SIMULATING WAREHOUSE COSTS:

A MICROCOMPUTER APPLICATION IN PUBLIC ADMINISTRATION

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INTRODUCTION

The concept that the human decision making process involved in public administration can be expressed as a computer based mathematical model is certainly interesting. Though it will be many years before computer based models will come close to totally simulating the complex human decisions involved in public administration, the ability presently exists, using microcomputers, to model important management science oriented aspects of public administration. The focus of this paper is centered on a practical microcomputer based model which can aid in deciding the optimal refrigerated warehouse configuration for frozen food distribution. Public administrators involved with State and Federal food distribution programs are under much pressure to control costs and to increase productivity. Perhaps the greatest strides in program effectiveness will come not from higher levels of funding but from increasing decision making process effeciency. The model to be presented serves as a useful tool for the public administrator to decide the effecient location of refrigerated warehouses needed for storage of frozen food prior to final consumption.

The decision making process in an organization can be classified as either Programmable or Nonprogrammable [1]. Programmable decisions are those decisions that occur on a regular basis and are simple in nature requiring little specialized knowlege. Often these decisions are made at the lower levels of the organization and can be prespecified as rules or procedures. It is interesting to note that Max Weber's classic study of bureaucracy, which is associated with the Closed Model of organizations, lists rules and procedures as indigenous to rational administration [2]. Perhaps he was the first to recognize programmed decision making in administration prior to the age of Management Information Systems philosophy. Examples of programmable decisions include standard methods to deal with requests for food stamps and preparation of police and fire reports.

Nonprogrammable decisions in contrast are those decisions which can not be made on a routine basis and require highly specialized knowlege. They often involve complex relationships and long time horizons. Characteristically, these decisions are made at the higher levels of the organization by those ultimately resoponsible for policy and strategic planning. From an theoretical perspective, Nonprogrammable decisions fit best into the Open Model of organizations; dealing with nonroutine tasks and unstable conditions [3]. The location of a manufacturing plant by a large corporation or the handling of an international crisis by a major world power are both excellent examples of Nonprogrammable decisions.

With the advent of microcomputers, public managers are realizing that a larger porportion of organizational decisions are programable than once thought. Microcomputers are inexpensive and easy to use. With the task orientation of spreedsheet software, many find use of the microcomputer enjoyable, fullfilling, and productive while at the same time extremely helpful in solving unstructured, ad-hoc problems. An "end user revolution" is occuring with greater numbers of people using the computer than ever before. No longer does the line manager need to depend totally on the Information Services Department for access to a mainframe computer and software programming support. Public administrators are able to apply textbook management science techniques, previously too complex to perform by hand, with the power and flexability of the microcomputer at their fingertips.

An invevitable result of the microcomputer revolution is that organizations will have increasing numbers of uncertainty absorption systems:

> Uncertainty adsorption takes place when inferences are drawn from a body of evidence and the inferences instead of the evidece itself are then communicated. The gatekeeping function performed with respect to environmental information includes deciding what and how environmental information is to be communicated to organizational decision makers [4].

Microcomputer based models serve as uncertainty adsorption systems sprinkled throughout all levels of organizations. They frame the body of evidence for decision making.

Herbert Simon states that managers make only "satisficing" decisions due to their limited scope of rationality [5]. Simon further argues that the rational model of decision making is theoretically consistant but in practice fails because it is seldom that a manager has complete knowlege of alternatives and their costs. The increased use of computer based models serves to expand the limits of bounded rationality producing better decisions.

A model can be defined as a simplified representation of the real world that includes those characteristics that the designer of the model feels are important [6]. Physics provides several sound examples of models [7]. In 1660, Robert Boyle demonstrated that the volume of a sample of gas is inversely porportional to the pressure, provided that the temperature of the gas is kept constant. Boyles law can be expressed mathematically as:

P(1) * V(1) = P(2) * V(2)

P = PRESSURE

V = VOLUME

Later, Jacques Charles (1787) determined the relationship between the volume and temperature of a gas when the pressure is kept constant:

V(1) * T(1) = V(2) * T(2)

