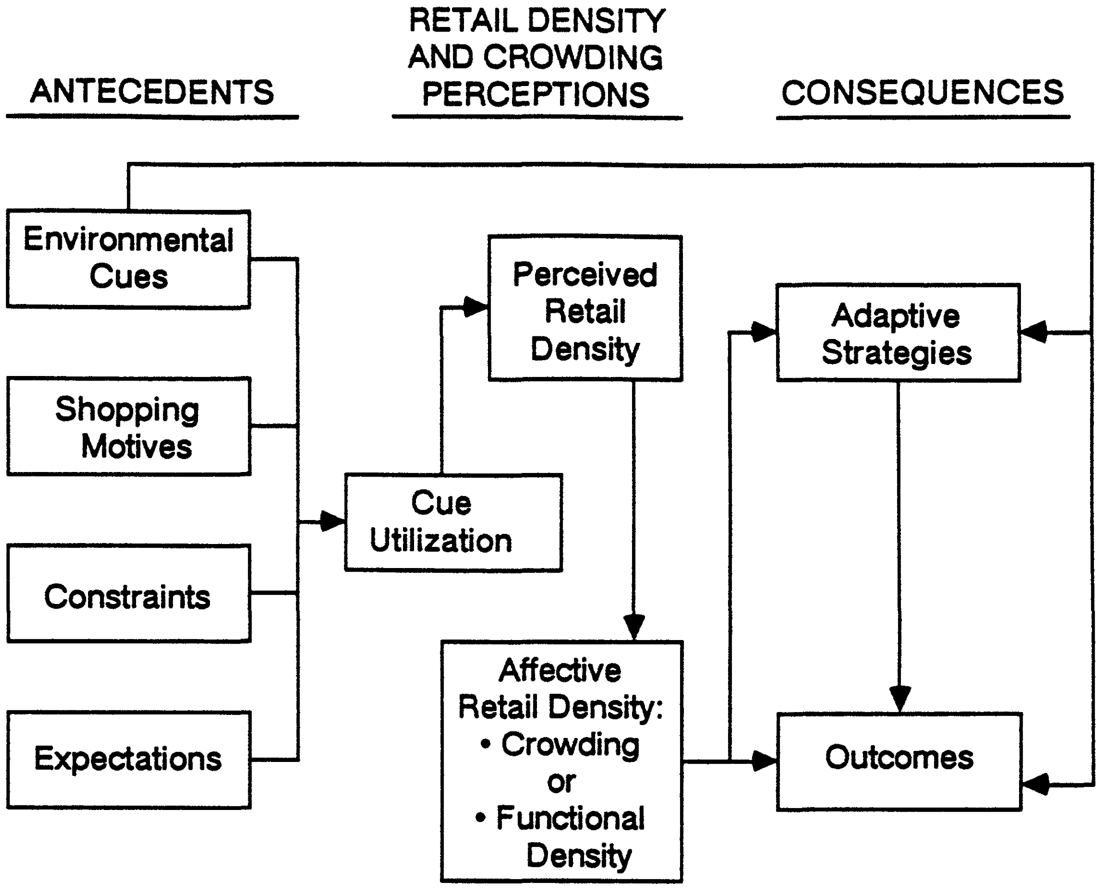
Some of the most interesting recent work in Environmental Psychology has studied the effects of crowding in retail environments. An ATM lobby may not represent a retail environment in the strictest sense of the term, but I propose that it is just that: ATM's are the "point of sale" for many of the customer services a bank provides. For many customers, a primary decision variable in their choice of a bank is the quality of the ATM network.

I also suggest that "crowding" and "queueing" are analogous: their perception by customers is as important if not more important than their reality, and they can be managed proactively to stimulate or dissipate customer anxiety.

1. The "Retail Crowding" Framework

In their paper, "Retail Crowding: Theoretical and Strategic Implications", Eroglu and Harrell propose a useful framework for discussing some of the insights on crowding offered by environmental psychology. In summary, those authors describe crowding as a "subjective state with spatial/social antecedents and psychological and behavioral outcomes." This description applies equally well to the experience of queuing. Eroglu and Harrell's description translates into the three-piece "Extended Model of Retail Crowding", which divides a customer's experience in terms of antecedents, perceptions, and consequences. I found this model to be a useful tool for identifying some of the psychological and environmental variables which will affect customer perceptions of the new ATM lobby. I present the model and my analysis below.

a) "An Extended Model of Retail Crowding", Eroglu and Harrell, 1986.



b) Antecedents

Antecedents are situational "cues" which precede and trigger customer perceptions of crowding. The four key antecedents, as shown in the model, are motives, constraints, expectations, and the environment.

Motives, Constraints, and Expectations

In an ATM lobby, we can intuit how the first three of these antecedents will affect customer perceptions of crowding. First, the motivation of ATM customers is purely task-oriented: customers use ATM's out of necessity, rather than for pleasure. There may be further subtle differences in the motives of different classes of customers. Withdrawal customers may be more often motivated by a reactive need for cash, while depositors may be motivated by proactive desires to augment their account: these motivational differences may result in the depositors' perceiving more inherent value in their transaction, and may decrease their sensitivity to crowding or queuing somewhat. In general, however, we would predict that the task-oriented motivation of the customers will increase their sensitivity to crowds and queues.

Second, customers may feel constrained by time pressures and perhaps some perceived risk while in an ATM lobby. Again, I propose that these constraints are felt to different degrees by different classes of customers. Where cash withdrawal customers may be particularly aware of time pressures (a cash withdrawal may necessarily precede some other activity), and have relatively little concern for perceived risks (such as other customers seeing their transaction, balances, or open pocketbook/wallet), the opposite is likely to be true for depositors. This suggests that withdrawal customers will perceive crowds and queues negatively since they represent impediments to a quick transaction and the activity to follow, while depositors will be sensitive to congestion to the degree that it reduces privacy and security.

A third antecedent, which is the degree of crowding anticipated by customers, may actually increase customers' tolerance for the congested conditions in the lobby. It has been shown that customers who arrive in a crowded area expecting to find crowded conditions actually perceive less crowding than customers who have not anticipated the crowd (Baum and Greenberg). Given the experience of regular ATM customers at Branch X, we would expect that they have developed expectations for a high level of crowding, and that they would not be surprised to find a crowd in the ATM lobby. For bank customers who are unfamiliar with this branch, however, the lobby conditions may be somewhat overwhelming, and may lead to a higher perception of density.

Environment

The three antecedents discussed above all affect the way customers will respond to the fourth antecedent, which is the environment itself. Impressions of the environment can also reinforce or mitigate these other antecedents as they act together to shape customer perceptions.

Environmental factors in the perception of crowding have been studied by Desor, who looked at how various architecural features altered perceptions of crowding. Desor's experiment was to have subjects place small figures, representing people, in scale model "rooms", until the subjects felt the "rooms" looked overcrowded. Each of the model rooms had different architectural features, and the purpose of the experiment was to determine how these architectural features affected the number of figures subjects placed in the spaces before they perceived them to be overcrowded. The two architectural variables included in Desor's experiment which are most interesting to our situation were the number of wall openings and the shape of the room.

Desor found that increasing the number of wall openings generally reduced the number of figures subjects placed in the model rooms; he proposed that this was due to the "increased reception of social stimuli" provided by the added views out of the space. I suggest that this conclusion will not apply in our case; indeed, I suspect that the wall openings in the new lobby will reduce the perceived level of crowding by reducing the potentially corridor-like feeling in the long, narrow ATM lobby, thereby increasing the perceived area of the space.

Desor's experiment to investigate the effects of the shape of the room found that subject placed more figures in a rectangular room than in a square room of the same floor area. He proposes that "interpersonal perception" within a space can be as strong a determinant of perceived crowding as the actual density, and that "making a room more rectangular will increase the mean interpersonal distance and thereby reduce overall level of interpersonal perception." This could be interpreted as good news for the new lobby, since the average "interpersonal distance" may be greater in the new, rectangular lobby than it is in the current one, but I have several problems with the application of Desor's conclusions to this situation.

First, Desor's experiment assumed that people would be evenly distributed across the space, and this is unlikely to be so in the new lobby. High customer density near the entry may discourage customers from pressing through the crowd to the far end of the lobby. This will be a self-perpetuating condition: as more customers cluster near the entry, fewer will make the effort to press through, and the bottleneck will grow even tighter, and so on. This is actually a valuable conclusion in itself, as it suggests that one high leverage policy for decreasing perceived density may be to encourage an even distribution of customers through the space, thereby minimizing interpersonal perception.

Second, Desor's experiment assumed that the people in the space were not moving. When we introduce the additional condition that people must enter and exit the room through a single door, and move from one end of the space to the other, the "interpersonal perception" in a rectangular room may in fact be higher than in a square room. Indeed, in order to move to the machines in the back of the new lobby, it will be necessary to pass either through or very closely behind the people in queue in the front of the lobby; contact with others is much more likely than in the current lobby, where customers select queues and approach them from behind. This is also a valuable observation, since it indicates the potential value of providing a well-defined traffic pattern in the new lobby to minimize customer interaction.

Desor's conclusions may be encouraging from the standpoint of the space-constrained new lobby. He finds: "Decreasing density of people is by no means the only method of allieviating crowding... any architectural feature of a space that reduces interpersonal perception within that space should reduce the level of (perceived) crowding there." Thus one means of reducing customer perceptions of crowding and queuing congestion may be found in the details of the design.

c) Perceptions

Customers' perceptions of crowding (or queuing) are subjective measures of actual, objective functions, built on the antecedent variables discussed above. Eroglu and Harrell suggest that spatial and social aspects of the customers' experience determine their perceptions. Spatial effects include the architectural features discussed in the preceding section, while social effects involve the "level and rate of social interaction" among and between customers.

More specifically, I propose that customer perceptions are a function of the level of anxiety either produced or diminished by spatial and social aspects. In queuing environments in general, and ATM lobbies in particular, there are at least three potential sources of customer anxiety: unfairness, uncertainty, and crowding.

The degree to which the queuing environment does not ensure social justice, or doesn't provide service on a first come, first served basis, is one potential source of anxiety. This is largely a function of the environmental design of the space. Faced with a multiple line/multiple server system in the ATM lobby, customers must decide which line they expect will provide the fastest service, join that line, and hope for the best. Given the highly variable transaction time distributions and competence of the preceding customers in line, customer decisions are often suboptimal. This results in a frequent breakdown of social justice and may raise the level of anxiety among customers. Line switching is one solution to this problem, but indicates an already high anxiety level, and still may not provide the best result. It is interesting to consider how the introduction of machines with different functionality will affect customer perceptions of social justice. Will perceptions improve, since customers will be be more able to sort themselves according to intended transaction type? Or will perceptions deteriorate, because customers resent the explicit sorting by transaction type, or because the system may be less just, if more efficient, than it is with all full-service ATM's?

A second potential source of anxiety in the ATM lobby is uncertainty or lack of information about the system overall or the expected service time. This is also a function of the environmental cues available in the space. For example, if customers cannot see all the queues easily, in order to compare them and to decide which one to join, their anxiety levels will rise. Again, the introduction of machines with different functionality may raise customer anxiety, by forcing customers to base their decision of which queue they will join on a more complex, and perhaps more mysterious, set of variables. This will be particularly true if customers are given no means of predicting the difference in expected service times for the different machines.

A third source of anxiety is a function of social, rather than spatial cues: it involves the amount of interpersonal perception customers experience as they perform their tasks. If customers are forced to interact with each other by the constraints of the space, in order to enter and exit, or to pass through or behind queues, or to make room at a writing desk, for example, their anxiety levels may increase, since many people experience unnecessary interaction with strangers as undesirable, and perhaps risky, in the context of personal banking.

d) Consequences

To complete our model of the ATM lobby using the Retail Crowding analogy, we must consider the consequences of the perceptions discussed above. We can observe the consequences of customer perceptions in the short term in their adaptive strategies, or in the longer term by their repatronage decisions.

Adaptive Strategies

ATM customers have developed a number of adaptive strategies in response to the perceptions and anxieties described above.

To solve the problem of uncertain social justice, customers have several options. One is to tailor their transaction habits to avoid peak hours of congestion, using the ATM's only when the lines are short and the potential for social injustice low. Another option is for customers to initiate single queue systems themselves, or to adapt the single queue strategy to multiple queue systems by hovering behind a cluster of machines, delaying line selection as long as possible to maximize the information available to make an informed line choice. This strategy can be successful even in very complex queuing environments.

Customers have a more difficult time overcoming problems of uncertainty about the system. Observation of customers reveal that their queuing decisions are highly variable and far from optimal. While some customers make very intellegent assessments of the system, others appear to approach the problem passively, and show little understanding of system in their queuing decisions.

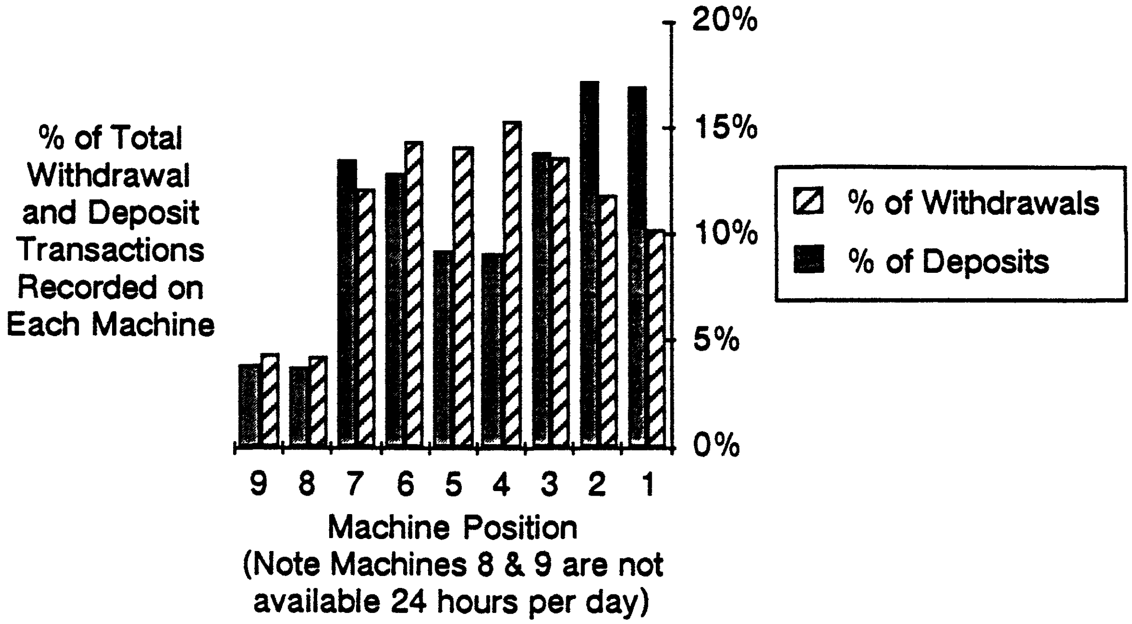
Customers respond to excessive crowding by a variety of methods. The most obvious of these is to balk, or to delay their transaction until another time when the crowding is less severe, or until they reach another ATM facility which is less congested. Unlike many retail transactions, where patrons may have invested time selecting items for purchase before joining a check-out line, ATM customers do not generally any invest any time in the transaction prior to queuing, so the cost of balking is relatively low. The amount of balking by customers is impossible to determine, because even perfect observation of customers who arrive at the facility and choose not to enter would not account for the customers who have patterned their transactions to avoid the facility at peak hours based on past experience.

A second, more subtle customer reaction to the high degree of social interaction came to light as I reviewed the transaction data for the current ATM lobby. It appears that some customers sort themselves according to transaction type. There is a notable difference in the mix of transactions across the row of machines, with the machines in the middle (closest to the door, in the current lobby) receiving heavy withdrawal traffic, and the machines at either end receiving a disproportionally high number of deposits. The monthly and peak hour distribution of transactions by machine and location is presented in charts following this section.

