MANAGEMENT POLICIES TO HANDLE MUTLI QUEUING SYSTEMS IN A SERVICE ORIENTED ORGANIZATION

A STUDY OF THE HENRI BOURASSA DRIVER LICENSING OFFICE IN THE CITY OF MONTREAL

Nadim G. Braidy

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ABSTRACT

MANAGEMENT POLICIES TO HANDLE MULTI QUEUING SYSTEMS IN A SERVICE ORIENTED ORGANIZATION:

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Service operations are often characterized as a seemingly endless series of waiting lines and servers. Almost every interaction between a consumer and the organization providing the service involves waiting in a queue. Capacity management is one response to the cry for a service performance improvement during the past decade. It represents the ability to balance demand and the capability of the service delivery system to satisfy the demand. A review of the literature reveals that an integrated approach of management strategies (demand and resources) is desirable. A feasible set of management policies to handle multi-tandem queuing systems characterized by stochastic demand is presented in this paper. This type of system is common in many high customer contact (HCC) service related organizations.

An extensive study of the city of Montreal driver licensing office (Henri Bourrassa Complex) was conducted and explored. A GPSS/H based simulation model was developed and employed to manipulate various policy variables (demand management, labor assignment and job flexibility) in an effort to provide options for increased system efficiency. The use of simulation analysis permits the incorporation of complex system characteristics, therefore providing a realistic representation of the effects of possible management actions. Customer arrival patterns during a three week period in January and July were compared using this model. Using a full-factorial design and given the statistical analysis, it was evident that a deterministic customer arrival rates produce significantly shorter mean system transit times. The results also revealed that job flexibility policy as well as the moving server model have been the most effective in decreasing the customer waiting time in the system and reducing servers idle time.

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Special thanks to my family and to my girlfriend Rima for her help, understanding and patience throughout this endeavor and the phases of my graduate studies.

This thesis is dedicated to my uncle Georges who passed away during the process of my defense.

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3.0- INTRODUCTION

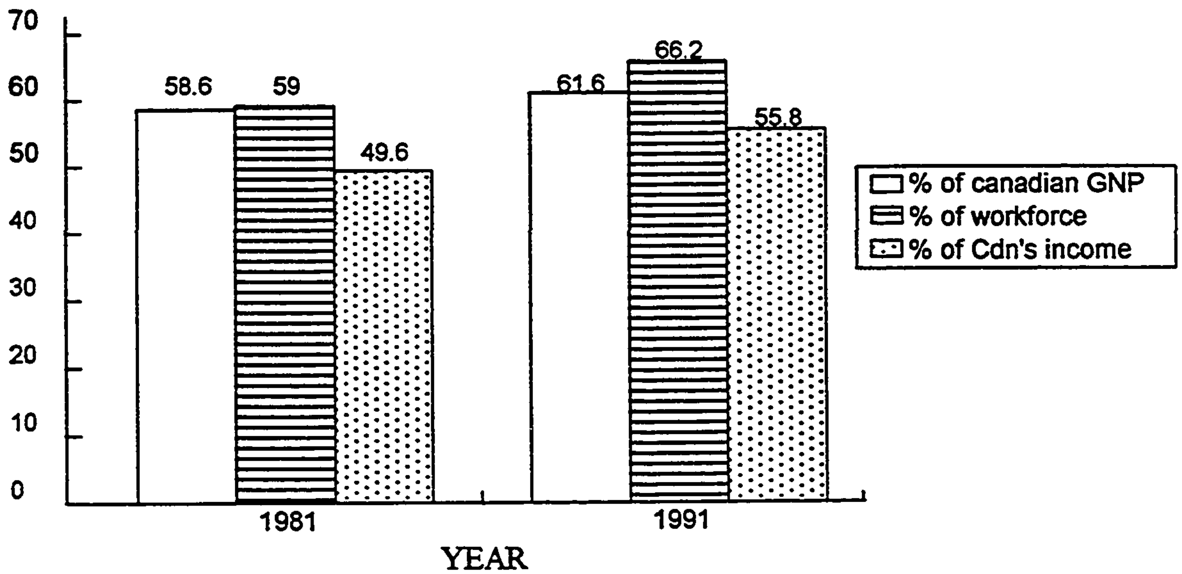
The service sector is fast-growing and has experienced significant economic increase over the past decade. In Canada, the service sector between 1980 and 1990 was exposed to around 10% increase in the total workforce (Figure 1). According to a Canadian economy observer, nearly 1.6 million jobs were created in the Canadian economy. Similarly, the United States have also been experiencing this increase in the output of their service sector which is revealed from the 85% of 12.6 million new jobs being created by this sector (Koepp, 1987). Towards the beginning of the 1990's, this translated into over 76 million U.S. workers in service related industries compared with only 25 million in more traditional manufacturing related sectors. In addition, the U.S. and Canadian service sectors also aided in diversifying their respective economies through the creation of many new job categories (for instance, specialized services for different cultures and handicaps).

Surprisingly enough, the growth in the service sectors coincided with an increase in the amount of research done on service related topics (Kaplan, 1991). A major topic concerning waiting lines and their impact on consumers' evaluations of service encounters began to arise. This new stream of research was unlike the previous management research on service time which mainly focused on consumers' perceptions of waiting (Gardner 1985). It, instead, focused on the goal of reducing actual waiting time and increasing resources utilization by effectively managing the service capacity.

As Clark, McCommon and Hammond (1990) put it, the structure of our modern society could be characterized as an endless series of waiting lines and servers. Almost every interaction between the public and those who wish to provide either a free or

Figure 1

Growth in the Canadian Service Sector in the 80's



Source : Kaplan, R.S. (1991) The Topic of Quality in Business School Education and Research. *Selection, 13-21*.

commercial service involves a "waiting" process. This phenomenon has spawned numerous Management Science techniques which attempt to find methods and tools for allocating scarce resources to meet changing demands for that resource while optimizing a function of the variables of the process. The optimized variable may be maximum profit in a commercial venture (Kramer and Bailey, 1982), it may be minimum cost in a public utility (Brachen, Calkins, Sanders and Thesen, 1985), or it may be today's most valuable resource: time, by maximizing labor productivity for various systems (Bechtold, 1991; Bechtold, Janaro and Summers, 1984). The main function or objective of a service operation characterized by High Customer Contact (H.C.C.), therefore, is low time in the system for customers and the efficient use of personnel resources in the service facilities.

During the last two decades, HCC service industries have become increasingly important to the national economy (Sasser, 1976). Employment in all types of services, such as health care, financial and government services, has increased, on average, by 2.1% during recessionary periods and 4.8% during expansion periods. In contrast, employment in the goods-producing sector has declined by an average of 8.3% and 3.8% during these same periods (Gronroos, 1990). Most importantly, the shift to employment in services (specifically in government establishments) has been accompanied by a substantial reduction in output per worker, often stated as productivity, as compared with manufacturing or agriculture. This might be due to lack of supervisory control, improper staffing, blocked lines of communication or just poor example setting.

Much of the growing economic importance of services is attributable to the generally faster rate of price increases that has characterized services as compared with goods.

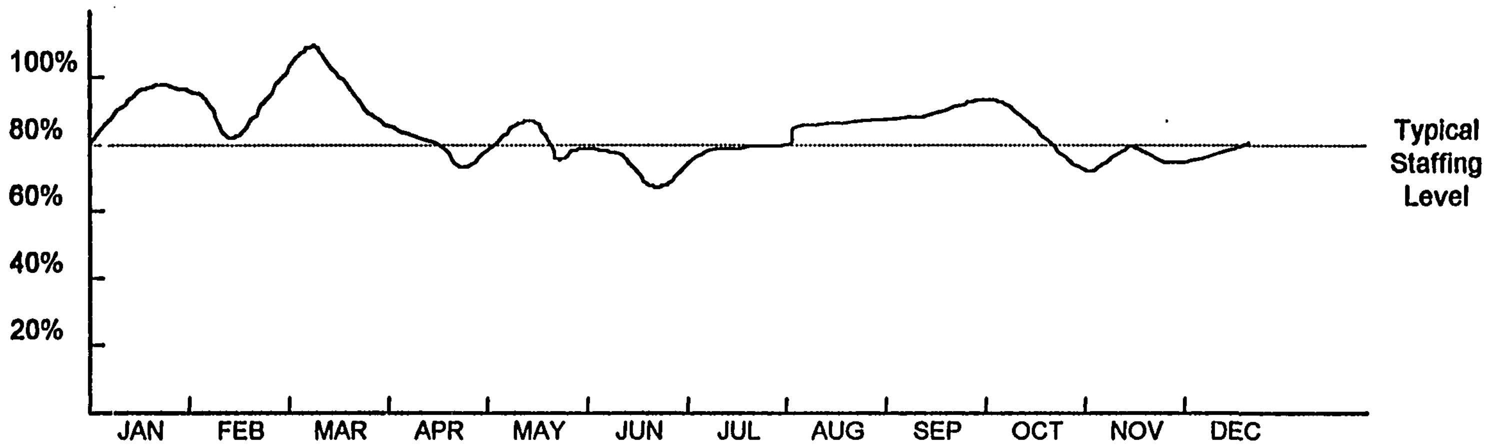
Therein lies the challenge for all HCC service operations managers to develop new management insights that will increase productivity in service organizations (Donthu 1991). His belief that this challenge cannot be met by simply adapting the present-product-oriented operations management techniques to a people-oriented endeavor. On the other hand, it is equally shortsighted to fall back on the misconception that service organizations are so unique as to be immune to the application of knowledge gained in the manufacturing sector. What is needed is a new perspective, in particular an enlarged system view that focuses on the unique characteristics of service organizations but, when appropriate, borrows from the knowledge gained in manufacturing over the past 100 years (Fitzimmons & Sullivan 1982).

In addition, the HCC service industry (specifically hospitals and government establishments) committed business "*hubris*", as it were. They believed that service operations were shielded against fluctuating demand as well as all other economic downturns . All they had to do was to provide service at a level somewhat less than capacity. The number of staff members is usually based on the average census of the prior year or an adaptation of that census. The staffing level is adjusted slightly - assigning a combination of full-time and part-time employees- to compensate for excessively high or low workloads (Bracken & al 1985). Under this arrangement, the degree to which staff are utilized differs day to day as the workload fluctuates in a random pattern over the year (Figure 2). The faults of this strategy (resulting in periods of idleness and overtime), were not obvious. However, under conditions of competition[1] and financial stringencies, HCC service operations managers can no longer justify

[1] Profit or not-for-profit service firms are subject to the same inherent limitations. Competition for profit firms could be represented as tax payers and others pressure for effectiveness on the not-for -profit ones.

Figure 2

Daily Workload as a Function of Capacity for a Service Operation



Source : Bracken *et al.(1985) A Strategy for Adaptive Staffing of Hospitals Under Varying Environmental Conditions"*. Health Care Management Review, 10,4,43-53.

extended periods of idleness or overtime and started to realize the flaws of the operating strategies.

3.1- OVERVIEW:

This thesis will model and analyze the operations of a typical service office and determine the most appropriate management policies to handle multi-tandem queuing systems characterized by stochastic demand. This type of system is common in many H.C. service related organizations. Section 4 will begin with an understanding of the common service system structures (capacity management) that is vital to improve productivity in the services sector, and discuss its different components. Section 5 takes an alternative view advocating the extent of customer contact with the service organizations as a major variable affecting system performance. Section 6 will review the literature on some effective approaches to managing service systems, especially those dominated by common complex queuing structures. Section 7 will be involved with a literature summary and its impact on the study in general. In Section 8, an extensive study of the city of Montreal driver licensing office will be presented and discussed. Based on the literature review and the study, a GPSS/H based simulation model is adapted and employed to test various design options for the system. *The multiple objectives of low time in the system for customers and the efficient use of personnel resources are employed to measure the benefits of policy options.* Finally, section 9 will conclude with a discussion about the results of the application presented in section 8, and some managerial implications for future research.

4.0- SERVICE OPERATING SYSTEMS:

Although many factors relate to improving performance in this competitive environment, a cornerstone of success involves the effective management of a service organization's current capabilities. Under cost-containment policies and the competitive environment of this decade, most institutions will need to implement policies that will permit the number of productive hours to match the workload as closely as possible (Hernandez & Kalozny, 1983).

The importance of the demand-output problem for service organization management is demonstrated by Zeithaml *et al.* (1985) in a national survey of 323 service firms. The survey sought to determine the key problems facing service managers and to identify the specific strategies used by management to overcome those problems. The results of the survey indicate that executives consider service capacity management to be the most serious issue faced by service organization, a finding consistent across all service industries sampled in the study. However, there could be an interaction between capacity management and quality management. According to Armistead and Clark (1993), many articles (Berry *et al* 1990; Collier 1987; Gronroos 1984) more often than not deal with questions relating to the definition of quality and the identification of measuring systems for quality management. While the authors recognize the influence on quality of the perceptions of management and service providers, they do not address in detail issues relating to the overall management of resources for the successful delivery of services, in particular, capacity management and the effect of service quality. Although this later has added another dimension to this problem and referred to by Collier (1987), Rhyme (1988) and Chase and Bowen (1991), management of capacity in services has received insufficient recognition.

According to Armistead (1985), the objective of service capacity management is to match the level of operations with the level of demand so as to find the best balance between cost and service levels. Voss *et al.* (1985) define service capacity management as the consideration of medium to long term demand and the development of strategies for the use of resources to accommodate changes in demand in the short term.

In addition, Sasser (1976) and Sasser *et al.* (1978) argue persuasively that services are particularly sensitive to the problems of demand variation because of their 'immediacy'. Sasser believes that the literature on service capacity management focuses on goods and manufacturing, and many researchers assume that services are merely goods with a few odd characteristics. Unfortunately, the implications of the perishability and simultaneity characteristics of services as opposed to other types of organizations were never fully explored.

When is managing service utilization the most appropriate strategy to use? Where would it make a difference in terms of decreasing the time a customer spends in the system and increasing server utilization? The next section will address these issues.

4.1- ENVIRONMENT:

HCC service systems have a high degree of interaction with their environment. Customers are direct inputs from the environment that actually become a part of the system. An environment most conducive to service capacity management of HCC service system is characterized by a <u>time perishable</u>, the <u>intangibility</u> and <u>heterogeneity</u> of the product, the <u>simultaneity</u> of production and consumption, the <u>difficulty</u> in measuring output, limited economies of scale and fluctuating demand (Chase & Bowen, 1991; Rhyme, 1988; Chase & Tansik ,1983; Slack, 1983; Thomas, 1978; Bateson, 1977; Regan, 1963).

4.1.1- Time perishable capacity:

Due to the necessity of customer-server interaction, a service is considered a 'perishable' commodity (Voss *et al.*, 1985). For instance, if a server is not in demand for a period of time, that service capacity is lost forever. Service capacity cannot be inventoried for future use. Instead, service capacity, facility utilization and idle server time must be balanced against customer waiting time. The utilization of service capacity would not be a problem, if only demand were constant. But, this is hardly the case.

4.1.2-. Wide Fluctuations in demand:

Overall, service organizations are considered inherently more inefficient than manufacturing operations (where tangible products are produced) due to the uncertainty of customer demand (Chase and Tansik, 1983). Demand for many services is highly seasonal. However, demand for services varies not only with the month of the year, but also with the day of the week and the hour of the day. Each service office will observe different demand patterns, depending on its geographical location and client orientation. This service facility must be accessible to customers. This is generally interpreted as a requirement for several, decentralized facilities located in close proximity to areas of high demand (Fitzsimmons and Sullivan, 1982). Consequently, a forecasting model may have to focus on small time intervals. Forecast of demand by hour of the day may be needed for work shift scheduling, customer routing, capacity planning and other fundamental operating decisions.

4.1.3- Intangibility of the product:

Services are intangible or much less tangible than physical goods; and because of the intangible nature of a service's output, establishing and measuring capacity levels for a service operation are often highly subjective and qualitative in nature (Sasser 1976). Consider, for example, a fast food restaurant; can demand be measured by the amount of food sold? Should the restaurant consider lost customers who depart avoiding long waiting lines? Should they consider the different attitudes of customers toward the service? Based on the above argument, the management of resources, especially labor, is considered to be extremely important in a service operation.

4.1.4-. Heterogeneity of the product:

It is difficult to establish standards for the output of a service firm and even harder to ensure that standards are met each time the service is delivered. In fact, there is a great deal of variability in the output of a single firm and even of a single service employee. The combination of the intangible nature of services and the presence of the consumer at the point of production attributes to this characteristic (Henderson *et al.* 1982). The services rendered and the output of the counter personnel for any service operation vary from day to day and from person to person on the same day.

4.1.5- Simultaneity of the production and consumption:

Service systems require a high degree of interaction with their customers, much more interaction than normally required by manufacturing systems which can produce to stock when demand is anticipated. This is because in service systems, production and consumption of service occur simultaneously. The services could include personnel information processing, knowledge and skill testing, photographing and so on, all of which require the customer's presence.

4.1.6- Diseconomies of scale:

Sizing a service to its immediate geographical market area removes the opportunity to gain economies of scale found in manufacturing. The close production marketing interface requires that the service offices must be located within the market and therefore sized for the specific market. Their fixed costs prevent their establishment in low-density population areas.

4.1.7- Difficulty in measuring output:

A service operation is an open transformation process of converting inputs (consumers) to desired outputs (satisfied customers) through the appropriate application of resources (facility, material, labor, information and the consumer as well). The indications from the survey demonstrated by Armistead and Clark (1992a and b), showed that organizations are not well equipped to measure when they are running out of capacity and they do not have strategies to cope in these circumstances. Measurement where it does occur, generally lags the event. The result is that it is inevitable that customers will often experience a fall in service quality. Whether this is significant may well be a function of whether other service providers are getting better at measuring the service delivery to minimize this effect on their customers. More importantly, can the system's performance be based on evaluating output alone when this assumes a homogeneous input? A more definitive evaluation of service performance is a measure of the change in each consumer from input to output state, a process known as a transactional analysis (Fitzimmons and Sullivan, 1982).

Here, there may be an analogy with the sinking of the Titanic. The captain and crew knew what icebergs were about but failed to measure what was happening. When things did go wrong and an iceberg was struck, the expectation was that this would not sink the ship. It did and more quickly than expected! A lesson in the need to measure and plan for a crisis and have a coping strategy.

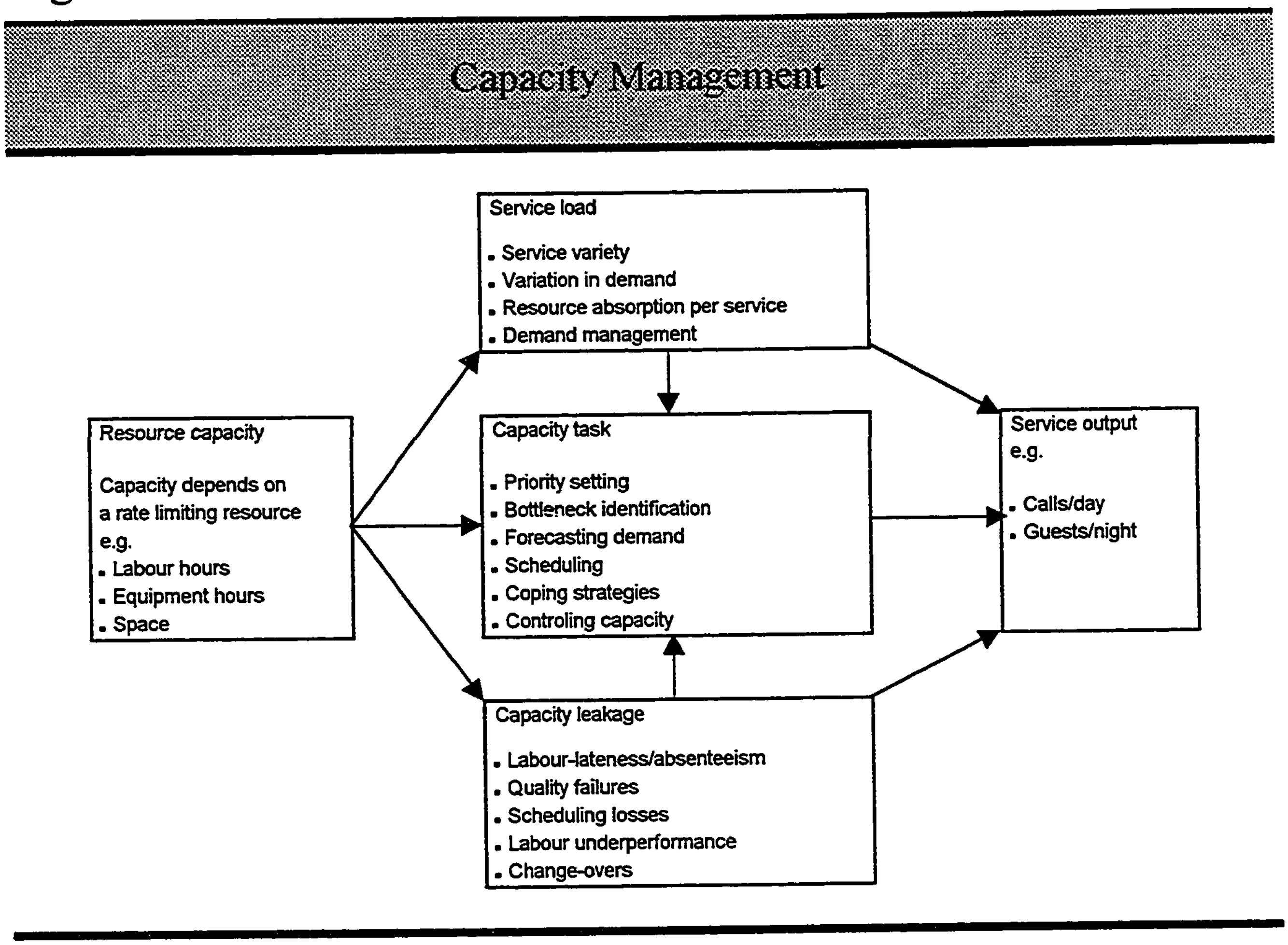
4.2- SERVICE CAPACITY MANAGEMENT PROBLEM:

Capacity Management relates the potential output from the resources available to actual output. The output achieved by any service delivery process depends on three main factors (Armistead & Clark, 1994); (Figure 3):

- The *service load* represented by the variety of the services being delivered, the resource absorption per service, the variation in the demand pattern and the way in which demand is managed for example by price changes or appointments.

- The way the *capacity task is managed* using techniques of forecasting, prioritizing, scheduling, managing bottle-necks, and altering capacity.

Figure 3



Source : Armistead C.G., & Clark, G.R. (1994) The coping capacity management strategy in services and the influence on quality performance. International Journal of Service Industry Management, 5(2)

- The extent of *capacity leakage* because key resources are not available, quality failures, scheduling losses, and lack of flexibility.

The essence of service capacity management problem is expressed by Lovelock & Quelch (1983) as follows: "In the absence of inventories to buffer supply and demand, strategies must be developed to bring productive capacity and customer demand into balance at specific points in time."

The scope of the demand side of the balance equation goes beyond the boundary of the delivery system into the market place. As mentioned earlier, the customer really drives the system and the customer must be understood. The service firm must do more than react to what shows at the door for business.

The importance of the service capacity management problem is investigated by Armistead & Clark (1992b) in a survey that was conducted by Cranfield School of Management in association with IFS publications. At the simplest level, the study visualized the balancing act which service capacity managers face day to day in attempting to match the level of demand with the available capacity as something like a see-saw effect. When there is a perfect balance between the demand for the services and the resources giving the capacity to satisfy them, the services are delivered to the desired service quality standards while still meeting resource productivity targets. However, as all service managers know, it is still difficult to achieve this perfect balance either by controlling the level of resources or by influencing demand. Consequently, service delivery is often in an unbalanced state. There is either more resource capacity than is needed for the level of demand, or demand from customers is in excess of available capacity.

5.0- CUSTOMER CONTACT SYSTEMS

While management skills can improve service systems, a manager is better off if he or she first has a clear understanding of the operating characteristics that set one service system apart from another. Chase & Tansik (1983) offer one view of services, which, if followed, results in a "rational approach to the rationalization" of services.

5.1- EXTENT OF CONTACT:

Service systems are generally classified according to the service they provide, as delineated in the Standard Industrial Classification (SIC). This classification, though useful in presenting aggregate economic data for comparative purposes, does not deal with the production activities through which the service is carried out. What the manager needs, it would seem, is a service classification system that indicates with greater precision the nature of the demands on his or her particular service system in terms of its operating requirements. In manufacturing, by contrast, there are fairly evocative terms to classify production activities (e.g. unit, batch and mass production), which, when applied to a manufacturing setting, readily convey the essence of the process.

It is possible to describe certain service systems using manufacturing terms, but in case of the SIC, the terms are insufficient for diagnosing and improving the system. An additional item that operationally distinguishes one service system from another in terms of what they can and cannot achieve in the way of efficiency is the extent of customer contact and creation of the service.

To elaborate, customer contact refers to the physical presence of the customer in the system, and creation of the service refers to the work process that is entailed in providing the service itself. Extent of the contact may be roughly described as the percentage of time the customer must be in the system relative to the total time it takes to serve him. Clearly, the greater the percentage of contact between the service system and the customer, the greater the degree of interaction between the two during the production process. Potential Operating Efficiency (POE) is equal to:

f = (1-customer contact time/service creation time)

Efficiency is seen here as the ratio of outputs to inputs for a given service facility; it does not account for customer utility functions or for organization-wide production or marketing performance. Service facilities characterized by high customer contact(HCC), such as those listed in Figure 4, are perceived as being inherently limited in their production efficiency because of the uncertainty that people (customers) introduce into the service creation process. Danet (1981) notes, relative to services in general, "clients...pose problems for organizations...by disrupting their routines, ignoring their offers for service, failing to comply with their procedures, making exaggerated demands, and so forth". This uncertainty derives from individual differences in customers' attitudes and behaviors. The customer can affect the time of demand, the exact nature of the service, and the quality of service since he tends to become involved in the process itself.

Systems characterized by low customer contact (LCC) are seen as being essentially free of this type of uncertainty and therefore, are capable of operating at high levels of production efficiency, analogous to that achieved in well-run manufacturing

Figure 4

Classification of service systems by extent of required customer contact in creation of the service

High Contact	**Pure Service** Health centers Hotels Public Transportation Restaurants Schools Personal services	Increasing freedom in designing efficient production procedures
	Mixed Service Branch offices of: Banks Computer companies Real estate Post offices Funeral homes	
	Quasimanufacturing Home offices of: Banks Computer companies Government administration Wholesale houses Post offices	
Low Contact	**Manufacturing** Factories producing durable goods Food processors Mining companies Chemical plants	

Source: **Chase, B.R., (1983) "Where does the customer fit in a service operation?"** ***Harvard Business Review.***

organizations. This efficiency effect leads fairly directly to a classification scheme for services.

5.1.1- A contact-based classification Scheme

Chase and Aquilano (1977) have proposed that common service systems could be grouped according to decreasing contact under three broad headings: pure services, mixed services, and quasimanufacturing. Pure services include those organizations whose production is carried on in the presence of the customers (medical care, restaurants, transportation, personal services); mixed services commonly involve a mix of face-to-face contact and variously coupled back office work (branch offices primarily); and quasi-manufacturing entails virtually no face-to-face contact (home offices and distribution centers)[2]. A better understanding of how the classification scheme can be obtained from Figure 5.

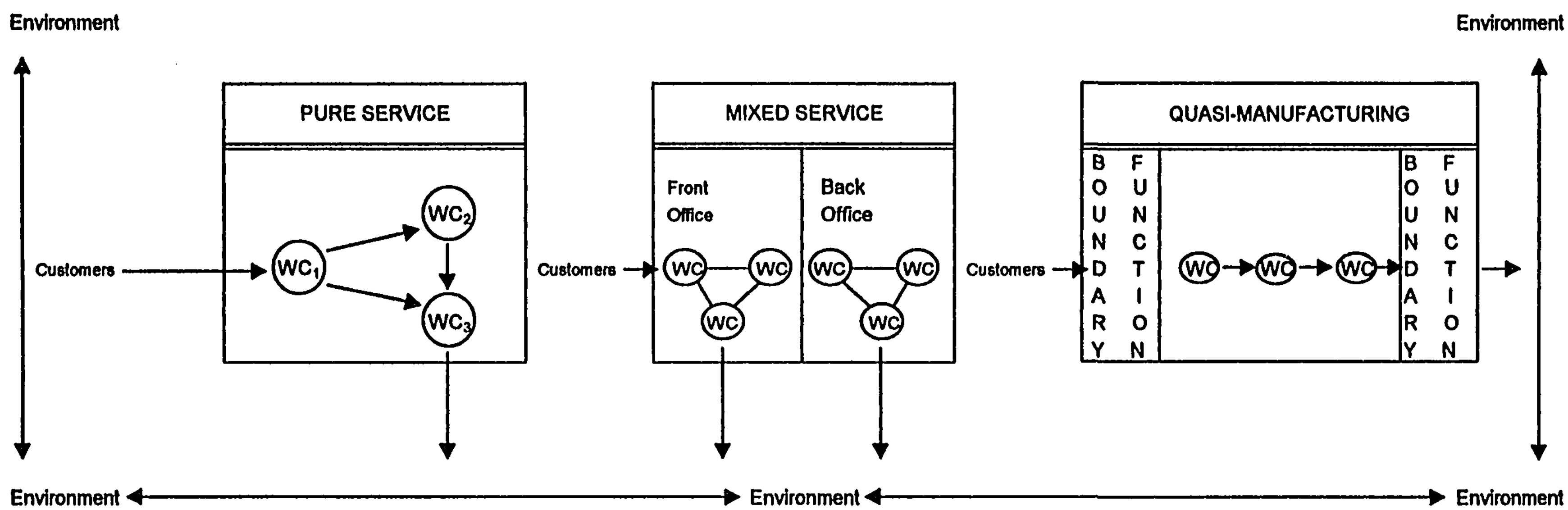
5.1.2- Decoupling and technical core

Decoupling refers to physically or organizationally separating activities of an organization and implies placing them under separate supervisions. Some of the potential benefits of decoupling (and the resultant regroupings which arise from it) are: matching each organizational unit to the task in hand, ease in objective setting, enhanced adaptiveness to localized changes, more effective use of productive facilities, and limiting the effects of disruptions or breakdowns to the unit of the organization where they occur.

[2]Pure services do have noncontact sometimes,but their main business entails heavy customer involvement.

Figure 5

Service System Models



Source : Chase, R.B. & Tansik, D.a., (1983) The customer contact model for organization design. Management Science, 49.

One way to conceive of high- versus low-contact business is that the low-contact system has the capability of decoupling operations and sealing off the 'technical core' from the environment, while the high-contact system does not.

Table 1 identifies two groups of factors which favor or operate against this action in practice. As Thompson (1967) has pointed out, "the technical core must be able to operate as if the market will absorb the single kind of product at a continuous rate, and as if inputs flowed continuously at a steady rate with a specified quality".

Several industries provide examples of shifts in customer contact through two or more of the stages given in Figure 4:

☆ Automatic banking tellers, with their 24-hour availability and their location for ease of access, illustrate pure services; branch offices, with their provision of drive-in tellers, coordinated waiting lines, and often visible back offices, illustrate mixed services; and home offices, designed for efficient receipt processing, and shipping of bank paper, illustrate quasimanufacturing.

☆ Airlines exhibit mixed service characteristics at their terminals (high-contact ticket counters and low-contact baggage handling), pure service characteristics within the planes, and quasimanufacturing characteristics in their billing and airplane maintenance operations.

☆ Many consulting firms switch back and forth between pure service and quasimanufacturing. Pure service takes place

when data are gathered at the clients facility, while "manufacturing" procedures take place when data are analyzed and reports are prepared at the firm's home offices.

Table 1:

Decoupling Operations:

Decoupling is favored when :	*Decoupling is not favored when:*
-Face to face contact for all operations is not technologically required (or desired by the customer).	-Face to face contact is seen as an essential marketing element of the service.
-Separate workers are required to produce the service.	-Rapid exchange of information with the customer is required.
-Task requirements can be easily segmented into interpersonal skills and technical skills.	-Hiring of additional supervisors would be impractical.
-Information exchange between service system and customer can be done by phone. or mail.	-Jobs are tightly prescribed by collective bargaining agreements.
-Price of the service is more critical to the customer than is convenience or customization.	-Tight coordination across task or departmental boundaries is critical.
	-Resultant job specification is counter to company philosophy.

5.2- EFFECT ON OPERATIONS:

Of course, the reason it is important to determine how much customer contact is required to provide a service is that it has an effect on every decision that production managers must make. Figure 6 is a list of some of the more interesting decisions relating to system design. The points made in this figure leads to four generalizations about the two classes of service systems.

First, high-contact systems have more uncertainty about their day-to-day operations since the customer can always make an input to (or cause a disruption in) the production process. Even in those high-contact systems that have relatively highly specified products and processes, the customer "can have it his way". Burger King will fill special orders, TWA will (on occasion) delay a takeoff for a late arrival, a hospital operating room schedule will be disrupted for emergency surgery, and so on.

Second, unless the system operates on an appointments-only basis, it is only by happenstance that the capacity of a high-contact system will match the demand on that system in any given time. The manager of a supermarket, branch bank, or entertainment facility can predict only statistically the number of people that will be in line demanding service at, say, 2 P.M. on Tuesday. Hence, employing the correct number of servers must also depend on probability.

Low-contact systems, on the other hand, have the potential to exactly match supply and demand for their services since the work to be done (e.g. forms to be completed, credit ratings analyzed) can be carried out following a resource-oriented schedule permitting a direct equivalency between producer and product. Third, by definition, the required skills of the work force in high-contact systems are characterized by a

Figure 6

Major design considerations in high- and low-contact systems

Decision	*High-contact system*	*Low-contact system*
Facility Location	Operations must be near the customer	Operations may be placed near supply, transportation or labor
Facility layout	Facility should accommodate the customer's physical and psychological needs	Facility should enhance production
Product design	Environment as well as the physical product define the nature of the service	Customer is not in the service environment so the product can be defined by fewer attributes
Scheduling	Customer is in the production schedule and must be accommodated	Customer is concerned mainly with completion date
Production planning	Orders cannot be stored, so smoothing production flow will result in loss of business	Both backlogging and production smoothing are possible
Worker skills	Direct work force comprises a major part of the service product and so must be able to interact well with the public	Direct work force need only have technical skills
Quality control	Quality standards are often in the eye of the beholder and hence variable	Quality standards are generally measurable and hence fixed
Time standards	Service time depends on customer needs, and therefore time standards are inherently loose	Work is performed on customer surrogates (e.g. forms), and time standards can be light
Wage payment	Variable output requires time-based wage systems	"Fixable" output permits output-based wage systems
Capacity planning	To avoid lost sales, capacity must be set to match peak demand	Storable output permits setting capacity at some average demand level
Forecasting	Forecasts are short term, time-oriented	Forecasts are long term, output-oriented

<u>Source:</u> Chase, B.R., (1983) "Where does the customer fit in a service operation?" ***Harvard Business Review.***

significant public relations component. Any interaction with the customer makes the direct worker in fact part of the product and therefore his attitude can effect the customers' view of the service provided.

Finally, HCC systems are at the mercy of time far more than low-contact systems. Batching of orders for purposes of efficient production scheduling is rarely possible in high-contact operations since a few minutes' delay or a violation of the law of the queue (first come first served) has an immediate effect on the customer. Indeed, "unfair" preferential treatment in a line at a box office often give rise to some of the darker human emotions, which are rarely evoked by the same unfair preferential treatment that is employed by a distant ticket agency whose mechanizations go unobserved by the customer.

5.3- MANAGERIAL IMPLICATIONS:

Several implications can be drawn from the foregoing discussion of differences between high-contact and low-contact systems. To start with, rationalizing the operations of a high contact system can be carried only so far. While technological devices can be substituted for some jobs performed by direct-contact workers, the worker's attitude, the environment of the facility, and the attitude of the customer will determine the ultimate quality of the service experienced.

Another point to keep in mind is that the often-drawn distinction between for-profit and not-for-profit services has little, if any, meaning from a production management standpoint. A not-for-profit office can be operated as efficiently as a for-profit office, and conversely a high contact for-profit branch is subject to the same inherent limitations on its efficiency as its not-for-profit counterpart.

Finally, it should be noted that two contrasting classes of worker skills and orientations exist: Public relations and interpersonal attributes for high-contact purposes and technical and analytical attributes for low-contact purposes. While mixing of duties might give a sharper note of diversity, one should recognize the considerable differences in the skills required between high- and low-contact systems.

6.0- SOLUTION APPROACHES:

Rhyme (1988) identifies the demand for services as following a cycle by hour, by day, by month, by season, or by some other interval of time. The fluctuations in demand over time have both explained (caused) and unexplained (random) components. A major part of the service capacity problem will be solved if the explained components are known, understood and managed (Slack, 1983). The solution to the service capacity problem is defined by Clark, Hammond and Cossik (1992) as a multi-dimensional and stochastic process needing a mathematical or simulation modeling program -depending on the complexity of the problem- that requires data such as customer arrival time (demand), customer waiting time and service time (supply) as well as estimates of customer routing and service alternatives.

There is no simple, quick, fixed solution in most services. For example, a customer reservation system, an 800 telephone number, or a take-a-number service line may be enough to "do the trick" i.e. decreasing customer waiting time, but much more will usually be required to achieve an effective service capacity management. This later can create an environment in which productivity improvement stem from both decreased customer flow, as well as decreased provider idle time and increased processing capacity. Such effects are well-documented and readily achievable in most service operation settings (Rising *et al.*, 1973).

Sasser (1976) believes that service organizations have two basic output rate management strategies: Chase-demand strategy and a level of output rate strategy. Utilizing chase-demand, capacity is either increased or decreased consistent with fluctuation in demand. Under a level-output strategy, a constant level of output is maintained. The choice between the two depends on a variety of factors such as labor skills required, training per employee, turnover costs, budgeting constraints, and forecasting. In addition, Sasser proposed several interesting demand and output rate management factors to help modify demand-output rate and thereby minimize production costs.

6.1- ALTERNATIVE STRATEGIES:

Although research has focused on resolving the demand-output problem in manufacturing systems, little interest has been given to it in service organizations. We contend that the perishability and simultaneity characteristics of services sufficiently differentiate the problem of demand-output management in a service organization from that in manufacturing. The opportunities for building inventories or back ordering demand are eliminated (Bateson, 1977; Sasser, 1976) leaving the productive system uninsulated and directly exposed to the inefficiencies produced by demand variations.

Understanding this problem and developing effective strategies for its resolution is vital. This development must start with the examination of relevant factors with which management can modify demand and output rates over time.