V = VOLUME

T = TEMPERATURE

Boyles Law and Charles Law became the experimental basis for a general relation between volume, pressure and temperature known as the General Gas Law:

[P(1) * V(1)] / T(1) = [P(2) * V(2)] / T(2)

P = PRESSURE

V = VOLUME

T = TEMPERATURE

Individually, Boyle and Charles experimentally developed a simple mathematical model that expressed a particular relationship or aspect of reality which interested them; Boyle was interested in pressure and volume but not temperature while Charles was interested in volume and temperature but not pressure. But, individually, each model did not accurately express all aspects of the real world. Even today, the general gas law predicts accuratly the pressure, volume, temperature properties of a gas under normal conditions but it is not clear if this law applies under extreme temperature conditions.

Jay Forrester, a well known developer of models from MIT goes as far as to state that the basic human thought process is actually a mental image or model of the real world [8]. It is not the real world!

Models serve several purposes [9]:

1. Models help to simplify and clarify thinking.

2. Important issues are identified through the use of models.

3. Suggested explanation of events can be obtained by analysis of a model.

4. Communication is aided through the use of models.

While models may be considered as representations-that is, likeness or images-of the real world, simulations are considered imitations of it [10]. Simulations differ from models in that they contain probability distributions and elements of random variables. The mathematical formulation to be described in this paper is considered a simulation; close cousin of the model.

A PRACTICAL PROBLEM

Every year the U.S government spends large amounts of money to purchase and distribute food to needy people. The public administrator is confronted with the problem of how to achieve defined goals of the food distribution program at the least possible cost. One of the biggest cost elements of a food distribution program that must be analyzed and controlled is refrigerated storage. As an example, the U.S. Department of Agriculture must store millions of pounds of commodity cheese and butter which needs to be held under refrigerated conditions.

The availability of frozen storage is limited and the costs are high. Only 450 independent public refrigerated warehouses are listed in the United States by the International Association of Refregerated Warehouses, the main industry trade group. The majority of refrigerated warehouses are located near large metropolitian areas. With construction cost of refrigerated storage nearly $100 per square foot, as compared to approximately $35 per square foot for dry storage, the U.S Government is forced to use large, privately owned, refrigerated warehouses (termed public refrigerated warehouses). The warehouses store foods for many different manufacturers, as well as the U.S. Government, and offer a consolidated outbound distribution service.

The U.S. government realizes several advantages by using large public refrigerated warehouses. First, the huge cost of constructing a U.S. Government owned refrigerated warehouse is avoided. If budget cutbacks reduce the amount of frozen and refrigerated food to be purchased and distributed, resulting in underutilized refrigerated warehouse capacity, a substantial sunk cost is eliminated.

Second, transportation cost can be reduced. Generally, the average order size for refrigerated food is less than fifteen-thousand pounds with a large fraction of orders less than eight-thousand pounds. State and private organizations have limited space for frozen foods and tend to order small amounts frequently, forcing the U.S. Government to carry the inventory in public refrigerated warehouses. Since no LTL (less than truckload) service exists for refrigerated shipments, it becomes very costly to ship product to the needy without using the outbound distribution service that a public refrigerated warehouse offers. Since a public refrigerated warehouse handles the products of many different food manufacturers, they can consolodate small Government orders with private customer orders, saving the Federal Governemt money.

In addition, public refrigerated warehouses are closer to the final points of distribution allowing for shorter order transit time and private organization pickups.

PUBLIC FROZEN WAREHOUSE COSTS

Refrigerated warehouse costs consist of the following:

1. Handling
2. Storage
3. Inbound Transportation
4. Outbound Transportation

A HANDLING charge is assessed when finished product is shipped into a public refrigerated warehouse. It is a one time only charge to cover labor and equipment needed to move product in and out of the warehouse. The initial charge covers both in and out handling.

STORAGE is charged on a monthly basis for product that resides in the facility. Two types of billing systems dominate the refrigerated food storage industry; SPLIT MONTH and ANNIVERSARY DATE.

SPLIT MONTH billing is defined by a major public refrigerated warehouse as follows:

A storage month will be split with a full months storage applied to product received from the 1st through the 15th and 1/2 the monthly storage rate applied to product received from the 16th to the last day of the month with all rebills applied to the first of each subsequent month.