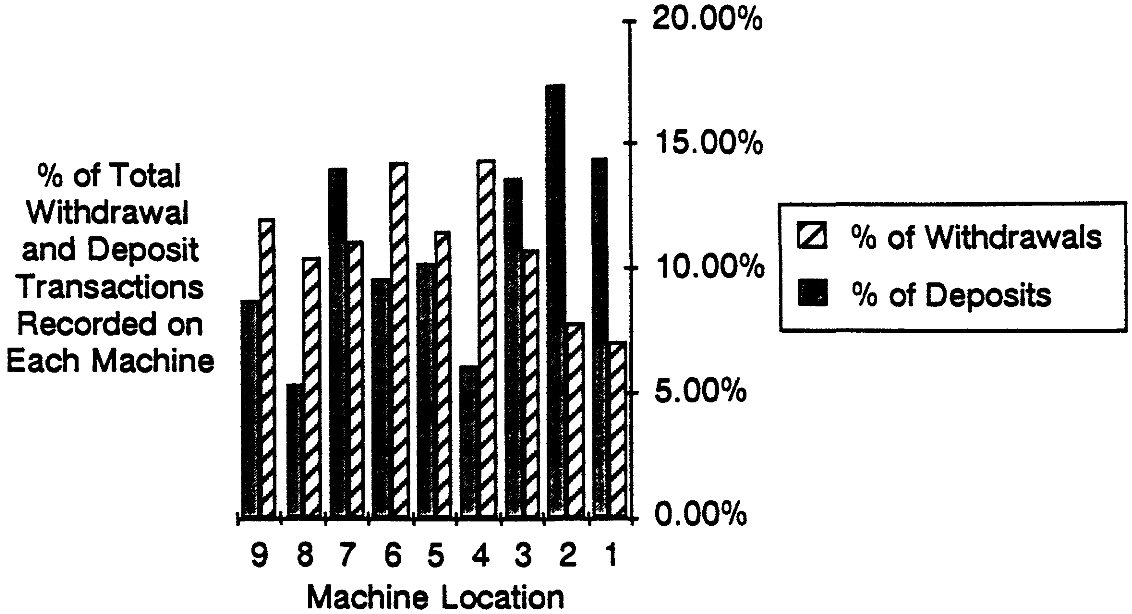
This self sorting may occur as a function of the placement of the tables in the lobby, or because depositors prefer a more private, less busy location for their transactions, or because cash withdrawal customers are in a rush and don't want to walk to either end of the lobby, but prefer to simply join the nearest line. More probably, withdrawal customers understand that they will reduce their expected waiting time by avoiding the lines which have customers holding deposit envelopes.

But why would depositors be willing to queue up together, rather than follow the same deposit-envelope-avoidance strategy as the withdrawal customers? As described under motivational antecedents, depositors may be somewhat less sensitive to longer lines, as they can occupy themselves while they stand in line by endorsing their checks, filling out their deposit slips, etc. They may also perceive greater value in their transaction, and therefore be willing to invest more time to perform it. This seems a sensible explanation: I would be less anxious waiting in a five-minute line to perform a transaction which I expected to take two minutes than in a five minute line to perform a transaction which I anticipated would take thirty seconds.

Monthly Transaction Distribution by Machine Location and Type



Peak Hour Transaction Distribution by Machine Location and Type



Outcomes

The fact that current customers show a range of coping mechanisms for dealing with an environment which they perceive to be stressful and unjust should be of small comfort to the bank management. More drastic, though less obvious measures are certainly available to deal with a service system which provides high expected levels of crowding, uncertain social justice, and excessive levels of customer interaction.

One obvious solution, and most serious from the point of view of bank management, is for unsatisfied customers is to take their business elsewhere. If there are competitors who can offer compatible banking services, with a more serviceable ATM network, they are likely to draw some of these customers. If there are not any such competitors now, they will certainly appear if the opportunity to steal away customers persists.

B. Solutions Provided by Perception Management

Having now described the anticipated customer perceptions of the new ATM lobby in the terms of environmental psychology, we can now explore how these perceptions (or the reality) of the new ATM lobby might be managed to make it a more attractive place for customers to perform their transactions. Successful applications of perception management are generally recorded as anecdotes; it is now time to create some solutions which will be recorded in the lore. Below, I will apply five perception management methods, in more or less direct response to the perceptual problems anticipated above for the new lobby.

1. Minimize Perceived Waiting Time

One of the precepts of perception management is to minimize the customer's perception of waiting. One way to do this is to distract customers and make them forget they are in line. Examples of successful distraction devices are mirrors in elevator lobbies, perpetual motion machines in airport terminals, participatory sculpture in subway stations, and television or live entertainment in bank lobbies. Details of these and other efforts have been well documented elsewhere (Larson, Martin, Maister).

I think this idea could be successfully applied in the ATM lobby at Branch X; television screens over the ATM's could provide news, weather, entertainment information, or bank product information to customers standing in line, distracting them from their wait. The opportunity for advertising seems particularly attractive. The bank could market its own products, advertise the services of neighboring establishments for a fee, or list cultural and social events as a public service. Since customers standing in line are looking for distractions, their attention to the message would be complete and easy to catch, if brief.

There are some hurdles which stand in the way of implementation of this concept. One is a concern about vandalism; since the ATM lobby is open twenty-four hours a day, opportunities for abusing or tampering with TV monitors would be abundant. A possible way to avoid this problem would be to use the screens during banking hours only, and install vandal-proof pull-down covers to protect the screens after hours.

A second concern is for keeping the decor of the ATM lobby in tune with the rest of the bank interior, and the lobby design as it now stands leaves no room to fit television screens above the ATM's. I suggest that the TV concept could probably be applied in other areas of the bank where customers have to wait: the decor of the bank would then become consistent with the ATM lobby.

Finally, there would be the expense of programming enough media to keep the screens interesting and informative on an ongoing basis. This might not be prohibitive, since the programming could be a fairly brief loop - ten minutes would be long enough so most customers wouldn't see the loop repeat - and the cost could be spread out over a number of machines if monitors were installed in other branches in the network. Also, if the monitors were used for marketing, the cost of the project could be covered by increased customer awareness and use of the bank's services. (One possible barrier to this idea might be the Massachusetts Blue Laws, which control advertising in facilities open seven days a week. This would not be a problem if the monitors were only functional during banking hours.)

2. Maximize Perception of Social Justice

As we saw above, customer perception of a queuing system that is not socially just leads to anxiety and dissatisfaction. There are two options for managing this perception: we can either create a system which is more just or we can reduce the degree to which customers perceive the injustice.

An obvious way to improve the fairness of the system would be to encourage customers to form one queue for all the machines. (To reduce the anxiety of those who taught me operations management, I probably should have mentioned this earlier). This would guarantee service on a first-come, first-served basis, and could reduce customer anxiety significantly. It might also minimize the expected wait for arriving customers (more on this in the next chapter).

Unfortunately, there are some compelling drawbacks which might offset these benefits to some degree (or completely). First, it is difficult to design a barrier system which would be flexible enough to direct customers into a single queue when the traffic is heavy, but which would let them move directly to machines when the traffic is light, avoiding the detour around the barrier. Such a barrier would also depend on a high level of customer goodwill and attention, since no bank personnel is present in the lobby to observe traffic conditions. The ambiguity of such a system at slack times might actually be a source of anxiety, as some customers might be inclined to observe the single-queue discipline, while others would prefer to move straight to open machines. (This ambiguity sometimes occurs in short ski lines: some skiers still observe the pattern of the single-line maze and follow that circuitous route, while others ski under the ropes and directly onto the lift. Social justice is not achieved under these circumstances.)

Second, a single queue may be perceived to be longer than dispersed queues, even if composed of exactly the same number of people. This could be particularly true in the new ATM lobby: ten lines of three would appear to be shorter than one line of thirty, since the ten lines of three won't be fully visible, especially from the street. The ramifications of system overload in a single queue system could be more severe, as well: the queue could spill out the doors and onto the sidewalk if customer arrivals exceeded system capacity. This situation should be avoided at all costs, since it is a public demonstration that the system is inadequete to satisfy customer demand. With dispersed queues, the scene mightl be equally messy, but the chaos would be contained in the lobby; queues would probably not reach the sidewalks.

Finally, there would be some reduction in the capacity of the system with a single queue, since the time it would take the on-deck customer to see a machine become available, walk to the machine, and put in his card would be much greater than it is with multiple queues. This would increase the expected service times for all the machines, depending on their distance from the front of the line, which would reduce overall system performance.

The other route to reducing customer anxiety about social justice is to reduce awareness of any social injustice in the system. This may be an easier approach given that it will be difficult to observe queues other than those adjacent to one's own in the narrow new lobby. The more difficult question is how to handle the placement of the cash dispensers under this approach. On one hand, placing the cash dispensers at the back of the lobby will require customers seeking the shorter expected service times of those machines to walk the added distance to reach them. This would tend to bring the net time in the ATM lobby for customers of either type of machine closer, and would thus reduce social injustice in an absolute sense.

On the other hand, I anticipate that customers requiring full service ATM's will not resent the shorter service times of cash withdrawal customers, any more than customers with full carts in supermarkets resent express line customers. With this in mind, it makes more sense to situate the cash dispensers close to the front of the lobby, since both classes of customers are disturbed by the social interactions necessitated by lateral movement across or through the queues.

3. Maximize Information Available to Customers

A third tenet of perception management holds that we should inform customers to as great a degree as possible about the functioning of the system. This is consistent with our conclusions above that customer anxiety increases with lack of information. I will suggest what information is worth sharing with ATM customers, the potential positive effects to be gained by this effort, and then propose some methods by which information could be presented.

First, what information do customers want? I propose that they want to understand a little bit about the rationale that drove the system design, and enough facts about the expected performance and status of the system to allow them to select queues intellegently. If ATM's with different functionality are being introduced into certain branches to improve customer service, customers should be informed about both the rationale for and the expected performance of these machines.

This will have several positive effects. First, it will prevent customer misunderstandings about the machines: that they are reducing the level of performance of the system, for example, or that the bank is economizing at the expense of its customers. Second, it should help customers make better queue selection decisions. Knowing that the cash dispensers have an average service time per customer of fifty-five seconds at all times, while full service machines have an average service time per customer which ranges from fifty-five seconds to one minute and twenty five seconds, depending on the mix of arriving customers, customers will be able to compare similar lines for cash dispensers and full service ATM's more intellegently and with less anxiety.

A second layer of information which should be available upon entering the lobby is the complete status of the ATM system. Customers should not have to initiate a transaction to determine that an ATM has run out of cash or is out of service, and should not have to walk the full length of the lobby to compare the lengths of the queues. The machine status issue is a mechanical one, outside the scope of this paper: the ATM's could be programmed to alert customers when they are out of cash.

The issue of giving customers an easier way to compare queue lengths is closer the scope of this paper. Given the long, narrow shape of the new lobby, with the primary entrance at one end, and queues blocking both visual and physical access to the far end of the space, customers need an easy way to compare queues without actually pressing through the crowd to look at each one directly. One way to provide this remote visual access could be to locate mirrors along the ceiling or against the back wall, canted to reflect the images of queues for the machines at the far end of the lobby to customers who have just arrived in the front. The double-height ceiling would facilitate the implementation of this idea, and the mirrors could even be designed and installed as functional sculpture. This scheme would decrease customer anxiety due to uncertainty and social injustice, and improve system performance by allowing more optimal queuing decisions. Two conceptual diagrams are shown at the end of this section.

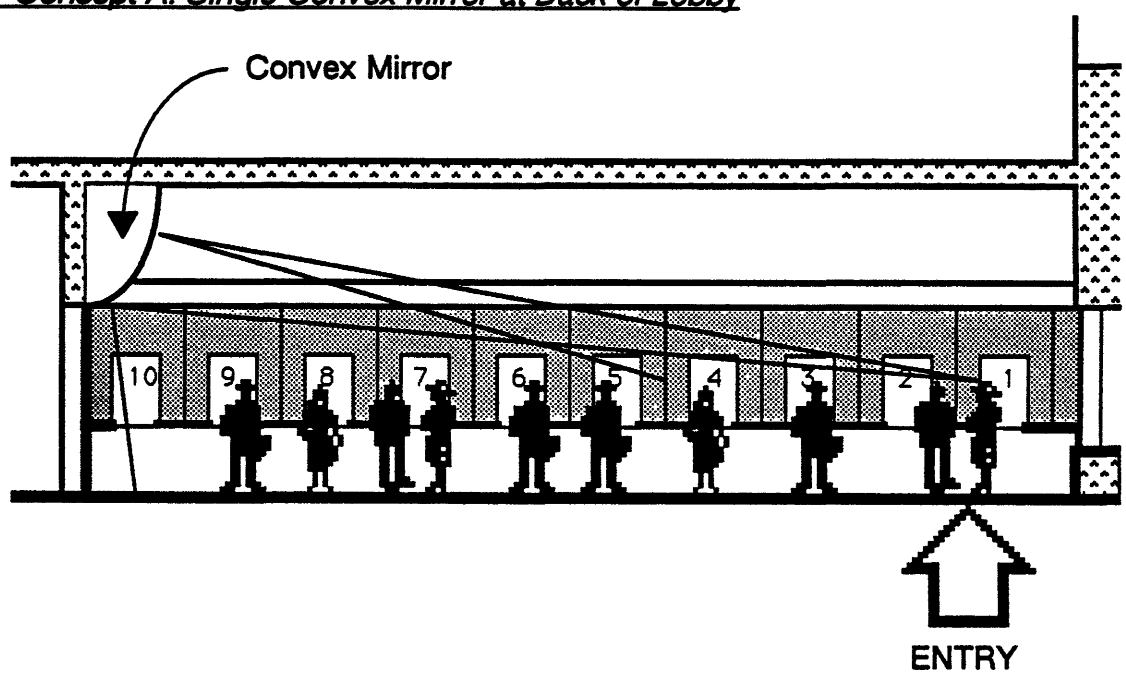
A perceptual management technique used with some success by the managers of the Disney amusement parks is to constantly inform customers about their expected wait at all points in the line. While such a system could be implemented in an ATM lobby, using lines on the floor to denote decreasing expected waiting times as one approached the front of the line, it could not be as precise as the Disney system, and would probably not be in keeping with the decor of the ATM lobby or the rest of the bank. This idea would be much more attractive and applicable if the bank ever tried to try a single queue approach in the lobby, and should definitely be considered if that situation arose, since customers would learn that the wait in what would look like a very long line would in fact be quite short.

Finally, there is the question of how to actually transmit all of this information to customers. I would suggest all of the usual signage, plus flyers in the lobby itself, and perhaps a brief note with the bank statement of all customers at Branch X, presenting the information outlined above.