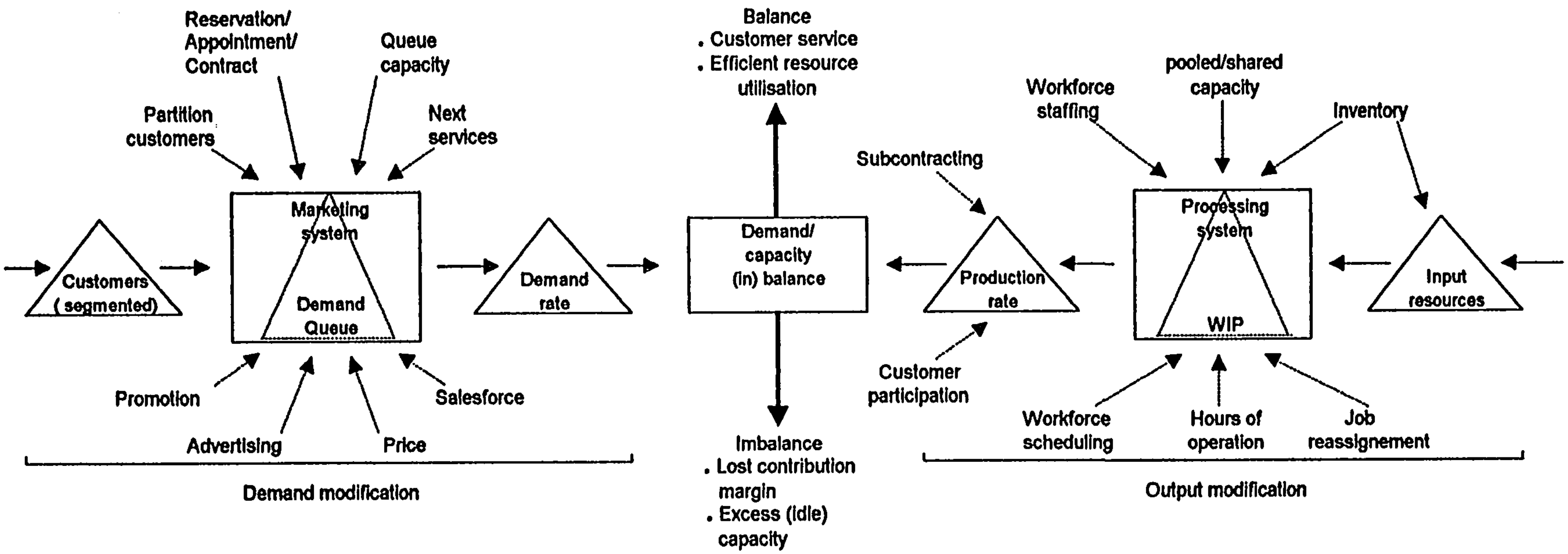
Figure 7 is a schematic representation of such a model which presents potential demand-capacity management factors classified according to their influence on demand rate (marketing strategy factors) or output rate (production policy factors) (Showalter & White, 1991). This model assumes that demand rate derives from one or more customer segments. The service organization will have a marketing system capable of modifying the demand rate actually experienced by the organization. Implicit in this marketing system is the notion that demand may be screened or filtered (queued) in some manner. Alternatively, production rate derives from an initial set of input resources that are passed through a processing system which can be manipulated in order to change the output rate. The resulting demand and output rates are therefore a function of these factor levels established by management. Theoretically, if the demand rate equals the output rate, the balance is achieved, and customer service is provided with the most efficient utilization of resources. However, if the final demand and output rates do not balance, the organization will incur lost (opportunity) contribution margins or excess (idle) capacity costs; the greater the imbalance, the larger these costs. Figure 8 shows the implications of cyclical Variations in demand relative to Capacity.

6.1.1- Strategies For Altering Demand (Marketing Factors):

In response to demand variability, management may apply one or more of several factors within the manufacturing system to modify (i.e. reduce, eliminate, shift or create) customer demand and thereby change its rate over time. For instance, one clear strategy is to modify and supplement the current service by providing variations in the service itself. Underlying this effort is the assumption that customers are willing to alter

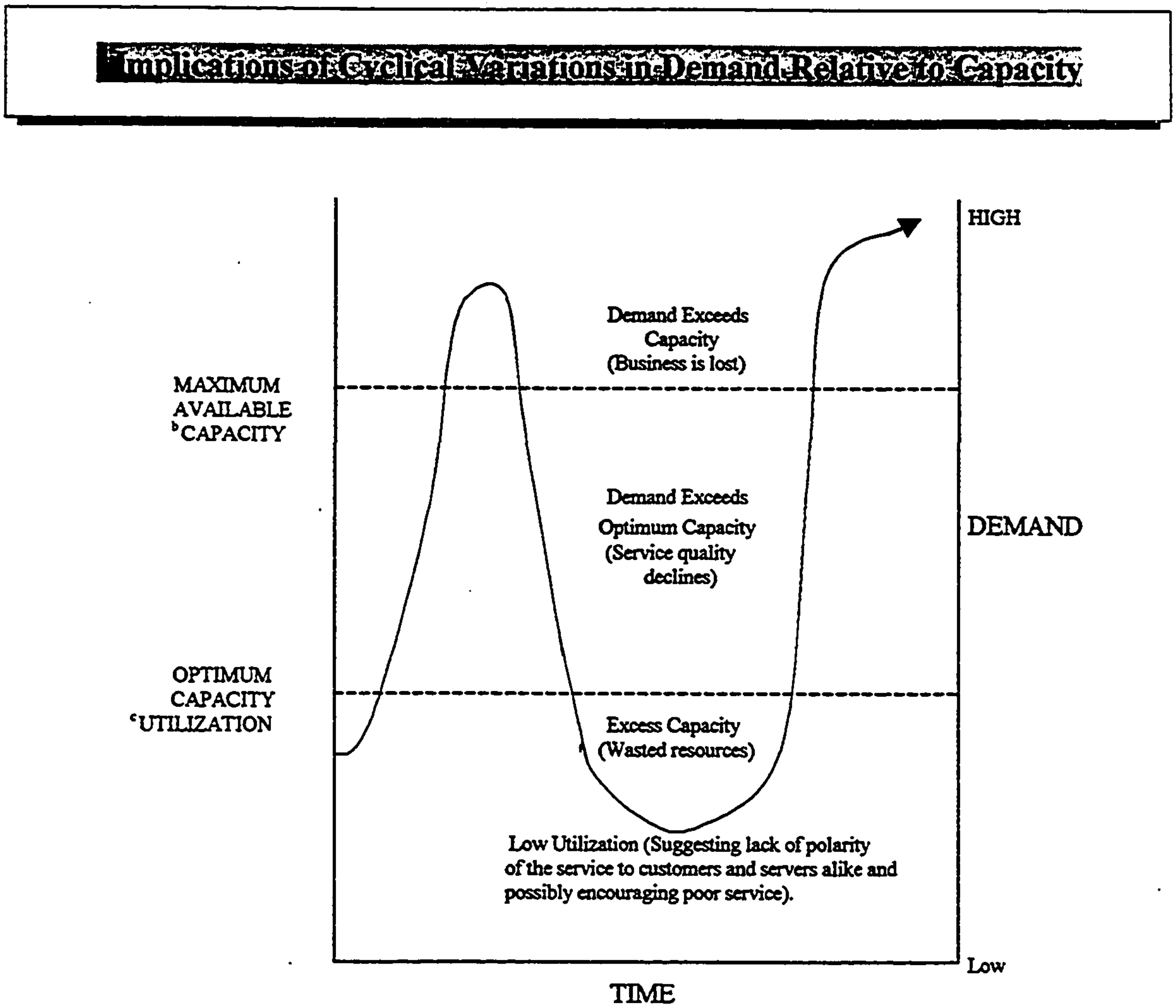
Figure 7

Managerially controllable factors Impacting on Demand Rate and Output Rate



Source : Showalter, M.J. & White, J.D., (1991) An integrated model for demand-output management in service organizations. International Journal of Operations & Production Management, 11(1), 51-67.

Figure 8



Source: Hesket, J.L., Sasser, W.E. & Hart, C.W.L., (1990) *Service Breakthroughs: Changing the rules of the Game.* Library of Congress Cataloging-in-Publication Data.

[a] Christopher H. Lovelock, *Services Marketing: Text, Cases & Readings,* 1984, p. 281. Adapted by permission of Prentice Hall, Inc., Englewood Cliffs, NJ.
[b] For simplicity, this diagram assumes no variations over time in the amount of capacity available.
[c] The optimum capacity is that level of utilization above which the perceived quality begins to deteriorate due to crowding. In some services, such as theaters and sports arenas, optimum and maximum capacity may be the same.

their demand patterns to accommodate service availability. Sasser has argued that the development of complementary services can result in shifting demand away from peak areas or by providing customers with alternative services while they are in a queuing state (Maister, 1985).

Differential pricing strategies (Thomas, 1978; Levitt, 1984) such as off-season rates for resorts, and peak-load pricing for utilities may also be employed. These strategies can result in two significant processes:

1-They help in transferring demand from peak to non-peak periods.

2- They may result in stimulating primary demand for the non- peak period, a process equally important and beneficial to the manager.

Advertising and promotion (Bloom, 1984; Lovelock & Quelch, 1983; Bessom, 1973) can also contribute to creating new demand during specific time periods as well as shifting it between periods. Also, the personal customer contact provided by a salesforce (Levitt, 1976) can produce an important advantage in emphasizing the importance and value to the customer of altering past behavioral patterns.

Job scheduling, however, takes a more forceful approach to the control of service demand by requiring a reservation or appointment system. Many others have made the point that although service managers cannot create an inventory of services, they can create an inventory of demand (Lovelock, 1984). By placing customers or their objects into a queue, the backlog of unmet demand can be controlled. The use of *reservation/appointment systems* forces a screening or filtering to fit management's desired demand rate (Sasser, 1976). Management may also be able to *partition peak-*

period demand by specifying which will be satisfied immediately and which will be added to a backlog and shifted to a future period (i.e. giving priority) (Chase & Tansik, 1983; Chase, 1981).

This job scheduling approach (i.e., reservations) has been successful for airlines, lawyers and other professional service providers (Bloom, 1984). For other business operations such as medical care, fine restaurants and hair stylists, a combination of reservation/appointment and walk-in service is more applicable. Although reservation systems are not feasible in situations requiring emergency service, they may certainly be a feasible option for a routine service such as obtaining or receiving a medical care card.

If job scheduling techniques do not succeed in dampening the fluctuations and large demand variations persist, the feasible choices are limited. The system must be willing to tolerate the waiting lines which occur when peak demand exceeds capacity or adopt supply control strategies to adjust service capacity to match demand. These are discussed in the next section.

6.1.2- Strategies for controlling supply (Production Factors):

In order to converge on demand-output balance, it is often necessary for management to modify the production system's output rate in accordance with the remaining demand rate variation. Management has a variety of means for expanding or contracting the capacity of the productive system, thereby altering its potential output rate over time. For example, just as demand may be added to an inventory to moderate short-term market fluctuations, capacity may be stored by building a work-in-process and/or raw materials inventory (Sasser *et al*, 1978). Management can utilize productive capacity during slack periods to produce a raw materials inventory or to create work-in-process inventories to be used to satisfy demand during peak periods. This, however, is contradictory for services where this action is not possible.

On the other hand, workforce factors are often used by management to modify the output rate. Labor scheduling is an approach to labor resource management that attempts to efficiently match server capacity to customer demand across the work day (Bechtold, 1991; Bechtold *et al.*, 1984; Mabert & Watts, 1982).

To be effective, this approach requires an accurate demand forecast. Managers may choose to match capacity to demand forecasts using traditional tour scheduling with overtime or undertime, supplemental part-time schedules, shift work, split shifts, or some form of alternative work schedule (Morris *et al.*, 1983; Buffa, 1983; Mabert & Watts, 1982). Alternative work schedules in Monday through Friday daytime operations may include flex-time (employee has some flexibility as to which hours are worked) and compressed work schedules (employees work 40 hour/week in four 10-hour days) (Bailey & Field, 1985; Thomas, 1982). While these alternative schedules cannot be 100% flexible, they do reduce tardiness and absenteeism by providing the flexibility for employees to attend to personal business during normal work hours; (Kramer *et al.*, 1982; Cunnigham, 1981; Albright, 1979). The availability of alternative scheduling is considered a major benefit in recruiting and retention of employees and often leads to increased levels of productivity, morale and satisfaction (Curry & Haerer, 1981).

Disadvantages to alternative schedules include planning, supervision and communication difficulties resulting from the variety of employee schedules within the organization (Thomas, 1982).

If alternative schedules are not feasible due to government regulation, company policy, labor contracts, flexibility for full time workers may be possible using part-time workforce. In fact, the part-time component of national employment has been continually growing throughout the past decade (Smith, 1986). While part-time employment reduces labor costs to the employer (i.e. no premium overtime wages), it creates a pool of employees not covered by retirement plans and other social benefits. In addition, the extra employees result in an increased workload for both the personnel department and supervising management.

Another resource management aimed at efficiently meeting varying consumer demand is job flexibility where alternative work assignments are used to compensate for changes in demand. This approach involves cross-training the workers into other skills so they can be assigned to more than one type of service and the system can be more flexible (Bracken *et al.*, 1985; Montagno, 1985). When bottleneck occurs in one area, an employee in another designated area with slack time is able to help clear the backlog in the congested area. For instance, at a bank, if the line in front of the information processing station is long, a worker at another station with idle time can help at this congested station, provided the operator has been properly trained. The benefits of placing cross-trained workers in a pool can be demonstrated mathematically using standard queuing theory analysis techniques for simple M/M/s and M/G/s systems (Render & Stair, 1991).

Training an employee in more than one work skill is a form of job enrichment which not only increase employee productivity, personal motivation but also decrease worker idle time and customer waiting time.

Moving servers: If cross-training is continued until all workers can perform all the required tasks in a service system, the management policy of moving servers can be employed. Under this policy, a server stays with the customer and the server/customer pair move as far through the station network (system) as possible, leaving the customer alone only when the customer is performing an individual act such as taking a test or completing an information form. A server returning to the pool takes the most advanced customer in the system each time, thus clearing any bottleneck that would prevent a smooth flow through the system.

If customers move through a series of server stations the system becomes a multi-channel, multi-phase system which is very difficult, if not impossible, to analyze mathematically (Murdick & Render, 1990). For these complex systems, computer simulation techniques are recommended (Render & Stair, 1991).

Finally, a service organization may find other opportunities to modify productive capacity than workforce factors. It may jointly acquire productive capacity with a similar service organization (Charlambidies, 1984); it can also include additional customer participation in the productive activities (Lovelock and Young, 1979); or it can even expand or contract the number of hours per period the productive system operates (Collier, 1985). Although this expansion does not change the output rate for the original hours, it does increase or decrease the potential output rate during the incremental hours of operation and may, indirectly, shift the pattern of demand variation. Depending on the relative impact of hours of operation on demand variation patterns, some service organizations may consider this a marketing strategy factor.

6.2- INTEGRATION OF THE TWO STRATEGIES:

In contrast to the work on integrated decision making in manufacturing with three notable exceptions, little attention has been given to the problem of capacity management within service firms. Lovelock (1984) discusses the problem of demand variability for service firms, and details a number of production and marketing strategies for dealing with excess demand, satisfactory demand and insufficient demand (excess capacity). However, he fails to integrate production strategies for managing capacity with the marketing strategies. Further, he fails to develop a framework for selecting a particular combination of strategies.

As noted earlier, the article by Zeithaml *et al.* (1985) discusses the importance of service capacity management and specifies 18 separate production and marketing strategies that might be used to manage demand and supply in service organizations. This work is valuable because it catalogues those strategies actually being employed by service firms. It does not, however, present an explicit model for integrating the production marketing strategies, nor does it provide any criteria for the selection of specific strategies.

According to Sasser (1976), selective use of the production and marketing factors provides management with the opportunity to control both demand and output. However, the integrative nature of the problem was fully addressed in his descriptive research.

The articles cited above are an important contribution to emerging research into the problem. The impact of these articles is two-fold. First, they validate the existence and relative significance of this problem to service management. Second, they identify many of the factors that management may utilize in resolving the problem. It is therefore desirable to extend this pioneering descriptive research by developing a broader understanding of the problem and/or developing integrated decision models for solving the problem.

6.2.1- An Integrated cost-effectiveness Model:

Showalter and White (1991) were the first to offer a model which was able to deal with the inconsistencies of the above models; first, there has been no explicit consideration of cost and effectiveness trade-offs among the marketing/production factors. Second, previous research assumes an essentially independent marketing/production planning format. No consideration is given to these marketing and production decisions within an integrated structure, despite the fact that previous manufacturing research literature demonstrates that an integrative marketing and production planning approach yields superior results. Third, previous research does not consider the possibility of imbalance costs. Although many situations exist in which costs can be minimized by matching demand with output, many more situations may arise in which total cost may increase as a result of such a strategy, i.e. management would prefer to tolerate some level of demand-output imbalance over time.

Quantitative specification: By synthesizing their research, Showalter & White have expanded on Sasser's original description of the problem so as to enumerate the complete set of marketing strategy and production policy factors. From this verbal description, they have specified a quantitative decision model formulation for solving the demand-output rate management problem.

The objective function specifies the costs and volume usage for all marketing and production modification factors relative to the costs of demand-output imbalance in each time period. The constraint defines the relationship between the use of these marketing/productive capacity factors and the degree of demand-capacity imbalance.

The model formulation suggests that as management specifies levels for each factor of marketing strategy and production policy, the demand and production rates are revised so that a demand-output rate balance, or imbalance, is obtained. The objective function is a summation of the relevant marketing and production factor usage costs and any associated imbalance costs.

The optimal decision and its opposition:

Showalter and White discuss that the optimal management decision involves sequentially selecting, in descending order, those marketing and/or production factors with minimum cost and maximum effectiveness in order to balance the demand-output rate. However, such thinking neglects two concerns. First, very few marketing/production factors have equivalent degrees of effectiveness and low costs; nor does their relationship remain constant over all levels of usage. Second, both the effectiveness of all factors and all cost functions are dynamic and will change in the future. Cost functions are most susceptible to change owing to external market and industry forces, whereas changes in the effectiveness functions are subject to more direct management control (i.e. selection of advertising media, scheduling of workforce). Management must be cognizant of this potential for *improving* factor effectiveness functions when selecting factors for demand-output rate modification. Finally, management must be vigilant not to utilize factors whose cost function exceeds the costs of imbalance to the service organization. For example, the effectiveness of increased advertising may in turn increase demand; likewise, more overtime activity may increase output. Selection of factors with low effectiveness and high cost may imply a situation in which costs of achieving balance may exceed the costs of imbalance.

The problem discussed is a continuing one, which potentially limits the long-term efficiency and effectiveness of service organizations. On the other hand, another side of this problem -yet to be fully studied in the literature- is addressed in the next section.

6.2.2- The Coping Strategy in Services

Operations managers in a service organization will either succeed or fail in the process of balancing supply and demand. Armistead and Clark (1994) examined more closely the factors in the management of capacity in services and considered that even though service managers may be concerned about capacity management, they tend more to manage capacity by "feel" rather than intent or design to a greater extent than their manufacturing counterparts.

Following the authors' argument, 'Chase" and 'Level' are not enough. It is inevitable that all service organizations will at times run out of capacity to satisfy demand within the time frame expected by customers. This is the area which most service managers would recognize as coping. In these circumstances, there are two possible courses of action: To allow service quality standards to fall in an uncontrolled way or to try to control the fall, thereby protecting the core service. The alternative scenario is when capacity is in excess of demand leading to lower efficiency and in some cases lower quality. In these circumstances, the coping is concerned with minimizing these effects, perhaps by accepting the situation as a period of rest and recovery for service staff or engaging them in other activities.

The Strategy:

The concept of a coping strategy for managing service resources has a particular link to service recovery (Hart *et al.,* 1990) and unconditional service guarantees (Hart, 1988; Hart *et al.*, 1992). There is growing evidence, from both these areas of literature and a recent research carried out by Armistead and Clark (1992; a, b) that service operations managers would not be aware of when they are entering the coping zone and how to respond quickly and effectively when things go wrong. Hence, the intricacies of understanding what is needed to ensure that service delivery is achieved consistently through a multi-stage operation may be missed. The same criticism can be leveled at the Sasser model (1976) which suggests looking at the whole of the service delivery. What is needed is a means of bringing together information which focuses on the critical aspects of service delivery at different stages and to consider the general capacity management issues and the specific coping issues at each stage.

Coping Action Mapping:

Armistead & Clark revealed that a combination of a model of "operational focus" (adapted from Larsson and Bowen, 1989) and of "resource activity mapping" (adapted from Armistead and Clark, 1993) offer an improved approach. The concept is to display the main capacity strategy (Chase or Level) and to develop coping approaches or issues (i.e. customer waiting) with reference to the main stages in delivering the total service while taking into account the critical attitude (price, reliability, etc.) and sensitive hygiene (customer records, routine maintenance, etc.) customer service dimensions. The operational focus for each activity is also displayed. In practice, it has been found that most service delivery can be reduced to between five to seven main activities.

The coping action mapping matrix developed from these factors is shown in Figure 9.

The use of the matrix is to examine coping issues and approaches in relation to the customer service dimensions at each stage. It represents a way of augmenting the strategies of Chase and Level capacity management. Such a strategy involves:

- Improving the basis of capacity management in forecasting and scheduling
- Measurement of service quality and utilization of critical resources
- Instituting a measuring system which will warm when the coping zone is being approached
- Deciding whether to reduce service quality levels and how this should be done
- Deciding how to bring in additional resources.

Figure 9

Basic Coping Action Map

	Activities in service delivery			
	Activity 1	Activity 2	Activity 3	Activity 4
Operational focus				
Main capacity strategy				
Customer service dimensions				
(1) Critical				
(2) Sensitive hygiene				
Approaches/ issues of coping				

Source : Armistead C.G., & Clark, G.R. (1994) The coping capacity management strategy in services and the influence on quality performance. International Journal of Service Industry Management, 5(2)

6.3- TRADE-OFF PROCESS:

As mentioned before, capacity management is the ability to balance demand from customers and the capability of the service delivery system to satisfy the demand. Operations managers must understand the composition of their capacity, the degree to which it can be changed, and the speed of reaction (Slack, 1983) and the costs involved (Heskett *et al.,* 1990). Being aware of these issues creates a balancing mechanism with trade-off between variables, prompt customer service on the one-hand and operations, marketing and human resource managers costs on the other (Sharman, 1984).

Figure 10 represents the most important relationships in a service encounter. The above mentioned trade-off, although sometimes very obvious, need some explanations.

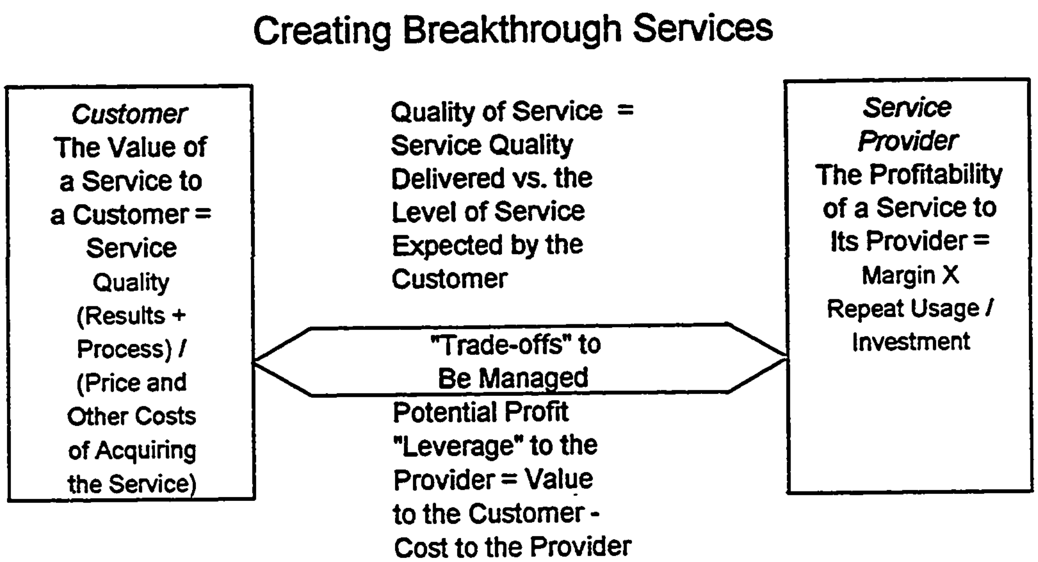
The difference between the value of a service to a profit potential is what we call profit leverage. The extent to which it is fully captured by the service provider depends on its pricing policy. What we receive for what we pay is the basis for measuring value in services. One perception of what we receive in a service, however, is based both on results obtained and the manner in which the results are achieved.

High-value service results in part from high quality. But service value has another component, cost. This includes both the price of the service and the less easily measurable costs of acquiring it, i.e. employees workload.

The cost of a service to its provider is influenced by, among other things: (1) the nature of the service offered to the customer, (2) the operating strategy of the service

Figure 10

The Service Encounter as a Set of Trade-Offs



Source : Heskett, J.L., *et al.*, (1990) Service Breakthroughs. Collier Macmillan Inc.

company, (3) its service delivery system, (4) the degree to which the server's capacity is utilized, and (5) the needs and attitudes of servers.

The first of these factors establishes a range of costs within which a service may be delivered. The development of an operating strategy and the design of a service delivery system further define the range of cost incurred, assuming a given level of capacity utilization. It then falls to the management of the service firm to both manage capacity and stimulate demand for it. But unless servers' needs are met and their attitudes toward service delivery developed, the finest operating strategy and service delivery system mean little. This underlines both the importance of the relationship between design and activation and the role of managers making it work. Consequently, this issue has generated various techniques or solution methods and tools attempting to reach a feasible trade-off. Next section will compare some of the tools that are heavily used in this domain.

6.4- SIMULATION VS MATHEMATICAL OPTIMIZATION MODELS:

A number of solution methods developed for service operations have been Mathematical Programming approaches that use deterministic demand estimates or statistical averages of demand in an attempt to find the optimum expected return, an estimate of what may happen if all estimates are correct and remain constant for the duration of the problem (Turban & Meredith,1991). A set of three alternative approaches can be used in problem solving, or more specifically in the design and analysis of this particular system: Mathematical, Experimentation and Simulation models. However, when the demand is generated by a process involving human consumers, the systems seldom reach the steady state condition required by the mathematical and experimentation models. The solution process rapidly becomes too complex to continue unless simplifying assumptions that remove reality from the problem are employed. In these situations, computer simulation modeling and analysis could become the preferred method.

Consumer demand and system service can be simulated by stochastic processes using ordered sets of random variables generated from probability distributions which emulate the pertinent elements of the system. By applying different management policies and a series of "what if analysis" model, the researcher can evaluate the effect of each policy on the entire system rather than a simple variable.

Computer simulation is recognized as an efficient tool for the study of existing or potential real life service systems. Simulation is mostly used as an alternative to the experimentation with the actual system because it is more economic, safer, faster and repetitive. As Hoover and Perry (1989) noted, simulation is becoming more accepted by managers as inexpensive insurance against costly mistakes. It also allows for the consideration of more factors than the physical experimentation would be. Some of the situations that have been the subject of simulation-based investigation are listed in Table 2. Simulation ranks very well among the other operations research techniques in terms of importance (Table 3). Despite the obvious advantages of systems simulation, the method does have some drawbacks (Appendix A).

Research for interdependency of simulation and mathematical models has been focused on manufacturing systems: Newchart, Stott and Vasko (1993) suggested that both methods could also be used in a separated but complementary manner to design the optimal capacity in a firm. Their approach consisted first in using mathematical

Table 2

Selected Applications of Simulation

Urban-social

Emergency-response vehicle location
Mass transit system design
Garbage collection patterns
Traffic light sequencing
Police beat design
Political redistricting
Educational planning
Political campaign strategies
World economic conditions
Facilities schedule
Air pollution control
Population patterns
Air traffic control
Airport design
Urban development
School bus routing
Urban dynamics
Courtroom scheduling

Health care

Health care planning
Emergency room design
Organ transplant strategies
Hospital staffing
Disease control strategies
Drug interaction control policies
Hospital admissions
Blood bank management
Diet management
Ambulance crew scheduling
Patient flow

Aerospace-military

Space system reliability
Equipment replacement policies
War games/strategies
Armed forces recruiting strategies
Search rescue strategies
Equipment distribution
Space defense systems
Satellite positioning

Service Industry

Portfolio management
Insurance and risk management
Professional sports draft strategies
Auditing strategies
Communication network design
Feedlot management
Fleet scheduling
Bank teller scheduling
Supermarket clerk scheduling
Telephone switching
Facility location

Industrial

Food and chemical blending
Inventory management
Facility layout
Repair crew scheduling
Design of distribution channels
Production scheduling
Product safety testing
Quality control
Tool crib personnel planning
Labor negotiations

Source: Budnick, McLeavy, and Mojena (1988)

Table 3

Ranks of the 12 Qualitative Techniques Educators and Practitioners Believe Are Most Important to teach Operations Research Majors According to Three Pairs of Questionnaires Sent to a Random Sample of ORSA[1] Members at Five-Year Intervals

Technique	1973 Educator N=106 Rank	1973 Practitioner N=92 Rank	1978 Educator N=98 Rank	1978 Practitioner N=88 Rank	1988 Educator N=89 Rank	1988 Practitioner N=96 Rank
Statistics	1	1	2	1	3	1
Linear Programming	2	2	1	2	1	3
Simulation	3	4	3	4	2	2
Math Programming	4	7	10	5*	6	5
Probability	5	3	9	3	7	4
Stochastic Processes	6	-	4	7*	4*	8
Network Analyses	7	-	6	11*	4*	-
Optimization	8	9*	-	5*	9	6
Dynamic Programming	9	-	-	-	10	-
Decision Theory	10*	9*	5	-	8	-
Queuing	10*	5*	8	7*	11	7
Inventory Control	10*	-	7	-	-	-

*** Indicates a tie**
- Indicates a technique was not ranked among the top 12.

Source: Budnick, McLeavy, and Mojena (1988)

[1] ORSA: Operations Research Society of America

programming to minimize the number of products held at different positions in the supply chain. Then, the use of spreadsheet simulations to estimate the need for safety stock with randomly distributed demand and lead times.

However, there is a growing interest in service organizations for the combination of the "what's best" method of optimization and the "what if" of the simulation. It allows the use of rather simple optimization models which bring some type of 'intelligence' to the simulation. It also allows the generation of stochastic transactions in a more tractable manner than with stochastic optimization models. Furthermore, we believe that the combination of both could better serve the real life implementation of the integrated production-marketing strategies concept since pure optimization is often too time-consuming to be used as a tactical tool. In addition, pure simulation lacks some intelligence when it comes to the search for optimality.

7.0- SUMMARY OF THE LITERATURE AND ITS IMPACT ON THE STUDY:

The difficulties inherent in achieving coordinated demand-output levels are compounded when the firm produces and markets *services* rather than physical goods. Services represent intangible activities or benefits, which are inherently perishable, as demonstrated by Thomas(1982), and Zeithaml *et al* (1985). This means that many services not consumed when available (e.g. empty airline seats) are lost forever. In addition, many of these same services must also be consumed as they are produced. Consequently, consumers are often unable, or unwilling, to wait. Service simultaneity and perishability increase the complexity of demand-output management because the opportunities for building inventories or back ordering demand are eliminated, leaving the productive system uninsulated and directly exposed to the inefficiencies produced by demand variations. A productive policy of constant, uniform output rate for service firms is extremely inefficient owing to lost sales when demand rate exceeds output rate, and from excess capacity when output rate exceeds demand.

As cited earlier, the work of Zeithaml *et al* reveals that a majority of surveyed firms report demand-output imbalance to be a recurring problem. In addition, Armistead & Clark indicated that literature has not yet recognized the fact that service quality has added another dimension to this problem where an interaction between capacity and quality management is needed.

In order to appreciate the nature of solving the problem, Chase & Tansik (1983) have a simple view: the less direct contact the customer has with the service system, the greater the potential of the system to operate at peak efficiency. And conversely, where the direct customer contact is high, the less the potential that exists to achieve high levels of efficiency. This distinction between high- and low-contact systems provides a basis for classifying service production systems that can enable the manager to develop a more effective service operation.

Given the persuasiveness of the demand-output management problem within service organizations and the continual growth of this sector of our economy, the literature argues that future research should focus on understanding this problem and developing effective strategies for its resolution. The following study responds to this need by modeling the process of simultaneous demand-output management in a HCC service organization (i.e. Henri Bourassa driver license office in Montreal). The variability in demand coupled with the direct exposure of the productive system to demand fluctuations suggests that balancing demand rate with output rate may represent an interdependent management problem with several previously unexplored ramifications. This interdependency must be considered if management is to achieve minimum costs for the organization. Although research has focused on resolving the interdependency in manufacturing systems, little interest has been given to it in service organizations. We contend that the perishability and simultaneity characteristics of services sufficiently differentiate the problem in a service organization from that in manufacturing and warrants in-depth study and evaluation.

7.1- IMPORTANCE OF THE STUDY:

Work of the type reported here is valuable for several reasons. First, service industries in Canada have become increasingly important to the national economy. Understanding common service system structures is vital to improving productivity in the service sector. Providing knowledge about effective approaches to managing service systems, especially those dominated by common complex queuing structures, is vital for improving their performance. Second, expanding our knowledge of the complex interaction between customer routing and service alternatives and service quality is an important element in improving overall system performance of typical structures. Third, development of knowledge about effective alternative methods of worker employment, development, and scheduling provides another avenue for increasing system productivity. Contributing to the growing body of knowledge in these areas is the intent and value of the research reported here.

7.2- CAPACITY MANAGEMENT: A FRAMEWORK

The preceding pages represent the first objective of this paper, i.e., an attempt to better understand the foundations of the Capacity Management Concept. A presentation of effective approaches to managing service systems and analytical tools through which successful demand-supply management can be implemented will be provided as well.

The table presented in the following pages summarizes the key concept in attempt to build a framework that will be applied to our extensive study of the HCC service operations at Henri Bourassa's driver licensing office in Montreal. The study seeks to improve operational efficiency and reduce customer congestion.

ACTIVITY	***ISSUES***
1- Analyzing the existing Capacity Management	
-Resource Capacity	-Service variety
-Service load	-Variation in demand
-Capacity leakage	-Demand management
-Capacity task	-Labor-lateness observation
	-Quality failures
	-Labor underperformance
	-Priority setting
	-Bottleneck identifications
	-Forecasting demand
	-Scheduling
	-Coping strategies
	-Controlling capacity

2- Building a GPSS/H simulation model of the entire existing operations

-Problem definition	-Customer routing
-Schematic development of system	-Service alternatives
-Data collection and analysis	-Model definition
-Simulation model building	(objective & endogenous variable)
-Model validation and verification	-Statistical testing

3- Analyzing output of the existing system model

-Customer waiting time	-Average customer waiting time at different stations
-Efficient use of personnel resources	-Average customer waiting time
	-Number of customers waiting at each station
	-Number of customers waiting in the system
	-Idle time for servers at each station

4- Applying Capacity Management strategies through Simulation (Experimental Design)

-Demand-smoothing strategies	-Marketing practices
	-Job scheduling techniques
	-Development of services
-Supply-Matching strategies	-labor scheduling
	-Job flexibility
	-Moving servers
	-Expanding hours of operation
-Integration of both strategies	-Uniform demand pattern
	-Job assignment
	-Job flexibility

5- Development of Metamodels

-Full factorial design

6- Achieving effective Capacity Management

-Evaluating trade-offs to be managed

-Application of the study

-Managerial Implications

-Nature of service (effective forecasting)

-Service operating strategy

-Service delivery system

-The extent of service capacity utilization

-Needs and attitudes of servers

8.0- APPLICATION OF A SIMULATION MODEL TO A DRIVER LICENSING OFFICE IN THE CITY OF MONTREAL:

The Societe d'Assurance d'Automobile du Quebec(SAAQ) is a Quebec government establishment responsible for the issuing of drivers licenses and related services to the public. Being a government-aided public sector, the SAAQ's operations are centralized in terms of budget, marketing, hiring employees costs, pricing and so on. However, the SAAQ has a decentralized location of offices all around Quebec. In the Island of Montreal, four offices are available: Henri Bourassa, Laval, Anjou and Maisonneuve. These offices have one thing in common in that their operations are centralized; the manager at the Henri Bourassa office can not make the full decision of hiring more full-time employees at a high-peak demand time, it is the government's responsibility to allocate a certain number of ETC's (emploi à temps complet i.e. complete time employment) to each service at each office. Moreover, the four offices in the island of Montreal offer different services: The Anjou and Maisonneuve offices do not offer testing services or issuing new driver licenses, while the office in Henri-Bourassa offers the widest and fullest range of services.

The H.B. complex is located in ville St. Laurent and was established in 1977 to provide a high customer contact system offering mixed services[3]. It is divided into two large departments: the smaller one offers renewal of licenses, duplicate of replacement, restriction change, special cases of reinstatement of license, complaints and so on. The larger department where the current study was done, offers other variety of services for which a high customer involvement is needed. These services include written tests (offered in more than thirty languages), road tests (light and heavy vehicles), addition of

[3] The clients waiting areas are planned in detail to convey a particular image, and back-offices are arranged for efficient noncontact work.

class (i.e. bus, taxi), driver's license equivalency from other provinces, and the issuance of the driver licenses.

Since the HB office is considered as a high customer contact system, it is located in an easy-to-reach area, in addition to being able to accommodate the full customers' physical and psychological needs. As discussed in the literature, in any HCC system, the direct workforce comprises a major part of the service product and must be able to interact smoothly with the public. Although the workers' skills at the HB office do include this "smooth interaction", however, the workers are not sufficiently job flexible to permit coverage of all of the positions at the service encounter. This problem is largely experienced at peaks of high demand where customers have to wait longer until the worker is ready or a more experienced worker is available. This also results in labor underperformance and causes a major problem at the office.

Furthermore, the HB office faces an inconveniality in that the majority of customers would rather wait for a convenient weather in order to pass their driving license exam. Therefore, typically in Montreal, demand fluctuates during the year: for example, during winter (December, January and February), demand drops off because most people try to avoid the cold weather and the heavy snow usually experienced at this time of the year. However, around March, a different pattern is observed. During the summer, demand is at its peak level but still it fluctuates since people take their vacations during this time of year and other wait for the typical weather condition. Hence, one needs to have a system that has the ability to quickly adapt to accommodate varying demand (Perrault: Interview 1996).

Moreover, most of the customers arrive to the office with an appointment taken one-month ahead of their visit (on average). However, the HB office tends to overbook their appointments by 20% as a way to manage the fluctuating demand. This overbooking saves this HCC system from appointments cancellations and no-shows but it results in having extremely peak demand at certain times of the day which the office has difficulties in dealing with.