ANNIVERSARY DATE billing, in contrast to SPLIT MONTH, can be defined as follows:

All charges for storage are on a month-to-month basis. Charges for any lot shall begin upon receipt in storage of the first unit of that lot and shall continue and include the storage month during which the last unit of that lot is delivered. Storage charges shall be assessed on the maximum number of units or weight in any particular lot in store during a storage month.

INBOUND TRANSPORTATION is the responsibility of the shipper and is usually accomplished by refrigerated truck or rail car.

OUTBOUND TRANSPORTATION is performed by the public refrigerated warehouse and is charged to the shipper. Small orders are consolidated with products from other frozen food manufacturers into truckload quantities (a full truck equals approximately 40,000 pounds).

With complex billing systems and uncertain demand, it becomes difficult for the public administrator to evaluate the cost of competing public refrigerated warehouses. Furthermore, for an individual warehouse, money may be saved or lost by the Government based on the billing system employed and its relationship to the demand pattern for products stocked. To cope with this intricate problem, a simulation programmed on a microcomputer can be a valuable tool.

ASSUMPTIONS AND PARAMETERS OF THE SIMULATION

The activity to be simulated using the microcomputer is best visualized as a flow or movement of a single commodity from the manufacturer to the eventual consumer (see Figure 1). Truck load quanties (a truck load equals 40,000 pounds) of refrigerated food is purchased from a supplier and shipped to a refrigerated warehouse for storage. From the refrigerated warehouse, smaller quantities (typically less than 8000 pounds) are shipped to the final consumer. This fanning-out distribution arrangement is the most efficient method to deal with leadtimes, demand uncertainty and transportation paths. It is superior to any method of directly moving goods from the manufacturer to the final consumer. The fanning-out distribution technique is very old, dating to the first recorded commercial trade transactions.

Common to the entire distribution network (Figure 1) is the measurement of CWT (1 CWT = 100 pounds). Every leg of product flow involves CWT and all warehouse/transportation charges are on a CWT basis. The simulation of warehousing costs involves measuring CWT at different, equally spaced, time intervals and acessing the proper charges. To be consistant, all simulations will be for a three month time period. Charges at the conclusion of three months will be summed to obtain a total system cost.

A final important characteristic of simulating warehousing costs is demand uncertainty. The major simulation assumption is that the weekly demand pattern for outbound shipments from a warehouse can best be expressed as a Normal Distribution with a specific mean and standard deviation. Normal Distributions occur in a wide range of business and scientific data. It is reasonable that the behavior of numerous organizations placing small orders for refrigerated or frozen food on a central warehouse will center around a mean demand per week with a given variance. Due to technical considerations, which will be discussed later, the simulation is run fifty times and the cost of the system recorded for each run. An average of the fifty costs is taken and serves as a comparison to future simulations with different parameters.

Several parameters must be inputed into the microcomputer prior to running the simulation. These inputs include:

WAREHOUSING COSTS

- Handling ($/CWT)
- Storage ($/CWT)
- Inbound Transportation ($/CWT)
- Outbound Transportation ($/CWT)

PROBABILITY DISTRIBUTION PARAMETERS

- Mean Demand (pounds/week)
- Standard Deviation (pounds/week)

SIMULATION PARAMETERS

Re-Order Quanty (weeks supply)
Costomer Service (% level)

INVENTORY CARRYING COSTS

Cost Per Pound ($/pound)
Interest Rate (annual %)

Warehousing Costs are obtained from the public refrigerated warehouse. Quotes can usually be obtained on short notice through phone contact.

Probability Distribution Parameters deal with the demand pattern desired for the simulation. The Mean Demand corresponds to the expected average CWT per week to be shipped from the warehouse. Since the demand is considered probabilistic, a small Standard Deviation will cluster the demands, generated by the simulation, close to the mean (normally distributed) and a large Standard Deviation will generate demands more widely dispersed from the mean. Historical demand patterns for a particular geographical area serve as a valid guide in which to base the mean and Standard Deviation of the simulation.