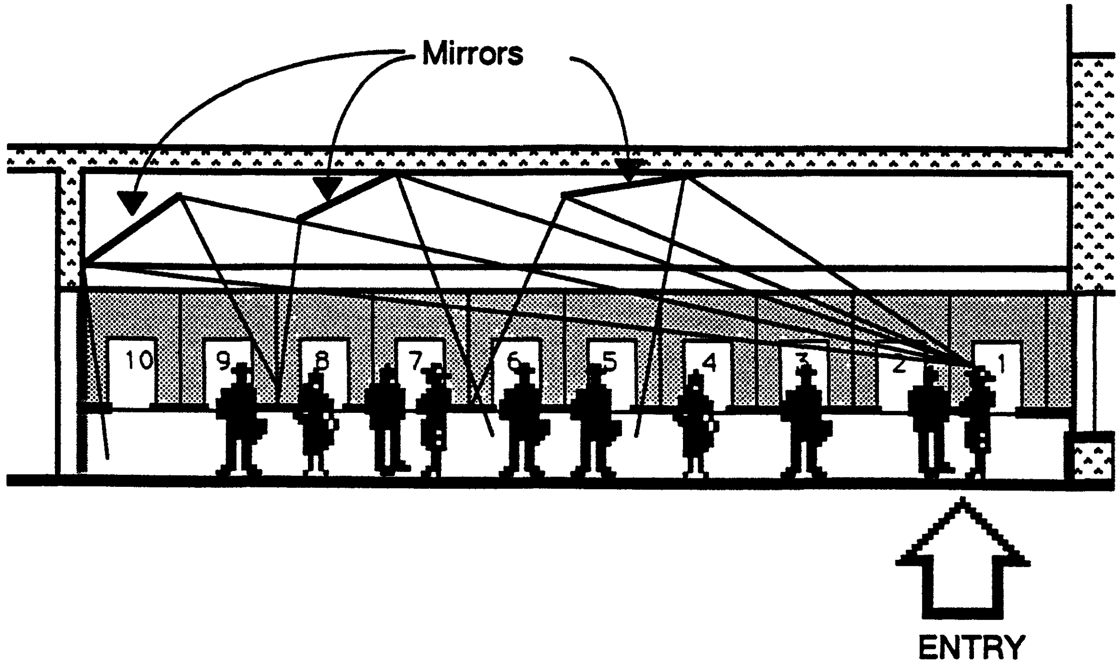
All of these measures should help improve customers' understanding and awareness of the system and its particulars, and should help improve customer perceptions of the level of service the sytem provides.

As an endnote to this section, I offer one final conjecture on the value of sharing information. I would not be surprised if sharing information about average transaction times led to a long-term decrease in average transaction times, by making customers aware of their own performance relative to some norms. Whenever I mention the topic of this thesis, people ask what average ATM transaction times I found, and then responded by comparing themselves either favorably or unfavorably to that norm. I suspect that many customers would try to speed up their transactions, to try to beat the standard established by a published mean. This is outside the conventional boundaries of perception management, but is related to some extent, since it affects customers perceptions about their performance relative to others.

a) Concept A: Single Convex Mirror at Back of Lobby



b) Concept B: Multiple Flat Mirrors on Ceiling of Lobby



4. Minimize Level of Intercustomer Perception

Another source of customer anxiety identified above was higher than desired interaction with other customers. There are a number of options available to reduce both the actual and the perceived amount of customer interaction. The basic formula for achieving this goal involves spreading customers evenly, reducing customer movement, and defining circulation paths.

By encouraging customers to spread themselves evenly across the lobby, we will eliminate pockets of high density, which are great centers of interaction. The question is, how can we implement this concept? One approach would be the mirror concept presented above: by making customers aware of the queuing conditions throughout the lobby, we can expect a more even distribution across the machines.

Another way to distribute customers more evenly would be to implement the single queue system outlined above. In this context, a single queue would ensure that customers were spread in an orderly fashion across the lobby, would minimize unnecessary movement in the queuing area, and would provide well-defined circulation paths to guide customers around each other, rather than through and into each other. Unfortunately, the problems of the single queue option, described above, still apply.

A third method to reduce the actual level of intercustomer perception would be to define and implement a pattern of circulation which would improve the flows of people into and out of the lobby. Entry and exit through the small vestibule could be eased by demarking a door for each purpose, for example, or a human attendant could serve as a prompter and director of flows during peak hours.

Finally, the movement of customers through the space could be reduced by serving the customers wishing cash withdrawals near the entry. Since we know these customers represent a high percentage of total volume, and we know that their average service time is much lower than that of deposit customers, it makes sense to turn them in and out of the lobby as quickly as possible. We can encourage this behavior by placing the cash dispensers close to the entrance and the writing tables for depositors in quieter areas away from the entrance. This will leave depositors, who have longer expected transaction times and probably longer waiting times overall, as well as a higher sensitivity to perceived risk, standing relatively undisturbed in queue out of the bustle of the entry area. It is important that all services are available reasonably close to the entry, so that customers will not feel uneasy going into the lobby late at night; this should not be a problem under this scheme.

These measures should contribute to the reduction of real and perceived interpersonal perception in the lobby, and should encourage positive responses among customers.

5. Facilitate Customer Adaptive Strategies

A final measure for maximizing customer perceptions of the new ATM lobby is simply to facilitate the adaptive strategies that customers already use.

The idea of locating the full service machines out of the main traffic routes, to offer depositors maximum privacy, has already been mentioned. A similar facilitating gesture would be to cluster machines of similar function together, so that customers can implement self-imposed single-line discipline when conditions allow. Finally, the evidence that customers already sort themselves by transaction type to some extent indicates that cash dispensers should be welcomed by customers, as it will perform perfectly a sorting policy they have already been trying to implement themselves. These machines must be clearly identified to facilitate continuing customer uses of these strategies.

IV. A SIMULATION MODEL OF THE ATM LOBBY

The Environmental Psychology and Perception Management approaches presented above offer insights and answers to some, but not all of our questions about the level of service in the new ATM lobby. Implicit in those approaches is the assumption that the real level of service has already been maximized.

Knowing that some important variables in the ATM lobby had been determined on a rather ad hoc basis, under time constraints and without the benefit of complete information about the performance of the system, I undertook a more rigorous, quantitative analysis of the queuing system. My goal was to optimize the real performance of the ATM system, and to reduce the real level of crowding and increase the overall level of service provided.

The key question in this situation was: what mix of cash dispensers and full service machines would provide the best level of service under the full range of operating conditions? We would expect the optimal mix to have enough full service machines to accommodate depositors at peak arrival rates, but also to draw on the sorting benefits and short expected transaction times provided by the cash dispensers.

A second question was: once this mix is determined, where should the cash dispensers be located to maximize their functionality and minimize any detrimental impacts on customer perceptions? The answer to this question must be jointly based on the preceding observations of perception management, and the lessons of the modeling results to follow below.

A. Background

A conversation with Professor Amadeo Odoni of the Operations Research Group at M.I.T. led me to the idea of developing a model to analyse the ATM queuing system at Branch X. His successful simulations of queuing and human flows in service buildings, particularly airports, suggested that a similar approach might be fruitful in my case.

With this in mind, I developed a simulation model based on transaction data, the environmental-psychology based customer profile, and observation of customer behavior in the current lobby. I used this model to experiment with different configurations of full function ATM's and cash dispensers, and to determine an optimal, or at least robust, solution.

After working with the model for some time, and largely as a result of observing the model execution and output, I recognized several facts about the nature of the optimal solution and about the character of the system that allowed me to intuit an apporiximate numerical solution to the problem. I continued to use the model after I had determined this solution, principally to verify that my intuition was correct.

Before I present descriptions of each of these tasks under the heading "methodology", I will briefly describe why I felt a simulation model provided the best modeling solution in this situation.

1. Why a Simulation Model?

In his 1969 book, "Principles of Operations Research", Wagner begins his chapter on simulation techniques with the heading "When all else fails...". Almost twenty years later, simulation is still the method of last resort for some complex situations, where no theoretical solutions exist. A recent article in the New York Times Magazine discussed the simulation models used by traffic engineers to model vehicle flows:

"Simply plugging in average values is not enough ... the natural variation of real world traffic (a slow or unresponsive driver, for instance) has a sharp effect on the simulations - usually slashing the capacity of a street or and intersection. Planners need to prepare their systems for such drivers...there's an old saying: 'There's a clunker in every queue'."

The occasional presence of "clunkers", as well as some additional complexities, places this particular ATM queuing system in the category of problems for which simulation provides the best solution. Other, more technical justifications for a simulation model are presented in Appendix Two.

While the ATM queuing system cannot be modeled in all its complexity, even in a simulation model, the situation can be represented adequately to determine the variable in question, that is, the appropriate number of cash dispensers for the new lobby.

B. Methodology

The modeling exercise broke down into four tasks:

1. Model Determination and Data Gathering
2. Experimental Design
3. Model Development
4. Execution and Evaluation.

I present my approach to each of these tasks below.

1. Model Determination and Data Gathering

In order to set up a realistic model of the new ATM lobby, I first defined the set of variables which would drive the model, and then quantified those variables using transaction data from the current system, observation of the current system, and conversations with the client bank and others familiar with ATM operations.

The variables required to determine the model were the following:

a.) Customer Arrival Rate: The maximum expected system demand at peak hours, in customers per hour.

b.) Expected Service Time: The anticipated distribution of service times in minutes for cash dispensers and full service ATM's.

c.) Customer Mix: The minimum and maximum percentages of arriving customers requiring full service ATM's or the equivalent percentage requiring only cash dispenser services.

d.) Patterns of Customer Behavior: Decision rules, preferences, etc. of ATM customers.

The client provided transaction data from the current ATM system at

Branch X for several hours of peak demand activity: from 12 noon to 2 pm on a Friday afternoon. As this data is maintained by the bank primarily for use as a record of transactions, and not for a basis for management decision making, it did not explicitly provide the information required to determine the model. But the raw data did include: customer identification, which allowed me to distinguish one transaction from the next; the times the central computer recorded various stages of each transaction; and the type of transaction the computer performed at each stage. With some manual compilation of this information, I was able to determine the necessary variables. My approach to determining each is presented below.

a) Customer Arrival Rate

In order to get an initial estimate for the arrival rate of customers at the peak hours of demand, I simply counted the number of transactions recorded in the two hours of transaction data. While this provides a useful starting point, several factors make this result a lower bound to the customer demand we can anticipate for the new ATM lobby.

First, at times of peak demand the facility operates at or near capacity. Using the mean expected service time and number of ATM's available, we can approximate the utilization rate of the current facility at the time the transaction data was recorded:

$$p = £\mu/S$$

p = Utilization Rate

£ = Arrival Rate

μ = Mean expected service time = 1.09 min./transaction

S = Number of servers = 9

Hour 1: £ = 461 customers/hr. = 7.68 customers/min.

$$p = (7.68*1.09)/9 = .93$$

Hour 2: £ = 482 customers/hr. = 8.03 customers/min.

$$p = (8.03*1.09)/9 = .97$$

At 93% to 97% utilization, the number of arrivals provides a measure of capacity, not demand.

In order to correctly determine demand, we must account for the customers who arrived at the bank desiring service, but balked upon seeing long queues, as well as those customers who have altered their transaction habits to avoid times of peak demand, based on their past experience with long queues at those times.

One way to estimate how much balking is occurring at this branch at peak hours would be to compare its weekly transaction profile to that of a neighboring branch, or a branch with a similar clientele, which is perceived to be handling its peak demand at satisfactory service levels. This comparison could reveal the degree to which the demand peaks are truncated at Branch X, when demand has reached or exceeded capacity. The actual number of customers who are balking could be estimated by rounding out the demand peaks at Branch X to match those at the other branch, and calculating what number of unserved customers are contained in the truncated demand peak (Larson). Unfortunately, I didn't have access to the data necessary to perform such an analysis for this paper, but this would be a relatively easy and valuable study for the bank to perform in future demand estimates.

While any service provider would ideally like to provide high-quality service to potential customers at all times, the high costs of installing and maintaing sufficient capacity to meet peak demand often prohibits such a solution. In this case, I think it is a safe assumption that peak hour demand for ATM services at Branch X will expand to meet whatever level of service can be provided (within the limits of this expansion, anyway). In other words, the level of unsatisfied demand at peak hours is high enough so that any additional capacity will be utilized at the same high levels as the current machines.

This observation has important implications for the solution of our optimal machine mix problem. It suggests that one key criterion for determining the configuration of machines should be system capacity. Even though queuing conditions in the new lobby may be equivalent to those in the old lobby, since the customers' disutility function for queuing and crowding should remain basically unchanged, these conditions will occur at higher arrival rates, with higher capacity. By maximizing capacity, we should expect to reduce the total number of balking customers, and improve the overall level of customer service provided.

b) Service Time Distributions

The transaction data also provided a means of estimating service time distributions. I determined these distributions by manually compiling the service times shown in the transaction data for two machines over the two hour period, and then dumping the data into a spreadsheet for aggregation and analysis.

In order for the transaction data to be useful, I had to assume the system was operating at or near capacity for the whole time of the sample, and that there were queues at all times behind each of the machines I studied. This assumption allowed me to use the departure time of one customer as the arrival time of the next: the interarrival time provided an estimate of the transaction time. This method would tend to overestimate service times if there were any gap between the departure of one customer and the arrival of the next, and my data may be biased towards overestimation of service times due to that effect. However, a comparison of my estimated average service time with the results of another study where average service times were determined (Kolesar) shows agreement within 2% (my mean service time being 2% higher than that found by Kolesar).

For the purposes of this model, I had to anticipate the service time distributions for both full service ATM's and cash dispensers. The transaction data included a transaction type code which allowed me to segregate the transaction types into two categories, which I defined to reflect the capabilities of the machines to be installed in the new facility. Any transactions which included a deposit function of any kind were placed in the full service category; these will require the use of a full service ATM in the new facility. Transactions including only withdrawals, transfers, or balance inquiries were sorted into the withdrawal category; these would be within the capabilities of either kind of ATM. The sorted service times in the former category provided an upper bound for the input service time distribution for the full service machines in the model, while the sorted service times for transactions in the latter category represents the input for the service time distribution for the cash dispensers in the model.

Effects of Customer Mix on Service Time Distributions

The service time distribution for the full service machines will be a function of how many withdrawal customers are using those machines, since varying the density of relatively quick withdrawal transactions on the full service machines shifts the service time distribution up and down. From the transaction data, I determined service time distributions for ATM's with 100% withdrawal transactions, 100% deposit transactions, and a mix of 75% withdrawals/25% deposits (which happened to be the overall mix of customers in the hours of the data). From those, I interpolated expected distributions for other mixes of transactions on the full service machines: 60%W/40%D, 50%W/50%D, and 25%W/75%D. A chart and table showing service time distributions for the various customer mixes is presented in Appendix I.

c) Customer Mix

The mix of customers requiring different kinds of transactions varies by day, week, and month, and determination of the extreme limits of this mix is important for determining the appropriate number of full service ATM's and cash dispensers in the new facility. Peak load on the system will most likely occur when the customer mix is most heavily weighted with depositors, as their expected transaction times are longest. I looked at both monthly and peak hour data for the current system to determine this range.

Surprisingly, the mix of full service transactions at peak hour was not significantly different from the overall monthly mix; both showed about 25% deposit transactions. Since the transaction data was for a Friday lunch hour, I would have expected a significantly higher percentage of deposit transactions, though this was the second Friday of the month, and it might be that the last Friday would show a greater density of deposits. For the purposes of this project, I assumed rather conservatively that the maximum mix of depositors for a given period was 35%.

d) Patterns of Customer Behavior

A final group of variables falls into the category "patterns of behavior". While these behaviors cannot be perfectly quantified, they must be included in our model of the system in order to represent it accurately. Some of these observations were gathered from the transaction data, while others were described in conversations with people knowledgeable about the system and ATM's in general.

First, personal observation and transaction data suggests that customers have a general preference for full service ATM's over cash dispensers. In ATM installations which have only two machines, one of each type, customers faced with the choice of a cash dispenser or a full service ATM with no queue for either will generally choose the full service machine regardless of their transaction needs. This behavior is included in the decision structure of customers in the model to as great a degree as possible, but I suggest that at the times of peak demand, customers will optimize to minimize their expected wait. If customers are not familiar with the cash dispensers when the lobby is first opened, they will learn quickly as they disoover the expected service time is shorter.

Second, I note the maximum queues which have been witnessed in the current lobby by various parties close to this project. Observations are generally for times when the bank is closed, and only seven machines are available for use. Estimates generally place the maximum queue per machine at seven to fifteen: this translates to 50 to 100 customers in the lobby at one time. This is consistent with the architects' estimates; they report observing a maximum of 100 to 120 people in the current lobby. These observations suggest a high threshold for crowding at peak times, or a highly inelastic customer demand for service at certain times. They also reinforce the earlier point that current demand as measured by transaction data severely underestimates actual demand at peak hours.