All these issues and the resulting problems posed above, should be literally overcome by forecasting. In a HCC system, forecasts are short-term and time oriented, while in a centralized operation that is government-aided, forecasting is limited. The government forecasts are based on 'the year before' data which do not reflect fluctuations in demand on a seasonal or a daily basis. These forecasts do not result in improvements since they are based on generalizations and not on considering low and high peak demand times. Unfortunately, the interviewer at the HB office and the person in charge in Quebec city refused to share any other information on their forecasting methods: Appendix B includes a copy of the letter and questionnaire sent to the SAAQ headquarter in Quebec City. This questionnaire sought to determine (i) the different forecasting methods that the government uses, (ii) the role of forecasting, and (iii) the determination of bottlenecks and the implementation of the forecasting results. As mentioned before, since the key participants in Quebec, did not accept to cooperate, our study was limited to the data collected in Henri Bourassa Complex (refer to section 8.4).

The HB office was able to overcome the problems resulting from labor lateness and absenteeism in that they have replacement workers (part-time, compressed-time and tour scheduling employees) available upon call. However, the people in the office are underexperienced in their quality failures because they have only two computer systems operating their services: Frisco Bay, which is the software responsible for the waiting-line (coupon) system according to the arriving sequence, and ETAP which is the software that written test is performed on. If one of these systems is faced with any kind of failure, the office has no backup .

Although the service managers are concerned with capacity management, they tend to manage capacity by intuition rather than design. Finally, it is good to mention that owners, taxpayers, contributors, and others upon whom this organization depends for its livelihood and existence are demanding proof of the results that nonprofit managers are achieving. Taxpayers are increasingly critical of the questionable effectiveness of the government at all levels. They are feeling the brunt of the demand for stricter accountability.

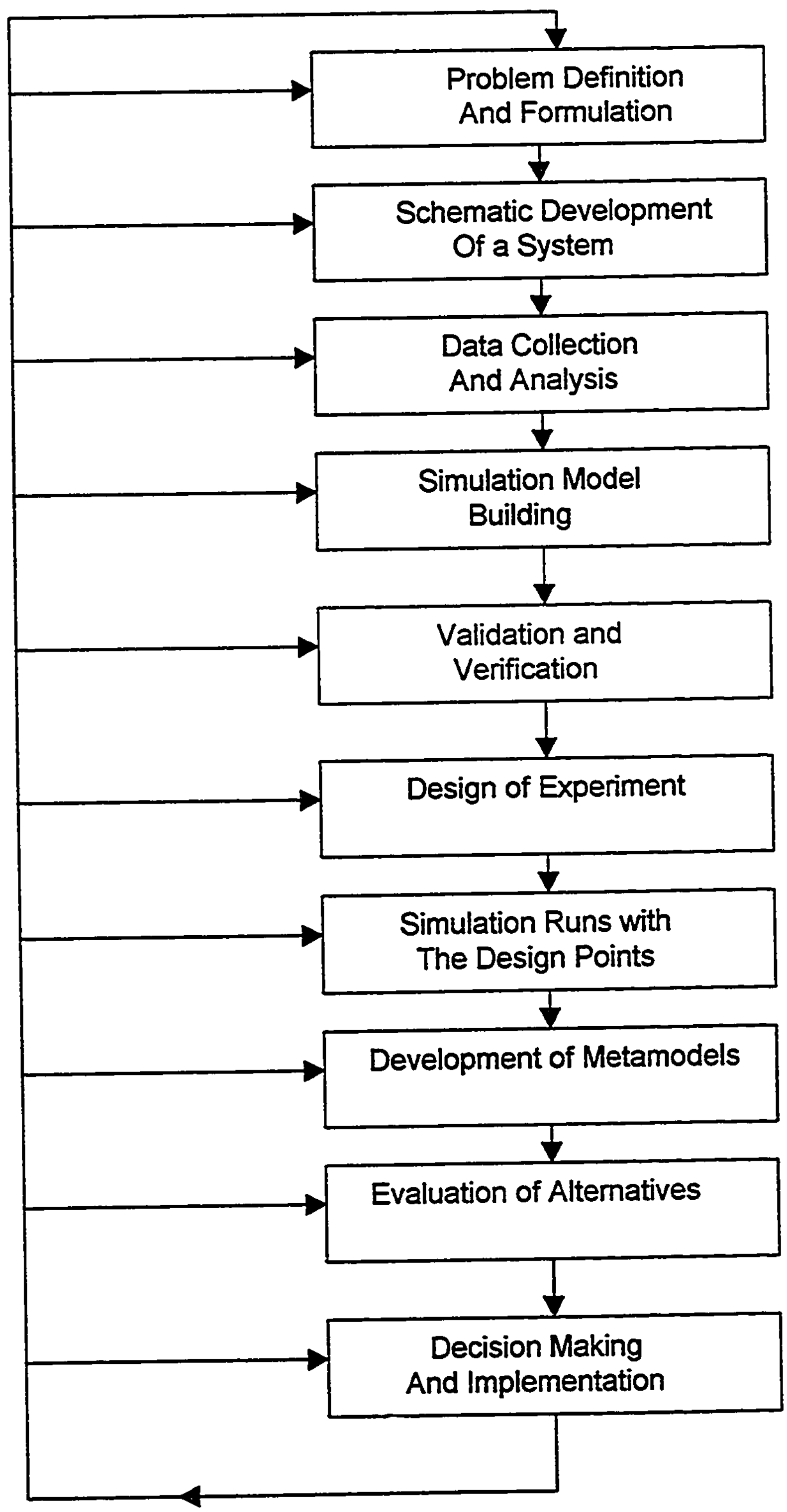
8.1- Construction of a Simulation Model:

Figure 11 is the tenet behind the discussions presented in the next sections. This figure shows a step-by-step procedure to construct simulation models. Each of these steps is sufficiently discussed and explained further in the study. The discussions on how to construct simulation models presented here are in some similar to those presented in many sources (Hoover & Perry, 1989; Solomon, 1983; Law & Kelton, 1982; Nance, 1981; Shannon, 1975), however, the researcher has added to this discussion the issue of experimental statistical designs since this is one of the major objectives of this research.

Although a sequential process is presented in Figure 11, the existence of feedback loops, as shown in this figure, indicates that some of the steps may be repeated as need be. The procedure is, therefore, iterative. Each of these elements listed in this figure is discussed in the following sections.

Figure 11

Construction of A Simulation Model



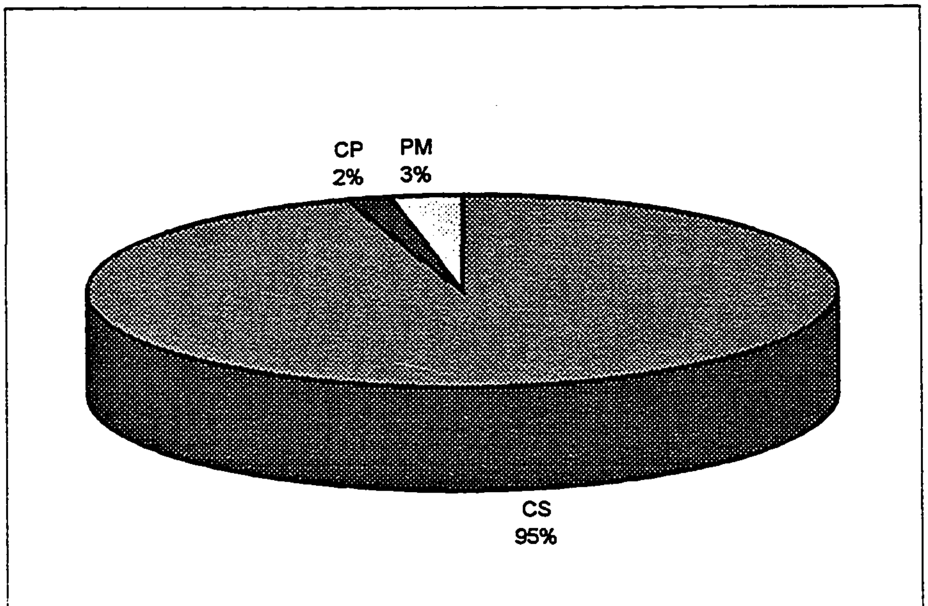
8.2- PROBLEM DEFINITION AND FORMULATION:

At several licensing offices in the area of Montreal and surroundings, waiting and service times for customers could easily reach several hours (Claudine Muret (Laval) & Dianne Perault (Henri Bourassa); Interviews 1996). The Henri Bourassa office was selected because it was identified as highly representative of all of the offices with long waiting times and extended service period. The situation had generated enough concern by both the managers and legislators to cause the province of Quebec to augment the office's capacity i.e. human resources and/or equipment (Perrault, 1996) and to provide additional locations (Caisse Populaire CP and Private Mandatory PM) where some driving transactions can be processed. These locations would represent a certain "back up" to the main driver licensing offices in order to decrease the offices demand and allow a faster service. However, while the full impact of these top level management policy changes had not been realized at the time of this study, it was apparent that approximately 95% of the customers requesting an issuing of a driver's license were processed in the driver licensing offices (CS, standing for Centre de Service) (Figure 12) and the problem of long waiting lines persisted.

This problem had grown steadily through the years due to the fast growth of the city of Montreal. The city's current population has increased significantly in the past two decades especially due to more immigrants moving to Montreal. This led to an increase in the city's driving population which resulted in a relative leap in the number of accidents per year (Table 4). Consequently, the legislators had to increase the level of difficulty in obtaining a driver license to a point where people living for more than three years in Quebec who do not speak at least one of the two official Languages (English and French) are not eligible for the license.

Figure 12

Issuence of a Driver License in Quebec



Source: *Regional office, Montreal; Statistics from January to October, 1996*

CS: Centre de Service (95% represents 36,899 issued licenses)
PM: Private Mandatory (3% represents 1,370 issued licenses)
CP: Caisse Populaire (2% represents 763 issued licenses)

TABLE 4

Number of Driver Licenses Issued According to Age and Sex, from 1978-1995

year	*sex*		*age group*					*total*	*# of Vehicle*
	male	female	< 16 yrs	16-24	25-44	45-64	65 +	*permits*	*Accidents*
1978	1944843	1176624	0	658854	1515600	794333	152680	3121467	401949
1979	1972795	1224566	0	670534	1556540	809176	161111	3197361	379898
1980	2008312	1285102	0	695231	1603232	825556	169395	3293414	359681
1981	2039928	1344455	0	707868	1650582	846075	179858	3384383	340995
1982	2061901	1393388	0	700773	1698534	865043	190939	3455289	289784
1983	2080367	1441153	0	688390	1773460	871825	187845	3521520	295347
1984	2105428	1492834	0	674103	1825746	898921	199492	3598262	332790
1985	2093296	1522157	0	640626	1845869	915252	213706	3615453	374074
1986	2125357	1578809	0	627555	1901023	947312	228276	3704166	369222
1987	2144767	1627025	0	611950	1942840	976581	240421	3771792	372811
1988	2191195	1678805	8247	599596	1988929	1014744	258484	3870000	355595
1989	2218573	1728381	7750	581923	2026586	1054125	276570	3946954	347369
1990	2251607	1781364	7839	570001	2064038	1095720	295373	4032971	322305
1991	2269568	1822800	7518	556945	2074856	1138281	314768	4092368	306719
1992	2273590	1856242	7694	529802	2071206	1186546	334584	4129832	301761
1993	2298002	1898199	8094	520736	2074749	1235825	356797	4196201	303774
1994	2320001	1938108	8188	517089	2067244	1285301	380287	4258109	306248
1995	2342158	1975406	8167	518642	2057221	1330183	403351	4317564	309512

Furthermore, most of the customers arrive at the office 5 minutes before or 10 minutes after their appointment time. Eventhough it is the case, they tend to receive service in any applied condition i.e. "first come, first serve" .In addition to overbooking, this process compensates for some of the uncertainties but introduces a new cost, the cost of making customers wait longer at high-peak periods.

However, is every waiting time considered to be a problem?

In considering the variety of service conditions under which delays can occur it becomes apparent that consumers can potentially run into many different types of delays (Gill, 1994). For instance, delays resulting from the normal delivery of a service; consumers ordering something from a phone service may reach a message telling them to wait because other people have called in ahead of them. In this case, consumers perceive such a delay as a normal part of the delivery of the phone service. This type of waiting can be referred to as *procedural delay.*

Consumers might also face delays which result from problems with the delivery of the service. These delays are perceived by customers as being not normally arising during the delivery of the service. For example, a person at the driver license office awaiting his appointment for a mechanized exam (on computer) can be told that an exam delay is imposed due to a computer system failure. This problem does not arise normally during the delivery of the service and its duration is also unknown. This delay can be referred to as a *correctional delay.*

Finally, consumers often face delays during service encounters for which no explanations are either apparent or offered by the service provider. This category of delays could represent a large proportion of the service delays consumers normally face in their day to day interfaces with service organizations. These delays are referred to as *unknown delays.*

Customers arriving at the driving license office case face two types of delays: a *correctional* and an *unknown delay.* The customers already have an appointment (taken several weeks ahead of their visit) yet no concrete explanation is offered by the service provider for the delay; "...it became natural to spend half of your day in here...", (Perault, 1996).

Evident from this problem definition is the fact that the customer is just a segment of the service line operation that is here viewed as an independent system. It is easier to analyze this system on its own. The problem of particular interest here is to minimize the customer waiting in the system. There are also other alternatives to achieve this goal. One alternative is to increase without bound the number of examiner stations. Now, how feasible is this option? It is apparent that space limitation, the cost of maintaining an infinite number of stations, the high preparation of idle time in the examiner's stations, and so on, may make this option inappropriate.

Another option is to establish trade-offs between the customer waiting time and both the number of examiner stations and the way these stations interact. This trade-off sounds feasible, since increasing waiting time may be attributed to the inability to serve clients in a timely and efficient fashion. In addition, due to budget limitations, the operation's manager may specify a tolerable average waiting time within which the optimization of the number of work stations can be conducted.

8.3- OBJECTIVE OF THE STUDY:

More and more services are moving towards a managed capacity system. The flow of customers through the interdependent, sequential functions of a service readily reveals strengths and weaknesses in the design and operation of current customer processing policies. Nonexistent customer waiting time or completely satisfied demand may imply unused capacity. On the other hand, long waiting times or frequent processing bottlenecks may indicate insufficient capacity or dissimilar rates of flow between interdependent functions. As bottleneck activities impede customer flow, customer waiting times and dissatisfaction increase. In addition, dissimilar processing capabilities may increase the provider's idle time, decreasing productivity and lowering morale. Once problems are identified, customer processing reorganization can help coordinate customer movement between interdependent activities. Moreover, various strategies can alter the demand for customer services, control the availability of service resources, and coordinate a service's processing capacity effectively.

The structure of multiple station - multiple queue service systems is addressed in this study. The operations of a typical multi-station (i.e. Montreal driver license office) are modeled and analyzed to determine the most appropriate operational management procedures to handle stochastic demand. The goal of this study is *to determine, through simulation modeling, a set of policies for reducing customers waiting time in the system and increasing resource utilization in the referent office.*

8.4- SCHEMATIC DEVELOPMENT OF THE SYSTEM:

A schematic development of the system is necessary to really understand how the real system operates. In fact, this is also a form of model building. A blueprint of the model is established to show the processes that take place in the system, its environment, and constraints and variables that influence the system's performance.

The basic flow of the system at the driver licensing office is more complicated than a typical bureaucratic office. The synthesis of possible customer routing at the different services offered by the "Centre d'évaluation des Conducteurs" (C.E.C.) is presented in Figure 13. Evident from this global graph is that there are many queues where the customers might wait. Notice that due to government policies, the same person cannot take a written and a road test on the same day. A margin of at least two to three weeks is recommended before he/she takes another appointment. To better describe each flow of transaction, every routing is gradually separated according to type of service; a separate graph of the following is presented in Appendix C.

Descriptive analysis[4]:

A/-Getting an appointment or information:

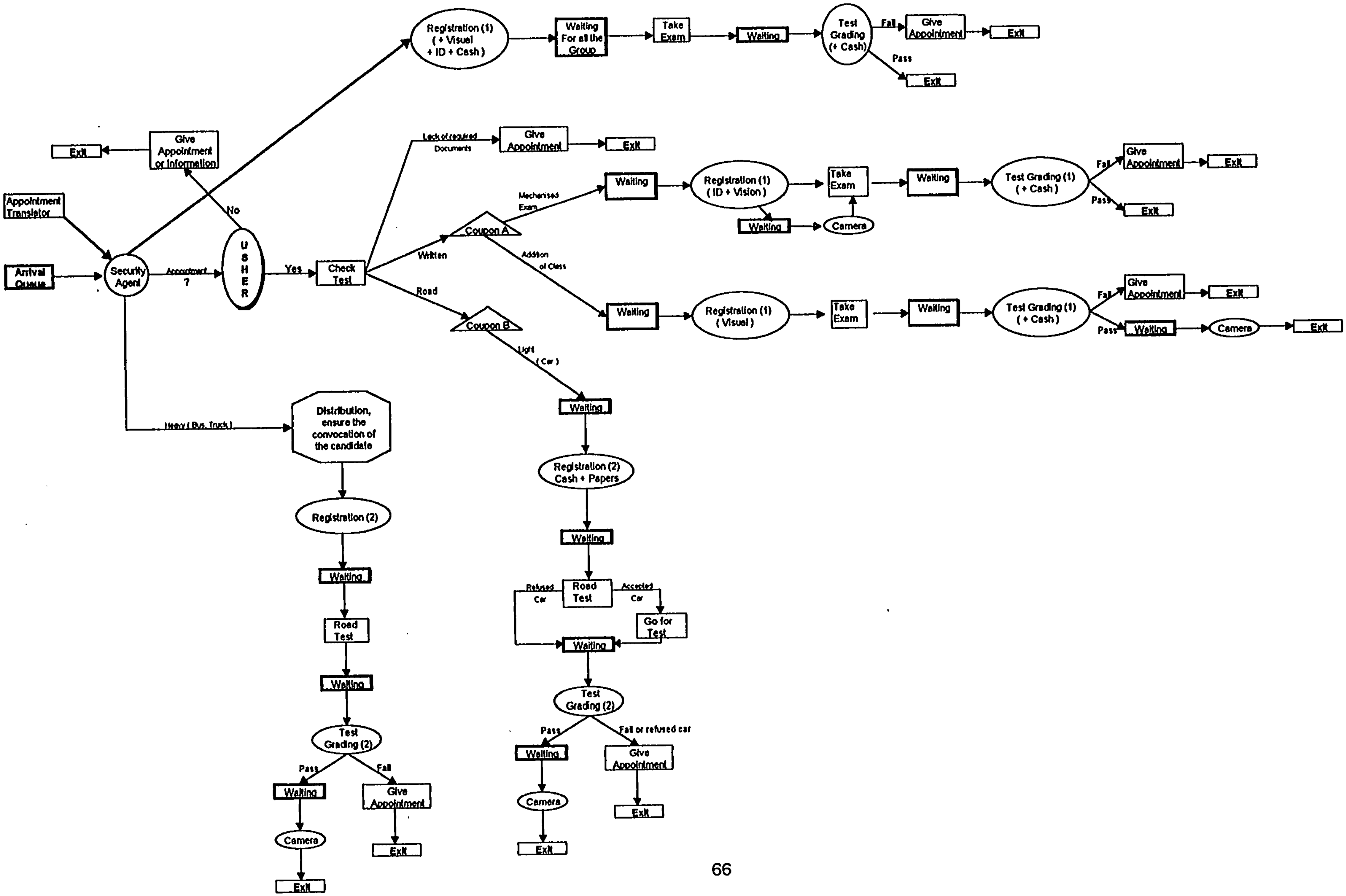
The majority of services offered at C.E.C primarily require an appointment. All clients arriving are required to see a security agent who checks if they have an appointment and/or directs them to their specific service area.

The client whose only objective is to get an appointment or certain information will be directed to one of the two tellers at the usher station.

[4] For the case of description, the masculine format is used in referring to people.

FIGURE 13: GLOBAL VIEW

Customer Routing at " Centre d'Évaluation des Conducteurs " (C.E.C.)



The teller will then provide an appointment to the client depending on the C.E.C's and the client's disponibilities.

B/-Written Exam: Mechanized Exam:

This routing concerns more than 80% of the theoretical evaluation. At the time of their appointment, the clients are intercepted by the security agent, who will direct them towards one of the two tellers at the usher station. The teller will then verify, with the use of a chronological list, the type of exam to be held. For a mechanized exam[5], he submits a service coupon "A" after making sure that the candidate possesses all the necessary documents.

The candidate enters the waiting room and awaits his number to appear on the board referred to as "FRISCO BAY"[6] that mentions the wicket number to which he must go to. One of the tellers (of wickets 1 to 12), with the use of a computer, takes care of the clients file and the payment of the required fee. The system shows if the client is passing the exam for the first time or not.

If applicable, the candidate has to pass a visual test in order to get an identification card just before he goes to the exam room. As soon as the candidate finishes his exam, the person at the exam room will give him a copy of the test results and a service coupon.

[5] Exam held on a computer system (ETAP system).

[6] Waiting lines system according to the arrival sequence.

The candidate then returns to the waiting room where he awaits his number at the call board for a second time. When his number appears, he goes to the wicket mentioned (1 to 12). The examiner checks the results obtained on the computer, collects the required fee and issue a temporary permit. In case of failure, the teller reschedules the candidate for another appointment.

At this point, the candidate has finished his evaluation process and exits the center.

C/-Written Exam- Addition of Class:

Candidates in this category differ from the ones in part B: customers arrive in the office already carrying their driving permit but requesting a different type of class (Taxi, Bus, etc.), or a reinstatement of license after 3 years of cancellation, or an equivalency of license issued in other provinces in Canada. The candidates are directed towards one of the two tellers at the time of their appointment by the security agent. The teller will then verify, with the use of a chronological list, the type of exam to be held. For a mechanized exam[7], he submits a service coupon "A" after making sure that the candidate possesses all the necessary documents.

The candidate enters the waiting room and awaits his number to appear on the board referred to as "FRISCO BAY" that mentions the wicket number to which he must go to. One of the tellers (of wickets 1 to 12), with the use of a computer, takes care of the clients file and the payment of the required fee.

If required, the candidate has to pass a visual test in order for him to get an identification card before he performs his exam. Depending on the evaluation form

[7] Exam held on a computer system (ETAP system).

demanded and the type of permit requested by the client, the teller will provide the necessary material. As soon as the candidate terminates his exam, an examiner in the room will correct it and file his results on the computer.

In case of failure, the teller gives the candidate an appointment and then leaves the center. On the other hand, the candidate who passes his exam returns to the waiting room and waits for his number to appear, he will then go to the appropriate wicket. The teller collects the necessary fee for delivering the client's driving license and gives him another coupon for his picture to be taken.

At the camera station, the teller provides the license with the client's picture on it. The candidate has terminated his evaluation process and exits the center.

D/-Written Exam, With a Translator:

The process of theoretical evaluation involving a translator requires several candidates to be put in groups. the candidates are directed by the security agent to a separate waiting queue. The tellers (in wicket 1 to 12) call them in order, and verify with the chronological list if the candidates have an appointment. They will then file the candidates information on the computer and collect the required fee.

The candidates will then take a visual test in order to get an identification card before their exam. The candidates are then regrouped in the waiting room. As soon as the group is formed, they go to the exam room with the translator.

When a candidate finishes his exam, the examiner in the room proceeds with the room proceeds with the corrections. A coupon is given and the candidate returns to the waiting room until he is called by one of the tellers at wickets 1 to 12.

The teller takes care of the clients results on the computer and in case of passing issues a temporary permit and collects the required fee. On the other hand, if the candidate fails, the teller reschedules him for a second appointment. The candidate has then terminated his evaluation process and exits the center.

E/-Road Test- Light Vehicle:

This routing concerns more than 85% of the road evaluations. The candidates are intercepted by the security agent who will direct them towards one of the wickets at the time of their appointment. The teller at the usher station verifies with the chronological list the type of exam to pass and if the candidate has at his disposal a vehicle. He submits a service coupon B after making sure that the candidate posses the necessary documents.

The candidate enters the waiting room and awaits his number to appear on the board referred to as "FRISCO BAY" that mentions the wicket number to which he must go to. One of the tellers of wickets 15 to 20 proceeds with the client's file on the computer and collects the necessary fee.

If required, the candidate performs a visual test. The teller then submits a service coupon to the client who returns to the waiting room reserved for the road test. An available inspector at the registration proceeds with the road evaluation. After his return, the inspector provides the client with a service coupon and directs him towards the waiting room.

In case of failure, the teller gives the candidate an appointment and then leaves the center. On the other hand, the candidate who passes his exam returns to the waiting room and waits for his number to appear, he will then go to the appropriate wicket. The teller collects the necessary fee for delivering the client's driving license and gives him another coupon for his picture to be taken. At the camera station, the teller provides the license with the client's picture on it. The candidate has terminated his evaluation process and exits the center.

F/-Road test- Heavy Vehicle;

The candidates are intercepted by the security agent –which is a different pattern than the one in part E- who directs them towards the distribution station at the time of their appointment; or they can present themselves directly. The teller at the distribution station checks that he has the appropriate candidates. He then directs them to wickets 15-20.

The teller at the appropriate wicket proceeds with the client's file and collects the registration fee. The candidate will then perform the visual test. As soon as the evaluator specialist of heavy vehicles is available, the candidate proceeds with the road evaluation.

After the test drive, in case of failure, the teller gives the candidate an appointment and then leaves the center. On the other hand, the candidate who passes his exam returns to the waiting room and waits for his number to appear, he will then go to the appropriate wicket.

The teller collects the necessary fee for delivering the client's driving license and gives him another coupon for his picture to be taken. At the camera station, the teller provides the license with the client's picture on it. The candidate has terminated his evaluation process and exits the center.

8.5- DEFINITION OF VARIABLES:

Before developing the simulation model, we identify the different variables that influence the system's performance. Also, the outcome measures that would be studied as the result of running the simulation model along with the objectives that we want to address are also identified.

1-Input Variables:

-Arrival pattern of customers to the C.E.C. (demand management)

-Number of examiners' stations

-Service time at each station

-Actual labor assignment at each station

-Customer routing depending on service alternatives

-Actual job flexibility

-Hours of operations: These hours are flexible in each station and also depend on the time of the year.

-Priority settings for special routing (i.e. Translators and heavy vehicles tests).

2-Outcome Variables:

-Average customer waiting time in the system

-Average customer waiting time at different stages in the system

-Idle time for servers at each stage

-Average number of customers in the system

3-Objectives:

-Minimize customer waiting time in the system.

-Minimize servers' idle time at the stations.

We define input variables as those variables that serve as input to the system of interest. They can be controllable or uncontrollable. For example, the arrival patterns of customers may be classified as uncontrollable. Eventhough customers show up with an appointment, the 20% overbooking practiced by the C.E.C. and the number of no-shows and cancellations have made arrival rates to follow a random process and are, therefore probabilistic. The operations manager has no control over this factor. There are, however, input variables that are controllable. For example, the manager may be able to control whether or not to have a sufficient job flexibility strategy to combat the long waiting times of customers and at some time, decrease the servers' idle time by permitting coverage of 'in-between' positions.

Outcome measures are used to represent the system's outputs. These variables are influenced directly by the input variables and the model's design (i.e. trade-off). For example, one of the major outcome variable identified is the waiting time in the system. It is obvious that if the number of stations (input) is increased and all other factors such as the arrival rates are constant, then the average waiting time will

decrease. Subsequently, such increase may also lead to an increase in the proportion of idle time of the stations.

We have noted two objectives of this particular system. These objectives are dependent on each other. As noted earlier, there are trade-offs in trying to optimize any of them. Since the significant variables that influence this system have been identified and the interaction between these variables established, the next step is data collection and analysis.

8.6- DATA COLLECTION AND ANALYSIS:

This study used multiple sources of data collection. The use of multiple data collection methods serves to validate the findings of the research by substantiating examination of the variables under study (Eisenhardt,1989; Yin,1994). This study benefits from two sources of data:

i)primary source: *interviews and observation.*

ii)secondary data source: *documentation.*

Multiple face-to-face interviews were conducted and represent a primary source of data collection (Davis & Cosenza, 1993). These interviews were individual, in-depth interrogations of individuals who were either managers or front line personnel (two service managers and three front line employees). These interviews lasted from 45 minutes to 2 hours, with the average time being 1 hour and 15 minutes. Additionally, documentation regarding the type of services and historical data were gathered during each of the key-informant interviews. The operation manager subsequently forwarded additional documentation that included copies of provincial reports, activities and statistics that fortified our study: These multiple interviews have equipped the researcher with the detailed description and explanation of every job type(service type), station patterns and waiting process that a customer might follow in the actual system.

Information about resource availability at each station in January or July was also gathered. Service managers were asked questions about "early warning signals"[8] which warn them that they are running out of capacity. The respondents talked about some fall in service standard and in particular, aspects of timing of customers complaining and staff showing signs of stress. These might be interpreted as showing some awareness at the level "Gosh we're busy" or "we're rushed off our feet" rather than "we need to be careful now and make sure we control what is happening". Some responses talked about measuring what is happening against a plan, which suggests a data-gathering exercise that might be sent and presented to Quebec city to be used to improve forecasting in the future. However, an action which may be important in reducing the coping zone in the future is not likely to help in the immediacy of the moment. Perhaps this reflects that to be good at coping, you must already be good at managing capacity so that the process is more controlled and the coping zone is reduced. As one respondent reported, "We got used to regard firefighting as part of our culture without recognizing what this is doing for customer service and cost".

As for the observation visits, the researcher was given many opportunities to visit the office. This provided a first hand view of the operation in progress and thus facilitated an understanding of the whole system. This would also help provide a richness in the data analysis.

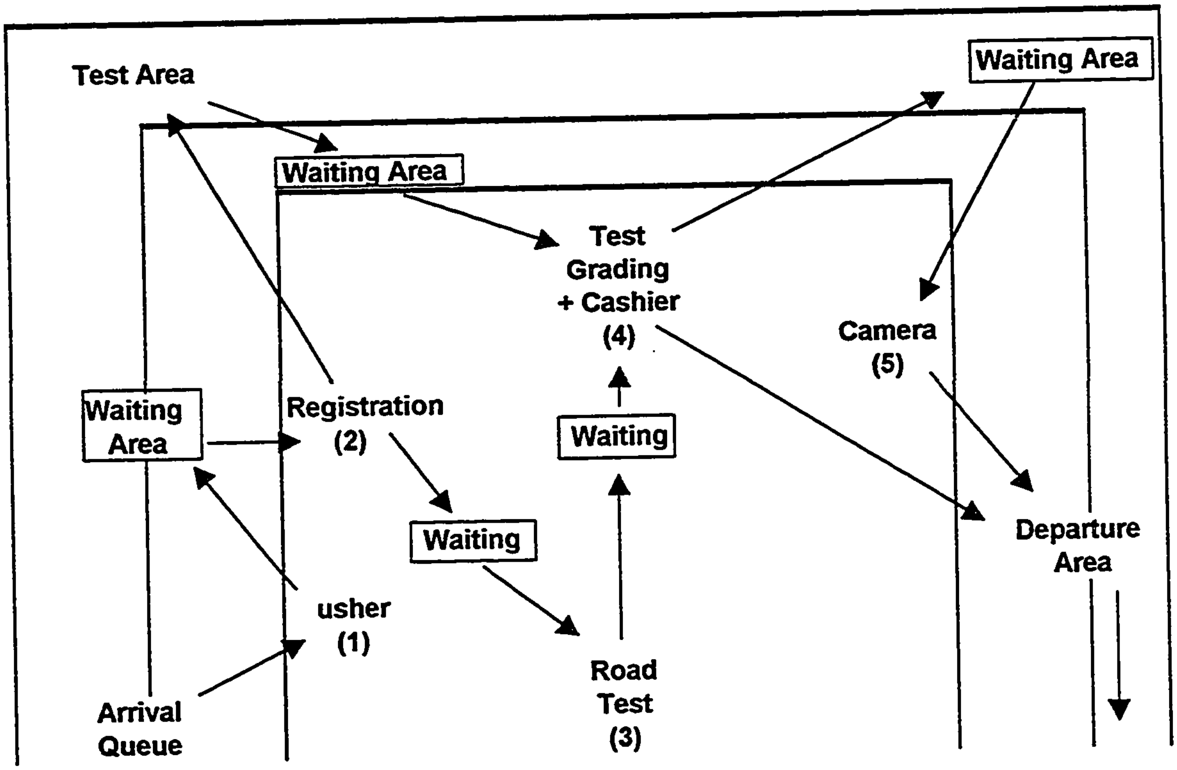
8.6.1- Detailed information:

A "closer look" diagram of the Henri Bourassa office in Montreal is shown in Figure 14. All customers except those with special routing, begin at station one where tellers greet

[8] During the researcher visits, two service managers were interviewed at the office.

Figure 14

A Closer look at the H.B. Driver License Office



Station 1: Examiners greet applicants, determine elegibility including papers and appointments. Assign waiting numbers.

Station 2: Examiners complete license forms, check papers and vision.
Operate the camera for ID registration.
Collect fees for written and/or road tests.
Assign waiting numbers for road tests.

Station 3: Examiners administer road tests.

Station 4: Examiners grade written and road tests and cash register.
Type original license forms.

Station 5: Examiners operate the camera for plastification of the driving license.

them, determine their eligibility (including papers and appointments) and assign them waiting numbers.

Between station one and two, those taken the written test move to the first waiting area and those taking the driving test move to the second waiting area (two different queues).

At station two, the examiners complete license forms, check papers and do the vision test if necessary. They also operate the camera for ID registration, collect fees for written and road tests and assign waiting numbers for those taking road tests only. Customers requiring written test go directly to the test area.

At station three, examiners administer road tests. Customers for both tests have to wait for station four to be free. At this latter, the tests are graded; appropriate fees are paid and original license forms are typed and plastified.

When all processing is completed, customers are photographed at station five and exit the office. They may also exit at any one of the other stations due to test failures, incomplete information, or because time conflicts require customers to leave for other businesses.

In the office modeled, two examiners work at station one, twelve at station two (written test), six at station two (road test), nineteen examiners administer the outside driving test (station three) and six examiners as camera operators. The hours of operation[9] are from 8:00 AM until 5:00 PM, with the servers taking rest and lunch breaks during the day. Work tours are staggered to provide coverage for the nine hours of operation, but

[9] Even though the official closing time is at 5:00 PM, it tends to alternate depending on how busy the system is as well as the time of year.

otherwise, this staffing remains constant during the day. Sufficient scheduling flexibility exists to permit coverage of all the positions during rest and lunch breaks.

Customers usually arrive before the office opens, forming a line that totally occupies the office servers in the early hours of operation.

After opening, the arrival process has a non-stationary mean that oscillates above and below the average service rate. The early morning and late afternoon arrivals exceed the service capacity, but the demand rate slows, not significantly, during the mid-day hours (refer to following section 8.6.2).

This oscillation causes the queue length to vary depending on the time of the day. At 5:00 PM, the outer door is closed to prevent additional arrivals but service continues until the customers inside the office have been served.

8.6.2- Arrival Distribution:

An extensive data collection effort was required using accepted work measurements and estimations based on discussions with the office manager to determine service times, types and patterns of licensing transactions as well as actual arrival times. Some of the data were provided by the department of Motor Vehicle's Management Information System (Frisco Bay: a copy of a part of the original is presented in Appendix D). In addition to the historical data, information for all types of transactions and service patterns was collected for three weeks of operation in the example office.

Due to the seasonality effect on demand at the office, the arrival rate during January and July[10] was collected to do the simulation study (i.e. the study was applied on each one of them independently). Since operation, patterns and mean arrival rate for each

[10] The same applies to both except: -hours of operations -demand - more examiners for road test (station 3) -number of computers.

day during the three weeks are essentially the same(Table 5), three weeks of data for each period was adequate (See Table 6 for a representation example and the rest in Appendix E). Arrivals per day were tested to see whether they follow a poisson distribution. Results from Table 7 clearly rejected this hypothesis. However, from observing the characteristics of the arriving customers, the interarrival times (A1, A2, etc.) are not identically distributed since the arrival rate λ (T) does in fact change as a function of time. This stochastic process (N(t), t>0) is said to be a *nonstationary Poisson process*. For statistical validation, the actual arrival times between 8:30 and 10:30 and between 1:30 PM and 3:30 PM were matched to this *time-varied* Poisson distribution using goodness-of-fit tests following the procedures of Law & Kelton (1982) (Tables 8a and b) (similar results were obtained for July).

An independent simulation has been done on the effects of time-varied arrival rates (Zhu *et al.,* 1992). This study was done before the licensing office simulation; it addresses the difficulties in applying the queuing model which involves the determination of a stationary arrival rate when the one in a real system varies substantially from hour to hour during the day. The authors modeled an emergency ambulance system using SLAM II, and found that the variation of their hourly demand pattern in their data could be fully described by a Poisson distribution with the stationary arrival rate over six 4-hour time durations. In the study of the licensing office, the researcher found that the customers arrival time was a function of the time of day, and modeled it accordingly. The study of the emergency ambulance service confirms the findings of our findings of the licensing center concerning the modeling of the arrival patterns of the customers.