The Simulation Parameters define the flow of product from the manufacturer, through the warehouse to the final consumer. Re-Order Quanity indicates the supply of product to be shipped from the manufacturer to the warehouse when an order is placed to re-stock the warehouse. Customer Service refers to the probability that stock will be available at the warehouse for shipment to final consumers. A Customer Service level of 99% indicates that a projected 1% of the time stock will not be available when a customer order is placed.

Finally, Inventory Carrying Cost allows for financial analysis of inventory value. As food product is purchased, an investment is made by the U.S. Government. If the purchase of food product is not made, the program administrator generally leaves money budgeted for purchases in the bank accumulating interest. The competing altenative to operating a food distribution program is the highest interest rate obtainable for zero risk investment (usually short term Treasury Notes). Thus Inventory Carrying Cost becomes the opportunity cost of holding inventory based on a predetermined Interest Rate.

In order to calculate opportunity cost, the value of the inventory (price/lb) must be inputed into the simulation. The calculation is as follows:

Opportunity Cost = Interest Rate x Cost/lb x Inventory Level

(NOTE: Inventory Level calculated by the simulation)

Used as an indicator of the effectiveness of budgeted funds expenditure, Opportunity Cost indicates the velocity at which food product (in dollar terms) moves through the distribution network. For the three month simulation, a low total Inventory Carrying Cost reflects rapid movement of food product from the manufacturer to the final consumer while a high inventory carrying cost reflects slow movement of food product through the network. High Inventory carrying costs mean the U.S. Government is not making the best use of money budgeted for a program goal.

APPLICATIONS OF THE SIMULATION

Often the billing system used at a public refrigerated warehouse is an open issue for negotiation. The problem arises as to which billing system results in the least cost option. Microcomputer simulation offers a quick solution to this problem.

For the same set of rates ($0.65/cwt for handling, $0.42/cwt for storage, $3.01/cwt inbound transportation and $3.37/cwt outbound transportation [11]) and the same parameters[12] a simulation was run on SPLIT MONTH billing and ANNIVERSARY DATE billing basis. In examining total system cost for the the two billing methods, ANNIVERSARY DATE billing results in a total three month cost of $95,793 while SPLIT MONTH billing results in a total three month cost of $96,022. A difference of $229 exists between the two billing systems. On an annual basis, a warehouse using SPLIT MONTH billing would charge $916 more than warehouses using ANNIVERSARY DATE billing for the identical amount of product stored. Keeping in mind that the simulation is for only a single commodity, it is quite possible that large sums of money could be saved in multiple commodity distribution operations. Clearly, given a choice, it would be best to negotiate ANNIVERSARY DATE billing rather than Split Month billing for a given set of rates. This fine difference in costing systems would go unnoticed without applying microcomputer simulation.

Another interesting aspect is that the annual turns[13] for ANNIVERSARY DATE billing can be lower than turns on a SPLIT MONTH basis and still have a lower system cost. The following data was obtained from the identical simulation as above except the Re-Order quantity for ANNIVERSARY DATE billing was increased slightly resulting in a lower turn rate (see Figure 2):

	SYSTEM COST	TURN RATE
ANNIVERSARY	$90,187	16.4
SPLIT MONTH	$85,985	16.3

In spite of a lower turn rate, ANNIVERSARY DATE billing results in the least cost option dispelling the notion that high turn rates through a warehouse always decreases total costs. This is important because it has been widely thought that the greater the turns through a warehouse the better. As proven by the simulation this is not always true. If a public administrator were to rely on turn rate as a sole indicator of productivity, it may be misleading.

The reason SPLIT MONTH billing results in higher total cost, even though the turn rate is high, is clarified through examination of the simulation. If product moves into the public refrigerated warehouse at the end of the month, one-half month storage is accessed. Since the product will partially remain in inventory at the beginning of the next month, a full months storage is applied in the form of a rebill. The total storage charged is much higher than if ANNIVERSARY DATE billing is used, with month to month billing.

Though SPLIT MONTH billing generally seems to be more expensive that ANNIVERSARY DATE billing there is some evidence that under extreme circumstances SPLIT MONTH billing can be the lowest cost system (see Figure 3). With all other parameters held constant, the Re-Order quantity was increased from one to six weeks supply by increments of one week supply. At lower Re-Order quantities ANNIVERSARY DATE billing results in lower system costs but at higher Re-Order quantities (4 weeks supply and greater) SPLIT MONTH billing becomes the least cost system.