2. Experiment Design and Optimization Criteria

In order to build and run the simulations models intellegently, I had to establish the range of service conditions over which the models would be tested, develop an ordered procedure for running the models so that results would be comparable, and determine a set of performance criteria by which the operating results would be judged. Below, I describe my approach to each of these issues.

a) Inputs

I submitted each of the models to a range of service conditions, to determine which configuration of machines would provide the most robust performance. Variability of system load is a function of customer arrival rate and the overall expected service time, which is a function of the mix of arriving customers. Peak load on the system is achieved when the product of arrival rate and expected service time is at its maximum; in other words, a smaller arrival pool which is heavily weighted with deposit customers, that is, customers with relatively long expected service times, may present a higher system load than a larger arrival pool which is composed of primarily withdrawal customers, who have shorter expected service times.

From my observation that peak hour demand would increase to match whatever level of service was supplied, I decided to run all the models near capacity, in order to compare their performance at peak load. I approximated this condition by setting the mean arrival rate at nine customers per minute, which represents a utilization rate in excess of 90% in all the models tested. (This translates to a rate of 570 customers per hour, a nearly 20% increase over the arrival rate recorded in the peak hour transaction data I was provided.) I also executed a run using an arrival rate of 8.5 customers per minute, or 540 customers per hour, to see if the relative performance of the models was the same at less-than-peak conditions.

As I described in the preceding section on data collection, I found from the transaction data provided by the client that the average mix of customers to be in the ratio of 25% depositors to 75% withdrawers, and proposed that the worst case would be 35% depositors. For each of the two arrival rates mentioned above, I decided to check the models with 15%, 25%, and 35% depositors, the last of these representing the peak load scenario.

b) Procedure

Ideally, I would have liked to run each model many times, Monte Carlo style, to determine the steady state of each configuration. Unfortunately, the long duration of execution runs, multiple modeling scenarios, and large data outputs prevented me from taking this approach.

What I ended up doing instead was to run each model to simulate one hour of service, and to use the ending conditions of a first run as the initial conditions of a second one-hour run. If the end conditions of this second run were close to the initial conditions, I knew that I had a close approximation of the steady state conditions. I used the output of these runs as a basis for comparing the models.

While the output of these models is an imperfect predictor of actual system performance, it does provides a means of comparing the various configurations of machines, which is the goal of this modeling exercise.

c) Optimization Criteria

Given the above modeling limitations, I evaluated the relative performance of the various machine configurations running with the same inputs and initial conditions. The variables I considered in comparing the runs included, in order of importance: system capacity, over a broad range of conditions; percent of customers delayed, overall and by type of transaction desired; expected delay for delayed customers, all customers, and by type of transaction desired; and expected queue length overall and by transaction type.

Because the output of the models cannot be taken as perfect representation of steady state conditions, the only one of these variables which I could confidently compare across models was capacity. I could tell which models were running closer to capacity by observing how many customers were served without queuing, and whether there were relatively less or more customers in queue at the end of the hour than at the beginning. The other results were also useful for comparing the models, but I put somewhat less weight on them as decision criteria.

It is difficult to judge how second-order effects may distort these decision criteria. The transaction capacity provided by the best of these systems may lead to an overload in another part of the system. For example, under the peak conditions simulated in the models, 570 customers must enter and leave the ATM lobby each hour through one set of double doors. The capacity of the system may in the end be determined by customer reaction to those kinds of limitations, in which case the configuration of the system could be relatively unimportant.

3. Model Development

In this section, I will describe the general structure and features of the models, after a brief discussion of how I decided to use the software package STELLA to perform the modeling.

(A complete presentation of the models is provided in Appendix 2. That Appendix includes a complete diagram of the model and the program code.)

a) Why STELLA?

While STELLA is not a conventional choice for simulation, I was unable to find a standard simulation program for my Apple Macintosh personal computer, and I felt that STELLA had a number of strengths to recommend its use for this purpose.

First, the structure and language of the program is very simple, and I was able to develop the logic of the models fairly quickly and intuitively. Second, the execution of the program was animated, so that the program logic as it represented customer decision rules could be observed in real time. This feature led to faster debugging, and a more intuitive understanding of how the model (and the real system) were affected by different customer decision rules. I also felt this animated execution feature could be an effective means of presentation to the client, if the program revealed any powerful insights which might be difficult to explain verbally or numerically. Finally, the output of the program could be downloaded into a spreadsheet in tabular form for analysis.

Having built and used STELLA for simulation modeling, I now understand its weaknesses for this kind of analysis, but still respect some of its strengths. The primary problem I experienced was that the execution of the models in their final form was too slow to run Monte Carlo style simulations, even on a faster Macintosh II Computer. In the end, I was forced to compare the results of single runs for each configuration of ATM's, rather than the averaged results of a large number of runs. I tried to make the runs more comparable by seeding the random numbers identically in all of the models, but this was largely unsuccessful, as the seeded random numbers generated in STELLA are dependent on the specifid compiled code in which the seeds exist. While the systematic effects of different machine combinations generally outweighed the noise created by the stochastic inputs and outputs, highly variable arrival rates generally made definitive conclusions difficult.

Another problem was the creation of stochastic arrival and service distributions in a program which is designed to run time-based, rather than event-paced simulations. Once I did clear these programming hurdles, the output was rather cumbersome to download into a spreadsheet, as the time-based simulation necessarily carries a lot of time intervals where nothing actually happened in the model. This would not be a problem in a system where the arrivals were more widely spaced, as larger time increments could be used within tolerable limits of accuracy. The arrival rate of one customer every 1.5 to 2 seconds in this model required a very small time increment and thus generated extremely large tables of data.

A final problem was that I was never able to derive a mathematical expression to describe the effect of customer mix and arrival rate on expected service time for the full service ATM's. For this reason, I was forced to settle on approximations to the service time distributions; I developed a set of six to cover all circumstances, and this may have led to significant approximation errors.

In retrospect, I think the problem is solveable with a simulation approach; unfortunately, I am not confident that I was able to do it here, largely for the reasons outlined above.

b) Features of the Models

The three models I built to simulate the different configurations of ATM's share the same logical structure, which is shown in abbreviated diagrammatic form following this section. The structure features stochastic arrival times, service time distributions taken from actual transaction data, and decision rules based on the observed behavior of customers in the current facility.

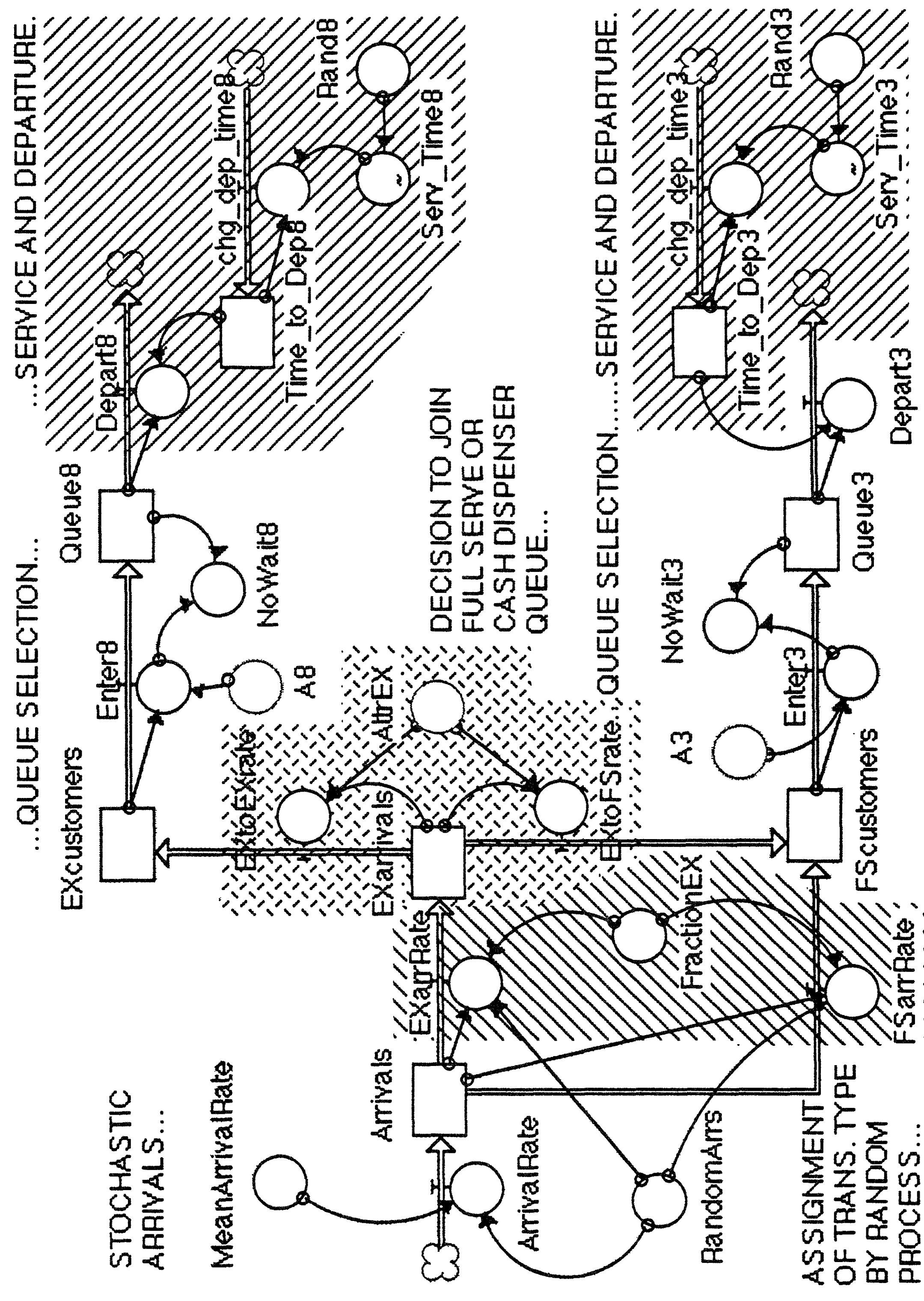
The key logical assumptions are the following. First, customers in the model use cash dispensers only if the shortest line for a cash dispenser is of equal or shorter length than the shortest line for a full service ATM. As lines get longer in near-capacity conditions, this assumption may not be completely accurate, as customers may perceive that joining a longer line for a cash dispenser would give them a shorter expected wait than joining a shorter full service line. This shortcoming in the model is not a major problem, as I found that this decision rule was critical only under very specific service conditions, when demand for full service machines was basically at capacity. In general, I am confident that this assumption leads to accurate results.

Another assumption implicit in the model is that customers, once they they have decided whether they will use a cash dispenser or a full service ATM, will join the queue which is shortest, or closest to their point of entry in the case of equal queues. While this assumes optimal behavior and perfect information on the part of the customers, it appears to be consistent with customer behavior at the current facility. In a model of the current facility, I was able to simulate the pattern of diminising demand at either end of the row of nine ATM's; at the new facility, I anticipate diminishing demand on the machines as they get farther from the lobby entrance near the street.

Finally, I assumed that customers would not switch lines once they had made their initial selection; this assumption is obviously at odds with the actual system, since some jockeying will always take place as customers see adjacent lines moving more quickly and leave their queue to join another. Observation of customer behavior leads me to believe that this is not as big a compromise as it may seem, as I saw numerous cases where machines would stand vacant while customers stood in line for occupied machines. This inclination to stay in the line one originally joined may result from the fear that another customer will get to the open machine first, leaving the switcher with possibly a longer expected wait than they would have had in their original line. Given this observed behavior, and the fact that imbalances in the queues in this model are very short-lived, given the high rates of arrival, I feel this lack of line switching is not an intolerable compromise. If anything, I suspect the model may represent customer behavior as more rational than it actually is in practice.

I assembled three models to simulate the following ATM configurations: eight full service machines and two cash dispensers, six full service machines and four cash dispensers, and four full service machines and six cash dispensers. Had time permitted, I would have also liked to check system performance with three and five cash dispensers; fortunately, I was able to look at these possibilities using a numerical approximation method.

Figure Showing the Logical Structure of the Models



c) Output

The output from the model included the real-time animation of the system, which included graphs of the queue lengths plotted over time, plus all the performance criteria outlined above under optimization criteria. Examples of model output are presented in Appendix 3.

4. Model Execution

I ran each of the models with the inputs and initial conditions as described above, and present the compiled results of the runs in the next section.

C. Results

I will first present the results of the simulation runs, and then a numerical approximation of the system, based on mean ATM service times, and finally the conclusions of a brief experiment in which I simulated the results of a single queue approach.

1. Results of Simulations

The results presented in Appendix Three do not offer strong conclusions about which configuration will provide the best service. In the first set of nine runs, which was supposed to simulate a peak load arrival rate of 570 customers per hour, arrivals ranged from 545 to 580, due to variation in the random arrival function across the models. This made the ATM configurations very difficult to compare, since differences in service quality could be overshadowed by the substantial differences in arrival rates.

There was one very clear conclusion from this run, however. With the concentration of depositors at 35% of arrivals, the model with only four full service machines was incapable of handling the load: the lines for the full service machines just kept growing. This suggests that that configuration of machines may not have the robust performance we are seeking.

The second set of runs, which were supposed to simulate an arrival rate of 540 customers per hour, gave a much more tightly distributed range of arrivals across the different models, but at lower than desired levels, from 467 to 476. Unfortunately, at these lower arrival rates, the difference in performance between the machines is less significant; one could make a case for any of the configurations being preferable, depending on which performance variables one favors.

The results of these simulations were imperfect, but leave us slightly wiser: it appears that six cash dispensers will be too many, and that, as expected, the mix of machines will only be critical at peak loads.

2. Numerical Approximation

A by-product of the modeling exercise was the insight which enabled me to do an approximate calculation of the peak capacities of the different ATM configurations. This solution is also presented in Appendix Three.

The approach is simple, but not easy to describe. For the different densities of depositors on the full service ATM's, there is an associated mean service time. I calculated the number of customers that could be served in an hour on one of these machines based on this mean service time. For the cash dispensers, the mean service time is always the same; I calculated the hourly throughput for these machines as well. Given these values, I calculated the capacity of the ten-machine system, based on different mixes of machines and customers.

The next step was to calculate what the mix of customers would use the full service machines, given the range of customer mix and machine configurations presented above. For example, we must determine what percentage of customers on full service machines will be withdrawers, given an arriving customer mix of 35% depositors and 65% withdrawers, and a machine configuration of seven full service ATM's and three cash dispensers.

Once I had this calculation, I could find which capacities were attainable under each of the machine mix and customer mix combinations. In the second page of tables, the percentage numbers in the boxes represent machine mix/customer mix combinations which are consistent: the percentage of withdrawers on the full service machines is at least as great as the percentage assumed in the capacity calculation. Looking back at the first page, I can then check the capacity which corresponds to the consistent combinations, and try to optimize the mix of machines.

By this method, the range of system capacities is not very wide under similar scenarios: the capacity improvement offered by having an extra cash dispenser is only 10 to 20 people per hour. One reason for this is that this approach doesn't account for the greater variance of service times on the full service machines: including the variance in the calculations would tend to make cash dispensers relatively more attractive.

The numerical approximation to a solution is not significantly more conclusive than the simulation runs, but together they leave us with a better understanding of the system. First, the system doesn't seem to be highly sensitive to the number of cash dispensers within our test conditions, as long as that number is less than or equal to four. Second, the mix of machines in these formulations didn't affect system performance dramatically, partly because the models were imperfect, but partly because the range of service times is not very large under average conditions.

3. Single Queue Simulations

Despite all the barriers to a single queue system described in the previous chapter, I decided to check the performance of such an approach using one of the simulation models. Assuming average arrival conditions of 75% withdrawers, and ten full service ATM's, system performance at an arrival rate of 570 per hour was quite satisfactory: the maximum line was 20 customers, and the steady state queue was around eight.