Table 5

Test For Equality of Means During Week-Days

		Unique Method				
		Sum of Squares	df	Mean Square	F	Sig.
Monday	Model	218.17	2	109.063	0.126	0.882
	Residual	51791	60	863.183		
	Total	52009.1	62	838.856		

		Unique Method				
		Sum of Squares	df	Mean Square	F	Sig.
Tuesday	Model	322.127	2	161.063	0.194	0.825
	Residual	49929	60	832.149		
	Total	50251.1	62	810.501		

		Unique Method				
		Sum of Squares	df	Mean Square	F	Sig.
Thursday	Model	212.603	2	106.302	0.123	0.884
	Residual	51655.7	60	860.929		
	Total	51868.3	62	836.586		

		Unique Method				
		Sum of Squares	df	Mean Square	F	Sig.
Friday	Model	501.841	2	250.921	0.311	0.734
	Residual	48412.8	60	806.879		
	Total	48914.6	62	788.945		

Table 6

ARRIVALS DURING THE FIRST WEEK OF JULY 96

TIME	MONDAY 1	TUESDAY 2	WEDNESDAY 3	THURSDAY 4	FRIDAY 5
7:30	0	0	0	0	0
8:00	27	9	0	11	28
8:30	48	54	1	57	49
9:00	78	73	0	78	91
9:30	111	108	22	101	119
10:00	81	96	61	92	87
10:30	73	80	89	77	91
11:00	80	85	100	91	93
11:30	90	97	98	93	95
12:00	77	82	91	77	71
12:30	68	58	90	71	79
1:00	68	76	60	67	55
1:30	50	66	82	70	79
2:00	98	96	102	76	82
2:30	86	104	93	84	84
3:00	87	76	104	90	106
3:30	55	66	55	69	76
4:00	61	54	53	54	45
4:30	17	41	19	38	17
5:00	7	4	0	1	0
5:30	0	0	0	0	0
TOTAL	1262	1325	1120	1297	1347

GRAND TOTAL = 6351

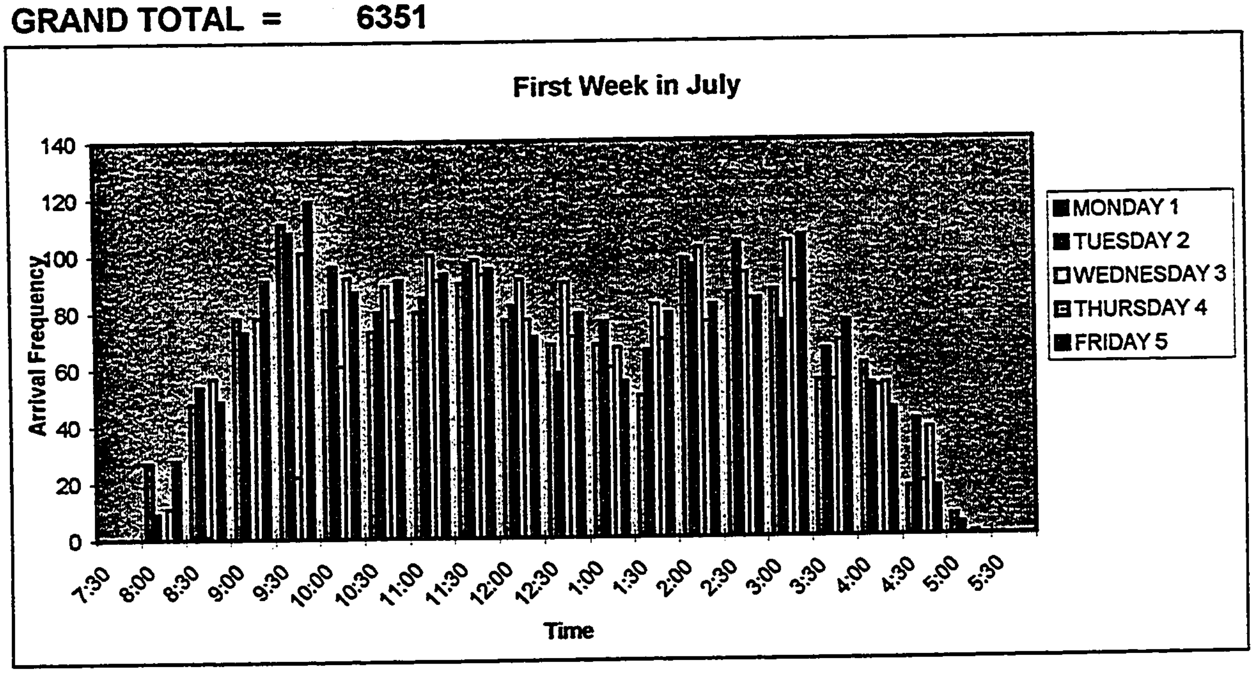


Table 7

Statistical Data Analysis for Customer Arrivals on Mondays During January 97

Number of customer arrivals	Class	Actual Frequency,Fo	*Mi* * *Fi*	Probability, P(X) Poisson with u(x)=*3.0526*	Theoretical Frequency *ft*= n * p(X)
0 -less than 15	0	9	0	0.045	2.565
15 -less than 30	1	2	2	0.1397	7.9629
30 -less than 45	2	3	6	0.2165	12.3405
45 -less than 60	3	17	51	0.2237	12.7509
60 -less than 75	4	15	60	0.1734	9.8838
75 -less than 90	5	11	55	0.1075	6.1275
90 -less than 105	6	0	0	0.0555	3.1635
105 -less than 120	7	0	0	0.0246	1.4022
120 -less than 135	8	0	0	0.0095	0.5415
135 -less than 150	9	0	0	0.0033	0.1881
Sum		57	174		
Mean		3.052631579			

Computation of Chi-Square Test Statistic For the Customer Arrivals on Mondays During January 97

Class	Fo	Ft	(Fo - Ft)	(Fo - Ft)	(Fo - Ft) / Ft
0	9	2.565	6.435	41.409225	16.14394737
1	2	7.9629	-5.9629	35.55617641	4.465229553
2	3	12.3405	-9.3405	87.24494025	7.069805944
3	17	12.7509	4.2491	18.05485081	1.41596678
4	15	9.8838	5.1162	26.17550244	2.648323766
5	11	6.1275	4.8725	23.74125625	3.874542024
6	0	5.2953	-5.2953	28.04020209	5.2953

Ho: The number of arrivals on Monday follows a Poisson Distribution
Ha: The number of arrivals on Monday does not follow a Poisson Distribution

Chi-square calc. = 40.9131
Chi-square crit. (5%, 6)= 12.592

Decision Rule: Reject Ho if Chi-square (calc.) > 12.592

Conclusion: Since 40.9131 > 12.592, We reject Ho. Thus, we may conclude that the number of arrivals does not follow Poisson distribution.

Table 8a:

Statistical Data Analysis for time-varied Poisson for Customer Arrivals between 8:30 to 10:00 AM

Number of Customer arrivals	Class	Actual Frequency Fo	Theoretical Frequency Ft	chi square
0 - 60	0	3	5.639277258	1.235226453
61 - 64	1	9	4.541634305	4.376623774
65 - 67	2	7	6.056484498	0.146986507
68 - 70	3	6	6.971830143	0.135467131
71 - 73	4	8	6.975064907	0.150606763
74 - 76	5	6	6.102680932	0.001727663
77 - 79	6	4	5.921093104	0.623296855
80 - 85	7	3	5.154728114	0.900697989
86 - +	8	2	0.639305461	2.896095439
	total	48		**10.46672857**
	mean	65		

Table 8b:

Statistical Data Analysis for time-varied Poisson for Customer Arrivals between 1:30 to 3:00 PM

Number of Customer arrivals	Class	Actual Frequency Fo	Theoretical Frequency Ft	chi square
0 - 60	0	6	4.832914838	0.281835667
61 - 64	1	9	5.689558262	1.926164387
65 - 67	2	9	5.934769014	1.583151927
68 - 70	3	4	6.775344183	1.13684783
71 - 73	4	6	6.778137047	0.089330927
74 - 76	5	8	5.974984878	0.686309058
77 - 79	6	2	4.664602258	1.52212446
80 - 85	7	3	5.251694333	0.965426974
86 - +	8	1	2.100223064	0.576362964
	total	48		**8.767554194**
	mean	69		

Ho: The number of arrivals follows a time-varied Poisson distribution
Ha: The number of arrivals does not follow a time-varied Poisson distribution

Chi-square calculated between 8:30 and 10:00 a.m. = 10.466
Chi-square calculated between 1:30 and 3:00 p.m. = 8.767
Chi-square critical = 15.507

Conclusion: Since 8.768 and 10.466 are lower than 15.507 we do not reject Ho and conclude that the number of arrivals follow a Poisson distribution

8.6.3- Structure of the Model:

To model the different patterns used by customers, the transaction job types (reinstatement of license, road test, and so on) were cross tabulated with the path followed by the customer through the five stations. The job types and paths through the stations are shown in Tables 9 and 10.

As each customer is generated, a two-step process assigns a job type (J) from the job distribution and then a system pattern (P) from the path distribution applicable to that job. The percentages for each type of job and service routing option for January and July are shown in Table 11. The data and structure were developed by the researcher and are based on multiple calculations, observations on the site and discussions with the service manager. A copy of part of the raw data collected is shown in Appendix F.

For example, 11.06 percent of all arrivals would need to reinstate a license (J2). Of the customers needing job type2, 5 percent of all arrivals would need to follow pattern 1 (P1), 20 percent would follow pattern 2 (P2), 25 percent would follow pattern 3 (P3), and so forth.

8.7- SIMULATION MODEL BUILDING:

As we discussed previously, our model is used as a representation of a real system. Imperatively, it must have something to offer that we may not be able to deduce directly from the real system. Thus, accuracy of the model is very important.

The simulation language GPSS/H was employed as the modeling vehicle because it mainly provided the flexibility to employ probability distributions and use experimental control (Appendix G). Considered as one of the most popular discrete-event simulation languages, General-purpose systems simulation is, by far, one of the easiest simulation

Table 9: *Types of Transactions*

Job Number	Type of Job
1	Information Only
2	Reinstatement of License
3	Temporary Permit
4	Eligibility Failure (1)
5	Road Test Only
6	Eligibility Failure (2)
7	Balk at Station One
8	Special Routing

Table 10: *Station Patterns*

Pattern Number	Pattern Routing
1	1– Exit (Immediate Exit)
2	1– 2 – Exit
3	1 – 2 – 4 – Exit
4	1 – 2 – 4 – 5 – Exit
5	1 – 2 – 3 – Exit
6	1 – 2 – 3 – 4 – 5 – Exit
7	1 – 2 – 3 – 4 – Exit
8	2 – 4 – Exit
9	2 – 3 – 4 – Exit
10	2 – 3 – 4 – 5 – Exit

Table 11:

Percentages of transactions and station Patterns For a three Week Period in January & July

Job type	Station Pattern P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	Total jobs Jan	Total Jobs Jul	% jobs
J1	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	67.51	87.82	0.46
J2	5.00	20.00	25.00	42.00	0.00	8.00	0.00	0.00	0.00	0.00	1623.17	2111.00	11.06
J3	1.00	10.00	80.00	0.00	0.00	0.00	0.00	9.00	0.00	0.00	4796.12	6239.00	32.68
J4	0.00	0.50	75.50	20.00	0.00	0.00	0.00	4.00	0.00	0.00	2757.62	3587.00	18.79
J5	2.00	1.00	0.00	0.00	5.00	60.00	32.00	0.00	0.00	0.00	3155.34	4105.00	21.50
J6	0.00	1.00	0.00	0.00	2.00	60.00	32.00	0.00	2.00	0.00	1721.49	2239.00	11.73
J7	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	66.04	85.91	0.45
J8	0.00	30.00	0.00	0.00	0.00	0.00	0.00	27.00	13.00	30.00	487.24	633.80	3.32
Total Jobs jan	327.27	1012.64	6323.89	1231.32	193.72	3057.01	1611.42	675.10	95.39	143.82	14676.00		100.00
Total Jobs jul	425.00	1317.00	8226.00	1602.00	252.00	3977.00	2096.00	878.20	124.10	187.10		19091.00	
%	2.23	43.09	8.39	1.32	20.83	10.98	4.60	0.65	0.98	100.00			

language (Madu & kuei, 1993). Although it is not as flexible as SIMSCRIPT in terms of allowing for integration of statistical analysis in the model coding, the extensions of GPSS to GPSS/H make it possible to incorporate FORTRAN-like codes in GPSS (Banks & Carson, 1989). This improves the flexibility and the power of GPSS as a simulation language[11].

In this discrete event simulation, a customer arrival is generated according to the applicable Poisson distribution. Customers arrive with a non-stationary interarrival time pattern with the mean of the pattern being a function of the time of any given day. Three weeks average in January and July were simulated independently. Furthermore, the researcher has considered Wednesdays as an "outlier" and was not counted in the customer arrival function. The reason is that the office closes every Wednesday morning (from 8:00 to 10:00 approximately) for a weekly meeting held at the C.E.C. It was felt that since the objective of our model is to base its output on *any given day,* its inclusion would create some variation in the average number of people arriving per half an hour per day.

Of critical importance in model coding is the identification of the transactions of physical entities that are in the system. The transactions in our study are the customers themselves. After each customer was generated, a two-step process assigned a job type (J) from the job distribution and a system pattern (P) from the applicable path distribution from the job. Customers then, cycle through the system network obtaining service or waiting in a queue when a server is not available. When the server is available, the length of service was determined from the appropriate service time table (Table 12).

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[11] For a comprehensive survey of simulation software, see Law and Haider 1989, or the yearly proceedings of the Winter Simulation Conference.

Table 12

Service Time Spent at each Station

Station	*Service Time (min/customer)*
Usher	0.75
Reg I	11.7 (first timer)
Reg I	7.7 (second timer)
Reg II	11.7 (first & second timers)
Test grading I	3.62 (if fail test)
Test grading I	1.0 (if pass test)
Inspector	30.0
Test grading II	3.62 (if fail test)
Test grading II	1.0 (if pass test)
Camera	3.5
Mechanized test	30.0 (on computer)
Translator test	30.0 (on paper)
Road test	30.0 (light vehicle)
Road test	40.0 (heavy vehicle)

Evident from the table that new and revisiting customers will not be allocated the same service time at the written registration (RegI). In addition, it is also evident from the model itself that the researcher considered the service time variance as a serious limitation. However, the assumption of exponential distribution have equipped the researcher with the possibility to address this limitation as efficiently as possible. Appendix H shows the modified model and its respective output as well as the test for its non significance difference from the original in terms of waiting time in the system.

These *transactions* are temporary entities that are randomly generated. They are subsequently destroyed after service has been rendered. Thus, temporary entities are used to represent the transactions that enter and leave the system during the course of the simulation (Gordon, 1975).

Each replication of the simulation would start with an empty system and simulate it for nine hours (approximately) i.e., random numbers were not reset between runs. This is an example of Terminating simulation, one that runs for some duration of time until some event stops the simulation (vs. running continuously). The simulation generated maximum randomness and was replicated for fifty runs. For this terminating simulation, we are interested in *short-term dynamic behavior.* Data was collected on the average time length of each queue, the percent of utilization of each server and the average time the customer spent in the system.

8.7.1- Variance Reduction Using Antithetic Variates:

As simulators, we have the ability to control the sources of variability in our experiments and to repeat experiments under identical "random conditions". This gives us a tremendous advantage over other professionals using statistical methods to analyze data from nonsimulation sources. Using our ability to control the randomness in our models, we are able to reduce the effect that random *noise* has on our analysis. For example, let X and Y be two observed output values of the same statistic. Let X represent the time in queue for the first run of a single line, single server queuing model, and let Y represent the time in queue for the second run.

The variance (X + Y) = VAR(X) + VAR(Y) + 2 * COVAR(X,Y).

The covariance of X and Y is zero if X and Y are independent. If a way can be found to induce a negative correlation between X and Y (causing the covariance to become negative) the variance of X and Y will be less than the sum of the variance of X and the variance of Y. Unfortunately, we usually have no control over the observed output. If the output is proportional to the input random variables, an indirect approach to inducing negative correlation between X and Y can be taken. Antithetic variates can be used for this induction. The general procedure is based on using complementary random numbers. For instance, if a sample from a distribution occurs at the 15th percentile, then the antithetic is obtained from the 85th percentile. These variates are requested by specifying negative seed values in a RMULT statement or a BRMULT block. Appendix I shows where and how to include this technique in the model and the comparision between the original output and the modified one using this technique for 26 runs, i.e. the decrease in standard deviation.

8.7.2- Verification:

The goal of verification is to establish that each segment of the simulation works correctly. It is concerned with the consistency of the model (Friedman & Pressman, 1988). One of the techniques used in verifying our model is output measures. These measures were observed to see if they are reasonable. We consistently checked to see if the queues are building up when fewer numbers of examiners are maintained. The second technique used was through diagnostic simulation runs: sample runs of the program had also been performed and the resulting reports were examined carefully. The number of transactions that visited each portion of the model had been scrutinized to ensure that the proper percent of transactions jump to each label.

In addition, we verified that the model's performance is consistent with the assumption that all the transactions that enter the system must depart before closing time.

8.7.3- Validation:

After making some pilot runs, we established a correspondence between the model and the real system i.e. the behavior of the real system is adequately represented by the simulation model.

According to Madu and Kuei (1993), a good approach to validate a model is to have the model reviewed by those familiar with the system. The simulation output was presented to the office manager and a structured *walk-through technique* was applied. Although this approach is not objective, further insights about the operation of the system and potential problems with the model have been gained since the right people were used: the analysis with the customer routing available at the office proved to be different from the process described by management. This let to an assumption that certain customer pattern is missing in the model. Validation attempts with the model indeed showed that the new law established by the government in 1996 -which states that every first timer customer coming for a written exam must do an identification card before entering the examination room- was missing. As a result, a second model was developed. Alternatively, the simulation program has been reevaluated and cross-checked for errors, especially with the logic and syntax of each segment of code. Its structure and results of its use are the focus of the remainder of the sections.

8.8- ANALYZING OUTPUT OF THE EXISTING SYSTEM:

The actual simulation output of the Henri Bourassa driver licensing office is shown in tables 13 a and b. The sysQ refer to the Customer Average waiting time in the system. It is the time required by each customer to transit the system from arrival to exit. It was apparent that on any given day, people are waiting much less on average in January with Confidence Interval between 105.282 and 113.282 minutes than in July (158.632-166.434)[12].

This difference might be due to the higher demand experienced during the month of July. However, both numbers are extremely high for customers who have already booked an appointment one month ahead of time.

In order to see where the discrepancy occurs, we should look at the time spent in each queue of the process. Again, evident from the tables that the major contributor to waiting time in January and July is the written test queue where customers almost spend 50% of their time(notice should be taken that the queue represents the people coming just before entering the exam room and those who have just finished their exam). On the other hand, the waiting time at RegII (i.e. road queue) and Inspectors (road1 queue) in July is completely the opposite of what is really the case in January. This is due to two reasons; first, the policy at the office is to hire more inspectors in July(26 of them) than January(19) which have resulted in a decrease of time spent at

[12] This time includes the time spent in the exam room or on the road.

TABLE 13a: OUTPUT OF EXISTING SYSTEM DURING JANUARY 97

AVERAGE MAXIMUM CONTENT FOR 50 RUNS

SYSQ	USHERQ	ROAD	ROAD1	CAMQ	WRITE
355.16	11.48	50.90	38.36	3.98	227.32

OVERALL AVERAGE CONTENT FOR 50 RUNS

SYSQ	USHERQ	ROAD	ROAD1	CAMQ	WRITE
197.75	1.06	16.14	14.39	0.03	100.77

AVERAGE CURRENT CONTENT FOR 50 RUNS

SYSQ	USHERQ	ROAD	ROAD1	CAMQ	WRITE
0.00	0.00	0.00	0.00	0.00	0.00

AVERAGE RESIDENCE TIME FOR 50 RUNS

SYSQ	USHERQ	ROAD	ROAD1	CAMQ	WRITE
109.28	0.58	11.53	26.78	0.06	50.69

OVERALL AVERAGE UTILIZATION FOR 50 RUNS

USHER	REGII	INSP	REGI	COMPUTER	CAMERA
59.57	80.74	88.02	86.76	45.97	24.71

CONFIDENCE INTERVAL FOR SYSTEM QUEUE

SD	LOWER LIMIT FOR 99% CI	UPPER LIMIT FOR 99% CI
10.554	105.282	113.282

TABLE 13b: OUTPUT OF EXISTING SYSTEM DURING JULY 1996

AVERAGE MAXIMUM CONTENT FOR 50 RUNS

SYSQ	USHERQ	ROAD	ROAD1	CAMQ	WRITE
663.42	44.14	173.12	48.80	88.44	406.26

OVERALL AVERAGE CONTENT FOR 50 RUNS

SYSQ	USHERQ	ROAD	ROAD1	CAMQ	WRITE
362.80	14.12	68.28	4.45	13.75	184.27

AVERAGE CURRENT CONTENT FOR 50 RUNS

SYSQ	USHERQ	ROAD	ROAD1	CAMQ	WRITE
0.00	0.00	0.00	0.00	0.00	0.00

AVERAGE RESIDENCE TIME FOR 50 RUNS

SYSQ	USHERQ	ROAD	ROAD1	CAMQ	WRITE
162.53	6.94	48.75	6.88	11.71	81.19

OVERALL AVERAGE UTILIZATION FOR 50 RUNS

USHER	REGII	INSP	REGI	COMPUTER	CAMERA
76.42	88.22	78.21	93.37	50.66	60.24

CONFIDENCE INTERVAL FOR SYSTEM QUEUE

SD	LOWER LIMIT FOR 99% CI	UPPER LIMIT FOR 99% CI
10.292	158.632	166.434

the Inspector queue in July and a relative high one in January. Furthermore, since the demand is much higher in July(specially for road test), the bottleneck at RegII that was not apparent in January is now becoming condensed during the summer.

The average residence time in each queue has a major reflect at its average utilization rate. RegII, Inspectors and RegI are the busiest at 80.74%, 88.02% and 86.76% of their time, respectively in January; and relatively the same in July. As for the camera operators and ushers, they are the less busy at only 60% and 76% of their time in July, respectively; and even less in January.

Overall use of customers examination computers averaged only around 30% in January and 60% in July. Although the office utilizes more computers in the summer, the daily use of all computers during the nine hour data collection interval was not marginally acceptable. As a result, the service categories that established relatively higher average residence time were the RegI, RegII stations; although their average use is relatively high, periods of congestion have occurred simultaneously. Moreover, since over 70% of all clients required any of these services (written and road test), they were designated as bottleneck activities, becoming the focus of additional analysis. Congestion results from temporal fluctuations in demand for services and less variability in the staff assignment, and flexibility required to provide these services.

8.9- DESIGN OF EXPERIMENTS:

The design of experiments is critical in conducting simulation experiments. Here, the researcher decides what values of the independent variables identified in the section on schematic development should be used in the experiment.

The values of these independent variables are chosen so that their respective effects on the system's performance measure (dependent variable) are understood. The input and outcome variables identified in the schematic development section represent the independent and dependent variables, respectively. It is not always easy to determine the typical values that should be assigned to the independent variables, because this often depends on what type of outcome is expected.

8.9.1- Application of management strategies:

In these preliminary terminating simulation experiments, we were interested in short-term dynamic behavior such as the average waiting time in the system and average utilization rate of each queue. Data collection and many preliminary experiments have been conducted at this stage to establish the appropriate input values (i.e. factors and their appropriate levels). Also, existing information, such as historical data on similar systems and the subjective judgments of decision makers, have been useful to accomplish this goal. Twenty-five runs were made for each level of factors with each run simulating a nine hour day of the existing service operations[13].

This initial experimentation with the model involved identifying the factors that most influenced the system. An exploratory 3-factor research design included job scheduling factor (i.e. demand management factor), a labor assignment factor(job assignment) and a job flexibility factor(job enrichment).

i) *Job scheduling:* The demand management factor used three levels for January:(1)Existing varying arrival pattern described earlier, (2) a constant mean arrival pattern to simulate smoothed demand described earlier, (3)one that increases demand

[13] Separate experiments were done for January and July i.e. appropriate levels were tested on two different arrival time functions and were chosen depending on the average waiting time in the system and stations utilization rate.

by opening two more hours at the end of each day[14] (allowing more customers to have appointments; thus increasing level of demand in January). The same levels have also been applied to July except the third level that was rejected since it did not improve the system significantly. This is logical because the demand in July has already reached its extreme(i.e. year high).

ii) *Labor assignment:* This factor included the present station configuration described earlier and was compared to two different patterns that (1)reassigned two station five examiners (Camera) to station two -written test(RegI) and (2) reassigned one station five examiner to station two -road test (RegII) and another one to station two -written test (RegI)[15].

iii) *Job flexibility:* This factor provided three different patterns of cross-trained workers. The flexibility was realized by giving the workers a secondary assignment when they were idle in their primary job. In the first level, existing flexibility was tested. In the second, station one examiners helped at station two(RegI), and station five examiners helped at station two(RegII). The third level had station one examiners helped at station two(RegI) and station five examiners helped at station two,(RegI) and (RegII)at the same time.

While each of these managerial policies has been treated extensively on an individual basis in the literature(Baily *et al.(1985), Globerson and Maggard (1984),* Begley *et al.(1983),* Hicks (1982)), they do interact in a complex operating system and should be

[14] This policy was developed based on discussions and data collection with office manager.
[15] Same remark as footnote 14.

considered simultaneously to assess their overall impact. This is possible using the simulation modeling approach.

8.10- DEVELOPMENT OF METAMODELS: FACTORIAL DESIGN

Metamodels are auxiliary or supplementary models that are used in the interpretation of more detailed models such as simulation (Gardenier (1990),Madu (1990),Friedman and Pressman (1988), Kleijnen(1987)). Box et al. (1978) indicate that full factorial designs are of importance for a number of reasons: (1) they can indicate major trends and so determine a promising direction for further experimentation, (2) they form the basis for two-level fractional factorial designs, (3) these designs and the corresponding fractional designs may be used as building blocks so that the degree of complexity of the finally constructed design can match the sophistication of the problem, and (4) the interpretation of the result is easy.

As mentioned before, initial experimentation with the model suggested three factors that affect the processing of customers. This structure provides a three factor design with three levels for each factor in January and a three factor design with three levels for two of the factors and two levels for the other in July.

This initial design provided a 3*3*3 cell matrix resulting in 27 possible combinations of management policies in January. It also gives us a 3*3*2 matrix yielding 18 possible combinations for evaluation in July. Both design matrices are shown in Figure 15a and 15b.

Initial testing suggested that twenty-five observations in each cell would be adequate given that the average time a customer spent in the system was used as the dependent

Figure 15A:

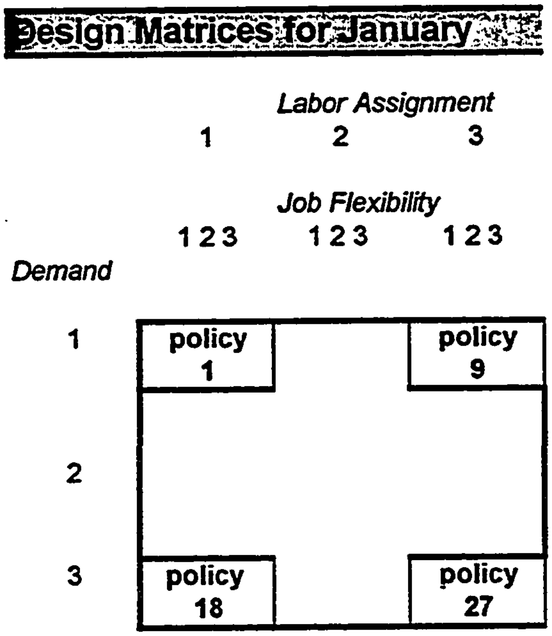
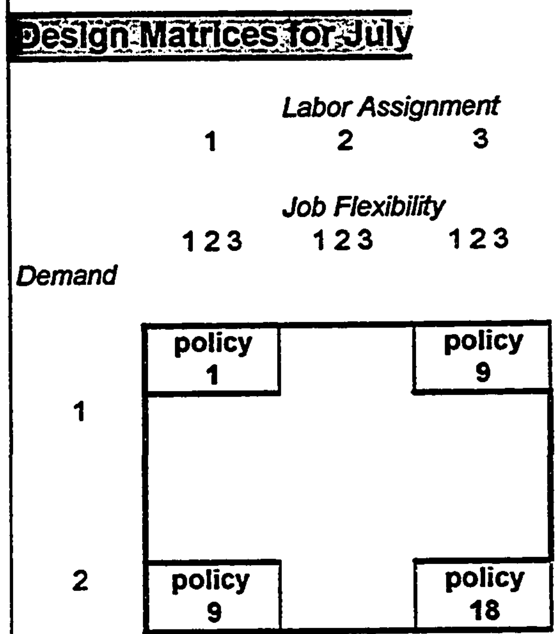


Figure 15B:



variable (see Tables 14 and 15 in Appendix J as well as the normality test assumption for performing valid ANOVA tests later on). Each observation constituted arrivals on any given day where about 982 customers in January and 1300 customers in July required service. Multiple times replication performed above, not only adds to the precision with which the effects of the factors can be measured, but it also gives information about the *variability* of the observed responses. This helps the researcher to ascertain whether the observed impacts are statistically significant or whether they are likely to have been caused by the random fluctuation inherent in simulation.

Variance reduction using common random numbers:

Since the variability that we observe in any given simulation is, we hope, an accurate reflection of that system, we will not attempt to eliminate this variability between each one of the combinations. Rather, we will attempt to reduce the effect of this variability when we compare the performance of the policies. To do this in GPSS/H, we use the RMULT statement to set the seed or starting point for the random number generator used to generate arrival intervals in each model. Before each 25 runs, the seeds in each combination are changed to the same value. This ensures that each combination uses the same sequence of uniform random numbers as the basis for generating customer arrival times.

The one way-ANOVA model was used to test simultaneously the difference between the policies, using SPSS for Windows (Marija j.Norusis 1993). The model form used was: $Y_{ij} = \mu + \gamma_j + \varepsilon_{ij}$. The results are provided in Figures 16a and 16b. The 'F prob' was highly significant for both periods indicating that some policies versus others created statistically different output results.

Figure 16A: January

One way ANOVA results (All Policies)

Analysis of Variance

	Sum of Squares	df	Mean Square	F	Sig,
Between Groups	388124.20	26.00	14927.85	138.43	0.00
Within Groups	69877.97	648.00	107.84		
Total	458002.10	674.00			

Figure 16B: July

One way ANOVA results (All Policies)

Analysis of Variance

	Sum of Squares	df	Mean Square	F	Sig,
Between Groups	493164.20	17.00	29009.66	410.62	0.00
Within Groups	30519.91	432.00	70.65		
Total	523684.20	449.00			

The Scheffee and Duncan multiple range procedures were applied to the data to determine which policies were different from others (Table 16). The more conservative Duncan procedure failed to produce any conclusive evidence of differences whereas the Scheffe test yielded a set of candidate policies for further testing.

The mean (average waiting time), standard deviations and error estimates are shown in Figure 17. It is obvious that the system behavior is quite variable. The ANOVA table for this set of data indicated a difference in policies at the .05 level of significance. The Duncan procedure showed no significant difference between the policies that share the common property of uniform arrival rates. In fact, of the initial data set (27 policies for January and 18 for July), some 60 t0 65 percent of the policies that yielded significantly better performance measures, had uniform arrivals as a common attribute. These results lead to several combinations about the nature and behavior of the system. These will be discussed later in Section 9.0.

8.10.1- Interactional effect:

Before any of these management policy approaches are selected for separate investigation, the issue of interaction among the policies will be addressed. As noted earlier, consideration of these interactions is important as this is an integral feature of such systems and one where the impact is impossible to mitigate. To provide information about the interactions, a three-way factorial experiment was performed using the design matrices of figures 15a and 15b.

During the month of January, it was evident that the Fprob for high order interactions (3-way) between the factors, was not significant, indicating that the impact of any two factors does not change when the level of the third factor changes. On the other hand,

Table 16: January

Scheffe Multiple Range Procedure

		Subset for alpha = .05					
Combinations	N	1	2	3	4	5	6
16	25	38.351					
14	25	38.862					
17	25	38.951					
11	25	39.77					
18	25	40.586					
15	25	41.965					
12	25	45.379					
13	25	46.949					
10	25	55.548					
26	25		76.659				
23	25		77.567	77.567			
25	25		81.338	81.338	81.338		
8	25		81.342	81.342	81.342		
5	25		82.342	82.342	82.342		
27	25		85.011	85.011	85.011		
7	25		86.074	86.074	86.074		
6	25		86.223	86.223	86.223		
9	25		86.223	86.223	86.223		
20	25		86.997	86.997	86.997		
2	25		89.468	89.468	89.468		
24	25		90.706	90.706	90.706		
3	25			95.155	95.155	95.155	
4	25				96.868	96.868	96.868
21	25				97.176	97.176	97.176
22	25				99.635	99.635	99.635
19	25					111.085	111.085
1	25						113.988
Sig.		0.134	0.639	0.1	0.056	0.298	0.142

Means for groups in homogeneous subsets are displayed.

Figure 17: January

Candidate Policies for further Testing

Combinations	N	Mean	Std. Deviation	Std. Error	95% CI for Mean Lower Bound	Upper Bound
5	25	96.868	9.764	1.952	78.311	86.372
8	25	86.074	10.576	2.115	76.976	85.708
10	25	86.223	6.749	1.349	52.762	58.334
11	25	55.548	4.194	0.838	38.055	41.518
12	25	45.379	6.331	1.266	42.766	47.993
13	25	46.949	6.068	1.213	44.444	49.454
14	25	38.826	1.98	0.396	38.008	39.643
15	25	41.965	3.706	0.741	40.435	43.495
16	25	38.351	1.975	0.395	37.535	39.166
17	25	38.951	1.373	0.274	38.384	39.518
18	25	40.586	3.033	0.606	39.334	41.838
23	25	77.567	12.305	2.461	72.488	82.647
26	25	76.659	11.086	2.217	72.083	81.235
27	25	85.011	15.134	3.026	78.764	91.259

all these factors individually are significant, as are the 2-way interaction effects between them. The results indicated a significant interaction between job scheduling and labor assignment and between job scheduling and job flexibility (Figure 18).

However, *during the month of July*, the results indicated that all factors individually are significant, as are all the interaction effects for all combinations of factors except a 2-way interaction between demand management factor and job flexibility. This implies that there are overlapping effects. That is, the decrease in waiting time gained from a better job scheduling include at least some of the gains from changing labor assignment policy and increasing the level of job flexibility. In addition, the rejected 2-way interaction might be due to a much higher need for flexibility in July in which the demand is level the highest of all year long (Figure 19).

Given these results, the primary candidates for further study became the labor assignment and job flexibility factors which were examined in the follow-on experiments one and two.

8.10.2- Follow-on experiment #1: January

The first follow-on experiment used a single factor design to investigate three labor assignment policies when the other factors were assumed constant. The test compared two non-traditional labor assignment methods-described earlier- with the existing one. The null hypothesis stated that the alternative methods will have no effect on the average time a customer spends in the system. The one way ANOVA model was used to test simultaneously the differences between the levels. The results indicated that both of the policies examined produced a significant performance variance from the original results. Therefore, the null hypothesis could be rejected (Table 17).

Figure 18: January

Three-way Interactions ANOVA

		Unique Method				
		Sum of squares	df	Mean square	F	Sig.
Main Effects	(Combined)	375267.3	6	62544.56	579.995	0
	Demand	335598.3	2	167799.2	1556.054	0
	Job Assignment	19316.31	2	9658.157	89.563	0
	Job Flexibility	20352.72	2	10176.36	94.369	0
2- Way Interactions	(Combined)	12384.01	12	1032	9.57	0
	Demand * Job Assignment	2229.181	4	557.295	5.168	0
	Demand * Job Flexibility	2277.615	4	569.404	5.28	0
	Job Assignment * Job Flexibility	7877.209	4	1969.302	18.262	0
3 - Way Interactions	Demand * Job Assignment * Job Flexibility	472.806	8	59.101	0.548	0.82
Model		388124.2	26	14927.85	138.431	0
Residual		69877.97	648	107.836		
Total		458002.1	674	679.528		

All effects entered simultaneously

Figure 19: July

Three-way Interactions ANOVA

		Unique Method				
		Sum of squares	df	Mean square	F	Sig.
Main Effects	(Combined)	483212.1	5	96642.43	1367.944	0
	Demand	460458.7	1	460458.7	6517.652	0
	Job Assignment	2992.009	2	1496.004	21.175	0
	Job Flexibility	19761.45	2	9880.724	139.859	0
2- Way Interactions	(Combined)	8702.722	8	1087.84	15.398	0
	Demand * Job Assignment	635.564	2	317.782	4.498	0.012
	Demand * Job Flexibility	109.754	2	54.877	0.777	0.461
	Job Assignment * Job Flexibility	7957.404	4	1989.351	28.159	0
3 - Way Interactions	Demand * Job Assignment * Job Flexibility	1249.379	4	312.345	4.421	0.002
Model		493164.2	17	29009.66	410.623	0
Residual		30519.91	432	70.648		
Total		523684.2	449	1166.334		

All effects entered simultaneously

Table 17: January

One way ANOVA results (folllow-on # 1)
Other Factors are Constant

Analysis of Variance

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8235.195	2	4117.597	34.059	0
Within Groups	8704.49	72	120.896		
Total	16939.7	74			

However, although both of the assignment alternatives produced lower average time in the system, the Bonferroni and Duncan multiple range procedures showed that the two alternative levels do not differ from each other (Table 18a and 18b).

In order to see the effect of the other factors on labor assignment, another test was performed assuming this time that other factors are not constant: again, the ANOVA test showed significant difference between the means (Table 19a); on the other hand, Scheffe and Duncan procedures showed that levels 2 and 3 are significantly different from level1 (current) but they also differ from each other (Table 19b). This implies that in the absence of other factors, the job assignment factor might improve the performance of the system but no clearly outstanding level could be isolated.

8.10.3- Follow-on experiment #1: July

The same process applied in January follow-on experiment#1 has been used in this section. However, different results are obtained: While the other factors were constant, the one-way ANOVA showed the same results as in January. However, if the other factors were not constant, the results showed that there was no significant difference between the means (Tables 20a, 20b, and 20c). This implies that when the demand for driver licenses is high, the effect of the presence of the other factors overcomes the gains achieved by the labor assignment factor alone.

The results obtained in January and July directed our in-depth analysis to a further stage.

Table 18a: Bonferroni

Labor Assignment Factor	Levels(i)	Levels(j)	Mean Difference (i-j)	Std. Error	Sig.	99.5% Confidence Interval Lower Bound	Upper Bound
Bonferroni	1	2	24.519	3.11	0	14.359	34.679
		3	18.832	3.11	0	8.672	28.992
	2	1	-24.519	3.11	0	-34.679	-14.359
		3	-5.687	3.11	0.215	-15.847	4.473
	3	1	-18.832	3.11	0	-28.992	-8.672
		2	5.687	3.11	0.215	-4.473	15.847

Table 18b: Duncan

Labor Assignment Factor

	Levels	N	Mean
Duncan	2	25	89.468
	3	25	95.155
	1	25	
	Sig.		0.072

Means for groups in homogeneous subsets are displayed.

Table 19a: January

One way ANOVA results (folllow-on # 1)
Other Factors are Not Constant

Analysis of Variance

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	19316.31	2	9658.157	14.795	0
Within Groups	438685.8	672	652.806		
Total	458002.1	674			

Table 19b: January

Duncan and Scheffe Tests
Other Factors are Not Constant

	Levels	N	Means 1	2	3
Duncan	2	225	67.99362		
	3	225		74.2699	
	1	225			81.09327
	Sig.		1	1	1
Scheffe	2	225	67.99362		
	3	225		74.2699	
	1	225			81.09327
	Sig.		1	1	1

Table 20a: July

One way ANOVA results (folllow-on # 1)
Other Factors are Constant

Analysis of Variance

	Sum of Squares	df	Mean Square	F	Sig,
Between Groups	7153.855	2	3576.9	42.374	0
Within Groups	6077.723	72	120.896		
Total	13231.58	74			

Table 20b: Scheffe

Labor Assignment Factor

	Levels	N	Means	
			1	2
Scheffe	2	25	140.4869	
	3	25	146.8027	
	1	25		163.6276
	Sig.		1	1

Means for groups in homogeneous subsets are displayed.