High Re-Order quantities, above 4 weeks supply, produce a drastic number of rebills under ANNIVERSARY DATE billing system. Again, without the help of simulation this relationship could not be quantified.

An additional aspect of great importance is the link between system cost and service level (see Figure 4). As Customer Service is reduced, the system cost decreases at a non linear rate. The costs of ensuring virtually zero stockouts (99.99% Customer Service) are very great compared to a lower level of Customer Service. By using this graph, the public administrator can determine the system cost of different Customer Service level alternatives. Policy making is thus quantified to a much higher degree than is possible with qualitative appraisals of Customer Service.

A final application of the simulation involves evaluation of two competing public frozen warehouses serving the same distribution area.

If a public administrator has to determine the cheapest way to distribute product manufactured in Erie, Pennsylvania to final destinations in densely populated Eastern metropolitian areas, where should the warehouse be located to store the goods (see Figure 5)? Common sense dictates that the cheapest alternative would be a location close to populated areas but it is often difficult to evaluate quotes from several different warehouses with different locations and billing systems. For example, two candidate warehouses list their charges in terms of cost per CWT for serving a major Eastern metropolitian area [14]:

	ALTERNATIVE 1 SYRACUSE, N.Y.	ALTERNATIVE 2 SECAUCUS, N.J.
HANDLING	.70	.86
STORAGE	.40	.60
INBOUND	1.57	2.19
OUTBOUND	3.55	3.29
BILLING SYSTEM	SPLIT MONTH	ANNIVERSITY

Which is the least cost location? Even though Syracuse has a lower Storage/Handling rate than Secaucus, which is located only a few miles outside New York City (a high priced labor area), billing is on a split month basis. Inbound transportation, as expected, is cheaper between Erie and Syracuse but outbound transportation is cheaper from Secaucus.

To answer this question a simulation, as defined earlier, was run to determine the least cost alternative. The results indicate that for a three month period, total cost equals $80,227 for Syracuse and $100,470 for Secaucus. By using Syracuse, rather than Secaucus, $20,193 can be saved during the three month period.

In conclusion, the evidence presented in this paper provides strong support that microcomputer simulation can be a very productive tool in the hands of a public administrator. Unstructured, complex, Nonprogrammable problems, such as the intricate issues of warehouse location and billing systems, can be analyzed and rationalized much more completely by using simulation techniques and the power of the microcomputer. The ultimate benefit to the public administrator is a superior decision making process.

TECHNICLE ASPECTS OF THE SIMULATION

The simulation described in this paper was developed based on ideas and experience gained by observing the TDP refrigerated warehousing system operated by Welch Foods Inc. Reasearch began in June, 1986 and involved numerous experiments culminating in the development of the final simulation. It is the opinion of the author, based on personal review of journals and conversations with others involved in warehousing, that the approach to simulating total cost resulting from various refrigerated warehouse billing systems is original and not previously documented.

An IBM-AT was the main hardware used for operation of the simulation although the simulation will run on an IBM-PC but at a much slower rate. Symphony (Lotus Development Corporation) was the sole software utilized. All aspects of the simulation are contained within a single spreadsheet, reducing complexity. The simulation is sized such that it can easily be saved on a floppy disk (a sample is enclosed).

The first step in simulating warehouse costs is to develop a method of generating patterns of weekly demand based on a predetermined probability distribution. Since warehouse charges are on a per CWT basis, demand is expressed in terms of pounds per week rather than the usual stockkeeping unit of cases of product per week.

Because demand is uncertain, it would be useless to design a simulation based on average demand per week. A better approach is to treat demand as probabilistic and use a monte carlo simulation to generate weekly demand. By using this technique, the weekly demands will more closely reflect actual week to week fluctuations in demand experienced through a warehouse. The option exists to increase or decrease the standard deviation utilized by the simulation so that the spread of data can be opened or closed in relation to the mean. If, for some reason, a uniform weekly demand is desired, the standard deviation can be adjusted to zero and the mean would appear as the weekly demand for the duration of the simulation (12 weeks).