I found this result to be encouraging, so I modified the model somewhat to account for the additional time it would take customers walk from the head of the queue to the open machine. I added 20 seconds to the transaction times for the machine farthest from the head of the queue, 18 to the next farthest, and so on down to 2 seconds for the ATM nearest the queue. This change had a dramatic effect on system performance, as would be expected: even at a lower arrival rate of 540 customers per hour, the line was still growing after an hour. It appears that the benefit of having customers immediately behind each machine, ready to begin the next transaction immediately, outweighs the efficiency of the single queue.

V. RECOMMENDATIONS AND CONCLUSIONS

From the above analyses, I recommend that the client place four cash dispensers in the new lobby, in the four locations closest to the entry. Full service ATM's would fill the remaining six locations. I feel that this configuration will provide the highest level of service to customers, and result in the best distribution and movement of customers through the space, which will minimize their perception of crowding.

The perception management approach offered some other solutions which I think would improve how customers will experience the new lobby. The most compelling of these are: installing televisions above the ATM's to distract customers in line; installing mirrors to allow entering customers to view and compare all of the queues at a glance; informing customers about both the rationale and the expected service times for the cash dispensers, using both signage and mailings; designing customer flows to minimize interaction, as by placing the cash machines closest to the entry; and finally, making it easy for customers to use the adaptive strategies they have already developed, as by placing the full service machines out of the main flow of traffic. The only additional measure that should be mentioned is the ongoing monitoring of customer reactions to the new lobby after it has opened, as this analysis may not have anticipated every key factor which will influence customer experiences. These recommendations all could improve the perceived and actual functioning of the new lobby.

The operations research approach did not uncover as great an opportunity for improvement of the performance of the system as I had anticipated, but it did show that the bank could install up to four costless cash dispensers, saving over $100,000, and improve the quality of service at the same time. The other contribution of the operations research and modeling approach was that it forced the identification and collection of pertinent data, an explicit statement of how the ATM system functions, and an objective reconciling of analytical results with observed activity. All of these can and should lead to better tracking and gathering of transaction data relevant to management of the ATM facilities, as well as an improved general level of understanding of these systems.

The perception management and operations research approaches were highly complimentary in assessing the levels of service both perceived and provided by this facility. Analyses similar to this one will prove invaluable to service companies in the future, as they come to rely more heavily on technology, and less on humans, to perform what used to be referred to as "face-to-face" transactions and services.

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A.

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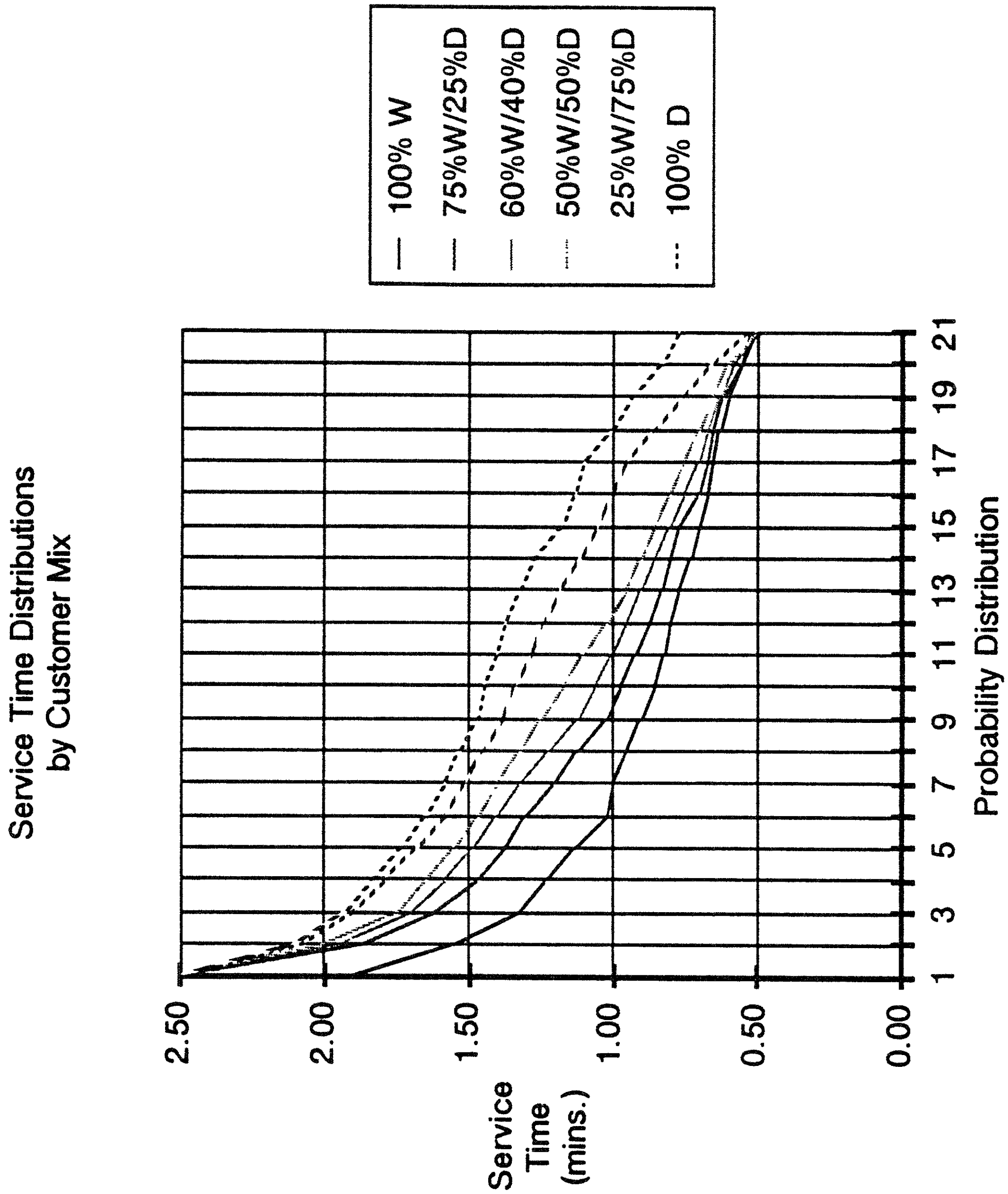
VII. APPENDIX 1: INPUT DATA

A. Service Time Distributions



Appendix1A:
Service Time Distribution by Customer Mix

	Customer Mix					
		75%W/	60%W/	50%W/	25%W/	
P(t)	100% W	25%D	40%D	50%D	75%D	100% D
0.00	1.90	2.50	2.50	2.50	2.50	2.50
0.05	1.55	1.87	1.95	2.00	2.08	2.10
0.10	1.33	1.62	1.70	1.75	1.90	1.93
0.15	1.23	1.47	1.58	1.65	1.79	1.83
0.20	1.13	1.37	1.48	1.55	1.68	1.73
0.25	1.02	1.30	1.40	1.47	1.58	1.65
0.30	1.00	1.20	1.32	1.40	1.51	1.58
0.35	0.95	1.12	1.22	1.32	1.45	1.53
0.40	0.90	1.02	1.12	1.25	1.38	1.47
0.45	0.85	0.97	1.06	1.17	1.34	1.45
0.50	0.82	0.92	1.00	1.10	1.28	1.40
0.55	0.80	0.87	0.95	1.02	1.24	1.37
0.60	0.77	0.83	0.90	0.95	1.18	1.32
0.65	0.73	0.80	0.85	0.90	1.11	1.27
0.70	0.70	0.77	0.80	0.85	1.05	1.17
0.75	0.67	0.70	0.75	0.80	1.00	1.13
0.80	0.65	0.67	0.70	0.75	0.95	1.10
0.85	0.63	0.65	0.67	0.70	0.85	1.00
0.90	0.60	0.62	0.63	0.65	0.75	0.93
0.95	0.55	0.55	0.58	0.60	0.65	0.83
1.00	0.50	0.52	0.50	0.50	0.53	0.77
Mean Service Time	0.92	1.06	1.13	1.18	1.32	1.43
Standard Deviation	0.35	0.49	0.51	0.51	0.49	0.43

(W = Withdrawals, D = Deposits)

VIII. APPENDIX 2: THE MODEL

A. Technical Reasons for a Simulation Model

Several features of this queuing system prevent an approach using standard mathematical queuing equations. First, the common theoretical models of multi-server queuing systems generally assume entering customers form a single line upon entering the system, from which they advance on a first-come, first-served basis to the servers as they become avaliable. Since the ATM lobby doesn't have a single queue, but multiple queues, one for each server, these methods can't be applied. Even if we were able to implement a single-line queueing system in the lobby, the theoretical solutions available to evaluate the performance of such systems require a service function with certain characteristics (i.e. a symmetric exponential distribution with a standard deviation equal to the mean), which this situation does not provide.

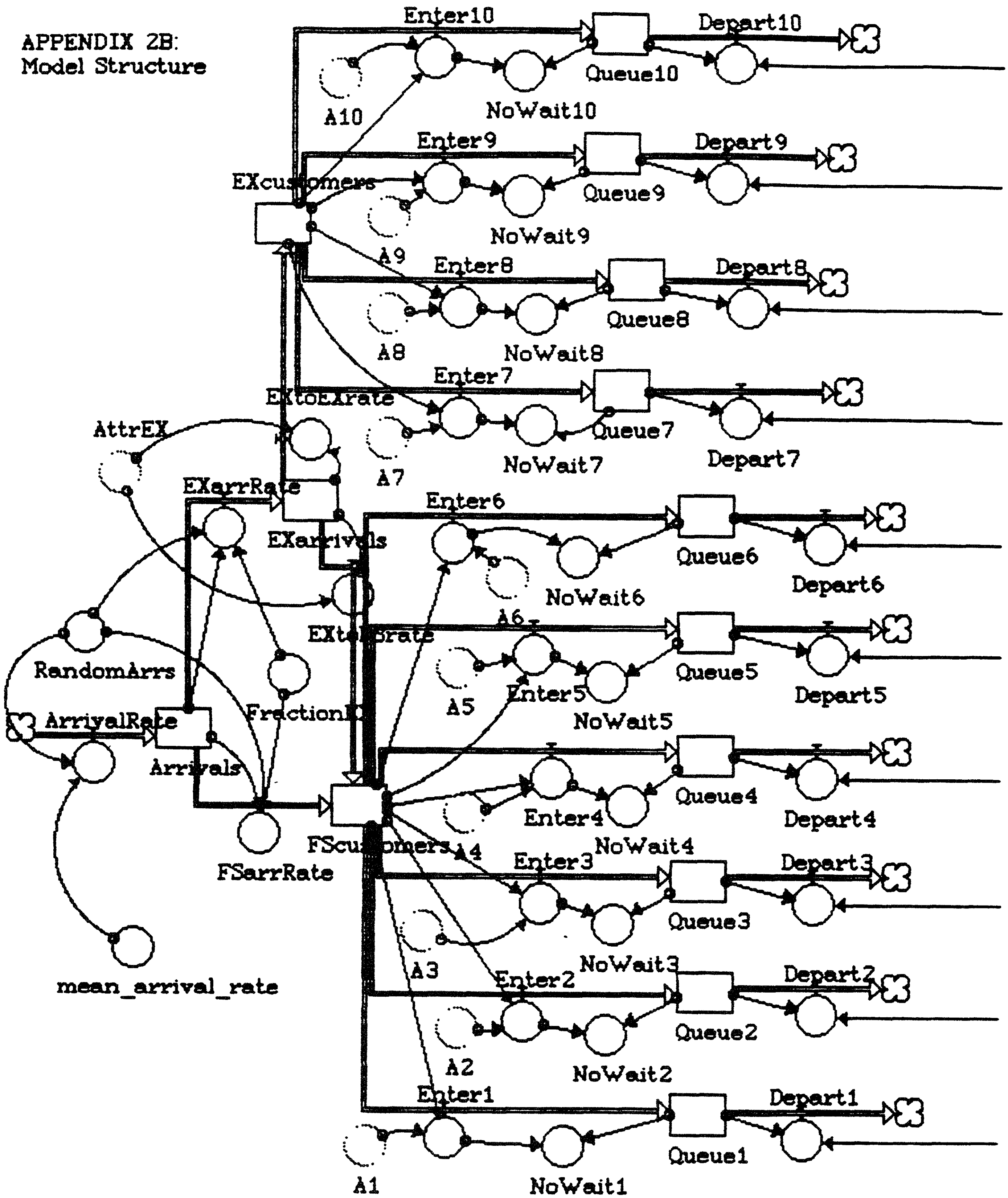
Second, the system involves some non-linear relationships which would be difficult to capture in approaches other than simulation. For example, the relationship between and among the three key variables: the mix of full service ATM's and cash dispensers, the percentage of arriving customers requiring the use of full service ATM's, and the distribution of service times for full service ATM's, became clear only through the simulation exercise. My intuitive understanding of this relationship when I first approached the problem was insufficient to take a more theoretical approach.

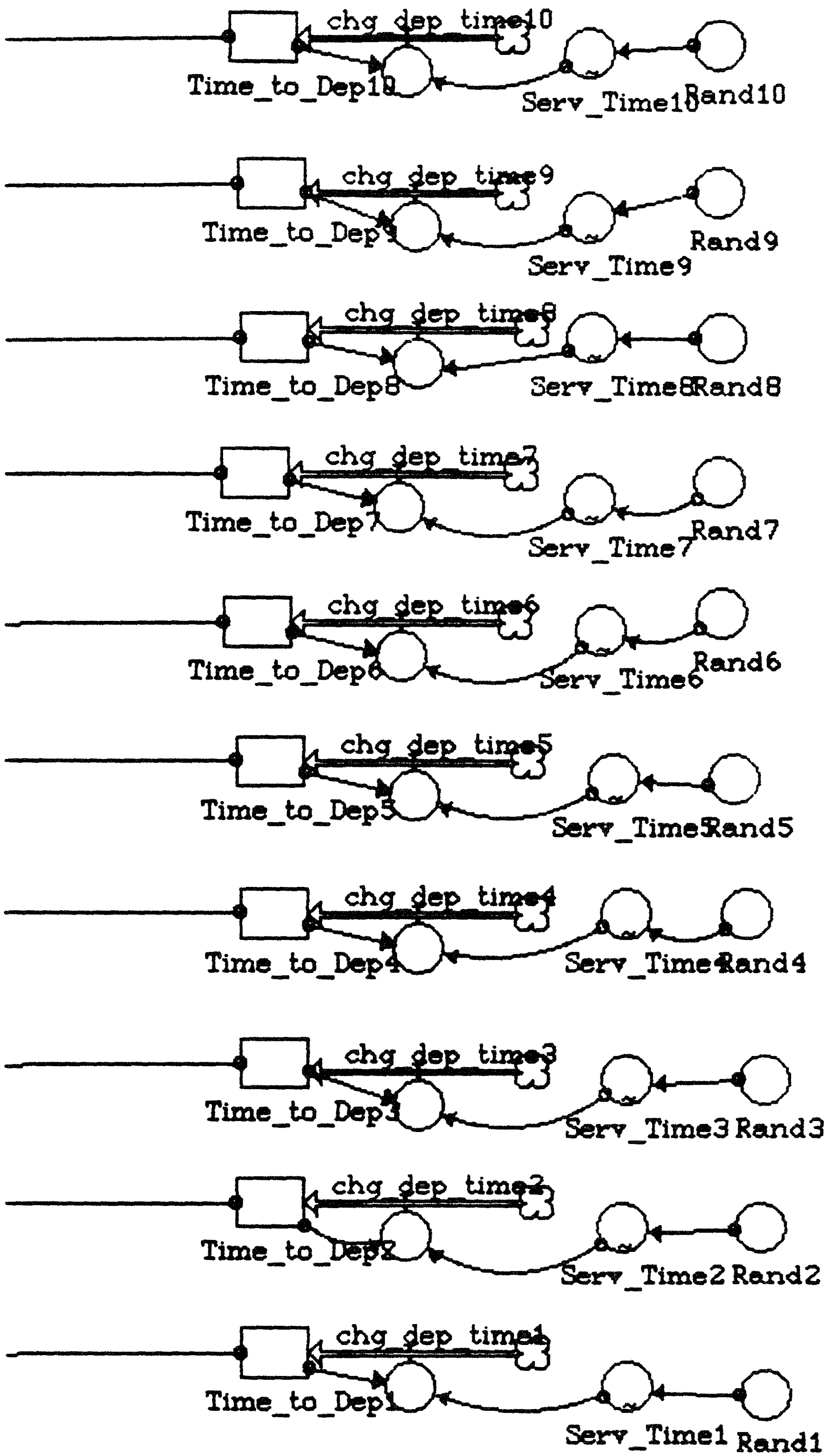
Third, I felt the effects of the decision rules used by customers to select which line they would join could be more easily incorporated in a simulation model than in a theoretical approach.