Table 20c: One-Way ANOVA

One way ANOVA results (folllow-on # 1)
Other Factors are Not Constant

Analysis of Variance

	Sum of Squares	df	Mean Square	F	Sig,
Between Groups	2992.009	2	1496.004	1.284	0.278
Within Groups	520692.1	447	1164.859		
Total	523684.2	449			

8.10.4- Follow-on experiment #2: January

The second follow-on policy experiment was a two-factor design that also used average time in the system as the performance variable. The first factor was demand management that includes three levels: the current arrival pattern (non-stationary poisson arrival), a smoothed demand pattern and one that expands operations for two more hours. The second factor includes five levels of job flexibility that describes the manner in which examiners assist one another. The structure of the experiment is summarized in Table 21. The current staffing with its existing assistance pattern was compared to the four other staffing patterns offering the greatest flexibility.

The basic management policy examined in this experiment is the moving server concept which is the highest level of flexibility (level#5). This method of pairing customers with servers is thought to produce a more efficient use of the labor resources. Building another computer program was needed and is shown in Appendix K. The researcher modeled a new system where all the customers arrive at the office and join a single queue. The server[16] then, captures the first customer in the line and the server/customer pair move as far through the station network as possible, leaving the customer alone only when the customer is performing an individual act such as a written test at the computer room or a road test with inspectors. A server returning to the pool (to the same queue), takes the second next customer, thus clearing any bottleneck that would prevent a smooth flow through the system. The applicants returning from their exam are given priority over the people that just arrived to the office because their next process is not time consuming any longer.

[16] The new model does not involve any particular station except the one for road test (inspectors) and computer examination room.

Table 21: Follow on # 2, January

Experimental design for demand/job flexibility policy

Level	Factor 1. Demand Management.
1	The current arrival pattern: non-stationary Poisson arrival.
2	A uniform arrival pattern.
3	Expanding 2 more hours of operation.

Level	Factor 2. Management Policy
1	The current flexibility with the present assistance pattern.
2	Usher helps Reg I and camera operator helps Reg II.
3	Camera operator helps Reg I and Reg II, and usher helps Reg I.
4	Both camera operator and usher help Reg I and Reg II.
5	Moving server: all workers are pooled as general examiners at one station.

The new model resulted in a dramatic decrease in customer transit time and full utilization of workers (Table 22). The null hypothesis is that job flexibility would have no effect on system transit time. A two-way ANOVA was conducted on the means for average time in the system grouped by task assignment policy and arrival pattern. The results, shown in Table 23, demonstrate that, as expected, the arrival pattern significantly affects the time in the system regardless of the labor pattern tested, thus confirming the results of earlier testing for other policies. The null hypothesis that job flexibility and moving servers will have no effect on the average time a customer spends in the system clearly was rejected.

The results also show that there is a significant interaction between the factors. The descriptive statistics in Figure 20 support our findings by investigating the change in the mean waiting time for every combination of the two factors. In addition, in order to check which level of the job flexibility factor caused a better performance, a pairwise comparison as well as the Duncan multiple contrasts test were performed (Table 24). This analysis indicates large reductions in the average time where labor resources are cross-trained, pooled and move with the customer. Indeed, following Duncan, the moving server level was grouped as different from the others and exhibits significantly better performance than the others. Finally, the graph shown in Figure 21, clearly confirm the better performance of the moving server policy at any level of demand.

8.10.5- Follow-on experiment #2: July

Again, same process was applied to July[17] and the results could be interpreted the same way (see Appendix L). However, this test proved that there is actually an

[17] As mentioned before, since expanding hours of operation did not give good results for July, this level was not tested in the second follow-on experiment.

TABLE 22 OUTPUT OF MOVING SERVER POLICY IN JANUARY

AVERAGE RESIDENCE TIME

REPLICATION NO:	SYSQ
1	75.179
2	68.626
3	63.818
4	73.938
5	67.300
6	79.496
7	79.952
8	91.451
9	86.707
10	88.387
11	72.517
12	78.716
13	89.758
14	90.270
15	91.069
16	76.512
17	59.596
18	77.433
19	86.937
20	70.353
21	83.445
22	68.885
23	100.570
24	104.698
25	97.838

AVERAGE RESIDENCE TIME FOR 25 RUNS

SYSQ
80.94

OVERALL AVERAGE UTILIZATION FOR 25 RUNS

INSP	COMPUTER	MOVING
82.97	52.66	85.89

CONFIDENCE INTERVAL FOR SYSTEM QUEUE

SD	LOWER LIMIT FOR 95% CI	UPPER LIMIT FOR 95% CI
11.692	74.437	87.439

Table 23: Follow-on # 2, January

Two-way ANOVA for the job flexibility assignment Policy and arrival pattern (Demand)

		Unique Method				
		Sum of Square	df	Mean Square	F	Sig.
Main Effects	(Combined)	154598	4	38649.5	359.084	0
	FACTOR 1	131249	2	65624.3	609.699	0
	FACTOR 2	23349.6	2	11674.8	108.468	0
2-Way Interactions	FACTOR 1 * FACTOR 2	1510.398	4	377.599	3.508	0.008
Model		156109	8	19513.6	181.296	0
Residual		23248.9	216	107.634		
Total		179357	224	800.703		

All effects entered simultaneously

Figure 20:

Descriptive Statistics between Demand Pattern (factor 1) and Job Flexibility (factor 2)

FACTOR 2	FACTOR 1	Mean	STD. Deviation	N
1				
	1	113.988	8.302	25
	2	55.548	6.749	25
	3	111.085	14.384	25
	Total	**93.54**	28.932	75
2	1	96.868	10.712	75
	2	46.949	6.068	25
	3	99.635	11.396	25
	Total	**81.151**	26.179	25
3	1	86.074	14.105	75
	2	38.351	1.975	25
	3	81.338	12.764	25
	Total	**68.587**	24.202	25
4	1	83.497	13.109	75
	2	38.45	1.458	25
	3	82.788	12.75	25
	Total	**68.245**	23.645	25
5	1	80.938	11.692	75
	2	35.097	2.589	25
	3	77.201	13.686	25
	Total	**64.412**	23.347	75
Total	1	92.273	16.801	125
	2	42.879	8.626	125
	3	90.409	18.201	125
	Total	**75.187**	27.422	375

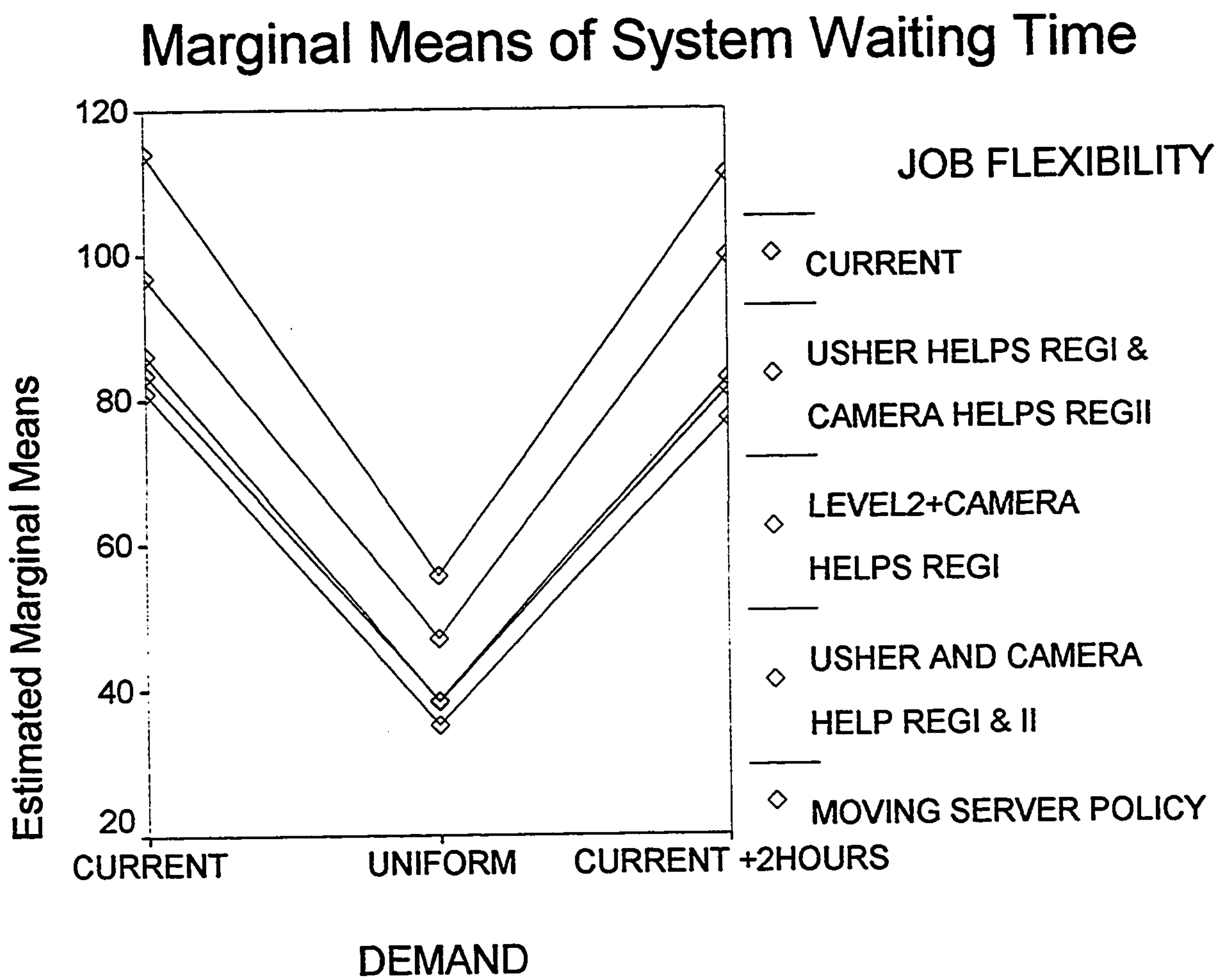
Table 24: Follow-on #2, January

Duncan & Scheffe Multiple Contrast Tests

	Levels	N	Means 1	2	3	4
Duncan	5	75	64.412			
	4	75		68.245		
	3	75		68.587		
	2	75			81.151	
	1	75				93.541
	Sig.		1	0.841	1	1
Scheffe	5	75	64.412			
	4	75	68.245			
	3	75	68.587			
	2	75		81.151		
	1	75			93.541	
	Sig.		0.202	1	1	

Means for groups in homogeneous subsets are displayed.
Based on type III Sum Of Squares

FIGURE 21: ***DEMAND PATTERN VS JOB FLEXIBILITY (JANUARY)***



interaction between job scheduling and job flexibility; thus an opposite conclusion than the one in section 8.10.1, Since job enrichment factor now includes two more levels with even greater degree of flexibility (levels #4 and 5), our earlier results for a need for further flexibility in July has been confirmed. Thus, these results lead to several conclusions that would be dealt with in the next section.

9.0- FINDINGS AND DOCUMENTATION

More than 95% of the customers arrive at the Henri Bourassa driver license office with an appointment taken one month ahead of their visit; more than 85% of those people arrive more than five minutes early (Dianne Perrault, 1996), thereby contributing significantly to their own waiting time; and above all, equal average number of arrivals per day for the three weeks has been experienced in January and July. All this is said, a significant variability by arrivals relative to the time of the day (Time-varied Poisson) is still emerging.

Given the analysis, it is evident that a recommendation to provide uniform customer arrival rates is warranted. The nine policies with the lowest mean waiting times all had uniform arrival patterns during both January and July. In fact, of the initial data set (24 and 18 policies), more than 60% of the policies that yield significantly better performance measures have deterministic arrivals as a common attribute. Follow-on experiments replicate the result that deterministic customer arrival rates produce significantly shorter mean transit times. Such behavior is to be expected as a system will have some average processing capacity over time and will behave favorably when system work loads are balanced to its service capacity.

Expanding the hours of operation in January did not result in a huge difference in the customer waiting time as compared to the operating one; but on the other hand, it would be a feasible option if the government is willing to match the level of demand of each season.

Although reservation system is feasible in situations requiring any type of service, it certainly shows that, in the context of this study, it does not exactly dampen the fluctuations and large demand variations persist during the day and by season. The actual government system must be willing to combine this block scheduling technique with another feasible resource policy in order to adjust service capacity to match demand.

The comparison of the two alternative labor assignment policies with the current one demonstrates that both of the policies produce a lower average time in the system during January and July. However, it is subject to two conditions: (1) no matter which policy is implemented, both have approximately the same average time and (2) assuming other factors are constant -since the results show that they are not significant compared to the existing policy in July if the other factors are not constant.

The system appears to be quite sensitive to the manner in which workers aid each other when work loads vary among the stations and as noted, to the pattern of customer arrivals. The dramatic results produced by the job flexibility policies and specially by the moving server model, indicate that this method may provide the most effective pairing of service resources with any level of customer demand.

The pattern of flexibility studied were not the only ones possible, but those that were easiest to implement in the actual system. The length of time in the system queue varies as flexibility patterns are altered. For example, when the camera operator helped RegII and usher was allowed to help RegI, the waiting time decreased significantly in both seasons. However, a significant amount of time was saved by simply applying a pattern where the workers (camera and usher) are allowed to help any other station(RegI and RegII); a greater flexibility is needed, specially in July.

Both of these situations are not great departures from the current practice and they appear to be good candidates for labor management policies. However, the policy of moving server which was the most effective in minimizing the time required waiting in the system queue, depart drastically from the current system. Although the model has used less number of examiners and stations, it limited the customer to only one queue and gave priority to the most advanced customer in the process. This later helps to expedite the movement of those being served by minimizing the time spent waiting in the queue.

Implementation of the moving server policy would possibly require the purchase of additional office equipment (such as visual tester and cameras) and space. The practicality of having enough space and equipment so that all workers could be preparing licenses at the same moment, would have to be tested and evaluated. Equipment costs, in this particular case, would have to be compared to the offset of savings realized by not hiring additional labor, satisfying their clients (tax payers) and create a positive image for the city.

9.1- LIMITATIONS OF THE STUDY

One approach is to smooth the variability in demand through the use of marketing practices. However, these procedures, such as development of complementary services, advertising and off-peak pricing discount generally damper or moderate peak demand fluctuations, but do not completely level the pattern. Since a province driver license is a form of "tax" collection for Quebec, a marketing approach may be more useful for motivating customers to pay within a thirty-day time frame than it would be for motivating them to arrive at the business office during low demand hours. A marketing approach may work for the segment of population that already have a license and need to renew it, for example; but generally, a marketing approach is not considered feasible for the referent office. This is due primarily to the nature of the office, government control, location of the office and type of customer served.

Another limitation to this research was service time variance. Although this limitation was addressed as efficiently as possible in the paper, it should remain as a serious limitation. When the demand and service are generated by a process involving human consumers, the system seldom reach a steady state and variability in service might always occur. Due to the lack of time, the liaison person (examiner) was often unavailable and was rushed to cooperate on the few available occasions during our attempt of service time data collection.

Forecasting was limited during the interviews to little information excluding any relevant details about the methods used and role of forecasting. Unfortunately, the person in charge in Quebec City refused to cooperate and to complete the follow-on questionnaire sent to the SAAQ headquarters. Ironically, the fact that this situation was "chaotic" would appear to be good reason to an in-depth study about Quebec's methods used to forecast.

9.2- APPLICATION OF THE STUDY

While the specific results of this study may not be universally applicable, the situation is general enough to have applications beyond the specific models and this referent office. The general decrease in flow time produced by a leveled demand pattern, by the flexible servers and by the moving server model with advanced customer priority may certainly be realized in other queuing systems such as fast food service, university registration, and most license office situations.

9.3- MANAGERIAL IMPLICATIONS

Customer-flow data collection activities should be initiated whenever capacity inefficiencies are not readily identifiable or baseline performance measures are desirable. The customer flow study provides a simple, yet effective, method for revealing problem areas through analysis of how customers are spending their time at any service facility. Capacity use studies can provide insight into an entire organization's operations, the activities of a specialized functional department, or the usage of a single piece of equipment. Using just simple observation and data collection procedures, along with straightforward summarization techniques, can provide valuable insights for capacity management.

After capacity use assessment, problem area identification, and specification of opportunities for improving effectiveness, a systematic review of demand-smoothing and supply-matching strategies can prompt the generation of management interventions appropriate to the situation. This can be done using simulation modeling. Although service providers are likely to interpret congestion as indicating a need for additional resources, effective capacity management requires both demand-altering and supply-controlling strategies in order to identify a coordinated set of interventions. Monitoring the impact of an integrated set of strategies should permit additional refinements, which will, in turn, benefit the service organization's effectiveness, personnel productivity, and customer satisfaction. Finally, achieving effective capacity management is influenced, among other things, by (1) accurate forecasting of demand, (2) nature of service and (3) the needs and attitudes of servers.

9.4- FUTURE DIRECTIONS

Several suggestions can be considered for future research in the area of achieving effective management strategies in service organizations: the effect of the pattern in which workers aid each other is less obvious. Very little has been documented about job flexibility with most of its treatment coming as an aside in job training studies (Globerson & Maggard, 1984). The patterns of flexibility studied were not the only ones possible, but those that were easiest to implement in the system. However, because the heuristics for the help patterns have not been fully developed and studied, a good bit more experimentation with flexibility must be conducted before any definitive conclusions can be drawn.

Another avenue for future research is that by being able to track overbooking statistics, no-shows and cancellations (historical and actual), a sophisticated forecasting model could be developed. Forecasting and anticipating demand might be the solution to literally overcome the demand-output management problem faced by service organizations.

The extent of customer contact is important because it has an effect on every decision that operating managers must make. Potential Operating Efficiency (POE) discussed in the literature, could be applied at any service organization with multiple stations – multiple queues. However, in this particular case, customer contact refers to the physical presence of the customer at each station. In other words, efficiency is seen here as the ratio of outputs to inputs for a given service station.

Service systems characterized by low customer contact (LCC) are seen in the literature as being essentially free of this type of uncertainty experienced by HCC systems. Therefore, similar study could be conducted on a LCC operating system to see whether it is capable of operating at high levels of production efficiency analogous to that achieved in well-run manufacturing organizations.

The most important conclusion of the study is the reaffirmation of the necessity to approach such systems with methods that allow their study without restricting assumptions. The model reported in this paper, provides a vehicle with which to analyze management options for this type of multi-station service system.

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APPENDIX A

ADVANTAGES AND DISADVANTAGES OF SIMULATION MODELING

THE ADVANTAGES AND DISADVANTAGES OF SIMULATION MODELING

Simulation, which is regarded as "an experiment in which we attempt to understand how something will behave in reality by imitating its behavior in an artificial environment that approximates reality as closely as possible" (Shogan[1], 1988) has both its advantages and disadvantages.

ADVANTAGES:

- *Realism:* Since Simulation models capture the actual characteristics of the systems being modeled, they can therefore be considered to be realistic. Mathematical models depending on equations, such as linearity, require unrealistic assumptions to support the mathematical manipulation. However, the number of complex systems requiring realistic, simulation-based solutions is more than the number requiring realistic mathematical modeling.
- *Non-existent systems:* The systems subject to simulation-based experimentation do not need to actually exist, it is enough to have them worked and planned in mind.
- *Time compression:* In simulation models, equivalent of days, weeks and months of real systems can be simulated in seconds, minutes or hours. Therefore, a large number of simulated alternatives can be investigated faster.
- *Deferred specification of objectives:* Simulation models do not require an initial formulation of an objective in comparison to mathematical models. This means that it is possible to keep a wider range of options and look for a system design suitable for a multicriterion decision environment. If the initial objectives are still not formulated, then this deferred specification can be advantageous.

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[1] Shogan, Andrew W. (1988) Management Science Prentice Hall, Englewood, N.J.

- *Experimental control:* In simulation, all variables can be kept constant except for the ones affecting the study. Therefore, unimportant factors need not be taken into account.
- *Reproducibility of random conditions:* In a simulation system consisting of elements that are random but statistically predictable can reproduce random events using pseudorandom numbers which show the characteristics of truly random numbers.
- *Training:* Simulation requires less mathematical techniques and understandings in comparison to mathematical modeling making it easier and more favorable.
- *Winning over the client:* Simulation concepts are easily understood, hence, simulation-based recommendations are favored over mathematical ones by clients. Clients tend to understand the full concepts of simulation-based models.

DISADVANTAGES:

- *Failure to produce exact results:* A simulation model is considered to provide estimates not exact results since averages (of waiting time for example) are used. This provides an estimate of the expected result.
- *Lack of generality of results:* Simulation results apply only to the situations where they have been simulated. This lack of generalization of applying a model in related situations requires modification according to the situation.
- *Failure to optimize:* Simulation is not considered an optimizing technique since it provides alternative solutions and answers instead of absolute ones.
- *Long lead times:* In order to conduct a simulation study, months of efforts are needed to gather data; validate modes, design experiments, evaluate results and so on. This, therefore, asks for the study to start well before results are needed.

- *Costs for providing a simulation capability:* In order to implement and maintain a simulation study and commit to its long lead time requires high costs. The costs include educated personnel, software, hardware, training and other support costs.
- *Misuse of simulation:* Since simulation models require a comprehensive study involving educated personnel, not any person with a minimal understanding of simulation can reproduce a well-defined model.

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APPENDIX B

LETTER AND QUESTIONNAIRE SENT TO QUEBEC CITY

INTRODUCTORY LETTER

October 18, 1996

Nadim Braidy
18 Hudson Apt#3
Montreal, Quebec
H3R 1S6

Dear Ms. Brilland,

As agreed in our telephone conversation, here is the research project in which I am involved. I am presently in the Master of Science (Administration) program at Concordia University (Montreal). I am interested in doing research in Service Operations Management. Specifically for my thesis purposes, I am conducting a study in understanding the various operations issues at the Regie de l'Assurance Automobile de Quebec. Professor Mohan Gopalakrishnan, Ph.D, will be my supervisor and guide for this thesis .

In Montreal, I have started the early stages of my research by conducting a preliminary study of the Henri Bourassa Regie, where I have interviewed Ms Diane Perrault, chief of division, several times for the last couple of months. I have collected information regarding the flow of transactions, resource availability and budget constraints. I have been introduced to the terminology you use in forecasting i.e. Effectif à Temps Complet (ETC) as well as to some strategic plannifications the Regie is looking for. The conclusion of the preliminary studies pointed out that I need more in-depth information from head-quarters (in Quebec) in order to understand better the overall forecasting process and the role it plays in the planning horizon.

The focus of my research is to understand your planning process in depth. In order to make the visit successful, I have enclosed a sample of the interview questions, which could start the process of collecting information. In order to increase my level of understanding, I request you to provide at least one hour of your valuable time (on October 29). In addition, I would appreciate if you can arrange for me to meet with other individuals who are actually involved in this process and also, provide me, if there is no restriction, with documentations used by the department, for example, reports, directories and charts.

Please be assured that there is no risk to the interviewees or to the department and all information will remain totally confidential. In any publication of the research, names both of the individuals involved as well as the firm would remain anonymous. Since third party observations frequently help to clarify issues and offer a new global perspective of a situation, I am sure this research will benefit both your department and myself.

Until I contact you in the near future for reconfirming the 29th of October as a first meeting, I look forward to the possibility and thank you for the consideration you are giving this request.

Thank you,

Nadim G. Braidy

Department of Decision Sciences and M.I.S

QUESTIONNAIRE

IN-DEPTH INTERVIEW QUESTIONS FOR KEY-PARTICIPANTS

Concerning the way forecasting is been done,

I. *How do you do forecasting?*

a) What are the different types of data you use as input into your forecasting? (ex. Demographics, # of driving schools, immigration levels , etc.)

b) How do you forecast demand? (i.e. What methodology do you use?)

c) Who does the forecasting and at what levels? Is it done only at Quebec level or do the Regies do their own local forecasting?

II. *Role of forecasting?*

a) What role does the forecasting plan play ?

b) Is it only for budget allocation or does it also involve demand forecasting?

c) In terms of budget allocation, does the ETC include only personnel planning? If yes, then how are the equipments, supplies and materials planned?

d) How does forecasting help in improving the productivity of workers handling information i.e. advanced equipment that the workers have access to or share information directly with Quebec..?

e) Since the forecasting process is centralized, do you think that it is reliable enough in itself to supply the regies with an excellent quality of information on their needs or changing their requirements?

f) Looking at the Data, do you see any need for more sophisticated modeling, i.e. including more variables into the process?

III. *Bottleneck?*

a) What, in your opinion, are the current inefficiencies in the system?

b) What are the bottlenecks in the system? Where did you overall spend more or less than what it should be?

c) Do you think that the regies are satisfied with the forecasting process and results in terms of budget and resource allocation?

d) What kind of direction do your local measures take? Is it towards decreasing waiting time? Or increasing customer satisfaction? Or both?

e) What is your demand management process? Is it related to resource allocation or utilization of resources or both?

IV. *Future?*

a) In the future, are the process and the whole system technologically oriented? I.e. Internet base exams with control points at CAA for example?

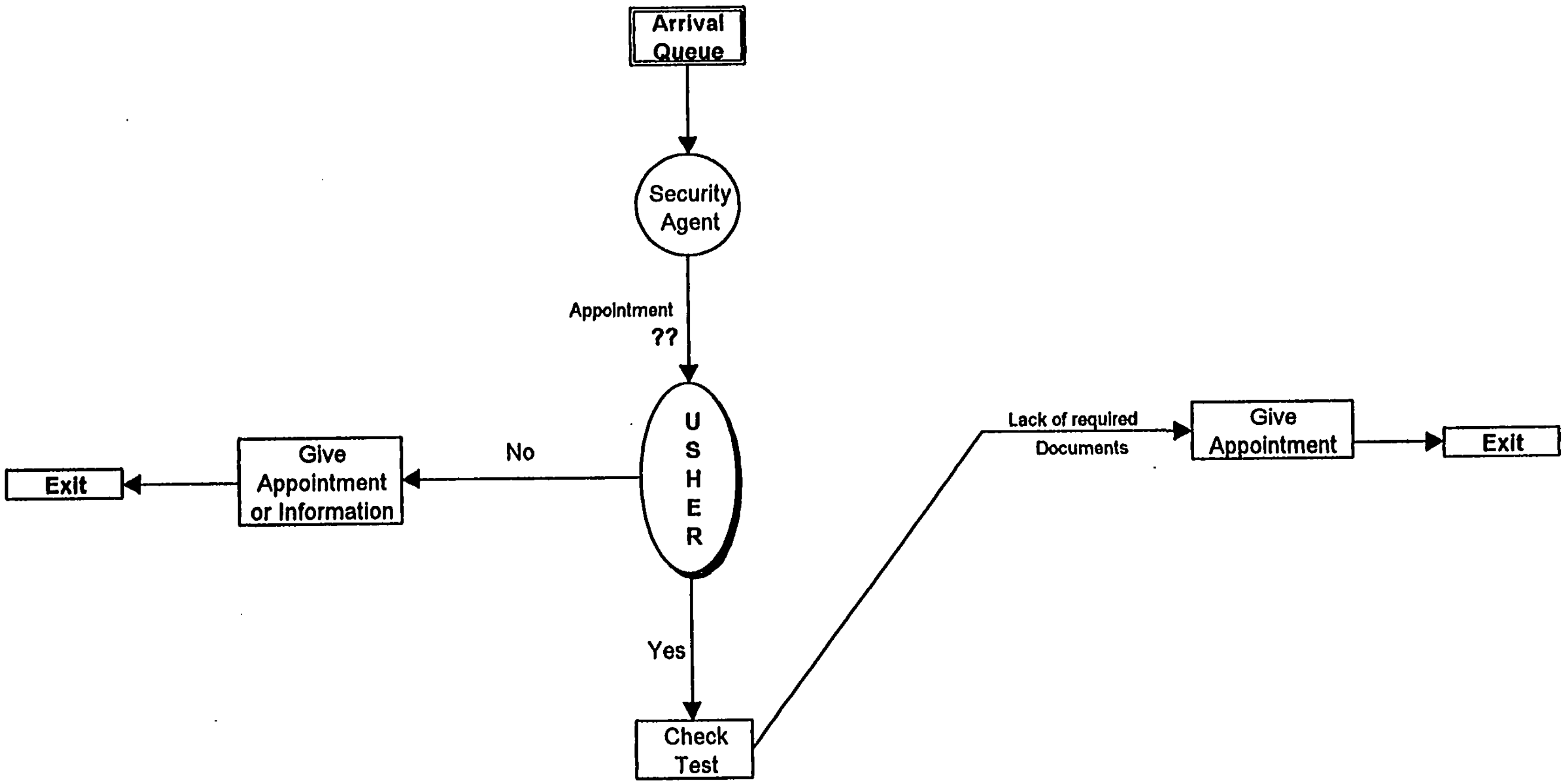
b) How would you foresee a major step forward in forecasting in order to decrease exam bottlenecks or even offices in the province?

APPENDIX C

CUSTOMER ROUTING AT DIFFERENT SERVICES OFFERED BY THE C.E.C.

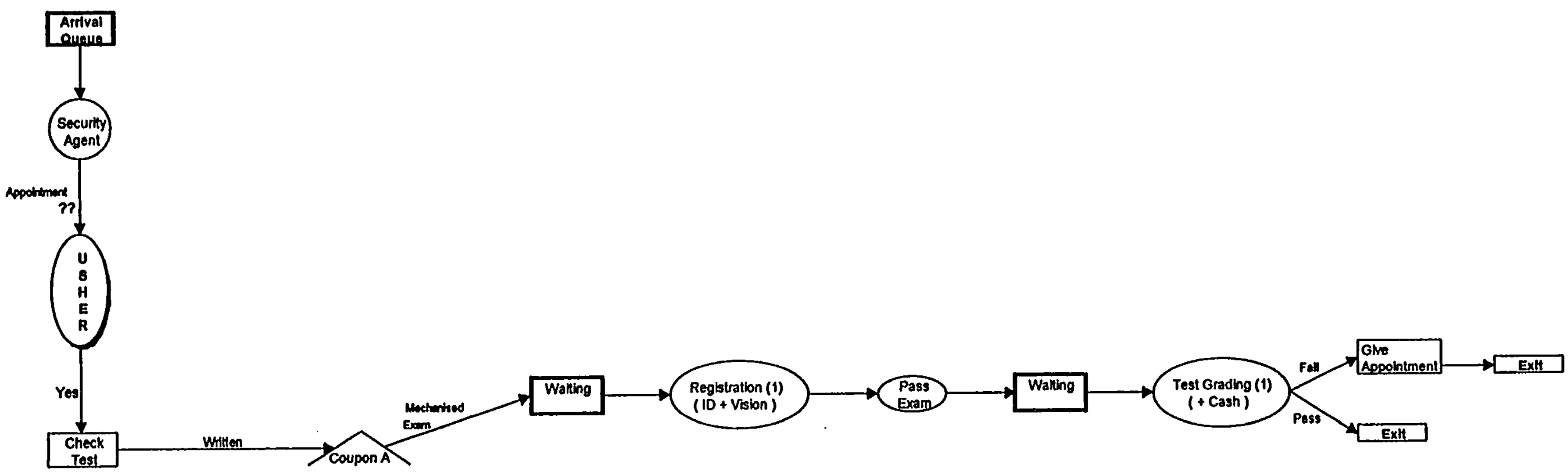
Customer Routing at " Centre d'Évaluation des Conducteurs " (C.E.C.)

1- Getting an Appointment or Information



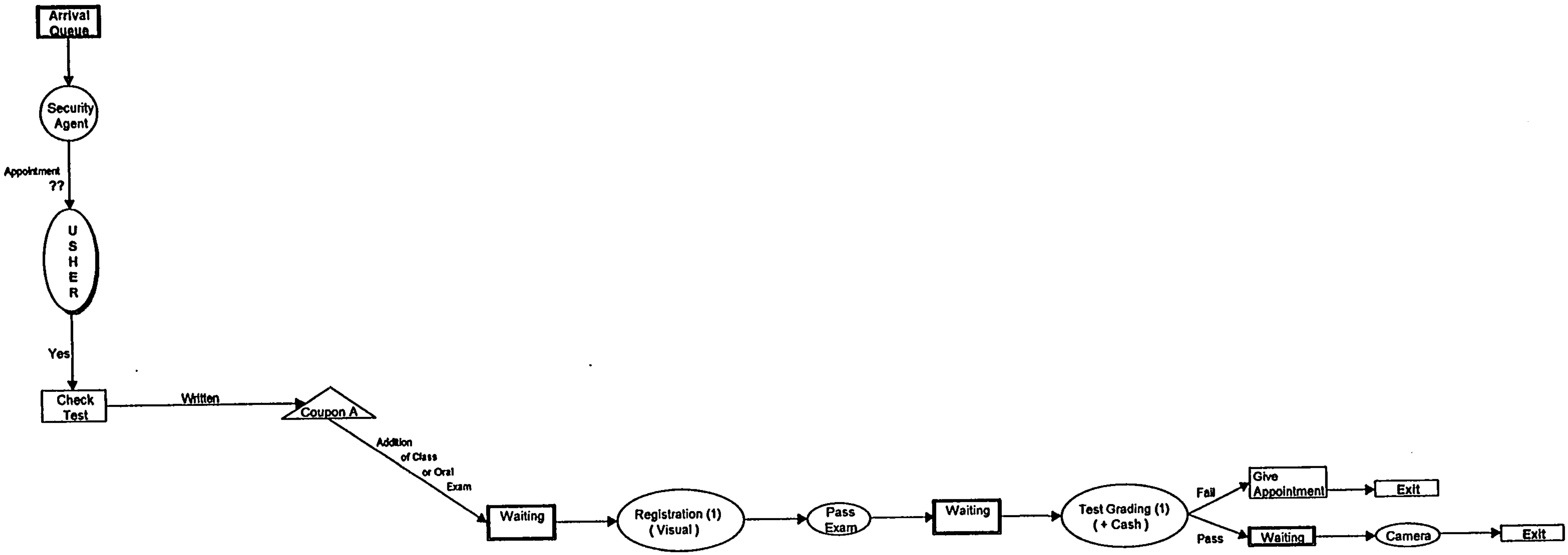
Customer Routing at " Centre d'Évaluation des Conducteurs " (C.E.C.)

2- Written Exam - Mechanised Exam



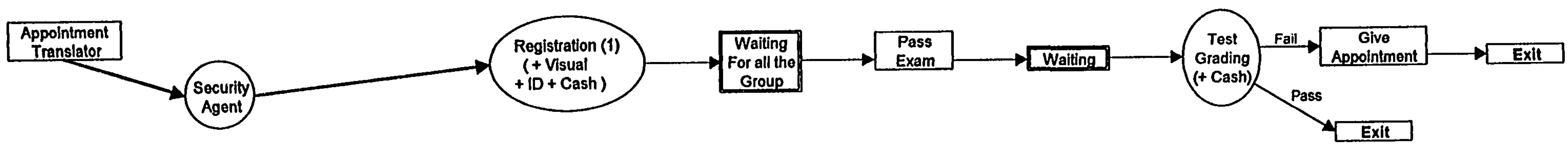
Customer Routing at " Centre d'Évaluation des Conducteurs " (C.E.C.)

3- Written Exam - Addition of Class or Oral Exam



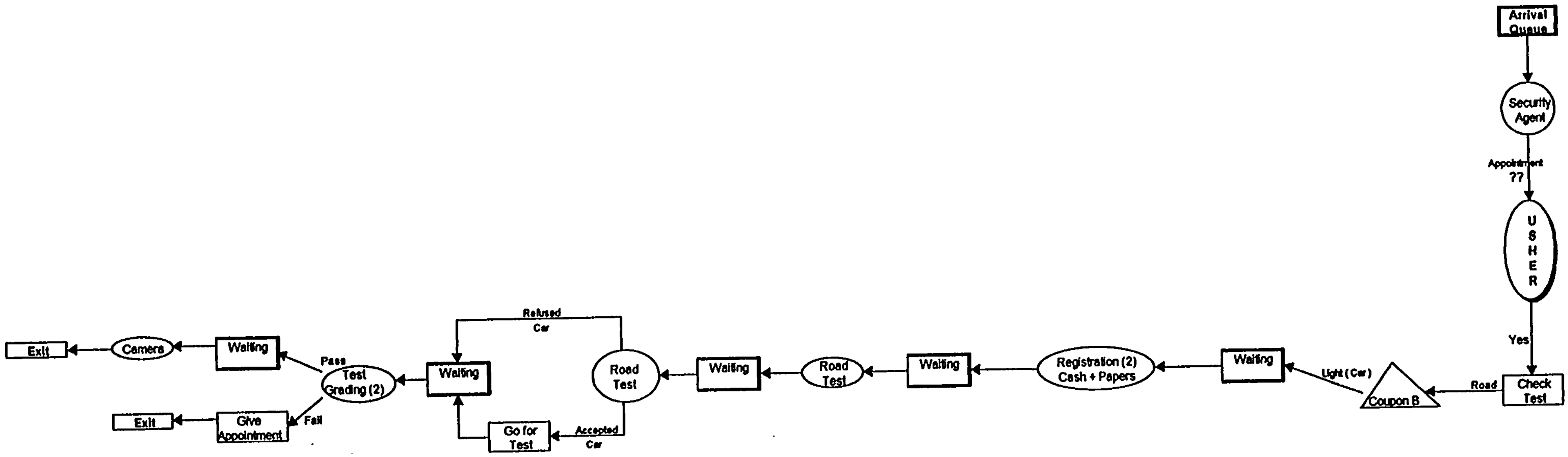
Customer Routing at " Centre d'Évaluation des Conducteurs " (C.E.C.)

4- Written Exam - Translator



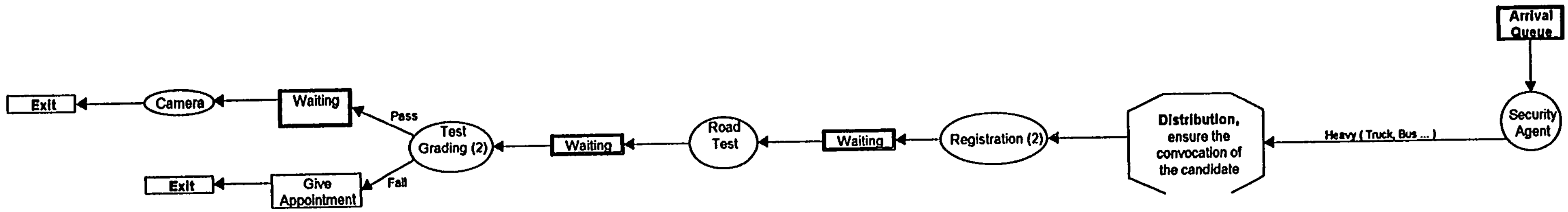
Customer Routing at " Centre d'Évaluation des Conducteurs " (C.E.C.)