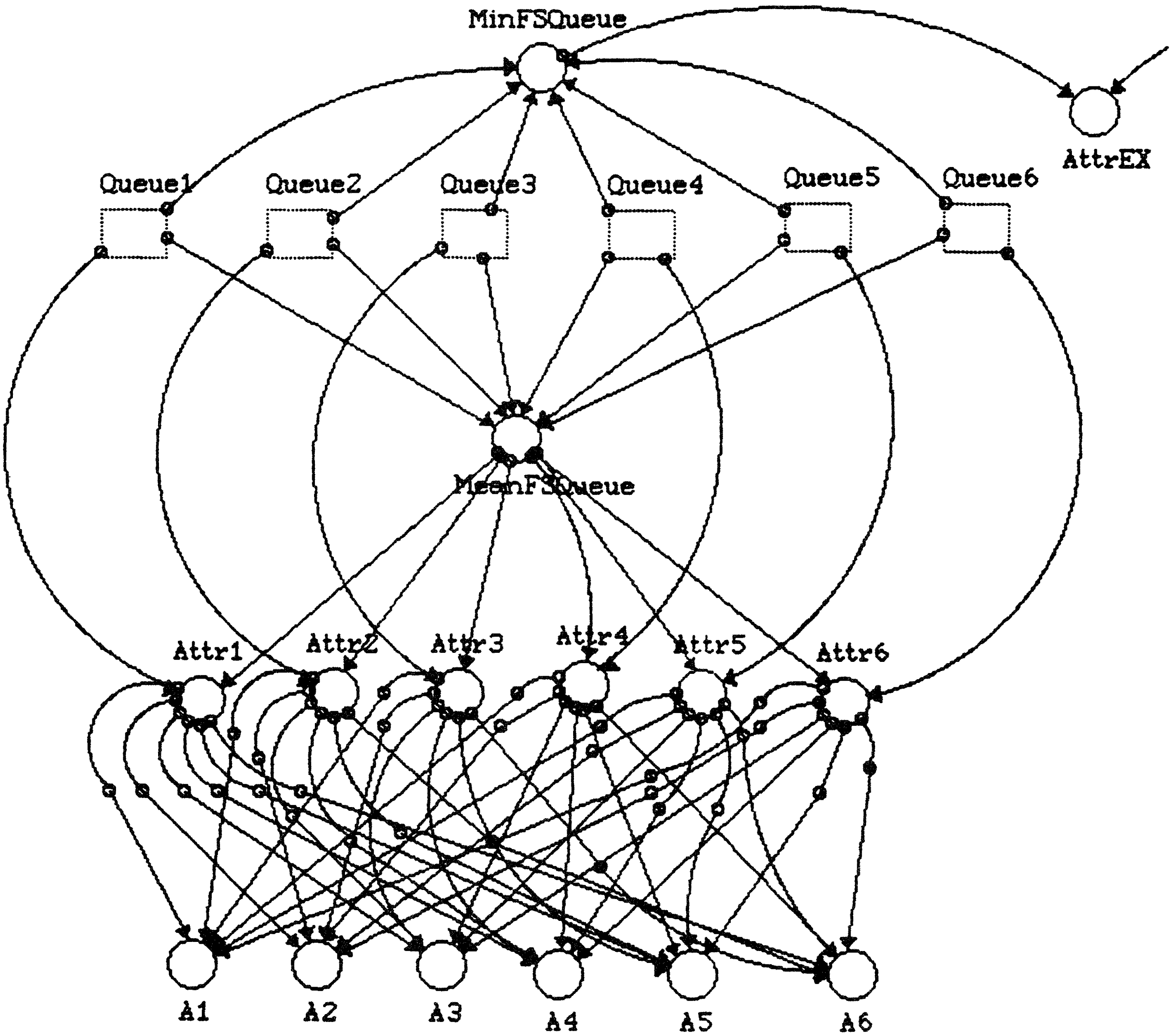
B. Structure

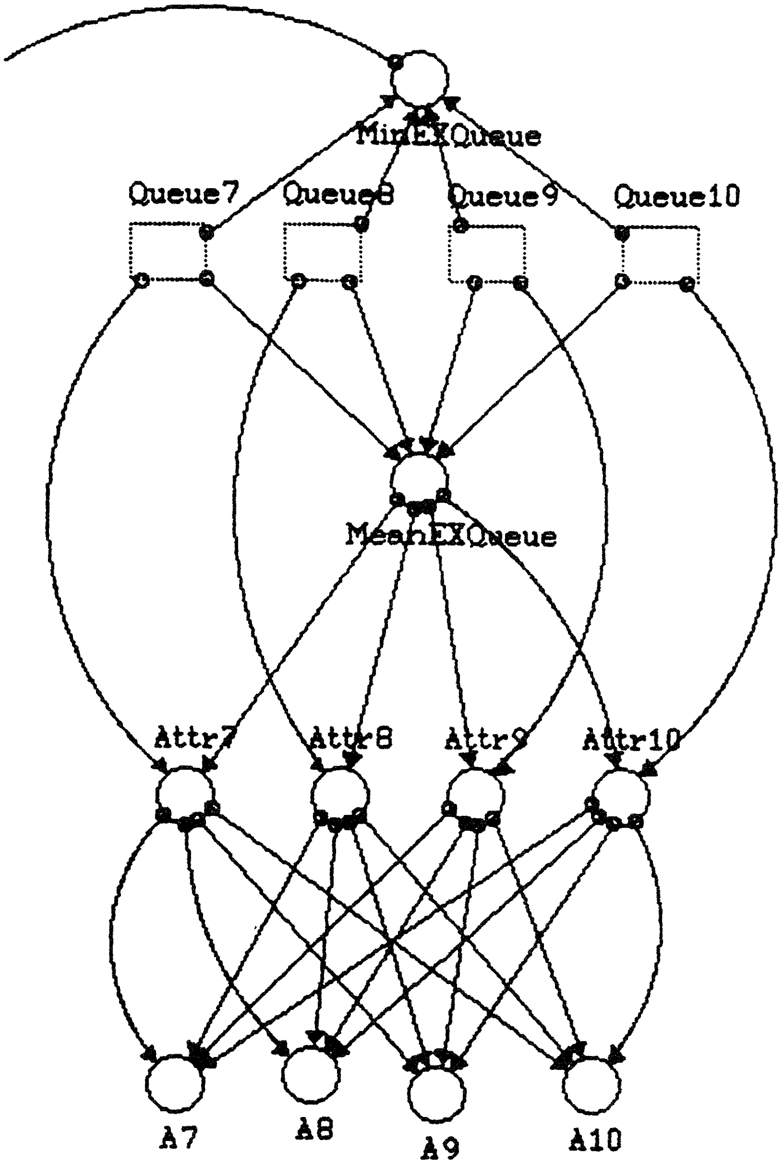
C. Equations

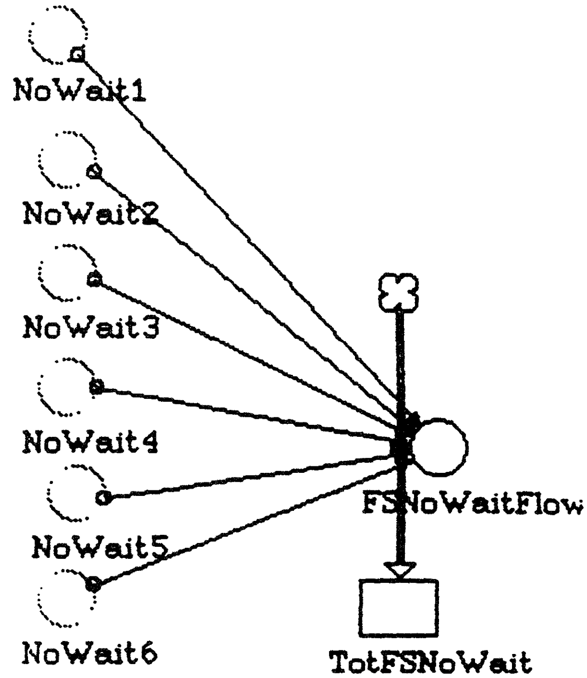
APPENDIX 2B:
Model Structure

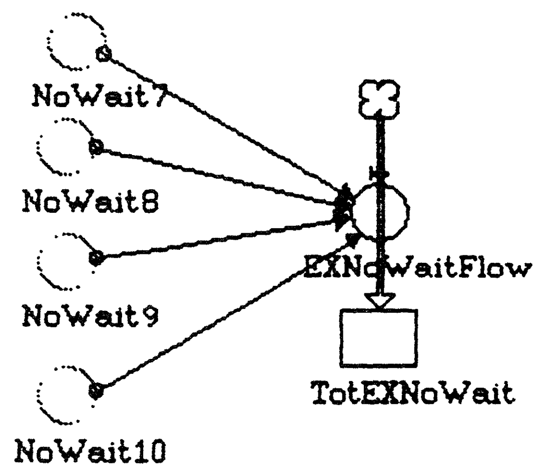



chg_dep_time10
Time_to_Dep10
Serv_Time10
Rand10
chg_dep_time9
Time_to_Dep9
Serv_Time9
Rand9
chg_dep_time8
Time_to_Dep8
Serv_Time8
Rand8
chg_dep_time7
Time_to_Dep7
Serv_Time7
Rand7
chg_dep_time6
Time_to_Dep6
Serv_Time6
Rand6
chg_dep_time5
Time_to_Dep5
Serv_Time5
Rand5
chg_dep_time4
Time_to_Dep4
Serv_Time4
Rand4
chg_dep_time3
Time_to_Dep3
Serv_Time3
Rand3
chg_dep_time2
Time_to_Dep2
Serv_Time2
Rand2
chg_dep_time1
Time_to_Dep1
Serv_Time1
Rand1


MinFSQueue
AttrEX
Queue1
Queue2
Queue3
Queue4
Queue5
Queue6
MeanFSQueue
Attr1
Attr2
Attr3
Attr4
Attr5
Attr6
A1
A2
A3
A4
A5
A6


MinEXQueue
Queue7
Queue8
Queue9
Queue10
MeanEXQueue
Attr7
Attr8
Attr9
Attr10
A7
A8
A9
A10


NoWait1
NoWait2
NoWait3
NoWait4
NoWait5
NoWait6
FSNoWaitFlow
TotFSNoWait


NoWait7
NoWait8
NoWait9
NoWait10
EXNoWaitFlow
TotEXNoWait

APPENDIX 2C:
STELLA Model Equations

```
Arrivals = Arrivals + dt * ( -FSarrRate + ArrivalRate - EXarrRate)
INIT(Arrivals) = 0
EXarrivals = EXarrivals + dt * (EXarrRate - EXtoFSrate -
EXtoEXrate)
INIT(EXarrivals) = 0
EXcustomers = EXcustomers + dt * ( EXtoEXrate - Enter10 - Enter9
- Enter8 - Enter7 )
INIT(EXcustomers) = 0
FScustomers = FScustomers + dt * ( FSarrRate - Enter5 - Enter4 -
Enter3 - Enter2 - Enter1 - Enter6 + EXtoFSrate )
INIT(FScustomers) = 0
Queue1 = Queue1 + dt * ( Enter1 - Depart1 )
INIT(Queue1) = 3
Queue10 = Queue10 + dt * ( Enter10 - Depart10 )
INIT(Queue10) = 3
Queue2 = Queue2 + dt * ( Enter2 - Depart2 )
INIT(Queue2) = 3
Queue3 = Queue3 + dt * ( Enter3 - Depart3 )
INIT(Queue3) = 3
Queue4 = Queue4 + dt * ( Enter4 - Depart4 )
INIT(Queue4) = 3
Queue5 = Queue5 + dt * ( Enter5 - Depart5 )
INIT(Queue5) = 3
Queue6 = Queue6 + dt * ( Enter6 - Depart6 )
INIT(Queue6) = 3
Queue7 = Queue7 + dt * ( Enter7 - Depart7 )
INIT(Queue7) = 3
Queue8 = Queue8 + dt * ( Enter8 - Depart8 )
INIT(Queue8) = 3
Queue9 = Queue9 + dt * ( Enter9 - Depart9 )
INIT(Queue9) = 3
Time_to_Dep1 = Time_to_Dep1 + dt * ( chg_dep_time1 )
INIT(Time_to_Dep1) = TIME + Serv_Time1
Time_to_Dep10 = Time_to_Dep10 + dt * ( chg_dep_time10 )
INIT(Time_to_Dep10) = TIME + Serv_Time10
Time_to_Dep2 = Time_to_Dep2 + dt * ( chg_dep_time2 )
INIT(Time_to_Dep2) = TIME + Serv_Time2
Time_to_Dep3 = Time_to_Dep3 + dt * ( chg_dep_time3 )
INIT(Time_to_Dep3) = TIME + Serv_Time3
Time_to_Dep4 = Time_to_Dep4 + dt * ( chg_dep_time4 )
INIT(Time_to_Dep4) = TIME + Serv_Time4
Time_to_Dep5 = Time_to_Dep5 + dt * ( chg_dep_time5 )
INIT(Time_to_Dep5) = TIME + Serv_Time5
```

APPENDIX 2C:
STELLA Model Equations

```
Time_to_Dep6 = Time_to_Dep6 + dt * ( chg_dep_time6 )
INIT(Time_to_Dep6) = TIME + Serv_Time6
Time_to_Dep7 = Time_to_Dep7 + dt * ( chg_dep_time7 )
INIT(Time_to_Dep7) = TIME + Serv_Time7
Time_to_Dep8 = Time_to_Dep8 + dt * ( chg_dep_time8 )
INIT(Time_to_Dep8) = TIME + Serv_Time8
Time_to_Dep9 = Time_to_Dep9 + dt * ( chg_dep_time9 )
INIT(Time_to_Dep9) = TIME + Serv_Time9
TotEXNoWait = TotEXNoWait + dt * ( EXNoWaitFlow )
INIT(TotEXNoWait) = 0
TotFSNoWait = TotFSNoWait + dt * ( FSNoWaitFlow )
INIT(TotFSNoWait) = 0
A1 = If Attr1=MAX (Attr1,Attr2,Attr3,Attr4,Attr5,Attr6) THEN 1 ELSE 0
A10 = If Attr10 =MAX (Attr7,Attr8,Attr9,Attr10) THEN 1 ELSE 0
A2 = If Attr2=MAX(Attr1,Attr2,Attr3,Attr4,Attr5,Attr6) THEN 1 ELSE 0
A3 = If Attr3=MAX(Attr1,Attr2,Attr3,Attr4,Attr5,Attr6) THEN 1 ELSE 0
A4 = If Attr4=MAX(Attr1,Attr2,Attr3,Attr4,Attr5,Attr6) THEN 1 ELSE 0
A5 = If Attr5=MAX(Attr1,Attr2,Attr3,Attr4,Attr5,Attr6) THEN 1 ELSE 0
A6 = If Attr6=MAX(Attr1,Attr2,Attr3,Attr4,Attr5,Attr6) THEN 1 ELSE 0
A7 = If Attr7 = MAX (Attr7,Attr8,Attr9,Attr10) THEN 1 ELSE 0
A8 = If Attr8 = MAX (Attr7,Attr8,Attr9,Attr10) THEN 1 ELSE 0
A9 = If Attr9 = MAX (Attr7,Attr8,Attr9,Attr10) THEN 1 ELSE 0
ArrivalRate = IF (mean_arrival_rate*DT>RandomArrs) THEN (1/DT)
ELSE 0
Attr1 = IF (Queue1≤0) THEN (.1^(-1)) ELSE
(1.002*(Queue1/MeanFSQueue))^(-.985)
Attr10 = IF (Queue10≤0) THEN (.1^(-.975)) ELSE
(1.0035*(Queue10/MeanEXQueue))^(-.975)
Attr2 = IF (Queue2≤0) THEN (.1^(-.99)) ELSE
(1.0025*(Queue2/MeanFSQueue))^(-.99)
Attr3 = IF (Queue3≤0) THEN (.1^(-.98)) ELSE
(1.003*(Queue3/MeanFSQueue))^(-.98)
Attr4 = IF (Queue4≤0) THEN (.1^(-.975)) ELSE
(1.0035*(Queue4/MeanFSQueue))^(-.975)
Attr5 = IF (Queue5≤0) THEN (.1^(-.97)) ELSE
(1.003*(Queue5/MeanFSQueue))^(-.97)
Attr6 = IF (Queue6≤0) THEN (.1^(-.965)) ELSE
(1.0025*(Queue6/MeanFSQueue))^(-.965)
Attr7 = IF (Queue7≤0) THEN (.1^(-1)) ELSE
(1.002*(Queue7/MeanEXQueue))^(-.985)
Attr8 = IF (Queue8≤0) THEN (.1^(-.99)) ELSE
(1.0025*(Queue8/MeanEXQueue))^(-.99)
Attr9 = IF (Queue9≤0) THEN (.1^(-.98)) ELSE
```

APPENDIX 2C:
STELLA Model Equations

```
(1.003*(Queue9/MeanEXQueue))^(-.98)
AttrEX = IF (MinEXQueue≤MinFSQueue) THEN 1 ELSE 0
chg_dep_time1 = IF (Time_to_Dep1 > TIME) THEN 0 ELSE (((TIME
+Serv_Time1)-Time_to_Dep1)/DT)
chg_dep_time10 = IF (Time_to_Dep10 > TIME) THEN 0 ELSE (((TIME
+Serv_Time10)-Time_to_Dep10)/DT)
chg_dep_time2 = IF (Time_to_Dep2 > TIME) THEN 0 ELSE (((TIME
+Serv_Time2)-Time_to_Dep2)/DT)
chg_dep_time3 = IF (Time_to_Dep3 > TIME) THEN 0 ELSE (((TIME
+Serv_Time3)-Time_to_Dep3)/DT)
chg_dep_time4 = IF (Time_to_Dep4 > TIME) THEN 0 ELSE (((TIME
+Serv_Time4)-Time_to_Dep4)/DT)
chg_dep_time5 = IF (Time_to_Dep5 > TIME) THEN 0 ELSE (((TIME
+Serv_Time5)-Time_to_Dep5)/DT)
chg_dep_time6 = IF (Time_to_Dep6 > TIME) THEN 0 ELSE (((TIME
+Serv_Time6)-Time_to_Dep6)/DT)
chg_dep_time7 = IF (Time_to_Dep7 > TIME) THEN 0 ELSE (((TIME
+Serv_Time7)-Time_to_Dep7)/DT)
chg_dep_time8 = IF (Time_to_Dep8 > TIME) THEN 0 ELSE (((TIME
+Serv_Time8)-Time_to_Dep8)/DT)
chg_dep_time9 = IF (Time_to_Dep9 > TIME) THEN 0 ELSE (((TIME
+Serv_Time9)-Time_to_Dep9)/DT)
Depart1=IF(TIME ≥ Time_to_Dep1) AND (Queue1≥1) THEN (1/DT) ELSE 0
Depart10 = IF (TIME ≥ Time_to_Dep10) AND (Queue10 ≥ 1) then (1/DT)
else 0
Depart2=IF (TIME≥Time_to_Dep2) AND (Queue2≥1) THEN (1/DT) ELSE 0
Depart3=IF (TIME≥Time_to_Dep3) AND (Queue3≥1) THEN (1/DT) ELSE 0
Depart4=IF (TIME≥Time_to_Dep4) AND (Queue4≥1) THEN (1/DT) ELSE 0
Depart5=IF (TIME≥Time_to_Dep5) AND (Queue5≥1) THEN (1/DT) ELSE 0
Depart6=IF (TIME≥Time_to_Dep6) AND (Queue6≥1) THEN (1/DT) ELSE 0
Depart7=IF (TIME≥Time_to_Dep7) AND (Queue7≥1) THEN (1/DT) ELSE 0
Depart8=IF (TIME≥Time_to_Dep8) AND (Queue8≥1) THEN (1/DT) ELSE 0
Depart9=IF (TIME ≥ Time_to_Dep9) AND (Queue9≥1) then (1/DT) else 0
Enter1 = If (FScustomers≥1) AND (A1 = 1) then (1/DT) ELSE 0
Enter10 = If (EXcustomers≥1) AND (A10 = 1) then (1/DT) else 0
Enter2 = If (FScustomers≥1) AND (A2 = 1) then (1/DT) else 0
Enter3 = If (FScustomers≥1) AND (A3 = 1) then (1/DT) else 0
Enter4 = If (FScustomers≥1) AND (A4 = 1) then (1/DT) else 0
Enter5 = If (FScustomers≥1) AND  (A5=1) THEN (1/DT) ELSE 0
Enter6 = If (FScustomers≥1) AND (A6 = 1) then (1/DT) else 0
Enter7 = If (EXcustomers≥1) AND (A7 = 1) then (1/DT) else 0
Enter8 = If (EXcustomers≥1) AND (A8 = 1) then (1/DT) else 0
Enter9 = If (EXcustomers≥1) AND (A9 = 1) then (1/DT) else 0
```

APPENDIX 2C:
STELLA Model Equations

```
EXarrRate = IF (Arrivals>0) AND (RandomArrs≤FractionEX) THEN
(1/DT) ELSE 0
EXNoWaitFlow = (NoWait7+NoWait8+NoWait9+NoWait10)
EXtoEXrate = IF (EXarrivals>0) AND (AttrEX=1) THEN (1/DT) ELSE 0
{Rate at which EXcustomers choose EXpress cash machines}
EXtoFSrate = IF (EXarrivals>0) AND (AttrEX=0) THEN (1/DT) ELSE 0
{Rate at which EXpress customers defect to full service machines}
FractionEX = .75
FSarrRate = IF (Arrivals>0) AND (RandomArrs>FractionEX) THEN
(1/DT) ELSE 0
FSNoWaitFlow =
(NoWait1+NoWait2+NoWait3+NoWait4+NoWait5+NoWait6)
MeanEXQueue = (Queue7+Queue8+Queue9+Queue10)/4
MeanFSQueue = (Queue1+Queue2+Queue3+Queue4+Queue5+Queue6)/6
mean_arrival_rate = 9
MinEXQueue = MIN(Queue7,Queue8,Queue9,Queue10)
MinFSQueue = MIN(Queue1,Queue2,Queue3,Queue4,Queue5,Queue6)
NoWait1 = IF (Enter1=50) AND (Queue1≤0) THEN (1/DT) ELSE 0
NoWait10 = IF (Enter10=50) AND (Queue10≤0) THEN (1/DT) ELSE 0
NoWait2 = IF (Enter2=50) AND (Queue2≤0) THEN (1/DT) ELSE 0
NoWait3 = IF (Enter3=50) AND (Queue3≤0) THEN (1/DT) ELSE 0
NoWait4 = IF (Enter4=50) AND (Queue4≤0) THEN (1/DT) ELSE 0
NoWait5 = IF (Enter5=50) AND (Queue5≤0) THEN (1/DT) ELSE 0
NoWait6 = IF (Enter6=50) AND (Queue6≤0) THEN (1/DT) ELSE 0
NoWait7 = IF (Enter7=50) AND (Queue7≤0) THEN (1/DT) ELSE 0
NoWait8 = IF (Enter8=50) AND (Queue8≤0) THEN (1/DT) ELSE 0
NoWait9 = IF (Enter9=50) AND (Queue9≤0) THEN (1/DT) ELSE 0
Rand1 = RANDOM(1)
Rand10 = RANDOM(10)
Rand2 = RANDOM(22)
Rand3 = RANDOM(333)
Rand4 = RANDOM(4444)
Rand5 = RANDOM(55555)
Rand6 = RANDOM(666666)
Rand7 = RANDOM(7777777)
Rand8 = RANDOM(88888888)
Rand9 = RANDOM(999999999)
RandomArrs = RANDOM(1234567)
Serv_Time1 = graph(Rand1)
(0.0,2.50),(0.0500,2.00),(0.100,1.75),(0.150,1.65),(0.200,1.55),(0.250,1.47),(0.3
00,1.40),(0.350,1.32),(0.400,1.25),(0.450,1.17),(0.500,1.10),(0.550,1.02),(0.600
,0.950),(0.650,0.900),(0.700,0.850),(0.750,0.800),(0.800,0.750),(0.850,0.700),(
0.900,0.650),(0.950,0.600),(1.00,0.500)
```

APPENDIX 2C:
STELLA Model Equations

Serv_Time10 = graph(Rand10)
(0.0,1.90),(0.0500,1.55),(0.100,1.33),(0.150,1.23),(0.200,1.13),(0.250,1.02),(0.3
00,0.980),(0.350,0.950),(0.400,0.900),(0.450,0.850),(0.500,0.820),(0.550,0.800
),(0.600,0.770),(0.650,0.730),(0.700,0.700),(0.750,0.670),(0.800,0.650),(0.850,
0.630),(0.900,0.600),(0.950,0.550),(1.00,0.500)
Serv_Time2 = graph(Rand2)
(0.0,2.50),(0.0500,2.00),(0.100,1.75),(0.150,1.65),(0.200,1.55),(0.250,1.47),(0.3
00,1.40),(0.350,1.32),(0.400,1.25),(0.450,1.17),(0.500,1.10),(0.550,1.02),(0.600
,0.950),(0.650,0.900),(0.700,0.850),(0.750,0.800),(0.800,0.750),(0.850,0.700),(
0.900,0.650),(0.950,0.600),(1.00,0.500)
Serv_Time3 = graph(Rand3)
(0.0,2.50),(0.0500,2.00),(0.100,1.75),(0.150,1.65),(0.200,1.55),(0.250,1.47),(0.3
00,1.40),(0.350,1.32),(0.400,1.25),(0.450,1.17),(0.500,1.10),(0.550,1.02),(0.600
,0.950),(0.650,0.900),(0.700,0.850),(0.750,0.800),(0.800,0.750),(0.850,0.700),(
0.900,0.650),(0.950,0.600),(1.00,0.500)
Serv_Time4 = graph(Rand4)
(0.0,2.50),(0.0500,2.00),(0.100,1.75),(0.150,1.65),(0.200,1.55),(0.250,1.47),(0.3
00,1.40),(0.350,1.32),(0.400,1.25),(0.450,1.17),(0.500,1.10),(0.550,1.02),(0.600
,0.950),(0.650,0.900),(0.700,0.850),(0.750,0.800),(0.800,0.750),(0.850,0.700),(
0.900,0.650),(0.950,0.600),(1.00,0.500)
Serv_Time5 = graph(Rand5)
(0.0,2.50),(0.0500,2.00),(0.100,1.75),(0.150,1.65),(0.200,1.55),(0.250,1.47),(0.3
00,1.40),(0.350,1.32),(0.400,1.25),(0.450,1.17),(0.500,1.10),(0.550,1.02),(0.600
,0.950),(0.650,0.900),(0.700,0.850),(0.750,0.800),(0.800,0.750),(0.850,0.700),(
0.900,0.650),(0.950,0.600),(1.00,0.500)
Serv_Time6 = graph(Rand6)
(0.0,2.50),(0.0500,2.00),(0.100,1.75),(0.150,1.65),(0.200,1.55),(0.250,1.47),(0.3
00,1.40),(0.350,1.32),(0.400,1.25),(0.450,1.17),(0.500,1.10),(0.550,1.02),(0.600
,0.950),(0.650,0.900),(0.700,0.850),(0.750,0.800),(0.800,0.750),(0.850,0.700),(
0.900,0.650),(0.950,0.600),(1.00,0.500)
Serv_Time7 = graph(Rand7)
(0.0,1.90),(0.0500,1.55),(0.100,1.33),(0.150,1.23),(0.200,1.13),(0.250,1.02),(0.3
00,0.980),(0.350,0.950),(0.400,0.900),(0.450,0.850),(0.500,0.820),(0.550,0.800
),(0.600,0.770),(0.650,0.730),(0.700,0.700),(0.750,0.670),(0.800,0.650),(0.850,
0.630),(0.900,0.600),(0.950,0.550),(1.00,0.500)
Serv_Time8 = graph(Rand8)
(0.0,1.90),(0.0500,1.55),(0.100,1.33),(0.150,1.23),(0.200,1.13),(0.250,1.02),(0.3
00,0.980),(0.350,0.950),(0.400,0.900),(0.450,0.850),(0.500,0.820),(0.550,0.800
),(0.600,0.770),(0.650,0.730),(0.700,0.700),(0.750,0.670),(0.800,0.650),(0.850,
0.630),(0.900,0.600),(0.950,0.550),(1.00,0.500)
Serv_Time9 = graph(Rand9)
(0.0,1.90),(0.0500,1.55),(0.100,1.33),(0.150,1.23),(0.200,1.13),(0.250,1.02),(0.3
00,0.980),(0.350,0.950),(0.400,0.900),(0.450,0.850),(0.500,0.820),(0.550,0.800

),(0.600,0.770),(0.650,0.730),(0.700,0.700),(0.750,0.670),(0.800,0.650),(0.850,
0.630),(0.900,0.600),(0.950,0.550),(1.00,0.500)

IX. APPENDIX 3: OUTPUT

A. Charts Showing Simulation Results

1. Case 1: £ = 570 customers per hour
2. Case 2: £ = 540 customers per hour

B. Numeric Solution

C. Sample STELLA Output

1. Copies of model in process
2. Graphs of Queues through simulated interval

APPENDIX 3A1:
CHART OF RESULTS FOR SIMULATION RUN #1

% Depositors of Arrivals	Arrival Rate = 9.0/min. = 570/hr.	Full Serve/Cash Dispenser Ratio: 8/2	6/4	4/6
35%	Total Customer Arrivals:	580	562	546
	# Using Cash Dispensers:	132	260	356
	# Using Full Service ATM's:	448	302	190
	# W Customers Using FS ATM's:	224	96	0
	% of Trans's. on FS ATM's which are W's:	50%	32%	0%
	% Assumed in the Model:	50%	25%	0%
	# of Withdrawers who don't wait in line:	0%	0	83
	# of Depositors who don't wait in line:	0	0	0
	% of All Customers who don't wait:	0%	0%	0%
	Average Overall Queue Length:	4.74	4.14	4.01
	Average Queue for Cash Dispensers:	5.03	4.12	1.82
	Average Queue for FS ATM's:	4.67	4.14	7.30
	Initial # of Customers in Queue (total):	30	30	30
	# of Customers in Queue at end (total):	54	52	52
	Maximum queue at Cash Dispenser:	7	6	4
	Maximum queue length at FS ATM:	6	6	11

APPENDIX 3A1:

CHART OF RESULTS FOR SIMULATION RUN #1 (continued)

% Depositors of Arrivals	Arrival Rate = 9.0/min. = 570/hr.	Full Serve/Cash Dispenser Ratio: 8/2	6/4	4/6
	Total Customer Arrivals:	575	561	545
25%	# Using Cash Dispensers:	126	252	364
	# Using Full Service ATM's:	449	309	181
	# W Customers Using FS ATM's:	282	156	39
	% of Trans's. on FS ATM's which are W's:	63%	50%	22%
	% Assumed in the Model:	60%	50%	25%
	# of Withdrawers who don't wait in line:	0	0	80
	# of Depositors who don't wait in line:	0	0	17
	% of All Customers who don't wait:	0%	0%	18%
	Average Overall Queue Length:	3.09	3.42	2.45
	Average Queue for Cash Dispensers:	3.36	3.58	2.10
	Average Queue for FS ATM's:	3.02	3.32	2.45
	Initial # of Customers in Queue (total):	30	30	30
	# of Customers in Queue at end (total):	31	30	15
	Maximum queue at Cash Dispenser:	5	5	5
	Maximum queue length at FS ATM:	5	5	5