5- Road Test - Light Vehicle



Customer Routing at " Centre d'Évaluation des Conducteurs " (C.E.C.)

6- Road Test - Heavy Vehicle



APPENDIX D

COPY OF PART OF THE RAW DATA COLLECTED

lients arrivés par jour - Clientes servis

uccursale : C.E.C. Montrea

endredi 12 juil 1996

er in	Clients arrivés a	B	C	D	E	F	Clients servis a	B	C	D	E	F
7:30	0	0	0	0	0	0	0	0	0	0	0	0
8:00	7	1	0	2	0	0	2	1	0	2	0	0
8:30	38	5	1	21	13	0	16	1	0	12	9	0
9:00	30	2	10	18	17	8	33	4	2	20	16	0
9:30	22	3	11	15	32	11	34	4	16	17	29	17
0:00	13	2	26	18	26	16	16	2	7	10	23	9
0:30	14	3	20	17	26	15	13	3	25	11	16	17
1:00	19	0	17	17	31	15	21	1	26	19	20	10
1:30	21	0	19	6	37	15	17	0	10	19	14	14
2:00	18	1	9	12	22	14	15	0	21	11	19	18
2:30	9	1	17	12	21	13	20	2	16	9	20	12
3:00	24	0	19	18	22	10	17	0	18	15	21	9
[illegible]	20	1	15	11	22	5	20	1	12	20	21	10
[illegible]	33	2	16	16	26	9	26	2	11	15	19	4
4:30	21	4	19	11	21	12	26	4	23	9	16	16
5:00	12	2	21	7	24	15	19	1	23	9	27	15
5:30	1	3	16	5	13	18	3	4	19	4	11	19
6:00	2	0	21	0	15	15	1	0	19	1	16	13
6:30	0	0	1	0	4	6	0	0	3	0	5	7
17:00	0	0	0	0	0	0	0	0	0	0	0	0
17:30	0	0	0	0	0	0	0	0	0	0	0	0
18:00	0	0	0	0	0	0	0	0	0	0	0	0
Total	304	30	258	206	372	197	299	30	251	203	302	190

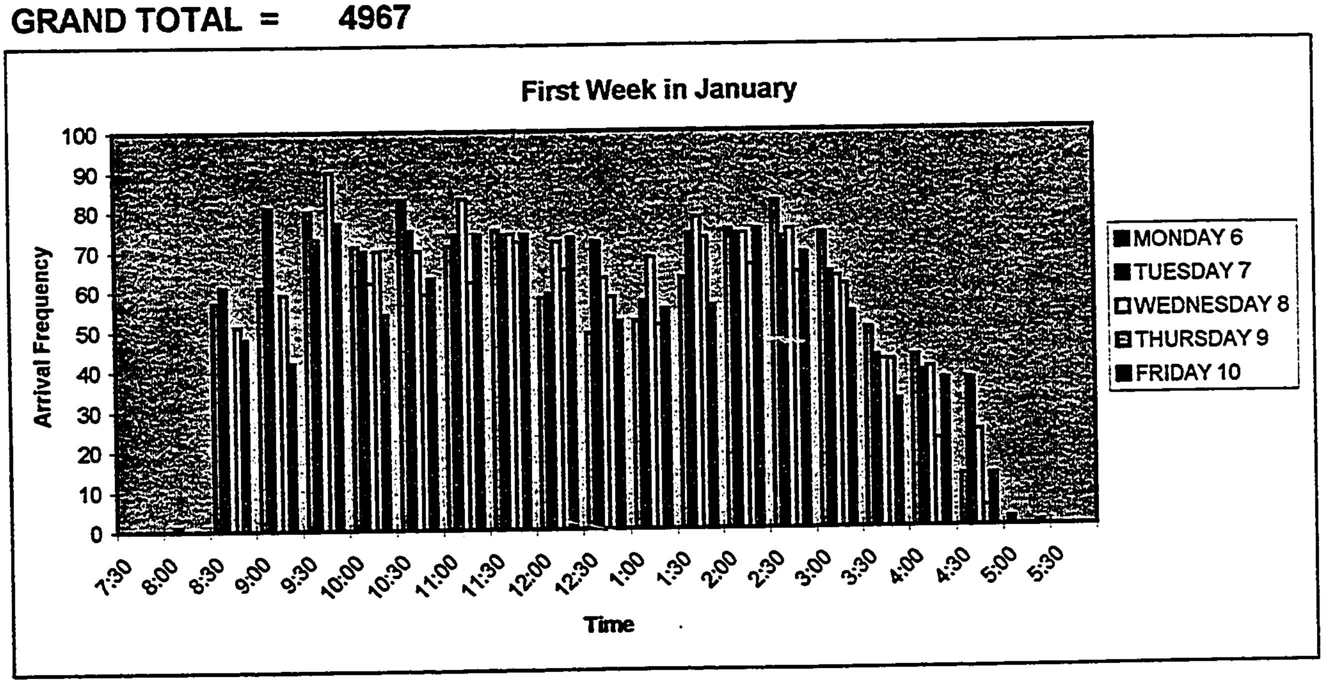
APPENDIX E

CUSTOMER ARRIVALS FOR THREE WEEKS DURING JANUARY AND JULY

ARRIVALS DURING THE FIRST WEEK OF JANUARY 97

TIME	MONDAY 6	TUESDAY 7	WEDNESDAY 8	THURSDAY 9	FRIDAY 10
7:30	0	0	0	0	0
8:00	0	1	0	0	0
8:30	57	61	0	51	48
9:00	61	81	0	59	42
9:30	80	73	0	90	77
10:00	71	70	62	70	54
10:30	83	75	70	59	63
11:00	71	74	83	62	74
11:30	75	74	74	72	74
12:00	58	59	72	65	73
12:30	49	72	63	58	52
1:00	52	57	68	51	55
1:30	63	74	78	73	56
2:00	75	74	74	66	75
2:30	82	73	75	64	69
3:00	74	64	63	61	54
3:30	50	43	42	42	32
4:00	43	39	40	22	37
4:30	13	37	24	5	13
5:00	2	0	0	0	1
5:30	0	0	0	0	0
TOTAL	1059	1101	888	970	949

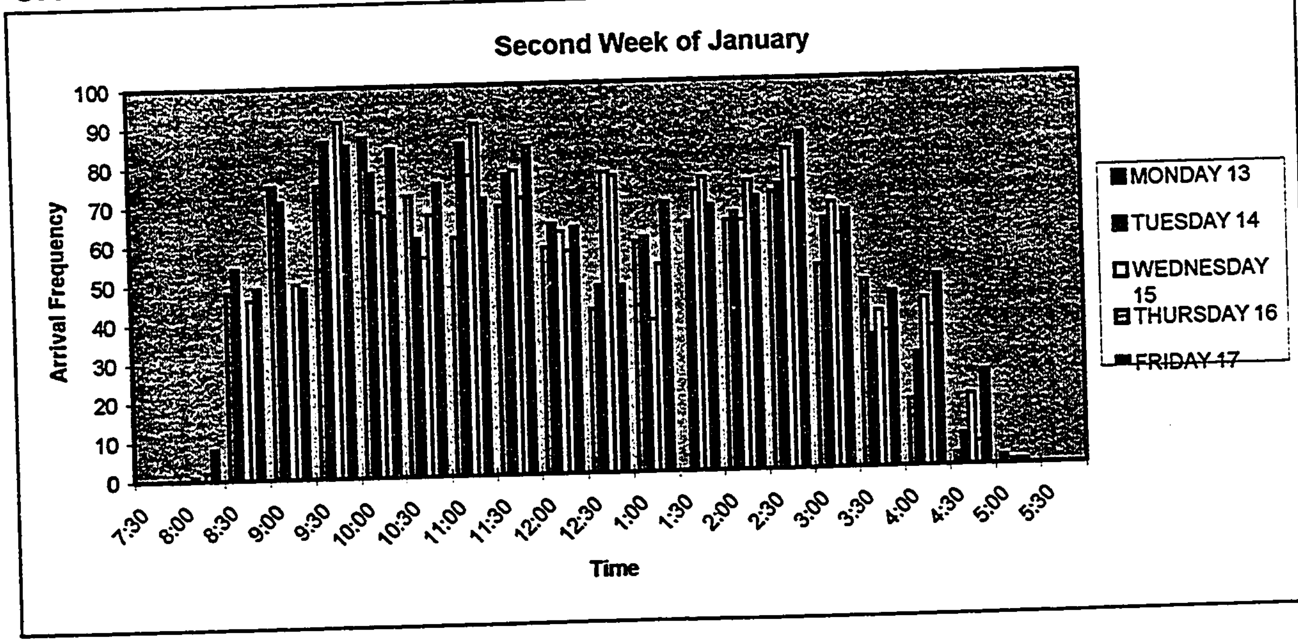
GRAND TOTAL = 4967



ARRIVALS DURING THE SECOND WEEK OF JANUARY 97

TIME	MONDAY 13	TUESDAY 14	WEDNESDAY 15	THURSDAY 16	FRIDAY 17
7:30	0	0	0	0	0
8:00	0	1	0	2	8
8:30	48	54	0	46	49
9:00	75	71	0	50	49
9:30	75	86	0	91	85
10:00	87	78	68	67	84
10:30	72	61	56	67	75
11:00	61	85	77	90	71
11:30	69	77	78	71	84
12:00	58	64	62	57	63
12:30	42	48	77	76	48
1:00	59	60	39	53	69
1:30		64	72	75	68
2:00	64	66	64	74	70
2:30	71	73	82	74	86
3:00	52	64	68	60	66
3:30	48	34	40	35	45
4:00	17	29	43	36	49
4:30	3	8	18	6	24
5:00	2	1	1	1	0
5:30	0	0	0	0	0
TOTAL	903	1024	845	1031	1093

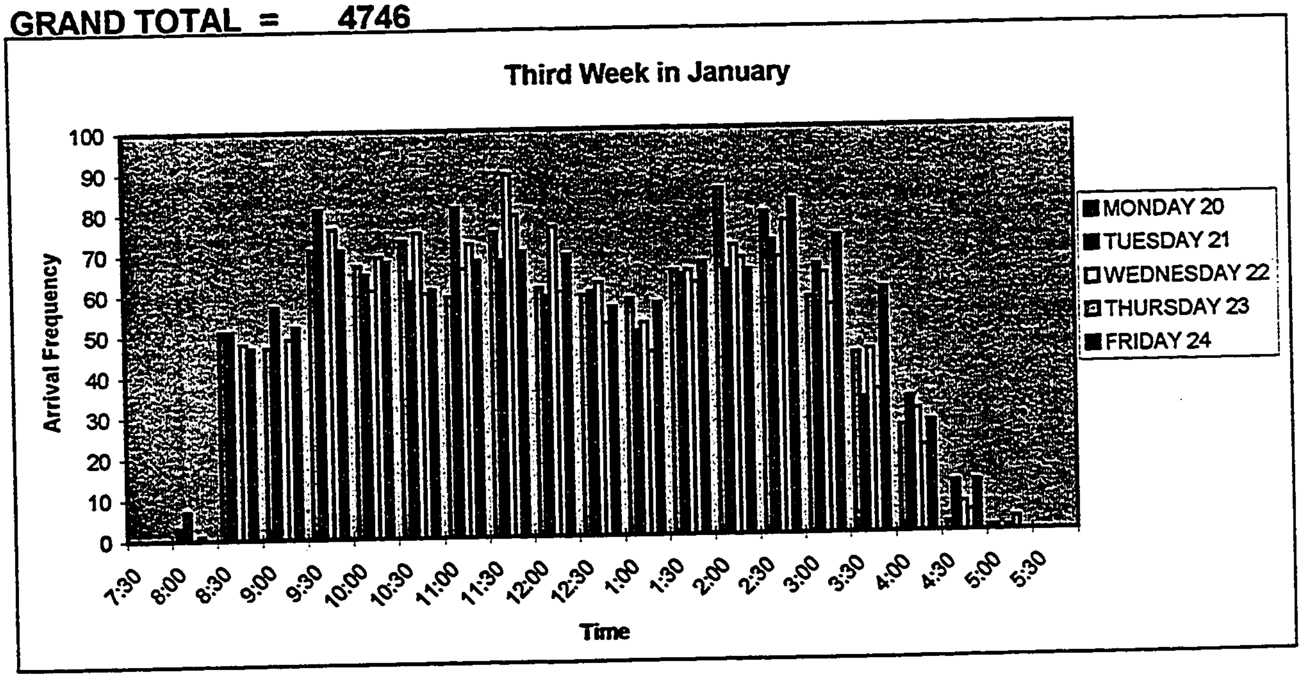
GRAND TOTAL = 4896



ARRIVALS DURING THE THIRD WEEK OF JANUARY 97

TIME	MONDAY 20	TUESDAY 21	WEDNESDAY 22	THURSDAY 23	FRIDAY 24
7:30	0	0	0	0	0
8:00	3	7	0	1	0
8:30	51	51	0	48	47
9:00	47	57	0	49	52
9:30	71	81	0	76	71
10:00	67	65	61	69	68
10:30	73	63	75	60	61
11:00	59	81	66	72	68
11:30	75	68	89	79	70
12:00	61	59	76	60	69
12:30	59	60	62	52	56
1:00	58	50	52	45	57
1:30	65	64	65	62	67
2:00	85	65	71	68	65
2:30	79	72	68	77	82
3:00	58	66	64	56	73
3:30	44	33	45	35	60
4:00	26	33	30	21	27
4:30	2	12	7	5	12
5:00	1	0	1	3	0
5:30	0	0	0	0	0
TOTAL	984	987	832	938	1005

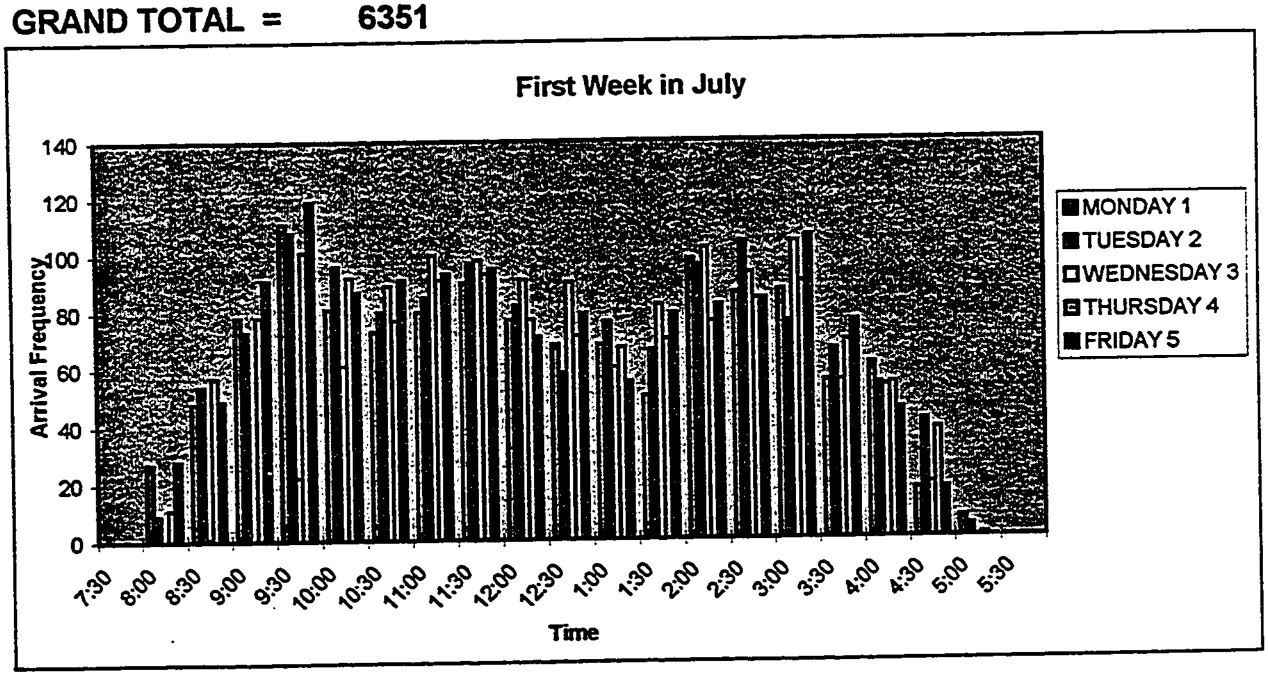
GRAND TOTAL = 4746



ARRIVALS DURING THE FIRST WEEK OF JULY 96

TIME	MONDAY 1	TUESDAY 2	WEDNESDAY 3	THURSDAY 4	FRIDAY 5
7:30	0	0	0	0	0
8:00	27	9	0	11	28
8:30	48	54	1	57	49
9:00	78	73	0	78	91
9:30	111	108	22	101	119
10:00	81	96	61	92	87
10:30	73	80	89	77	91
11:00	80	85	100	91	93
11:30	90	97	98	93	95
12:00	77	82	91	77	71
12:30	68	58	90	71	79
1:00	68	76	60	67	55
1:30	50	66	82	70	79
2:00	98	96	102	76	82
2:30	86	104	93	84	84
3:00	87	76	104	90	106
3:30	55	66	55	69	76
4:00	61	54	53	54	45
4:30	17	41	19	38	17
5:00	7	4	0	1	0
5:30	0	0	0	0	0
TOTAL	1262	1325	1120	1297	1347

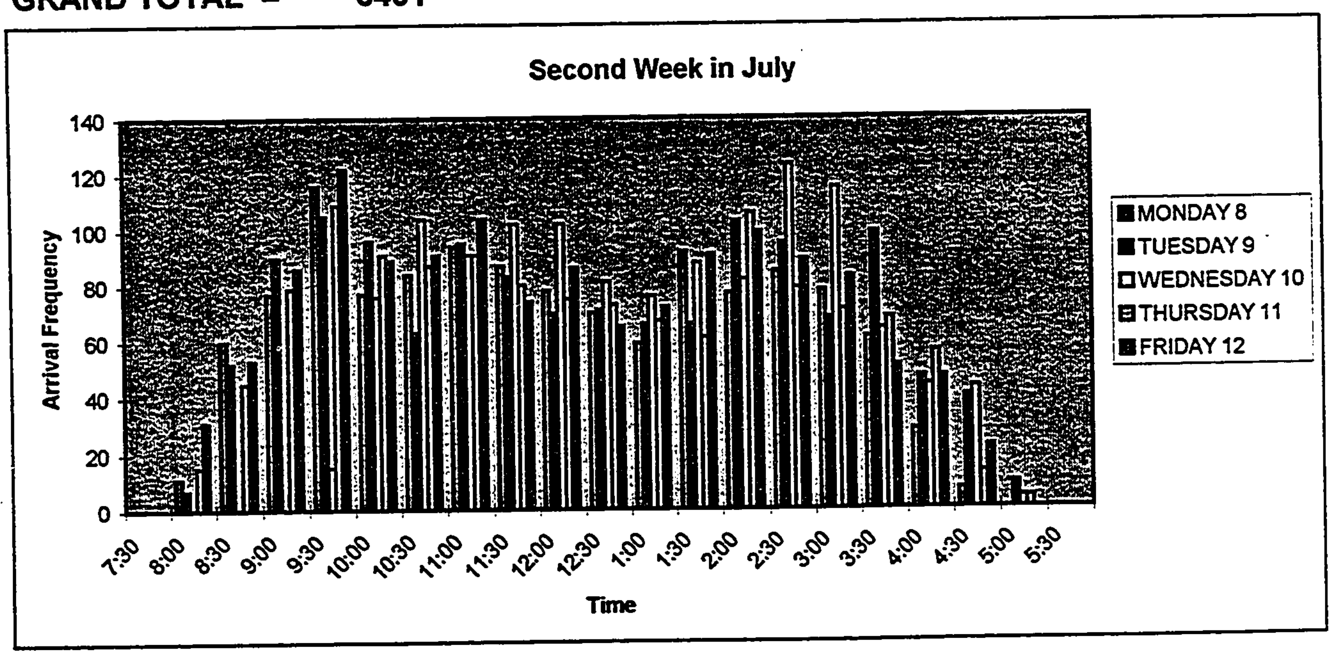
GRAND TOTAL = 6351



ARRIVALS DURING THE SECOND WEEK OF JULY 96

TIME	MONDAY 8	TUESDAY 9	WEDNESDAY 10	THURSDAY 11	FRIDAY 12
7:30	0	0	0	0	0
8:00	11	7	0	15	31
8:30	60	52	0	45	53
9:00	77	90	0	79	86
9:30	116	105	15	109	122
10:00	77	96	76	91	89
10:30	84	63	104	87	91
11:00	94	95	91	91	104
11:30	87	83	102	80	74
12:00	78	70	102	75	86
12:30	70	71	81	73	65
1:00	59	66	76	67	72
1:30	92	66	88	61	91
2:00	77	103	82	106	99
2:30	85	95	123	79	89
3:00	78	68	115	71	83
3:30	61	99	64	68	51
4:00	28	47	44	56	47
4:30	7	40	43	13	22
5:00	0	9	4	4	0
5:30	0	0	0	0	0
TOTAL	1241	1325	1210	1270	1355

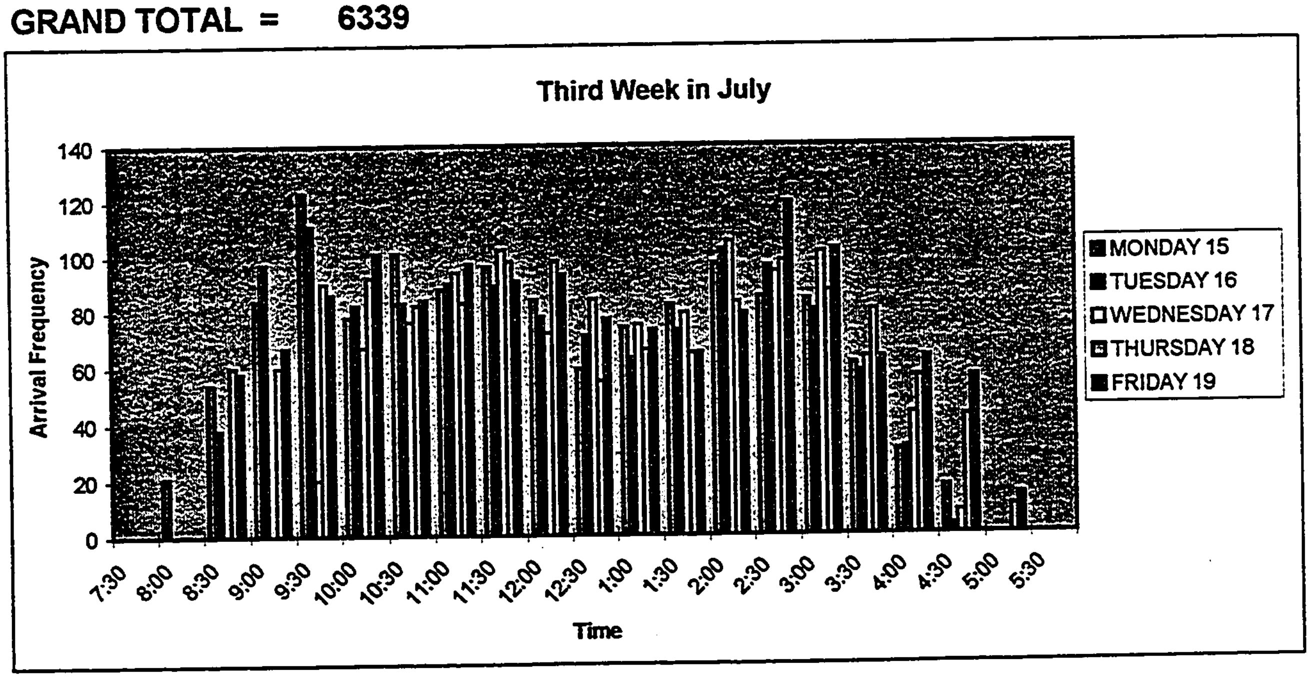
GRAND TOTAL = 6401



ARRIVALS DURING THE THIRD WEEK OF JULY 96

TIME	MONDAY 15	TUESDAY 16	WEDNESDAY 17	THURSDAY 18	FRIDAY 19
7:30	0	0	0	0	0
8:00	21	0	0	0	0
8:30	54	38	0	60	58
9:00	84	97	0	60	67
9:30	123	111	20	90	86
10:00	78	82	67	92	101
10:30	101	83	76	82	84
11:00	88	90	94	83	97
11:30	96	89	102	98	91
12:00	84	78	72	98	93
12:30	59	71	84	55	77
1:00	74	63	75	66	73
1:30	82	73	79	65	65
2:00	97	102	105	83	79
2:30	85	96	94	98	119
3:00	84	80	101	87	102
3:30	61	58	63	80	63
4:00	30	31	43	56	63
4:30	17	3	8	42	56
5:00	0	0	0	10	14
5:30	0	0	0	0	0
TOTAL	1318	1245	1083	1305	1388

GRAND TOTAL = 6339



APPENDIX F

COPY OF PART OF THE RAW DATA COLLECTED FOR JOB AND PATH DISTRIBUTION PERCENTAGES

Bureau : 06241 C.E.C. MONTREAL

Région : 62 Ile-de-Montréal

TRANSACTIONS 1996

96-09-16
16:09:52
Rap_tx.r1

Mois	GRAND TOTAL	PERMIS DE CONDUIRE — Émissions: Apprent. conduc.	Émissions: Permis régulier plast.	Émissions: Permis régulier papier	Émissions: Total	Renouvellement: Appren. conduc.	Renouvellement: Permis régulier plast.	Renouvellement: Permis régulier papier	Renouvellement: Total	Remplacement: Avec plast.	Remplacement: Permis papier	Photos RAMQ seul	Autres tx. permis	TOTAL avec plastique	TOTAL permis	Examens Visuels	EXAMENS: Théoriques	Pratiques: Prom-	Pratiques: Moto	Pratiques: Lourds	TOTAL EXAMENS
9601	35,898	1,939	2,273	7	4,219	384	19	47	450	140	146	15	5,306	2,455	10,282	2,255	11,411	2,921	0	155	14,487
9602	38,282	2,233	2,250	7	4,490	435	3	44	482	51	171	0	5,597	2,312	10,799	2,679	12,514	2,905	0	165	15,664
9603	38,000	1,923	2,261	17	4,201	399	7	37	443	90	185	5	4,775	2,363	9,699	2,110	10,131	2,867	0	190	13,188
9604	38,295	1,699	2,234	27	3,960	359	1	23	383	75	183	7	4,725	2,317	9,333	2,175	9,437	2,940	41	218	12,636
9605	50,027	2,408	3,077	50	5,535	520	3	34	557	72	236	7	6,211	3,159	12,610	3,306	13,696	3,789	356	247	18,088
9606	47,503	2,327	2,639	55	5,021	469	3	26	498	83	202	10	6,129	2,795	12,003	3,105	13,545	3,620	204	183	17,552
9607	51,056	2,618	2,926	51	5,595	570	3	18	591	93	181	15	6,594	3,037	13,069	3,442	14,656	3,924	160	190	18,930
9608	52,275	2,902	2,769	24	5,695	572	2	23	597	93	144	16	6,751	2,070	13,294	3,757	15,050	3,703	139	189	19,951
TOTAL	352,246	18,049	20,409	238	38,776	3,708	41	252	4,001	705	1,448	81	46,086	21,316	91,097	22,989	101,240	26,829	896	1,537	130,502

Rap_tx.r6

Mois	IMMATRICULATION — Renouv.	Acquis. parti.	Acquis. commer.	Autoris. partic.	Autres trans.	TOTAL immat.	AUTRES TRANSACTIONS — Veh.non confor.	ODIV	Indemn.	Aide techniq.	P R P	Percep.	O D U	C P O	Gestion des R.V.	Dem. renseign. comptoir	Dem. renseign. télépho.	Tx. spécial.	Suppression	Divers	TOTAL AUTRES
9601	2	0	0	0	0	2	73	60		0	0	1,445	2,328	137	5,400	731	587	366		0	11,127
9602	3	0	0	0	1	4	92	27		0	0	1,500	2,666	144	5,666	792	525	415		0	11,015
9603	1	0	0	0	0	1	75	34		0	0	1,611	2,151	185	4,999	531	532	335	4,667	0	15,120
9604	2	0	0	0	0	2	82	57		0	0	1,665	2,149	269	4,965	882	502	276	5,497	0	16,324
9605	15	0	0	0	0	15	84	39		0	0	2,065	3,254	350	6,203	740	558	310	6,505	0	20,108
9606	4	0	0	0	0	4	126	38		0	0	1,757	3,031	269	5,994	602	473	327	5,459	0	18,066
9607	1	0	0	0	2	3	115	58		0	0	1,812	3,344	222	6,056	731	528	322	5,060	0	19,066
9608	2	0	0	0	0	2	104	60		0	0	1,707	3,405	190	7,006	765	550	291	4,862	0	19,028
TOTAL	30	0	0	0	3	33	741	373	0	0	0	13,650	22,308	1,744	47,069	5,774	4,255	2,662	32,050	0	130,614

Matrice décisionnelle (à jour)
Région: 62 Ile-de-Montréal

Date 96-09-16 16:09:56
Rap_matr.r6

Du
Mois
9608

Bureau		EFFICIENCE Au comp.	EFFICIENCE hors comp.	EFFICIENCE Total	PERFORMANCE % util. effect.	PERFORMANCE %réalis. charge t.	PERFORMANCE C.T./ effect.
HENRI-BOURASSA	06001	1.19	1.20	1.19	80.20	94.08	117.31
ANJOU	06002	.94	1.08	.96	112.13	102.56	91.48
DORVAL	06003	1.02	.99	1.02	94.05	97.12	102.39
MAISONNEUVE	06004	.90	.99	.98	97.07	95.26	97.34
C.R.C. MONTRÉAL	06241	1.03	.81	.99	96.01	90.86	96.33
RÉGIONAL	Total	1.04	.93	1.02	93.05	93.66	99.77
PROVINCIAL	TOTAL	1.00	1.01	1.00	97.30	94.57	97.10

DÉLAIS DE RENDEZ-VOUS

Bureau	THÉORIQUES --PROM. ET AUTRES-- Nombre	Moyen	% >20jrs	--MOTO-- Nombre	Moyen	% >20jrs	--LOURD-- Nombre	Moyen	% >10jrs	PROMENADE Nombre	Moyen	% >20jrs	MOTO Nombre	Moyen	% >20jrs	LOURD Nombre	Moyen	% >10jrs
HENRI-BOURASSA																		
ANJOU																		
DORVAL																		
MAISONNEUVE																		
C.R.C. MONTRÉAL	60,011	9.8	12.9	3,055	1.0	0.0	3,081	.9	0.0	30,766	9.2	15.2	482	4.9	.2	3,010	6.5	17.1
RÉGIONAL	60,011	9.8	12.9	3,055	1.0	0.0	3,081	.9	0.0	30,766	9.2	15.2	482	4.9	.2	3,010	6.5	17.1
PROVINCIAL	197,649	6.6	5.0	22,315	2.5	.1	14,978	1.9	1.8	101,676	7.8	8.0	9,010	6.6	4.2	12,213	6.6	15.5

Bureau		TAUX D'ÉCHECS Total théor.	Pratiques prom.	Pratiques lourd	TAUX D'ABSENTÉISME AUX EXAMENS DE CONDUITE Théo.	Pratique Prom.	Pratique Moto	Pratique Lourd	SUPPORT INFORMATIQUE Hres non product.	Pannes (heures) Étap	Photo	Réseau	Autres
HENRI-BOURASSA	06001								54.0	0.0	0.0	44.2	9.0
ANJOU	06002								19.0	0.0	0.0	0.0	19.0
DORVAL	06003								7.5	0.0	0.0	7.5	0.0
MAISONNEUVE	06004								5.0	0.0	.5	4.5	0.0
C.R.C. MONTRÉAL	06241	37.9	40.2	30.0	33.00	25.7	20.9	29.6	490.3	407.2	10.4	62.0	29.9
RÉGIONAL	Total	37.9	40.2	30.0	33.00	25.7	20.9	29.6	575.7	407.2	10.9	98.9	58.7
PROVINCIAL	TOTAL	25.2	20.0	10.9	24.72	17.3	21.9	22.0	1612.8	399.0	93.5	620.7	91.3

Bureau	DÉLAIS D'ATTENTE -GUICHET ADMINIS.- Moyen	% > 30min.	% jours N.norme	-POSTE PHOTO- centile (min.) 50ième	90ième	ÉCARTS DE CAISSE Nbr. sess.	Nbr. écarts	% en écart	Surplus	Déficit	TEMPS SUPPLÉ-MENTAIRE
HENRI-BOURASSA	8.6	5.0	4.2	3.05	7.36	3167	126	4	6969	3216	153
ANJOU	17.5	16.5	25.6	10.74	10.71	2091	62	3	2891	1017	156
DORVAL	10.4	5.5	4.2	2.72	5.80	1849	57	3	3001	1469	84
MAISONNEUVE	12.4	7.4	0.3	6.03	10.16	2033	54	3	2451	360	216
C.R.C. MONTRÉAL				6.10	10.60	4581	147	3	271	-801	190
RÉGIONAL	12.3	8.0	10.6	6.22	10.90	13721	446	3	8076	5159	799
PROVINCIAL	14.0	12.1	10.0	4.56	9.02	63691	1703	3	12592	15067	4352

APPENDIX G

SIMULATION MODEL OF THE EXISTING SYSTEM AT THE HENRI BOURASSA DRIVER LICENSING OFFICE

(JANUARY AND JULY ARE PRESENTED IN THE SAME MODEL JUST FOR EASE OF COMPARISION)

```
         SIMULATE
*        JANUARY & July
         REAL
&SD,&LOWLIM,&UPLIM,&AVGU1,&AVGU2,&AVGU3,&AVGU4,&AVGU5,&AVGU6,_
&AVGR1,&AVGR2,&AVGR3,&AVGR4,&AVGR5,&AVGR6,&AVGC1,_
&AVGC2,&AVGC3,&AVGC4,&AVGC5,&AVGC6,&AVG1,&AVG2,&AVG3,_
&AVG4,&AVG5,&AVG6,&AVGM1,&AVGM2,&AVGM3,&AVGM4,&AVGM5,_
&AVGM6,&TSTAT,&X(50),&R1,&R2,&SUMSQDF
*
         INTEGER      &I,&J,&H,&M
         LET          &M=50
         LET          &TSTAT=2.68
         LET          &J=450000
         RMULT        &J
         REALLOCATE   COM,800000
 IAT     FUNCTION     C1,D19    customers arrival distribution in January
0,23/30,611/60,693/90,956/120,850/150,812/180,868/210,888/240,746/270,672
300,666/330,798/360,847/390,902/420,748/450,501/480,379/510,140/540,11

*IAT     FUNCTION     C1,D19    customers arrival distribution in July
*0,160/30,628/60,960/90,1301/120,1062/150,996/180,1091/210,1073/240,969/270,817
*300,806/330,860/360,1098/390,1104/420,1150/450,807/480,572/510,313/540,49

         STORAGE FOR JANUARY
S(REGII),6/S(REGI),12/S(INSP),19/S(USHER),2/S(COMPUTER),55/S(CAMERA),6
*
*        STORAGE FOR JULY
*S(REGII),6/S(REGI),12/S(INSP),26/S(USHER),2/S(COMPUTER),60/S(CAMERA),6

         GENERATE     RVEXPO(4,30/(FN(IAT)/12))
         QUEUE        SYSQ
*
         TRANSFER     .023,,HEAVY              Transfer 2.3% to heavy.
         TRANSFER     .053,,TRANS              Transfer 5.3% to translator.
*
*
         QUEUE        USHERQ                   Customer arrival queue
         ENTER        USHER                    at the usher station.
         DEPART       USHERQ
         ADVANCE      0.75
         LEAVE        USHER
         TRANSFER     .026,,EXIT               Transfer 2.6% to exit.
         TRANSFER     .636,,WRI                Transfer 63.6% to written test
*                                              to differentiate between various
*                                              road test customers.
*Road Test Modeling
*Light vehicle
 JANUARY TEST LE      AC1,480,EXIT
*JULY    TEST LE      AC1,440,EXIT
         BLET         PH(ROAD)=6               Light vehicle road test.
         BLET         &R2=6.0                  Service time at regII.
         BLET         &H=30                    Road test time.
         TRANSFER     ,RR
 HEAVY   TEST LE      AC1,480,EXIT             January
*        TEST LE      AC1,450,EXIT             July
         BLET         PH(ROAD)=10              Heavy vehicle road test.
         BLET         &R2=6.0                  Service time at regII.
```

```
         BLET       &H=40                    Road test time.
*
RR       QUEUE      ROAD                     Queue at registrationII station
         ENTER      REGII                    for road test.
         DEPART     ROAD
         ADVANCE    &R2                      Service time at regII.
         LEAVE      REGII
*
         TEST E     PH(ROAD),10,TT           Testing for heavy truck drivers.
         TRANSFER   .27,,EXIT                Rejection at registration.
         TRANSFER   ,RR1
*
TT       TEST E     PH(ROAD),6,CAMERA
         TRANSFER   .011,,EXIT               1.1% rejection at registration.
         TRANSFER   .041,,REJCAR             4.1% has no conditioned car.
*
RR1      QUEUE      ROAD1                    Queue at the Inspectors station.
         ENTER      INSP
         DEPART     ROAD1
         ADVANCE    &H                       Road test time.
         LEAVE      INSP
*
         TEST E     PH(ROAD),10,TT1          Heavy vehicle customers.
         TRANSFER   .4,,RFAIL1               40%of HV customers failed.
         BLET       PH(ROAD)=PH(ROAD)-3      HVC passed has value 7.
         TRANSFER   ,TT4
*
TT1      TRANSFER   .35,,RFAIL               35% of LV customers failed.
         BLET       PH(ROAD)=PH(ROAD)+1      LVC passed has value 7
TT4      BLET       &R2=3.62                 Service time for passed LV&HV.
         TRANSFER   ,RR
*
RFAIL1   BLET       PH(ROAD)=PH(ROAD)-2      HVC failed has value 8.
         TRANSFER   ,TT3
*
RFAIL    BLET       PH(ROAD)=PH(ROAD)+2      LVC failed has value 8.
TT3      BLET       &R2=1.0                  Service time for failed LV&HV.
         TRANSFER   ,RR
*
*
REJCAR   BLET       PH(ROAD)=9               Reject cars has value 9.
         BLET       &R2=1.0                  Service time for reject cars.
         TRANSFER   ,RR
*
*
CAMERA   TEST E     PH(ROAD),7,EXIT          LV&HV for camera.
         QUEUE      CAMQ
         ENTER      CAMERA
         DEPART     CAMQ
         ADVANCE    3.5
         LEAVE      CAMERA
         TRANSFER   ,EXIT
*
*
*
```