APPENDIX 3A1:

CHART OF RESULTS FOR SIMULATION RUN #1 (Continued)

% Depositors of Arrivals	Arrival Rate = 9.0/min. = 570/hr.	Full Serve/Cash Dispenser Ratio: 8/2	6/4	4/6
15%	Total Customer Arrivals:	558	552	548
	# Using Cash Dispensers:	124	245	366
	# Using Full Service ATM's:	434	307	182
	# W Customers Using FS ATM's:	339	218	97
	% of Trans's. on FS ATM's which are W's:	78%	71%	53%
	% Assumed in the Model:	75%	75%	50%
	# of Withdrawers who don't wait in line:	15	49	96
	# of Depositors who don't wait in line:	91	106	55
	% of All Customers who don't wait:	19%	28%	28%
	Average Overall Queue Length:	2.15	1.94	2.00
	Average Queue for Cash Dispensers:	2.49	2.14	2.05
	Average Queue for FS ATM's:	2.07	1.81	1.92
	Initial # of Customers in Queue (total):	30	30	30
	# of Customers in Queue at end (total):	16	13	10
	Maximum queue at Cash Dispenser:	5	5	5
	Maximum queue length at FS ATM:	5	5	5

APPENDIX 3A2:

CHART OF RESULTS FOR SIMULATION RUN #2

% Depositors of Arrivals	Arrival Rate = 8.5/min. = 540/hr.	Full Serve/Cash Dispenser Ratio: 8/2	6/4	4/6
35%	Total Customer Arrivals:	476	472	467
	# Using Cash Dispensers:	124	231	293
	# Using Full Service ATM's:	352	241	174
	# W Customers Using FS ATM's:	170	63	1
	% of Trans's. on FS ATM's which are W's:	48%	26%	1%
	% Assumed in the Model:	50%	25%	0%
	# of Withdrawers who don't wait in line:	76	153	244
	# of Depositors who don't wait in line:	275	174	27
	% of All Customers who don't wait:	74%	69%	58%
	Average Overall Queue Length:	0.91	0.91	1.31
	Average Queue for Cash Dispensers:	1.11	0.85	0.67
	Average Queue for FS ATM's:	0.86	0.94	2.28
	Initial # of Customers in Queue (total):	10	10	10
	# of Customers in Queue at end (total):	5	8	21
	Maximum queue at Cash Dispenser:	3	2	2
	Maximum queue length at FS ATM:	3	3	5

APPENDIX 3A2:

CHART OF RESULTS FOR SIMULATION RUN #2 (continued)

% Depositors of Arrivals	Arrival Rate = 8.5/min. = 540/hr.	Full Serve/Cash Dispenser Ratio: 8/2	6/4	4/6
25%	Total Customer Arrivals:	474	472	469
	# Using Cash Dispensers:	125	241	323
	# Using Full Service ATM's:	349	231	146
	# W Customers Using FS ATM's:	226	110	28
	% of Trans's. on FS ATM's which are W's:	65%	48%	19%
	% Assumed in the Model:	60%	50%	25%
	# of Withdrawers who don't wait in line:	79	184	276
	# of Depositors who don't wait in line:	302	177	95
	% of All Customers who don't wait:	80%	76%	79%
	Average Overall Queue Length:	0.80	0.82	0.75
	Average Queue for Cash Dispensers:	1.05	0.92	0.73
	Average Queue for FS ATM's:	0.73	0.75	0.80
	Initial # of Customers in Queue (total):	10	10	10
	# of Customers in Queue at end (total):	9	7	8
	Maximum queue at Cash Dispenser:	3	3	2
	Maximum queue length at FS ATM:	2	3	3

APPENDIX 3A2:

CHART OF RESULTS FOR SIMULATION RUN #2 (continued)

% Depositors of Arrivals	Arrival Rate = 8.5/min. = 540/hr.	Full Serve/Cash Dispenser Ratio: 8/2	6/4	4/6
15%	Total Customer Arrivals:	473	469	467
	# Using Cash Dispensers:	125	244	344
	# Using Full Service ATM's:	348	225	123
	# W Customers Using FS ATM's:	273	154	54
	% of Trans's. on FS ATM's which are W's:	78%	68%	44%
	% Assumed in the Model:	75%	75%	50%
	# of Withdrawers who don't wait in line:	82	183	293
	# of Depositors who don't wait in line:	305	199	109
	% of All Customers who don't wait:	82%	81%	86%
	Average Overall Queue Length:	0.76	0.74	0.68
	Average Queue for Cash Dispensers:	1.06	0.95	0.79
	Average Queue for FS ATM's:	0.69	0.6	0.51
	Initial # of Customers in Queue (total):	10	10	10
	# of Customers in Queue at end (total):	9	8	7
	Maximum queue at Cash Dispenser:	2	3	3
	Maximum queue length at FS ATM:	2	2	2

APPENDIX 3B:

A Numerical Approach to the ATM Configuration Problem:

	% Withdrawers on FS ATM's:					
	90%	75%	60%	50%	25%	0%
	Corresponding Mean Service Times (minutes):					
	0.97	1.06	1.13	1.18	1.32	1.43
	Capacity per Full Service ATM (trans/hour):					
	62	57	53	51	45	42
# FS ATM's	Total FS ATM Capacity (customers/hour)					
10	619	566	531	508	455	420
8	495	453	425	407	364	336
7	433	396	372	356	318	294
6	371	340	319	305	273	252
5	309	283	265	254	227	210
4	247	226	212	203	182	168
	Mean Cash Dispenser Service Time (minutes):					
	0.92	0.92	0.92	0.92	0.92	0.92
	Capacity per Cash Dispenser (trans/hour):					
# Cash	65.22	65.22	65.22	65.22	65.22	65.22
Dispensers	Total Cash Dispenser Capacity (customers/hour)					
0	0	0	0	0	0	0
2	130	130	130	130	130	130
3	196	196	196	196	196	196
4	261	261	261	261	261	261
5	326	326	326	326	326	326
6	391	391	391	391	391	391

# FS ATM's/# CD's	System Capacity (customers/hour)					
10/0	619	566	531	508	455	420
8/2	625	583	555	537	494	466
7/3	629	592	567	552	514	489
6/4	632	600	579	566	534	513
5/5	635	609	592	580	553	536
4/6	639	618	604	595	573	559

APPENDIX 3B:

A Numerical Approach to the ATM Configuration Problem (continued)

	% Withdrawers on FS ATM's:					
	90%	75%	60%	50%	25%	0%

For 35% Depositors:

# Cash Dispensers	% Withdrawals on FS ATM's is:					
0	65%	65%	65%	65%	65%	65%
2	56%	55%	54%	54%	52%	51%
3	49%	48%	47%	46%	43%	42%
4	40%	38%	36%	35%	32%	29%
5	28%	25%	22%	20%	15%	11%
6	10%	5%	1%	-2%	-10%	-17%

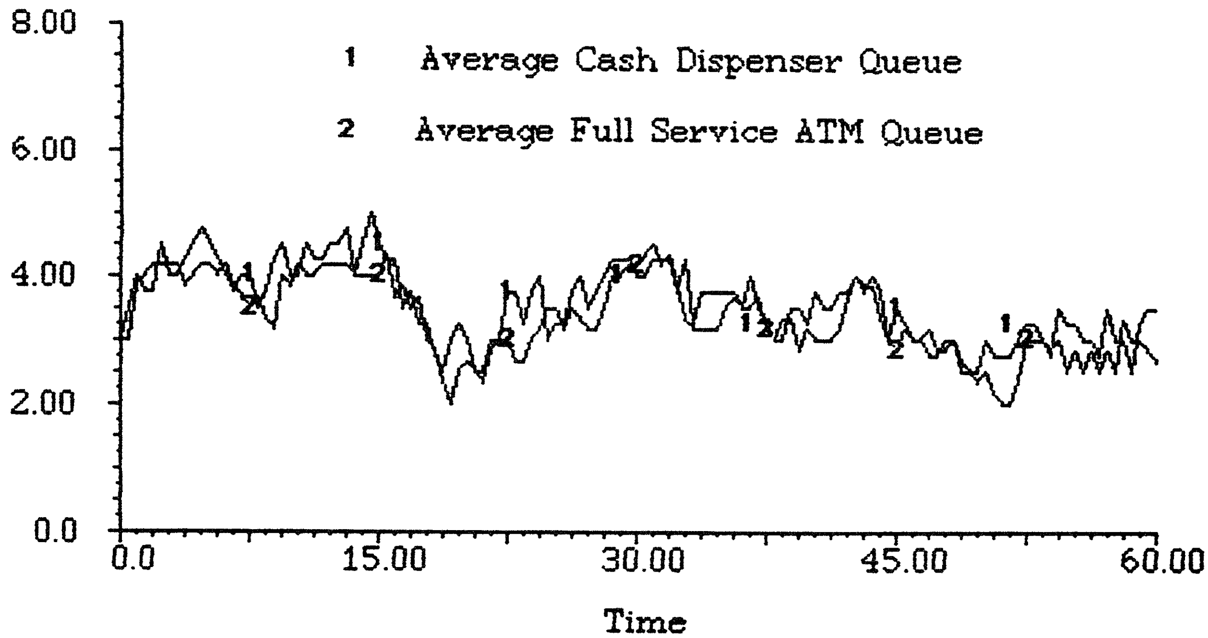
For 25% Depositors:

	% Withdrawals on FS machines is:					
0	75%	75%	75%	75%	75%	75%
2	68%	68%	67%	67%	66%	65%
3	64%	63%	62%	61%	60%	58%
4	57%	56%	55%	54%	51%	49%
5	49%	46%	44%	43%	39%	36%
6	35%	32%	29%	27%	21%	17%

For 15% Depositors:

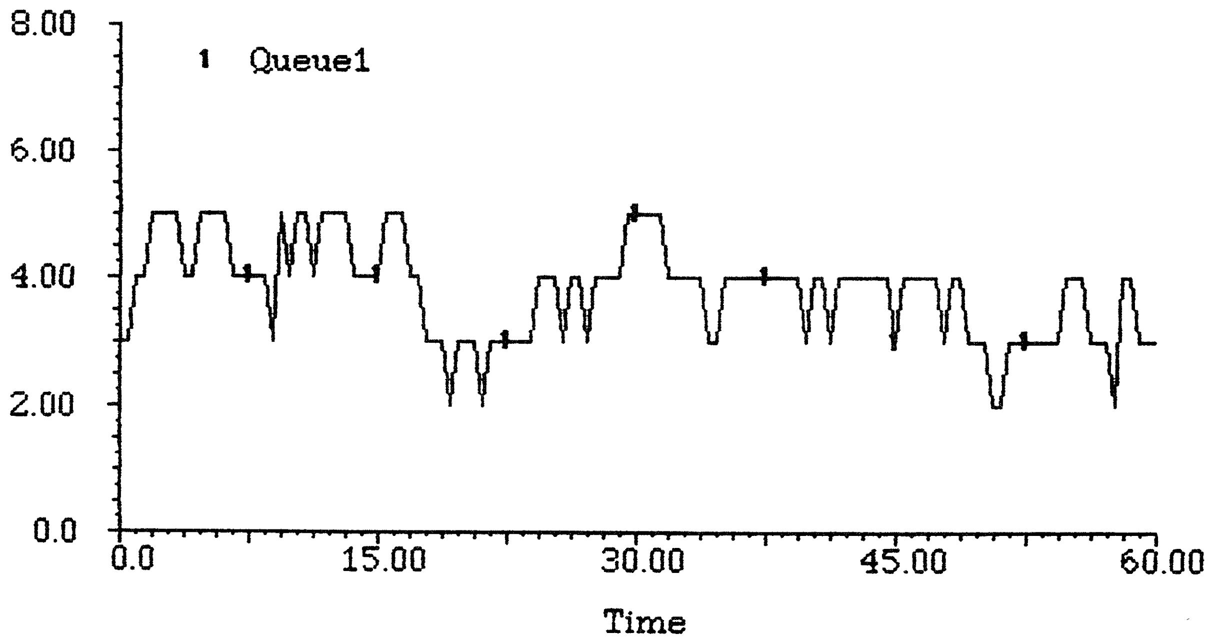
	% Withdrawals on FS machines is:					
0	85%	85%	85%	85%	85%	85%
2	81%	81%	80%	80%	80%	79%
3	78%	78%	77%	77%	76%	75%
4	74%	73%	73%	72%	71%	69%
5	69%	68%	67%	66%	63%	62%
6	61%	59%	57%	56%	53%	50%

APPENDIX 3C:
Graphs of Queues Through Simulated Interval



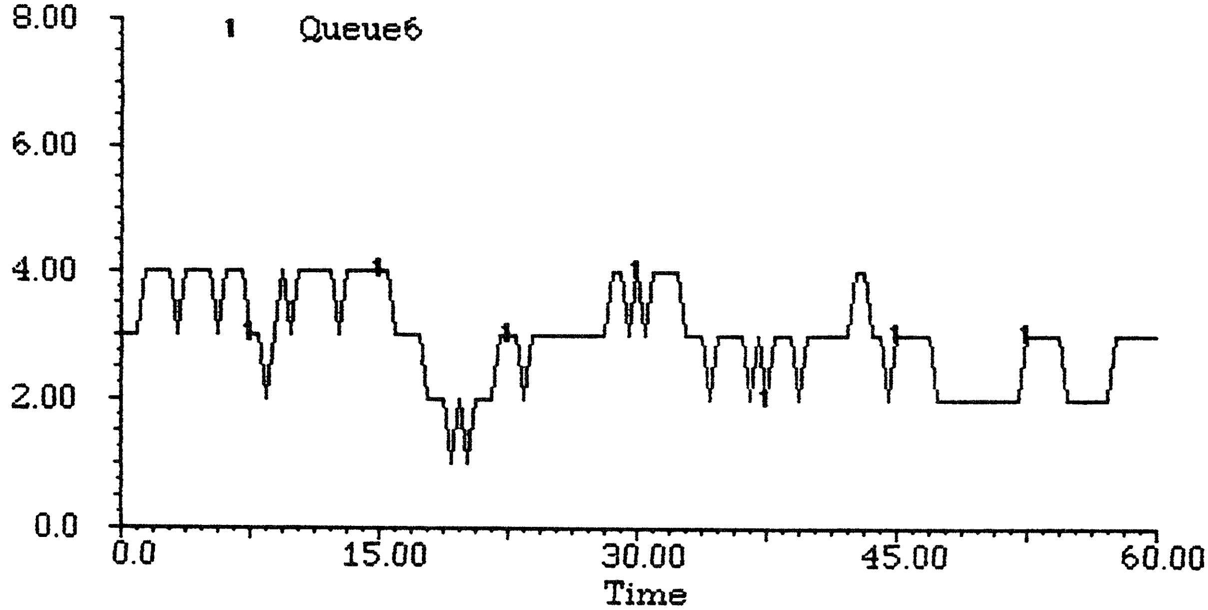
STELLA Output showing average queues for both cash dispensers and full service ATM's in steady state.
Arrival Rate = 570 customers per hour.
ATM Configuration: 4 cash dispensers
6 full serve ATM's

APPENDIX 3C:
Graphs of Queues Through Simulated Interval



STELLA Output showing queue for machine #1, a full service ATM in this model, over course of one-hour simulation.

APPENDIX 3C:
Graphs of Queues Through Simulated Interval



STELLA Output Showing Queue for Machine #6, a cash dispenser in this model, during the one-hour simulation.