*__Written exam modeling__

```
*
 WRI      TEST LE      AC1,450,EXIT          January
*         TEST LE      AC1,440,EXIT          July
          TRANSFER     .17,,ACE              17% Addition of Class Customers.
*
*         TRANSFER     .381,,SEC             Difference b/W 1st and 2nd timer
*
          BLET         PH(WRITE)=1           1st time written exam customers.
          BLET         &R1=11.7              Registration time for WEC.
          TRANSFER     ,WR1Q
*
 SEC      BLET         PH(WRITE)=6           2nd time WEC.
          TRANSFER     ,BB5
*
 ACE      BLET         PH(WRITE)=2           ACE customers.
 BB5      BLET         &R1=7.7               Registration time for ACE.
*
 WR1Q     QUEUE        WRITE
          ENTER        REGI
          DEPART       WRITE
          ADVANCE      &R1
          LEAVE        REGI
          TEST E       PH(WRITE),1,NN2       Get ID card if 1st timer.
          QUEUE        CAMQ                  Get your picture at the camera.
          ENTER        CAMERA
          DEPART       CAMQ
          ADVANCE      3.5
          LEAVE        CAMERA
*
 NN2      TEST E       PH(WRITE),7,BB6       Translator exam customers.
          TRANSFER     .11,,EXIT             TEC rejection at registration.
          TRANSFER     ,TEXAM                Different exam for TEC.
*
 BB6      TEST E       PH(WRITE),3,BB2
          TRANSFER     ,EXIT
*
 BB2      TEST E       PH(WRITE),4,BB3
          TRANSFER     ,EXIT
*
 BB3      TEST E       PH(WRITE),5,BB4
          QUEUE        CAMQ
          ENTER        CAMERA
          DEPART       CAMQ
          ADVANCE      3.5
          LEAVE        CAMERA
          TRANSFER     ,EXIT
*
 BB4      TEST E       PH(WRITE),6,MM1       Testing for 1st WEC.
          TRANSFER     .008,MM2,EXIT         Rejection of 1st WEC at reg.
*
 MM1      TEST E       PH(WRITE),1,MM3       Testing for 2nd WEC.
          TRANSFER     .112,MM2,EXIT         Rejection of 2nd WEC at reg.
*
 MM3      TRANSFER     .230;MM2,EXIT         Rejection of ACE at reg.
*
*
```

```
MM2      ENTER        COMPUTER              Mechanized exam
         ADVANCE      30,5                  Computers are always available.
         LEAVE        COMPUTER
*
         TEST E       PH(WRITE),1,KK        1st time WEC customers.
         TRANSFER     .4,,WFAIL             40% of WEC failed.
*
         BLET         PH(WRITE)=PH(WRITE)+2 1st WE pass have a value 3.
KK1      BLET         &R1=3.62              Service time.
         TRANSFER     ,WR1Q
*
WFAIL    BLET         PH(WRITE)=PH(WRITE)+3 1st WE fail have a value of 4.
KK2      BLET         &R1=1.0
         TRANSFER     ,WR1Q
*
KK       TEST E       PH(WRITE),6,KK3       2nd time WEC
         TRANSFER     .8,,WFAIL2            2nd WE passed
         BLET         PH(WRITE)=PH(WRITE)-3 2nd WE passed have a value 3
         TRANSFER     ,KK1
*
WFAIL2   BLET         PH(WRITE)=PH(WRITE)-2 2nd WE fail have a value 4
         TRANSFER     ,KK2
*
KK3      TRANSFER     .37,,WFAIL1           37% of AC failed
         BLET         PH(WRITE)=PH(WRITE)+3 AC passed have a value of 5
         TRANSFER     ,KK1
*
WFAIL1   BLET         PH(WRITE)=PH(WRITE)+2 AC failed have a value of 4.
         TRANSFER     ,KK2
*
*
TRANS    TEST LE      AC1,480,EXIT
         BLET         PH(WRITE)=7
         BLET         &R1=11.7
         PRIORITY     10
         TRANSFER     ,WR1Q
*
TEXAM    ADVANCE      30,5                  Service time for TEC(on paper).
*
         TRANSFER     .001,,WFAIL3          Diff b/w pass&fail TEC.
         BLET         PH(WRITE)=PH(WRITE)-4 Passed TEC have a value 3.
         TRANSFER     ,EXIT
*
WFAIL3   BLET         PH(WRITE)=PH(WRITE)-3 Failed TEC have a value of 4.
         TRANSFER     ,KK2
*
EXIT     DEPART       SYSQ
         TERMINATE    0
*
January  GENERATE     570
*July    GENERATE     600
         TEST E       Q(SYSQ),0
         TERMINATE    1
*
```

```
PUTPIC        FILE=CARL1,LINES=6
        MAXIMUM CONTENT
        ---------------

REPLICATION NO:      SYSQ    USHERQ   ROAD   ROAD1   CAMQ   WRITE
---------------      ------  -------  -----  -----   -----  -----
*
        DO            &I=1,&M
        CLEAR
        RMULT         ,,,&J+&J*&I
        START         1,NP
        PUTPIC
FILE=CARL1,LINES=1,(&I,QM(SYSQ),QM(USHERQ),QM(ROAD),QM(ROAD1),QM(CAMQ),QM(WRITE)
        *                  ***      ***        ***       ***         ***      ***
*
        LET            &AVGM1=&AVGM1+QM(SYSQ)
        LET            &AVGM2=&AVGM2+QM(USHERQ)
        LET            &AVGM3=&AVGM3+QM(ROAD)
        LET            &AVGM4=&AVGM4+QM(ROAD1)
        LET            &AVGM5=&AVGM5+QM(CAMQ)
        LET            &AVGM6=&AVGM6+QM(WRITE)
        ENDDO
*
        PUTPIC         FILE=CARL1,LINES=6
        AVERAGE CONTENT
        ---------------

        REPLICATION NO:   SYSQ   USHERQ   ROAD   ROAD1   CAMQ   WRITE
        ---------------   ----   ------   ----   -----   ----   -----
*
        DO            &I=1,&M
        CLEAR
        RMULT         ,,,&J+&J*&I
        START         1,NP

        PUTPIC
FILE=CARL,LINES=1,(&I,QA(SYSQ),QA(USHERQ),QA(ROAD),QA(ROAD1),QA(CAMQ),QA(WRITE))
          *              ***.***    ***.***    ***.***   ***.***     ***.***    ***.***
*
        LET            &AVG1=&AVG1+QA(SYSQ)
        LET            &AVG2=&AVG2+QA(USHERQ)
        LET            &AVG3=&AVG3+QA(ROAD)
        LET            &AVG4=&AVG4+QA(ROAD1)
        LET            &AVG5=&AVG5+QA(CAMQ)
        LET            &AVG6=&AVG6+QA(WRITE)
        ENDDO
*
        PUTPIC         FILE=CARL,LINES=6

        CURRENT CONTENT
        ---------------

        REPLICATION NO:     SYSQ    USHERQ    ROAD    ROAD1    CAMQ    WRITE
        ---------------     ----    ------    ----    -----    ----    -----
```

```
*
        DO              &I=1,&M
        CLEAR
        RMULT           ,,,&J+&J*&I
        START           1,NP
*
        PUTPIC
FILE=CARL,LINES=1,(&I,Q(SYSQ),Q(USHERQ),Q(ROAD),Q(ROAD1),Q(CAMQ),Q(WRITE))
          *            ***       ***       ***      ***     ***     ***
*
        LET             &AVGC1=&AVGC1+Q(SYSQ)
        LET             &AVGC2=&AVGC2+Q(USHERQ)
        LET             &AVGC3=&AVGC3+Q(ROAD)
        LET             &AVGC4=&AVGC4+Q(ROAD1)
        LET             &AVGC5=&AVGC5+Q(CAMQ)
        LET             &AVGC6=&AVGC6+Q(WRITE)
        ENDDO
*
        PUTPIC          FILE=CARL,LINES=6
        AVERAGE RESIDENCE TIME
        ----------------------

        REPLICATION NO:     SYSQ    USHERQ    ROAD     ROAD1    CAMQ     WRITE
        ---------------     ----    ------    ----     -----    ----     -----
*
        DO              &I=1,&M
        CLEAR
        RMULT           ,,,&J+&J*&I
        START           1,NP

        PUTPIC
FILE=CARL,LINES=1,(&I,QT(SYSQ),QT(USHERQ),QT(ROAD),QT(ROAD1),QT(CAMQ),QT(WRITE))
          *            ***.***   ***.***   ***.***  ***.***   ***.***   ***.***
*
        LET             &AVGR1=&AVGR1+QT(SYSQ)
        LET             &AVGR2=&AVGR2+QT(USHERQ)
        LET             &AVGR3=&AVGR3+QT(ROAD)
        LET             &AVGR4=&AVGR4+QT(ROAD1)
        LET             &AVGR5=&AVGR5+QT(CAMQ)
        LET             &AVGR6=&AVGR6+QT(WRITE)
        LET             &X(&I)=QT(SYSQ)
        ENDDO
*
        PUTPIC          FILE=CARL,LINES=6
        AVERAGE UTILIZATION
        -------------------

        REPLICATION NO:     USHER   REGII     INSP   REGI     COMPUTER   CAMERA
        ---------------     ----    ------    ----   -----      ----     -----
*
        DO              &I=1,&M
        CLEAR
        RMULT           ,,,&J+&J*&I
        START           1,NP
*
```

```
        PUTPIC
FILE=CARL,LINES=1,(&I,SR(USHER)/10,SR(REGII)/10,SR(INSP)/10,SR(REGI)/10,
                  SR(COMPUTER)/10,SR(CAMERA)/10)
          *        ***.***   ***.***    ***.***  ***.***    ***.***
                    ***.***        ***.***
*
        LET             &AVGU1=&AVGU1+SR(USHER)/10
        LET             &AVGU2=&AVGU2+SR(REGII)/10
        LET             &AVGU3=&AVGU3+SR(INSP)/10
        LET             &AVGU4=&AVGU4+SR(REGI)/10
        LET             &AVGU5=&AVGU5+SR(COMPUTER)/10
        LET             &AVGU6=&AVGU6+SR(CAMERA)/10
        ENDDO
*
        LET             &AVGM1=&AVGM1/50
        LET             &AVGM2=&AVGM2/50
        LET             &AVGM3=&AVGM3/50
        LET             &AVGM4=&AVGM4/50
        LET             &AVGM5=&AVGM5/50
        LET             &AVGM6=&AVGM6/50
*
        PUTPIC
FILE=CARL,LINES=6,(&AVGM1,&AVGM2,&AVGM3,&AVGM4,&AVGM5,&AVGM6)
       AVERAGE MAXIMUM CONTENT FOR 50 RUNS
       -----------------------------------

       SYSQ     USHERQ    ROAD     ROAD1    CAMQ     WRITE
       ----     ------    ----     -----    ----     -----
       ***.**   ***.**    ***.**   ***.**   ***.**   ***.**
*
        LET             &AVG1=&AVG1/50
        LET             &AVG2=&AVG2/50
        LET             &AVG3=&AVG3/50
        LET             &AVG4=&AVG4/50
        LET             &AVG5=&AVG5/50
        LET             &AVG6=&AVG6/50
*
        PUTPIC        FILE=CARL,LINES=6,(&AVG1,&AVG2,&AVG3,&AVG4,&AVG5,&AVG6)
       OVERALL AVERAGE  CONTENT FOR 50 RUNS
       -----------------------------------

       SYSQ     USHERQ    ROAD     ROAD1    CAMQ     WRITE
       ----     ------    ----     -----    ----     -----
       ***.**   ***.**    ***.**   ***.**   ***.**   ***.**
        LET             &AVGC1=&AVGC1/50
        LET             &AVGC2=&AVGC2/50
        LET             &AVGC3=&AVGC3/50
        LET             &AVGC4=&AVGC4/50
        LET             &AVGC5=&AVGC5/50
        LET             &AVGC6=&AVGC6/50
 *
```

```
        PUTPIC
FILE=CARL,LINES=6,(&AVGC1,&AVGC2,&AVGC3,&AVGC4,&AVGC5,&AVGC6)
        AVERAGE CURRENT CONTENT FOR 50 RUNS
        -----------------------------------
        SYSQ      USHERQ    ROAD      ROAD1     CAMQ      WRITE
        ----      ------    ----      -----     ----      -----
        ***.**    ***.**    ***.**    ***.**    ***.**    ***.**
*
        LET              &AVGR1=&AVGR1/50
        LET              &AVGR2=&AVGR2/50
        LET              &AVGR3=&AVGR3/50
        LET              &AVGR4=&AVGR4/50
        LET              &AVGR5=&AVGR5/50
        LET              &AVGR6=&AVGR6/50
*
        PUTPIC
FILE=CARL,LINES=6,(&AVGR1,&AVGR2,&AVGR3,&AVGR4,&AVGR5,&AVGR6)
        AVERAGE RESIDENCE TIME FOR 50 RUNS
        ----------------------------------

        SYSQ      USHERQ    ROAD      ROAD1     CAMQ      WRITE
        ----      ------    ----      -----     ----      -----
        ***.**    ***.**    ***.**    ***.**    ***.**    ***.**

        LET              &AVGU1=&AVGU1/50
        LET              &AVGU2=&AVGU2/50
        LET              &AVGU3=&AVGU3/50
        LET              &AVGU4=&AVGU4/50
        LET              &AVGU5=&AVGU5/50
        LET              &AVGU6=&AVGU6/50
*
        PUTPIC
FILE=CARL,LINES=6,(&AVGU1,&AVGU2,&AVGU3,&AVGU4,&AVGU5,&AVGU6)
        OVERALL AVERAGE UTILIZATION FOR 50 RUNS
        ---------------------------------------

        USHER     REGII     INSP      REGI      COMPUTER  CAMERA
        ----      ------    -----     -----     --------  -------
        ***.**    ***.**    ***.**    ***.**    ***.**     ***.**
*
        DO               &I=1,&M
        LET              &SUMSQDF=&SUMSQDF+(&AVGR1-&X(&I))*(&AVGR1-&X(&I))
        ENDDO
*
        LET              &SD=SQRT(&SUMSQDF/(50-1))
        LET              &LOWLIM=&AVGR1-&TSTAT*(&SD/SQRT(50))
        LET              &UPLIM=&AVGR1+&TSTAT*(&SD/SQRT(50))
*
        PUTPIC           FILE=CARL,LINES=6,(&SD,&LOWLIM,&UPLIM)
        CONFIDENCE INTERVAL FOR SYSTEM QUEUE
        ------------------------------------
        SD            LOWER LIMIT        UPPER LIMIT
                      FOR 99% CI         FOR 99% CI
        ----          ----------         ------------
        ***.***       ***.***             ***.***
        END
```

OUTPUT FOR ONLY ONE RUN: PROOF OF RUNNING

```
LINE# STMT#  IF DO  BLOCK#  *LOC   OPERATION     A,B,C,D,E,F,G   COMMENTS

  1     1                          SIMULATE
  2     2                    *     JANUARY
  3     3                          REAL          &R1,&R2
  4     4                          INTEGER       &H
  5     5                    *     LET           &M=5
  6     6                    *     LET           &TSTAT=2.78
  7     7                    *     LET           &J=450000
  8     8                    *     RMULT         &J
  9     9                          REALLOCATE    COM,800000
 10    10                     IAT   FUNCTION     C1,D19                 customers arrival distribution
 11    11                    0,23/30,611/60,693/90,956/120,850/150,812/180,868/210,888/240,746/270,672/300,666/330,798/360,847
 12    12                    390,902/420,748/450,501/480,379/510,140/540,11
 13    13                           STORAGE      S(REGII),6/S(REGI),12/S(INSP),19/S(USHER),2/S(COMPUTER),55/S(CAMERA),6
 14    14                    *
 15    15                    *
 16    16            1              GENERATE     RVEXPO(4,30/(FN(IAT)/12))
 17    17            2              QUEUE        SYSQ
 18    18                    *
 19    19            3              TRANSFER     .023,,HEAVY             transfer 2.3% to heavy
 20    20            4              TRANSFER     .053,,TRANS             transfer 5.3% to translator
 21    21                    *
 22    22                    *
 23    23            5              QUEUE        USHERQ
 24    24            6              ENTER        USHER
 25    25            7              DEPART       USHERQ
 26    26            8              ADVANCE      0.75
 27    27            9              LEAVE        USHER
 28    28                    *
 29    29           10              TRANSFER     .026,,EXIT              transfer 2.6% to exit
 30    30           11              TRANSFER     .636,,WRI               transfer 63.6% to written test
 31    31                    *
 32    32                    *                                           to differentiate between various
 33    33                    *                                           road test customers
 34    34                    *
 35    35           12              TEST LE      AC1,480,EXIT
 36    36           13              BLET         PH(ROAD)=6              light vehicle road test
 37    37           14              BLET         &R2=6.0                 service time at regII
 38    38           15              BLET         &H=30                   road test time
 39    39           16              TRANSFER     ,RR
 40    40                    *
 41    41                    *
 42    42           17    HEAVY     TEST LE      AC1,480,EXIT
 43    43           18              BLET         PH(ROAD)=10             heavy vehicle road test
 44    44           19              BLET         &R2=6.0                 service time at regII
 45    45           20              BLET         &H=40                   road test time
 46    46                    *
 47    47           21    RR        QUEUE        ROAD
 48    48           22              ENTER        REGII
```

```
23          DEPART      ROAD
24          ADVANCE     &R2                   service time at regII
25          LEAVE       REGII
    *
26          TEST E      PH(ROAD),10,TT        testing for heavy truck drivers

27          TRANSFER    .27,,EXIT             rejection at registration
28          TRANSFER    ,RR1
    *
29  TT      TEST E      PH(ROAD),6,CAMERA
30          TRANSFER    .011,,EXIT            1.1% rejection at registration
31          TRANSFER    .041,,REJCAR          4.1% has no conditioned car
    *
32  RR1     QUEUE       ROAD1
33          ENTER       INSP
34          DEPART      ROAD1
35          ADVANCE     &H                    road test time
36          LEAVE       INSP
    *
37          TEST E      PH(ROAD),10,TT1       heavy vehicle customers
38          TRANSFER    .4,,RFAIL1            40%of HV customers failed
39          BLET        PH(ROAD)=PH(ROAD)-3   HVC passed has value 7
40          TRANSFER    ,TT4
    *
41  TT1     TRANSFER    .35,,RFAIL            35% of LV customers failed
42          BLET        PH(ROAD)=PH(ROAD)+1   LVC passed has value 7
43  TT4     BLET        &R2=3.62              service time for passed LV&HV
44          TRANSFER    ,RR
    *
45  RFAIL1  BLET        PH(ROAD)=PH(ROAD)-2   HVC failed has value 8
46          TRANSFER    ,TT3
    *
47  RFAIL   BLET        PH(ROAD)=PH(ROAD)+2   LVC failed has value 8
48  TT3     BLET        &R2=1.0               service time for failed LV&HV
49          TRANSFER    ,RR
    *
    *
50  REJCAR  BLET        PH(ROAD)=9            reject cars has value 9
51          BLET        &R2=1.0               service time for reject cars
52          TRANSFER    ,RR
    *
    *
53  CAMERA  TEST E      PH(ROAD),7,EXIT       LV&HV for camera
54          QUEUE       CAMQ
55          ENTER       CAMERA
56          DEPART      CAMQ
57          ADVANCE     3.5
58          LEAVE       CAMERA
59          TRANSFER    ,EXIT
    *
    *                                         written exam modeling
    *
```

```
60   WRI    TEST LE     AC1,450,EXIT
61          TRANSFER    .17,,ACE              17% Advanced Class Customers
      *
62          TRANSFER    .381,,SEC             diff betn 1 & 2 written examers
      *
63          BLET        PH(WRITE)=1           1st time written exam customers
64          BLET        &R1=11.7              registration time for WEC
65          TRANSFER    ,WR1Q
      *
66   SEC    BLET        PH(WRITE)=6           2nd time WEC

67          TRANSFER    ,BB5
      *
68   ACE    BLET        PH(WRITE)=2           ACE customers
69   BB5    BLET        &R1=7.7               registration time for ACE
      *
70   WR1Q   QUEUE       WRITE
 71          ENTER       REGI
72          DEPART      WRITE
73          ADVANCE     &R1
74          LEAVE       REGI
75          TEST E      PH(WRITE),1,NN2
76          QUEUE       CAMQ
77          ENTER       CAMERA
78          DEPART      CAMQ
79          ADVANCE     3.5
80          LEAVE       CAMERA
      *
81   NN2    TEST E      PH(WRITE),7,BB6       translator exam customers
82          TRANSFER    .11,,EXIT             TEC rejection at registration
83          TRANSFER    ,TEXAM                different exam for TEC
      *
84   BB6    TEST E      PH(WRITE),3,BB2
85          TRANSFER    ,EXIT
      *
86   BB2    TEST E      PH(WRITE),4,BB3
87          TRANSFER    ,EXIT
      *
88   BB3    TEST E      PH(WRITE),5,BB4
89          QUEUE       CAMQ
90          ENTER       CAMERA
91          DEPART      CAMQ
92          ADVANCE     3.5
93          LEAVE       CAMERA
94          TRANSFER    ,EXIT
      *
95   BB4    TEST E      PH(WRITE),6,MM1       testing for 1st WEC
96          TRANSFER    .008,MM2,EXIT         rejection of 1st WEC at reg
      *
97   MM1    TEST E      PH(WRITE),1,MM3       testing for 2nd WEC
98          TRANSFER    .112,MM2,EXIT         rejection of 2nd WEC at reg
      *
```

```
 99  MM3     TRANSFER   .230,MM2,EXIT         rejection of ACE at reg
    *
100  MM2     ENTER      COMPUTER
101          ADVANCE    30,5
102          LEAVE      COMPUTER
    *
103          TEST E     PH(WRITE),1,KK        1st time WEC customers
104          TRANSFER   .4,,WFAIL             40% of WEC failed
    *
105          BLET       PH(WRITE)=PH(WRITE)+2 1st WE pass have a value 3
106  KK1     BLET       &R1=3.62              service time
107          TRANSFER   ,WR1Q
    *
108  WFAIL   BLET       PH(WRITE)=PH(WRITE)+3 1st WE fail have a value of 4
109  KK2     BLET       &R1=1.0

110          TRANSFER   ,WR1Q
    *
111  KK      TEST E     PH(WRITE),6,KK3       2nd time WEC
112          TRANSFER   .8,,WFAIL2            2nd WE passed
113          BLET       PH(WRITE)=PH(WRITE)-3 2nd WE passed have a value 3
114          TRANSFER   ,KK1
    *
115  WFAIL2  BLET       PH(WRITE)=PH(WRITE)-2 2nd WE fail have a value 4
116          TRANSFER   ,KK2
    *
117  KK3     TRANSFER   .37,,WFAIL1           37% of AC failed
118          BLET       PH(WRITE)=PH(WRITE)+3 AC passed have a value of 5
119          TRANSFER   ,KK1
    *
120  WFAIL1  BLET       PH(WRITE)=PH(WRITE)+2 AC failed have a value of 4
121          TRANSFER   ,KK2
    *
    *
122  TRANS   TEST LE    AC1,480,EXIT
123          BLET       PH(WRITE)=7
124          BLET       &R1=11.7
125          PRIORITY   10
126          TRANSFER   ,WR1Q
    *
127  TEXAM   ADVANCE    30,5                  service time for TEC(exam on paper)
    *
    *
    *
128          TRANSFER   .001,,WFAIL3          diff betn pass&fail TEC
129          BLET       PH(WRITE)=PH(WRITE)-4 passed TEC have a value 3
130          TRANSFER   ,EXIT
    *
131  WFAIL3  BLET       PH(WRITE)=PH(WRITE)-3 failed TEC have a value of 4
132          TRANSFER   ,KK2
    *
133  EXIT    DEPART     SYSQ
```

```
202   202          134          TERMINATE    0
203   203                  *
204   204          135          GENERATE     570
205   205          136          TEST E       Q(SYSQ),0
206   206          137          TERMINATE    1
□
207   207                       START        1
208   208                       END
```

ENTITY DICTIONARY (IN ASCENDING ORDER BY ENTITY NUMBER; "+" => VALUE CONFLICT.)

```
        Queues: 1=SYSQ       2=USHERQ     3=ROAD      4=ROAD1     5=CAMQ        6=WRITE

      Storages: 1=REGII      2=REGI       3=INSP      4=USHER     5=COMPUTER    53=CAMERA

     Functions: 1=IAT

 Halfword Parms: 3=ROAD       6=WRITE

 Random Numbers: 4

  Integer &Vars: 1=H

     Real &Vars: 1=R1         2=R2
```

Simulation begins.

RELATIVE CLOCK: 570.0000   ABSOLUTE CLOCK: 570.0000

BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL
1		1020	11		916	RR		678	31		327	TT1		297
2		1020	12		332	22		678	RR1	3	333	42		195
3		1020	13		330	23		678	33		330	TT4		205
4		993	14		330	24		678	34		330	44		205
5		939	15		330	25		678	35	19	330	RFAIL1		4
6		939	16		330	26		678	36		311	46		4
7		939	HEAVY		27	27		27	37		311	RFAIL		102
8		939	18		27	28		16	38		14	TT3		106
9		939	19		27	TT		651	39		10	49		106
10		939	20		27	30		330	40		10	REJCAR		10

BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL
51		10	61		550	71		1103	NN2		1103	91		51
52		10	62		450	72		1103	82		53	92		51
CAMERA		321	63		270	73		1103	83		52	93		51
54		205	64		270	74		1103	BB6		1050	94		51
55		205	65		270	75		1103	85		169	BB4		550
56		205	SEC		180	76		270	BB2		881	96		180

57	1	205	67		180	77		270	87		280	MM1		370
58		204	ACE		100	78		270	BB3		601	98		270
59		204	BB5		280	79		270	89		51	MM3		100
WRI		584	WR1Q		1103	80		270	90		51	MM2		500

BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL	BLOCK	CURRENT	TOTAL
101		500	KK		257	121		26	WFAIL3		0
102		500	112		180	TRANS		54	132		0
103		500	113		31	123		53	EXIT		997
104		243	114		31	124		53	134		997
105		138	WFAIL2		149	125		53	135		1
KK1		220	116		149	126		53	136		1
107		220	KK3		77	TEXAM		52	137		0
WFAIL		105	118		51	128		52			
KK2		280	119		51	129		52			
110		280	WFAIL1		26	130		52			

STORAGE	--AVG-UTIL-DURING-- TOTAL TIME	AVAIL TIME	UNAVL TIME	ENTRIES	AVERAGE TIME/UNIT	CURRENT STATUS	PERCENT AVAIL	CAPACITY	AVERAGE CONTENTS	CURRENT CONTENTS	MAXIMUM CONTENTS
REGII	0.849			678	4.281	AVAIL	100.0	6	5.092	0	6
REGI	0.917			1103	5.686	AVAIL	100.0	12	11.004	0	12
INSP	0.950			330	31.172	AVAIL	100.0	19	18.047	0	19
USHER	0.618			939	0.750	AVAIL	100.0	2	1.236	0	2
COMPUTER	0.478			500	29.999	AVAIL	100.0	55	26.315	0	55
CAMERA	0.538			526	3.499	AVAIL	100.0	6	3.229	0	6

QUEUE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	AVERAGE TIME/UNIT	$AVERAGE TIME/UNIT	QTABLE NUMBER	CURRENT CONTENTS
SYSQ	399	221.941	1020	1	0.1	124.026	124.147		0
USHERQ	13	1.015	939	339	36.1	0.616	0.964		0
ROAD	59	22.635	678	93	13.7	19.029	22.054		0
ROAD1	35	10.568	333	34	10.2	18.089	20.146		0
CAMQ	40	2.454	526	341	64.8	2.659	7.562		0
WRITE	266	116.012	1103	113	10.2	59.952	66.795		0

RANDOM STREAM	ANTITHETIC VARIATES	INITIAL POSITION	CURRENT POSITION	SAMPLE COUNT	CHI-SQUARE UNIFORMITY
1	OFF	100000	107570	7570	1.00
4	OFF	400000	401021	1021	0.33

APPENDIX H

ADDRESSING THE LIMITATION OF SERVICE TIME VARIANCE
(MODEL, OUTPUT AND TEST ARE INCLUDED)

```
         SIMULATE
*        JANUARY
         REAL          &SD,&LOWLIM,&UPLIM,&AVGU1,&AVGU2,&AVGU3,&AVGU4,&AVGU5,&AVGU6,_
                       &AVGR1,&AVGR2,&AVGR3,&AVGR4,&AVGR5,&AVGR6,&AVGC1,_
                       &AVGC2,&AVGC3,&AVGC4,&AVGC5,&AVGC6,&AVG1,&AVG2,&AVG3,_
                       &AVG4,&AVG5,&AVG6,&AVGM1,&AVGM2,&AVGM3,&AVGM4,&AVGM5,_
                       &AVGM6,&TSTAT,&X(50),&R1,&R2,&SUMSQDF
         INTEGER       &I,&J,&H,&M
         LET           &M=50
         LET           &TSTAT=2.68
         LET           &J=450000
         RMULT         &J
         REALLOCATE    COM,800000
 IAT     FUNCTION      C1,D19                   customers arrival distribution
0,23/30,611/60,693/90,956/120,850/150,812/180,868/210,888/240,746/270,672/300,666/330,798/360,847/390,902/4
20,748/450,501
480,379/510,140/540,11
         STORAGE       S(REGII),6/S(REGI),12/S(INSP),19/S(USHER),2/S(COMPUTER),55/S(CAMERA),6
*
*
         GENERATE      RVEXPO(4,30/(FN(IAT)/12))
         QUEUE         SYSQ
*
         TRANSFER      .023,,HEAVY             transfer 2.3% to heavy
         TRANSFER      .053,,TRANS             transfer 5.3% to translator
*
*
         QUEUE         USHERQ
         ENTER         USHER
         DEPART        USHERQ
         ADVANCE       RVEXPO(5,0.75)
         LEAVE         USHER
*
         TRANSFER      .026,,EXIT              transfer 2.6% to exit
         TRANSFER      .636,,WRI               transfer 63.6% to written test
*                                              to differentiate between various
*                                              road test customers
         TEST LE       AC1,480,EXIT
         BLET          PH(ROAD)=6              light vehicle road test
         BLET          &R2=6.0                 service time at regII
         BLET          &H=30                   road test time
         TRANSFER      ,RR
```

```
*
 HEAVY    TEST LE     AC1,480,EXIT
          BLET        PH(ROAD)=10              heavy vehicle road test
          BLET        &R2=6.0                  service time at regII
          BLET        &H=40                    road test time
*
 RR       QUEUE       ROAD
          ENTER       REGII
          DEPART      ROAD
          ADVANCE     RVEXPO(6,&R2)            service time at regII
          LEAVE       REGII
*
          TEST E      PH(ROAD),10,TT           testing for heavy truck drivers
          TRANSFER    .27,,EXIT                rejection at registration
          TRANSFER    ,RR1
*
 TT       TEST E      PH(ROAD),6,CAMERA
          TRANSFER    .011,,EXIT               1.1% rejection at registration
          TRANSFER    .041,,REJCAR             4.1% has no conditioned car
*
 RR1      QUEUE       ROAD1
          ENTER       INSP
          DEPART      ROAD1
          ADVANCE     RVEXPO(7,&H)             road test time
          LEAVE       INSP
*
          TEST E      PH(ROAD),10,TT1          heavy vehicle customers
          TRANSFER    .4,,RFAIL1               40%of HV customers failed
          BLET        PH(ROAD)=PH(ROAD)-3      HVC passed has value 7
          TRANSFER    ,TT4
*
 TT1      TRANSFER    .35,,RFAIL               35% of LV customers failed
          BLET        PH(ROAD)=PH(ROAD)+1      LVC passed has value 7
 TT4      BLET        &R2=3.62                 service time for passed LV&HV
          TRANSFER    ,RR
*
 RFAIL1   BLET        PH(ROAD)=PH(ROAD)-2      HVC failed has value 8
          TRANSFER    ,TT3
*
 RFAIL    BLET        PH(ROAD)=PH(ROAD)+2      LVC failed has value 8
 TT3      BLET        &R2=1.0                  service time for failed LV&HV
          TRANSFER    ,RR
```

```
*
 REJCAR  BLET        PH(ROAD)=9            reject cars has value 9
         BLET        &R2=1.0               service time for reject cars
         TRANSFER    ,RR
*
*
 CAMERA  TEST E      PH(ROAD),7,EXIT       LV&HV for camera
         QUEUE       CAMQ
         ENTER       CAMERA
         DEPART      CAMQ
         ADVANCE     RVEXPO(8,3.5)
         LEAVE       CAMERA
         TRANSFER    ,EXIT
*
*                                          written exam modeling
*
 WRI     TEST LE     AC1,450,EXIT
         TRANSFER    .17,,ACE              17% Advanced Class Customers
*
         TRANSFER    .381,,SEC             diff betn 1 & 2 written examers
*
         BLET        PH(WRITE)=1           1st time written exam customers
         BLET        &R1=11.7              registration time for WEC
         TRANSFER    ,WR1Q
*
 SEC     BLET        PH(WRITE)=6           2nd time WEC
         TRANSFER    ,BB5
*
 ACE     BLET        PH(WRITE)=2           ACE customers
 BB5     BLET        &R1=7.7               registration time for ACE
*
 WR1Q    QUEUE       WRITE
         ENTER       REGI
         DEPART      WRITE
         ADVANCE     RVEXPO(9,&R1)
         LEAVE       REGI
         TEST E      PH(WRITE),1,NN2
         QUEUE       CAMQ
         ENTER       CAMERA
         DEPART      CAMQ
         ADVANCE     RVEXPO(10,3.5)
         LEAVE       CAMERA
```

```
*
NN2      TEST E       PH(WRITE),7,BB6           translator exam customers
         TRANSFER     .11,,EXIT                 TEC rejection at registration
         TRANSFER     ,TEXAM                    different exam for TEC
*
BB6      TEST E       PH(WRITE),3,BB2
         TRANSFER     ,EXIT
*
BB2      TEST E       PH(WRITE),4,BB3
         TRANSFER     ,EXIT
*
BB3      TEST E       PH(WRITE),5,BB4
         QUEUE        CAMQ
         ENTER        CAMERA
         DEPART       CAMQ
         ADVANCE      RVEXPO(11,3.5)
         LEAVE        CAMERA
         TRANSFER     ,EXIT
*
BB4      TEST E       PH(WRITE),6,MM1           testing for 1st WEC
         TRANSFER     .008,MM2,EXIT             rejection of 1st WEC at reg
*
MM1      TEST E       PH(WRITE),1,MM3           testing for 2nd WEC
         TRANSFER     .112,MM2,EXIT             rejection of 2nd WEC at reg
*
MM3      TRANSFER     .230,MM2,EXIT             rejection of ACE at reg
*
MM2      ENTER        COMPUTER
         ADVANCE      RVEXPO(12,30)
         LEAVE        COMPUTER
*
         TEST E       PH(WRITE),1,KK            1st time WEC customers
         TRANSFER     .4,,WFAIL                 40% of WEC failed
*
         BLET         PH(WRITE)=PH(WRITE)+2     1st WE pass have a value 3
KK1      BLET         &R1=3.62                  service time
         TRANSFER     ,WR1Q
*
WFAIL    BLET         PH(WRITE)=PH(WRITE)+3     1st WE fail have a value of 4
KK2      BLET         &R1=1.0
         TRANSFER     ,WR1Q
*
```

```
KK       TEST E        PH(WRITE),6,KK3         2nd time WEC
         TRANSFER      .8,,WFAIL2              2nd WE passed
         BLET          PH(WRITE)=PH(WRITE)-3   2nd WE passed have a value 3
         TRANSFER      ,KK1
*
WFAIL2   BLET          PH(WRITE)=PH(WRITE)-2   2nd WE fail have a value 4
         TRANSFER      ,KK2
*
KK3      TRANSFER      .37,,WFAIL1             37% of AC failed
         BLET          PH(WRITE)=PH(WRITE)+3   AC passed have a value of 5
         TRANSFER      ,KK1
*
WFAIL1   BLET          PH(WRITE)=PH(WRITE)+2   AC failed have a value of 4
         TRANSFER      ,KK2
*
*
TRANS    TEST LE       AC1,480,EXIT
         BLET          PH(WRITE)=7
         BLET          &R1=11.7
         PRIORITY      10
         TRANSFER      ,WR1Q
*
TEXAM    ADVANCE       RVEXPO(13,30)            service time for TEC(exam on paper)
*
*
*
         TRANSFER      .001,,WFAIL3             diff betn pass&fail TEC
         BLET          PH(WRITE)=PH(WRITE)-4    passed TEC have a value 3
         TRANSFER      ,EXIT
*
WFAIL3   BLET          PH(WRITE)=PH(WRITE)-3    failed TEC have a value of 4
         TRANSFER      ,KK2
*
EXIT     DEPART        SYSQ
         TERMINATE     0
*
         GENERATE      570
         TEST E        Q(SYSQ),0
         TERMINATE     1
*        START         1                         N.B: Putpic for 50 runs remains the same
         END
```

OUTPUT FOR 50 RUNS

AVERAGE MAXIMUM CONTENT FOR 50 RUNS

SYSQ	USHERQ	ROAD	ROAD1	CAMQ	WRITE
298.90	18.74	40.94	42.48	19.22	176.76

OVERALL AVERAGE CONTENT FOR 50 RUNS

SYSQ	USHERQ	ROAD	ROAD1	CAMQ	WRITE
147.53	1.61	8.72	14.56	1.02	66.68

AVERAGE CURRENT CONTENT FOR 50 RUNS

SYSQ	USHERQ	ROAD	ROAD1	CAMQ	WRITE
0.00	0.00	0.00	0.00	0.00	0.00

AVERAGE RESIDENCE TIME FOR 50 RUNS

SYSQ	USHERQ	ROAD	ROAD1	CAMQ	WRITE
105.73	1.19	10.93	29.69	1.46	37.81

OVERALL AVERAGE UTILIZATION FOR 50 RUNS

USHER	REGII	INSP	REGI	COMPUTER	CAMERA
50.77	67.97	77.12	71.96	39.50	45.73

CONFIDENCE INTERVAL FOR SYSTEM QUEUE

SD	LOWER LIMIT FOR 99% CI	UPPER LIMIT FOR 99% CI
15.070	91.424	112.847

GROUP STATISTICS

	NUMBERS	N	Mean	Std.Dev	Std.Error
ORIGINAL	1	50	109.28	10.5541	1.4926
EXPONEN	2	50	105.74	10.9726	1.5518

T-TEST

		Levene's Test for Equality of Variances		t-test for Equality of Means					
								95% C.I. for the mean	
ORIGINAL	Equal	F	Sig.	t	df	Sig.(2-tailed)	Mean Diff.	lower	upper
	Variances Assumed	0.054	0.817	4.062	98	0.052	3.5467	-0.5153	7.6087
	Equal Variances not Assumed			4.062	97.852	0.052	3.5467	-0.5154	7.6088

APPENDIX I

COMPARISION BETWEEN THE ORIGINAL OUTPUT AND THAT USING ANTITHETIC VARIATES TECHNIQUE

(INCLUDED ARE THE RELEVANT ALTERATIONS IN THE MODEL AND THE EXPECTED IMPROVEMENT IN VARIABILITY)

```
        PUTPIC        FILE=CARL1,LINES=6        ALTERATIONS NEEDED FOR ANTITHETIC VARIATES
        AVERAGE RESIDENCE TIME
        ----------------------

        REPLICATION NO:        SYSQ
        ---------------        ----
*
        DO            &I=1,&M
*       LET           &M=13
        CLEAR
        RMULT         ,,,&J+&J*&I
        START         1,NP

        PUTPIC        FILE=CARL1,LINES=1,(&I,QT(SYSQ))
          *                  ***.***
*
        LET            &AVGR1=&AVGR1+QT(SYSQ)
        LET            &X(&I)=QT(SYSQ)
        ENDDO
*
        PUTPIC        FILE=CARL1,LINES=6
        AVERAGE UTILIZATION
        -------------------

        REPLICATION NO:        USHER     REGII     INSP     REGI     COMPUTER   CAMERA
        ---------------        ----      ------    ----     -----    ----       -----
*
        DO            &I=1,&M
        CLEAR
        RMULT         ,,,&J+&J*&I
        START         1,NP
*
     PUTPIC
FILE=CARL1,LINES=1,(&I,SR(USHER)/10,SR(REGII)/10,SR(INSP)/10,SR(REGI)/10,SR(COMPUTER)/10
,SR(CAMERA)/10)
          *                  ***.***   ***.***   ***.***  ***.***   ***.***   ***.***
*
        LET            &AVGU1=&AVGU1+SR(USHER)/10
        LET            &AVGU2=&AVGU2+SR(REGII)/10
        LET            &AVGU3=&AVGU3+SR(INSP)/10
        LET            &AVGU4=&AVGU4+SR(REGI)/10
        LET            &AVGU5=&AVGU5+SR(COMPUTER)/10
        LET            &AVGU6=&AVGU6+SR(CAMERA)/10
        ENDDO
*
        DO            &I=14,&K
*       LET           &K=26
        CLEAR
        RMULT         ,,,-&J-&J*(&I-13)
        START         1,NP

        PUTPIC        FILE=CARL1,LINES=1,(&I,QT(SYSQ))
          *                  ***.***
*
        LET            &AVGR1=&AVGR1+QT(SYSQ)
        LET            &X(&I)=QT(SYSQ)
        ENDDO
*
        PUTPIC        FILE=CARL1,LINES=6
        AVERAGE UTILIZATION
        -------------------
        REPLICATION NO:        USHER     REGII     INSP     REGI     COMPUTER   CAMERA
        ---------------        ----      ------    ----     -----    ----       -----
```

```
*
        DO          &I=14,&K
        CLEAR
        RMULT       ,,,-&J-&J*(&I-13)
        START       1,NP
*
   PUTPIC
FILE=CARL1,LINES=1,(&I,SR(USHER)/10,SR(REGII)/10,SR(INSP)/10,SR(REGI)/10,SR(COMPUTER)/10
,SR(CAMERA)/10)
        *               ***.***   ***.***    ***.***   ***.***    ***.***    ***.***
*
        LET          &AVGU1=&AVGU1+SR(USHER)/10
        LET          &AVGU2=&AVGU2+SR(REGII)/10
        LET          &AVGU3=&AVGU3+SR(INSP)/10
        LET          &AVGU4=&AVGU4+SR(REGI)/10
        LET          &AVGU5=&AVGU5+SR(COMPUTER)/10
        LET          &AVGU6=&AVGU6+SR(CAMERA)/10
        ENDDO
*
        LET          &AVGR1=&AVGR1/26
*
        PUTPIC       FILE=CARL1,LINES=6,(&AVGR1)
        AVERAGE RESIDENCE TIME FOR 26 RUNS
        -----------------------------------

        SYSQ
        ----
        ***.**

        LET          &AVGU1=&AVGU1/26
        LET          &AVGU2=&AVGU2/26
        LET          &AVGU3=&AVGU3/26
        LET          &AVGU4=&AVGU4/26
        LET          &AVGU5=&AVGU5/26
        LET          &AVGU6=&AVGU6/26
*
        PUTPIC       FILE=CARL1,LINES=6,(&AVGU1,&AVGU2,&AVGU3,&AVGU4,&AVGU5,&AVGU6)
        OVERALL AVERAGE UTILIZATION FOR 26 RUNS
        ---------------------------------------

        USHER     REGII     INSP      REGI      COMPUTER   CAMERA
        -----     ------    -----     -----     --------   -------
        ***.**    ***.**    ***.**    ***.**    ***.**      ***.**
*
        DO            &I=1,&M
        LET           &SUMSQDF=&SUMSQDF+(&AVGR1-&X(&I))*(&AVGR1-&X(&I))
        ENDDO
*
        LET           &SD=SQRT(&SUMSQDF/(26-1))
        LET           &LOWLIM=&AVGR1-&TSTAT*(&SD/SQRT(26))
        LET           &UPLIM=&AVGR1+&TSTAT*(&SD/SQRT(26))
*
        PUTPIC        FILE=CARL1,LINES=6,(&SD,&LOWLIM,&UPLIM)
        CONFIDENCE INTERVAL FOR SYSTEM QUEUE
        --------------------------------------
        SD            LOWER LIMIT         UPPER LIMIT
                     FOR 99% CI          FOR 99% CI
        ----          ----------          ------------
        ***.***       ***.***              ***.***
*
        END
```

OUTPUT OF ORIGINAL FOR 25 RUNS

AVERAGE RESIDENCE TIME

REPLICATION NO:	SYSQ
1	111.666
2	117.831
3	112.414
4	111.152
5	102.621
6	118.983
7	110.151
8	123.559
9	118.636
10	114.188
11	119.913
12	105.742
13	117.496
14	121.050
15	117.050
16	114.820
17	102.135
18	91.253
19	124.890
20	108.905
21	121.185
22	102.844
23	120.841
24	125.865
25	114.516

AVERAGE RESIDENCE TIME FOR 25 RUNS

SYSQ
113.99

OVERALL AVERAGE UTILIZATION FOR 25 RUNS

USHER	REGII	INSP	REGI	COMPUTER	CAMERA	CAMER1
59.41	82.33	89.62	85.38	45.14	24.79	0.00

CONFIDENCE INTERVAL FOR SYSTEM QUEUE

SD	LOWER LIMIT FOR 95% CI	UPPER LIMIT FOR 95% CI
10.303	109.372	118.605

OUTPUT USING ANTITHETIC VARIATES FOR 26 RUNS

AVERAGE RESIDENCE TIME

REPLICATION NO:	SYSQ
1	117.497
2	141.248
3	120.536
4	121.673
5	108.718
6	117.042
7	116.168
8	91.843
9	124.944
10	124.370
11	131.972
12	110.972
13	93.419
14	111.841
15	101.407
16	106.576
17	92.182
18	129.047
19	90.797
20	102.870
21	127.260
22	76.056
23	122.803
24	98.182
25	116.175
26	127.669

AVERAGE RESIDENCE TIME FOR 26 RUNS

SYSQ
111.43

OVERALL AVERAGE UTILIZATION FOR 26 RUNS

USHER	REGII	INSP	REGI	COMPUTER	CAMERA
57.68	79.21	87.30	84.45	44.27	51.88

CONFIDENCE INTERVAL FOR SYSTEM QUEUE

SD	LOWER LIMIT FOR 99% CI	UPPER LIMIT FOR 99% CI
8.048	106.955	115.912

APPENDIX J

TOTAL COMBINATIONS DURING JULY 96 (TABLE 14) AND JULY (TABLE15)

Table 14: Total Combinations in July for Average waiting time in the system

Jul-96	COMBINATIONS (Demand\labor assignment\job flexibility)							
REPLICATION #	1\1\1	1\2\1	1\3\1	1\1\2	1\2\2	1\3\2	1\1\3	1\2\3
1	165.45	150.611	151.55	139.268	143.971	143.515	138.157	134.731
2	158.521	156.729	137.159	137.184	137.312	134.569	143.769	145.367
3	163.475	137.399	138.702	121.246	131.425	136.733	130.989	136.926
4	148.026	128.984	132.003	120.471	132.528	122.452	115.748	111.809
5	168.049	158.264	139.516	152.507	148.587	151.01	151.547	156.495
6	165.886	140.118	144.607	132.271	134.426	140.169	132.123	136.516
7	172.802	148.959	137.706	146.077	147.429	151.593	139.677	167.547
8	167.422	149.299	134.239	134.571	137.87	146.072	136.81	139.981
9	160.713	162.295	156.557	151.777	152.11	139.933	138.339	140.577
10	171.381	156.131	144.244	150.528	159.917	147.743	144.681	157.155
11	166.496	144.467	145.092	145.381	142.336	148.231	137.293	143.01
12	156.208	142.945	139.736	125.481	139.986	135.265	114.815	128.279
13	169.449	147.929	135.481	136.778	148.797	134.039	130.756	147.641
14	169.729	134.207	135.311	127.225	133.904	136.18	126.768	135.535
15	171.096	148.475	160.705	137.498	140.305	141.939	128.588	137.31
16	160.025	147.605	156.983	135.967	148.724	140.047	147.221	143.17
17	155.003	144.025	131.12	121.749	120.554	129.251	129.218	132.336
18	170.354	149.562	136.365	148.229	156.989	141.518	145.451	140.695
19	183.446	156.529	157.351	146.302	154.772	158.149	132.832	142.777
20	152.342	122.29	125.356	122.2	128.631	126.338	128.452	117.5
21	146.662	145.687	133.547	122.813	136.257	129.634	128.03	135.838
22	161.701	146.735	128.033	133.174	135.293	138.348	128.273	130.075
23	154.263	147.442	128.798	118.838	134.231	134.145	125.12	120.377
24	166.354	159.936	142.884	136.799	139.06	144.744	137.842	141.049
25	165.838	143.445	139.127	129.632	138.803	128.242	146.566	141.147
SYSQ AVERAGE	**163.6276**	**146.8027**	**140.4869**	**134.9586**	**140.9687**	**139.1944**	**134.3626**	**138.5537**

1\3\3	2\1\1	2\2\1	2\3\1	2\1\2	2\2\2
141.344	99.554	86.229	87.656	75.446	67.071
142.719	102.72	86.199	86.689	80.746	68.732
126.757	100.409	95.383	75.195	78.02	77.46
118.281	104.596	72.077	76.882	69.645	72.593
150.311	99.593	80.337	88.368	78.983	71.647
144.269	91.643	82.424	74.066	88.146	73.003
143.812	105.193	82.884	89.676	86.706	69.691
139.135	93.39	94.618	85.7	69.511	69.684
139.003	100.131	71.756	69.579	73.301	72.171
150.534	92.002	78.408	82.467	82.528	77.822
138.913	102.676	84.634	84.179	76.429	72.495
119.421	107.042	89.898	89.391	85.191	78.282
142.615	99.204	92.477	89.357	78.699	78.508
126.399	103.266	82.246	84.71	84.952	77.163
129.27	107.888	73.892	91.912	86.416	72.425
146.142	89.985	73.567	81.386	71.158	59.927
118.303	91.56	70.068	90.972	85.705	51.809
146.77	104.799	83.472	76.833	77.62	66.252
148.238	88.508	89.213	81.847	79.623	74.478
117.132	95.027	81.771	75.447	86.577	69.804
127.603	92.495	70.295	92.155	71.223	61.597
138.41	91.361	88.26	83.282	76.268	70.45
135.585	103.889	91.485	77.742	62.598	72.994
133.378	97.756	75.036	90.15	78.142	74.836
143.398	86.097	71.265	70.026	85.513	71.022
136.3097	98.03136	81.91576	83.02668	78.76584	70.87664

2\3\2	2\1\3	2\2\3	2\3\3
79.352	61.779	83.08	80.06
79.279	75.28	73.468	71.312
74.351	69.917	71.879	81.983
66.546	69.215	67.224	76.021
79.038	70.998	71.526	67.286
58.321	60.334	79.862	63.536
81.945	63.904	84.834	71.107
66.435	71.762	76.009	72.273
60.518	65.182	66.368	73.242
77.197	68.382	80.166	77.925
82.493	71.579	66.701	69.82
83.551	76.609	76.079	76.293
68.054	77.495	67.683	76.668
79.23	77.894	77.655	75.708
77.07	76.862	75.042	74.551
77.964	72.227	61.669	67.276
59.836	62.975	57.019	72.503
71.601	66.754	62.732	64.405
69.872	69.561	66.285	62.173
68.669	71.32	60.054	76.779
72.83	66.598	66.143	75.269
75.667	70.089	77.952	68.735
76.315	71.227	82.789	69.854
69.481	70.411	68.157	80.465
61.362	73.247	68.734	68.618
<u>72.67908</u>	<u>70.06404</u>	<u>71.5644</u>	<u>72.55448</u>

Table 15: **Total Combinations in January for Average waiting time in the system**

Combinations (Demand\Labor assignment\Job flexibility)

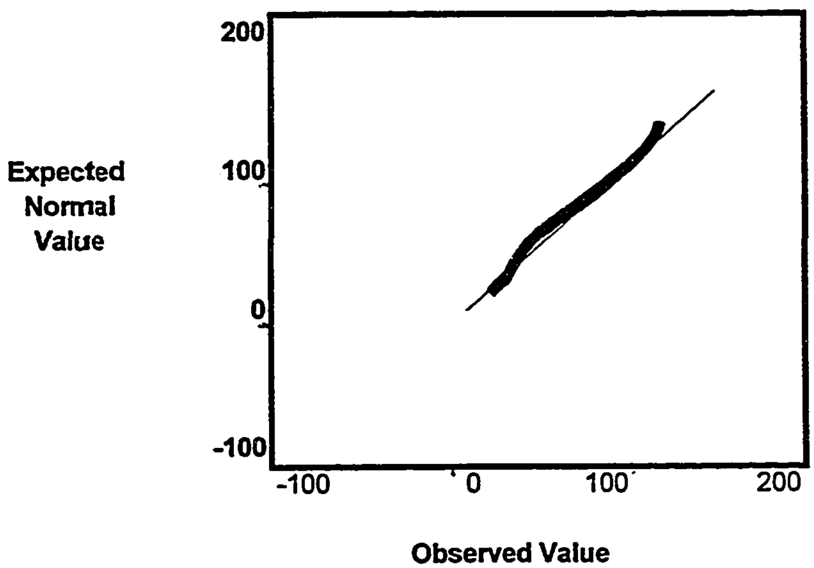
REPLICATION	1\1\1	1\2\1	1\3\1	1\1\2	1\2\2	1\3\2	1\1\3
1	111.666	99.134	91.154	104.348	76.638	83.140	85.182
2	117.831	85.902	90.291	79.511	77.293	86.670	83.681
3	112.414	82.330	90.606	87.738	84.430	74.447	57.578
4	111.152	101.759	79.345	103.895	83.661	96.589	85.624
5	102.621	77.418	85.405	90.595	77.165	81.045	72.649
6	118.983	91.122	104.603	110.889	88.498	95.509	87.470
7	110.151	81.255	85.942	114.728	67.654	81.326	89.967
8	123.559	95.580	87.313	81.999	72.343	87.599	81.256
9	118.636	103.592	94.331	103.995	92.861	93.656	98.954
10	114.188	71.286	74.812	97.006	76.826	95.733	85.119
11	119.913	93.961	101.475	86.759	86.999	81.930	87.272
12	105.742	77.604	94.254	99.681	83.859	86.234	81.256
13	117.496	81.814	98.977	100.347	80.672	90.198	95.249
14	121.050	100.388	108.726	105.883	87.617	84.844	96.615
15	117.050	90.049	107.442	106.281	92.345	98.773	81.644
16	114.820	70.060	81.919	88.568	70.510	72.337	76.845
17	102.135	81.440	87.174	92.480	84.792	69.593	59.876
18	91.253	78.755	96.953	87.132	81.085	70.615	79.541
19	124.890	98.614	102.667	104.269	83.168	95.247	93.584
20	108.905	70.975	67.876	73.125	56.372	58.605	63.829
21	121.185	101.521	116.218	102.438	98.331	95.564	109.622
22	102.844	94.506	121.380	94.953	75.108	79.522	83.527
23	120.841	98.310	98.053	109.620	87.885	101.508	92.173
24	125.865	109.996	104.070	89.212	96.942	94.909	106.406
25	114.516	99.343	107.906	106.248	95.507	99.985	116.941
Average SysQ	113.988	89.469	95.156	96.868	82.342	86.223	86.074

1\2\3	1\3\3	2\1\1	2\2\1	2\3\1	2\1\2	2\2\2	2\3\2	2\1\3
79.875	83.140	55.055	47.883	42.694	43.854	37.242	55.267	37.794
82.961	86.670	60.945	35.364	39.030	57.863	39.130	45.015	38.440
67.932	74.447	56.803	41.230	44.228	46.338	37.728	39.986	37.501
81.966	96.589	55.014	36.764	47.456	38.551	38.603	38.670	36.457
73.767	81.045	58.755	38.926	39.877	55.411	39.485	43.940	43.982
77.989	95.509	51.061	40.952	41.861	40.763	40.730	37.583	37.431
86.088	81.326	45.558	44.482	46.061	46.369	38.588	40.506	39.328
81.728	87.599	51.940	38.903	37.054	41.271	40.721	41.488	38.294
79.104	93.656	59.595	37.532	39.080	50.614	36.735	40.380	39.070
79.134	95.733	50.954	40.773	45.887	45.305	39.730	38.876	39.211
83.094	81.930	65.389	40.356	55.816	49.268	40.345	43.040	36.899
77.540	86.234	57.253	39.915	49.243	46.735	37.051	45.883	41.447
74.113	90.198	55.023	37.984	41.418	48.675	38.002	43.781	39.823
89.063	84.844	62.349	36.660	48.101	56.102	45.317	44.809	38.836
86.423	98.773	52.888	38.320	47.677	43.686	38.001	40.993	36.137
70.274	72.337	61.498	36.978	39.601	43.427	38.401	38.384	41.656
72.610	69.593	69.554	36.295	34.520	39.187	38.718	42.236	37.857
77.357	70.615	61.374	39.854	53.985	43.246	37.933	42.097	34.664
84.392	95.247	50.124	54.034	38.874	42.572	42.387	39.222	37.542
54.689	58.605	44.981	36.064	60.744	42.884	35.962	37.041	36.831
93.920	95.564	45.866	35.790	41.707	40.753	37.323	41.061	36.327
79.515	79.522	58.114	37.734	51.262	45.585	39.027	42.389	39.879
107.069	101.508	54.763	41.229	48.262	59.547	38.762	40.794	37.656
100.166	94.909	42.077	37.189	49.319	48.886	37.228	40.230	38.138
92.791	99.985	61.788	43.470	50.741	56.849	37.506	45.468	37.575
81.342	86.223	55.549	39.787	45.380	46.950	38.826	41.966	38.351

2\2\3	2\3\3	3\1\1	3\2\1	3\3\1	3\1\2	3\2\2	3\3\2
40.906	37.090	115.938	102.070	94.373	104.362	73.296	104.007
39.978	42.715	98.071	81.885	92.132	112.552	74.579	92.120
39.500	41.520	104.577	57.606	71.332	85.947	57.421	77.282
38.600	39.337	109.405	74.232	82.444	103.390	79.074	107.392
39.033	46.373	111.013	89.298	106.833	85.861	67.629	83.077
36.538	39.813	122.911	94.541	122.393	103.101	92.007	103.049
39.231	39.393	116.043	103.146	96.521	93.940	89.538	106.625
36.557	43.346	124.104	94.600	106.548	104.995	87.622	87.848
38.998	37.010	114.070	74.880	101.028	106.267	82.000	89.362
40.330	40.160	129.862	107.391	88.386	99.684	87.112	105.669
38.582	44.010	102.634	86.928	99.682	107.605	65.276	93.059
39.673	43.525	120.229	98.680	108.534	115.446	80.937	94.316
39.038	39.031	134.439	98.099	114.142	119.070	105.504	94.407
39.440	45.132	86.572	64.301	66.664	83.766	62.921	66.651
40.499	41.320	89.771	85.428	106.727	97.114	88.255	102.368
36.050	37.208	92.165	81.661	90.118	92.254	67.156	79.530
37.270	38.873	121.873	90.168	106.244	101.595	84.837	103.059
37.901	36.442	122.544	90.900	98.997	85.663	75.612	96.935
39.304	37.356	109.223	82.118	108.973	103.624	78.491	82.705
40.013	47.468	116.346	100.413	98.459	101.699	78.265	99.316
38.642	40.662	138.810	111.147	124.126	119.036	97.379	99.685
37.442	38.295	93.801	71.431	101.470	96.350	70.737	77.244
41.547	38.258	90.497	63.972	78.307	75.943	59.885	79.928
39.560	40.938	99.064	64.453	71.101	85.349	59.220	63.655
39.149	39.387	113.173	105.581	93.876	106.275	74.444	78.384
38.951	40.586	111.085	86.997	97.176	99.636	77.568	90.707

3\1\3	3\2\3	3\3\3
85.445	77.490	83.166
93.726	73.689	87.854
62.678	54.277	56.771
76.203	69.975	74.464
76.557	87.110	92.371
94.443	92.962	89.178
106.528	87.749	99.420
103.115	91.116	104.058
77.395	79.441	86.907
87.887	74.781	81.673
70.501	72.641	70.407
86.863	87.564	96.141
101.044	83.379	89.821
58.906	57.299	63.959
82.851	77.386	67.690
79.826	66.082	76.040
87.990	80.608	110.326
74.401	81.581	86.508
77.352	69.827	87.989
86.160	64.714	97.924
86.088	95.450	117.142
72.175	78.617	87.815
61.199	70.164	66.245
63.572	58.580	62.441
80.555	84.005	88.988
81.338	76.659	85.012

Testing for Normality Assumption



APPENDIX K

SIMULATION MODEL OF MOVING SERVER POLICY (LEVEL 5 OF JOB FLEXIBILITY FACTOR)

```
        SIMULATE
*       JANUARY
        REAL           &SD,&LOWLIM,&UPLIM,&AVGU3,&AVGU5,&AVGU6,_
                       &AVGR1,&TSTAT,&X(25),&R1,&R2,&SUMSQDF
        INTEGER        &I,&J,&H,&M
        LET            &M=25
        LET            &TSTAT=2.78
        LET            &J=450000
        RMULT          &J
        REALLOCATE     COM,800000
 IAT    FUNCTION       C1,D19       Customers arrival distribution in January
0,23/30,611/60,693/90,956/120,850/150,812/180,868/210,888/240,746/270,672/300,66
6/330,798/360,847/390,902/420,748/450,501
480,379/510,140/540,11
*IAT    FUNCTION       C1,D19       Customers arrival distribution in July
*0,160/30,628/60,960/90,1301/120,1062/150,996/180,1091/210,1073/240,969/270,817
*300,806/330,860/360,1098/390,1104/420,1150/450,807/480,572/510,313/540,49
*
*       STORAGE FOR JULY
*S(MOVING),25/S(INSP),22/S(COMPUTER),48
        STORAGE FOR JANUARY
 S(MOVING),21/S(INSP),20/S(COMPUTER),48
*
        GENERATE       RVEXPO(4,30/(FN(IAT)/12))
        QUEUE          SYSQ
*
        TRANSFER       .023,,HEAVY            Transfer 2.3% to heavy
        TRANSFER       .053,,TRANS            Transfer 5.3% to translator
        TRANSFER       .026,,EX               Transfer 2.6% to exit
        TRANSFER       .636,,WRI              Transfer 63.6% to written test
        TRANSFER       ,EX1                   to differentiate between various
*                                             road test customers.
EX      QUEUE          MOVEQ                  Customers wait in only one queue
        ENTER          MOVING
        DEPART         MOVEQ
        ADVANCE        0.75
        LEAVE          MOVING
        TRANSFER       ,EXIT
*ROAD TEST MODELING
 EX1    TEST LE        AC1,480,EXIT          January
*       TEST LE        AC1,440,EXIT          July
        BLET           PH(ROAD)=6            Light vehicle road test
        BLET           &R2=6.0               Service time at regII
        BLET           &H=30                 Road test time
        QUEUE          MOVEQ
        ENTER          MOVING
        DEPART         MOVEQ
        TRANSFER       ,RR
*
 HEAVY  TEST LE        AC1,480,EXIT          January
*       TEST LE        AC1,450,EXIT          July
        BLET           PH(ROAD)=10           Heavy vehicle road test
        BLET           &R2=6.0               Service time at regII
        BLET           &H=40                 Road test time
        QUEUE          MOVEQ
        ENTER          MOVING
        DEPART         MOVEQ
```

```
*
 RR       ADVANCE       &R2                         service time at regII
          LEAVE         MOVING
*
          TEST E        PH(ROAD),10,TT              testing for heavy truck drivers
          TRANSFER      .27,,EXIT                   rejection at registration
          TRANSFER      ,RR1
*
 TT       TEST E        PH(ROAD),6,CAMERA
          TRANSFER      .011,,EXIT                  1.1% rejection at registration
          TRANSFER      .041,,REJCAR                4.1% has no conditioned car
*
 RR1      QUEUE         ROAD1
          ENTER         INSP
          DEPART        ROAD1
          ADVANCE       &H                          Road test time
          LEAVE         INSP
          PRIORITY      25
*
          TEST E        PH(ROAD),10,TT1             Heavy vehicle customers
          TRANSFER      .4,,RFAIL1                  40%of HV customers failed
          BLET          PH(ROAD)=PH(ROAD)-3         HVC passed has value 7
          TRANSFER      ,TT4
*
 TT1      TRANSFER      .35,,RFAIL                  35% of LV customers failed
          BLET          PH(ROAD)=PH(ROAD)+1         LVC passed has value 7
 TT4      BLET          &R2=3.62                    Service time for passed LV&HV
          TRANSFER      ,XX1
*
 RFAIL1   BLET          PH(ROAD)=PH(ROAD)-2         HVC failed has value 8
          TRANSFER      ,TT3
*
 RFAIL    BLET          PH(ROAD)=PH(ROAD)+2         LVC failed has value 8
 TT3      BLET          &R2=1.0                     Service time for failed LV&HV
          TRANSFER      ,XX1
*
*
 REJCAR   BLET          PH(ROAD)=9                  Reject cars has value 9
          BLET          &R2=1.0                     Service time for reject cars
          PRIORITY      25
          TRANSFER      ,XX1
*
 XX1      QUEUE         MOVEQ
          ENTER         MOVING
          DEPART        MOVEQ
          ADVANCE       &R2
          LEAVE         MOVING
          TRANSFER      ,TT
*
 CAMERA   TEST E        PH(ROAD),7,EXIT             LV&HV for camera
          QUEUE         MOVEQ
          ENTER         MOVING
          DEPART        MOVEQ
          ADVANCE       3.5
          LEAVE         MOVING
          TRANSFER      ,EXIT
```

```
*WRITEN EXAM MODELING
*         TEST LE      AC1,440,EXIT          July
 WRI      TEST LE      AC1,450,EXIT          January
          TRANSFER     .17,,ACE              17% Advanced Class Customers
*
          TRANSFER     .381,,SEC             Diff b/W 1st & 2nd timers.
*
          BLET         PH(WRITE)=1           1st time written exam customers
          BLET         &R1=14.2              Registration time for WEC
          QUEUE        MOVEQ
          ENTER        MOVING
          DEPART       MOVEQ
          TRANSFER     ,WR1Q
*
 SEC      BLET         PH(WRITE)=6           2nd time WEC
          QUEUE        MOVEQ
          ENTER        MOVING
          DEPART       MOVEQ
          TRANSFER     ,BB5
*
 ACE      BLET         PH(WRITE)=2           ACE customers
          QUEUE        MOVEQ
          ENTER        MOVING
          DEPART       MOVEQ
 BB5      BLET         &R1=7.7               Registration time for ACE
*
 WR1Q     ADVANCE      &R1
          LEAVE        MOVING
*
          TEST E       PH(WRITE),7,BB6       Translator exam customers
          TRANSFER     .11,,EXIT             TEC rejection at registration
          TRANSFER     ,TEXAM                Different exam for TEC
*
 BB6      TEST E       PH(WRITE),3,BB2
          TRANSFER     ,EXIT
*
 BB2      TEST E       PH(WRITE),4,BB3
          TRANSFER     ,EXIT
*
 BB3      TEST E       PH(WRITE),5,BB4
          QUEUE        MOVEQ
          ENTER        MOVING
          DEPART       MOVEQ
          ADVANCE      3.5
          LEAVE        MOVING
          TRANSFER     ,EXIT
*
 BB4      TEST E       PH(WRITE),6,MM1       Testing for 1st WEC
          TRANSFER     .008,MM2,EXIT         Rejection of 1st WEC at reg
*
 MM1      TEST E       PH(WRITE),1,MM3       Testing for 2nd WEC
          TRANSFER     .112,MM2,EXIT         Rejection of 2nd WEC at reg
*
 MM3      TRANSFER     .230,MM2,EXIT         Rejection of ACE at reg
*
*
```

```
MM2     ENTER       COMPQ
        ENTER       COMPUTER
        LEAVE       COMPQ
        ADVANCE     30,5
        LEAVE       COMPUTER
        PRIORITY    20
*
        TEST E      PH(WRITE),1,KK               1st time WEC customers
        TRANSFER    .4,,WFAIL                    40% of WEC failed
*
        BLET        PH(WRITE)=PH(WRITE)+2        1st WE pass have a value 3
 KK1    BLET        &R1=3.62                     service time
        TRANSFER    ,VV1
*
 WFAIL  BLET        PH(WRITE)=PH(WRITE)+3        1st WE fail have a value of 4
 KK2    BLET        &R1=1.0
        TRANSFER    ,VV1
*
 KK     TEST E      PH(WRITE),6,KK3              2nd time WEC
        TRANSFER    .8,,WFAIL2                   2nd WE passed
        BLET        PH(WRITE)=PH(WRITE)-3        2nd WE passed have a value 3
        TRANSFER    ,KK1
*
 WFAIL2 BLET        PH(WRITE)=PH(WRITE)-2        2nd WE fail have a value 4
        TRANSFER    ,KK2
*
 KK3    TRANSFER    .37,,WFAIL1                  37% of AC failed
        BLET        PH(WRITE)=PH(WRITE)+3        AC passed have a value of 5
        TRANSFER    ,KK1
*
 WFAIL1 BLET        PH(WRITE)=PH(WRITE)+2        AC failed have a value of 4
        TRANSFER    ,KK2
*
 VV1    QUEUE       MOVEQ
        ENTER       MOVING
        DEPART      MOVEQ
        ADVANCE     &R1
        LEAVE       MOVING
        TRANSFER    ,BB6
*
*
 TRANS  TEST LE     AC1,480,EXIT
        BLET        PH(WRITE)=7
        BLET        &R1=11.7
        PRIORITY    10
        QUEUE       MOVEQ
        ENTER       MOVING
        DEPART      MOVEQ
        TRANSFER    ,WR1Q
*
 TEXAM  ADVANCE     30,5                         Service time for TEC(on paper)
        PRIORITY    20
*
*
        TRANSFER    .001,,WFAIL3                 Diff b/w pass&fail TEC
        BLET        PH(WRITE)=PH(WRITE)-4        Passed TEC have a value 3
        TRANSFER    ,EXIT
```

```
*
 WFAIL3  BLET          PH(WRITE)=PH(WRITE)-3    Failed TEC have a value of 4
         TRANSFER      ,KK2
*
 EXIT    DEPART        SYSQ
         TERMINATE     0
*
 January GENERATE      570
         TEST E        Q(SYSQ),0
*July    GENERATE      600
         TERMINATE     1
*
         PUTPIC        FILE=CARL2,LINES=6
         AVERAGE RESIDENCE TIME
         ----------------------

         REPLICATION NO:      SYSQ
         ----------------     ----
*
         DO            &I=1,&M
         CLEAR
         RMULT         ,,,&J+&J*&I
         START         1,NP

         PUTPIC        FILE=CARL2,LINES=1,(&I,QT(SYSQ))
           *                    ***.***
*
         LET            &AVGR1=&AVGR1+QT(SYSQ)
         LET            &X(&I)=QT(SYSQ)
         ENDDO
*
         PUTPIC        FILE=CARL2,LINES=6
         AVERAGE UTILIZATION
         -------------------

         REPLICATION NO:      INSP      COMPUTER        MOVING
         ----------------     ----      ------          ------
*
         DO            &I=1,&M
         CLEAR
         RMULT         ,,,&J+&J*&I
         START         1,NP
*
   PUTPIC
 FILE=CARL2,LINES=1,(&I,SR(INSP)/10,SR(COMPUTER)/10,SR(MOVING)/10)
           *                    ***.***     ***.***    ***.***
*
         LET            &AVGU3=&AVGU3+SR(INSP)/10
         LET            &AVGU5=&AVGU5+SR(COMPUTER)/10
         LET            &AVGU6=&AVGU6+SR(MOVING)/10
         ENDDO
*
         LET            &AVGR1=&AVGR1/25
*
*
*
```

```
 PUTPIC        FILE=CARL2,LINES=6,(&AVGR1)
 AVERAGE RESIDENCE TIME FOR 25 RUNS
 ------------------------------------

 SYSQ
 ----
 ***.**
*
 LET            &AVGU3=&AVGU3/25
 LET            &AVGU5=&AVGU5/25
 LET            &AVGU6=&AVGU6/25
*
PUTPIC        FILE=CARL2,LINES=6,(&AVGU3,&AVGU5,&AVGU6)
OVERALL AVERAGE UTILIZATION FOR 25 RUNS
----------------------------------------

INSP      COMPUTER      MOVING
----      ------        ------
***.**    ***.**        ***.**
*
DO              &I=1,&M
LET             &SUMSQDF=&SUMSQDF+(&AVGR1-&X(&I))*(&AVGR1-&X(&I))
ENDDO
*
LET             &SD=SQRT(&SUMSQDF/(25-1))
LET             &LOWLIM=&AVGR1-&TSTAT*(&SD/SQRT(25))
LET             &UPLIM=&AVGR1+&TSTAT*(&SD/SQRT(25))
*
PUTPIC          FILE=CARL2,LINES=6,(&SD,&LOWLIM,&UPLIM)
CONFIDENCE INTERVAL FOR SYSTEM QUEUE
---------------------------------------
SD            LOWER LIMIT         UPPER LIMIT
              FOR 99% CI          FOR 99% CI
----          ----------          ------------
***.***       ***.***              ***.***


END
```

APPENDIX L

OUTPUT ANALYSIS FOR FOLLOW-ON EXPERIMENT # 2 DURING THE MONTH OF JULY 1996

Table 25: Follow on # 2, July

Experimental design for demand/job flexibility policy

Level	Factor 1. Demand Management.
1	The current arrival pattern: non-stationary Poisson arrival.
2	A uniform arrival pattern.

Level	Factor 2. Management Policy
1	The current flexibility with the present assistance pattern.
2	Usher helps Reg I and camera operator helps Reg II.
3	Camera operator helps Reg I and Reg II, and usher helps Reg I.
4	Both camera operator and usher help Reg I and Reg II.
5	Moving server: all workers are pooled as general examiners at one station.

TABLE 26 OUTPUT OF MOVING SERVER POLICY IN JULY

AVERAGE RESIDENCE TIME

REPLICATION NO:	SYSQ
1	89.816
2	84.296
3	97.724
4	80.088
5	107.000
6	98.126
7	106.454
8	83.994
9	105.650
10	96.928
11	99.203
12	82.284
13	91.688
14	79.960
15	96.565
16	103.594
17	85.442
18	87.991
19	94.188
20	71.004
21	93.785
22	95.605
23	86.440
24	97.781
25	104.697

AVERAGE RESIDENCE TIME FOR 25 RUNS

SYSQ
92.81

OVERALL AVERAGE UTILIZATION FOR 25 RUNS

INSP	COMPUTER	MOVING
90.54	64.66	86.84

CONFIDENCE INTERVAL FOR SYSTEM QUEUE

SD	LOWER LIMIT FOR 99% CI	UPPER LIMIT FOR 99% CI
9.490	87.536	98.089

Table 27: Follow-on # 2, July

Two-way ANOVA for the job flexibility assignment Policy and arrival pattern (Demand)

Source		Type III Sum of Square	df	Mean Square	F	Sig.
Corrected model		328011.9	9	36445.77	580.013	0
Intercept		226268.2	1	2599071	41362.68	0
2-Way Interactions	FACTOR 1 * FACTOR 2	2895.681	4	723.92	11.521	0
Factor 1		226268.2	1	226268.2	3600.925	0
Factor 2		98848.05	4	24712.01	393.277	0
Error		15080.67	240	62.836		
Total		2942163	250			
Corrected Total		343092	249			

R-Squared= .956 (Adjusted R Squared= .954)

Table 28: Follow-on #2, July

Duncan & Scheffe Multiple Contrast Tests

	Levels	N	Means 1	2	3	4
Duncan	5	50	68.507			
	4	50		101.398		
	3	50		102.213		
	2	50			106.862	
	1	50				130.83
	Sig.		1	0.841	1	1
Scheffe	5	50	68.507			
	4	50		101.398		
	3	50		102.213	102.213	
	2	50			106.862	
	1	50				130.83
	Sig.		0.202	1	1	

Means for groups in homogeneous subsets are displayed.
Based on type III Sum Of Squares

Figure 22

Descriptive Statistics between Demand Pattern (factor 1) and Job Flexibility (factor 2)

FACTOR 1	FACTOR	Mean	STD. Deviation	N
1	1	163.627	8.302	25
	2	134.958	6.749	25
	3	134.958	14.384	25
	4	134.472	28.932	25
	5	92.812	10.712	25
	Total	**132.046**	6.068	125
2	1	98.031	11.396	25
	2	78.765	26.179	25
	3	70.064	14.105	25
	4	68.325	1.975	25
	5	44.201	12.764	25
	Total	**71.877**	24.202	125
Total	1	130.829	13.109	50
	2	106.862	1.458	50
	3	102.213	12.75	50
	4	101.398	23.645	50
	5	68.507	11.692	50
	Total	**101.962**	2.589	250

FIGURE 23: ***DEMAND PATTERN VS JOB FLEXIBILITY (JULY)***