One of Symphony's best kept secrets is that it is actually simple to design a spreadsheet for a monte carlo simulation.

The essential aspect of monte carlo simulation is calculating random numbers for use in a function that will generate variates based on a desired probability distribution. As mentioned previously, the Normal Distribution was selected as a suitable approximation of weekly demands expected to be placed on a warehouse. The Normal Distribution, however, is a continuous function expressed as:

$$f(x) = 1/\sqrt{2\pi}\,\sigma \cdot e^{-(x-\mu^2)/2\pi^2}$$

σ = standard deviation

μ = mean

X = continuous random variable

for $-\infty < x < \infty$

In order to develop a cumulative probability distribution from the above function integration has to be performed.

$$F(a) = \int_{-\infty}^{a} \left(\frac{1}{\sqrt{2\pi}\,\sigma}\right) e^{-(x-\mu)^2/2\sigma^2}$$

Evaluation of this "intractable" intregral is oftened performed by computer employing a FORTRAN program. The estimated areas for numerous intervals are summed together and a cumulative distribution plotted.

As a shortcut to this procedure, a method which assumes the acceptability of a discrete approximation to the Normal Distribution was attempted. This technique fit well into spreadsheet programming and a cumulative probability distribution was developed, but the procedure offered only marginal statistical significance when a Chi-square test was performed on the output generated by a monte carlo simulation of the cumulative probability distribution.

A more acceptable alternative proved to be the Log and Trig Method of generating Z values which is considered very exact. The formula is expressed as [15]:

$$Z = [-2 * \ln(U(1))]^{1/2} * \cos(2 * \pi * U(2))$$

U(1) & U(2) are independent, uniformly distributed random variables

As a value of Z is generated it is translated into product demand using the following relation:

$$Z = (X - \mu)/\sigma$$

Solving for X:

$$X = \mu + \sigma Z$$

The values for mean and standard deviation are stipulated as part of the input to the simulation. Thus X represents demand, in terms of pounds per week, generated from a Normal Distribution specified by inputed mean and standard deviation values.

Columns 1 & 2 of Figure 2 (printout of actual spreadsheet simulation) represent U(1) and U(2). The @RAND function of Symphony was used to generate random numbers. Column 3 represents the calculation of Z by a cell entry of the Log and Trig formula. Demand, which appears in column 6, is calculated again by a cell formula that references the inputed mean and standard deviation as well as the calculated Z value. It should be noted that the demand appearing in the upper half of Figure 2 (SPLIT MONTH billing) matches the demand in the lower half of Figure 2 (ANNIVERSARY DATE billing). The common demand patterns were used so that a fair comparison of the two billing systems can be made for each simulation run.

Now that probabilistic demand has been established, the flow of finished product through the warehouse on a weekly basis can be simulated, for a three month time period, by subtracting weekly demand from inventory to arrive at a balance. The balance is compared to the reorder point. If the balance is less than the reorder point, the reorder quantity is added into the following week (leadtime = 1 week; constant for the entire three month period). A two week supply of inventory is assumed to begin the model (Week 1, Month A--Column 5). Symbolically, the above can be represented as:

INV(n) - DEMAND (n) = BALANCE(n)

IF BALANCE < REORDER POINT, THEN REORDER QUANITY + INV(n+1)

IF BALANCE > R.P., THEN 0 + INV(n+1)

NOTE: n IS EQUAL TO THE FIRST WEEK OF THE SIMULATION

The reorder point is calculated using a standard safety stock formula which incorporates service level. Please note the following:

R.P. = (u)(t) + S.S.

R.P. = Reorder Point

(u) = demand per week

(t) = leadtime

S.S. = Safety Stock = $K * \sigma$

Since the leadtime is one week, the first part of the above formula is equal to the average demand per week as inputed into the simulation. The amount of safety stock is dependent on the desired service level (service level corresponds to various K factors [16]). Re-Order quantities are designated as part of the simulation input.

As an example of the weekly replenishment cycle, in the upper half of Figure 2 the demand for week 1 of month A (62,059--Column 6) is subtracted from the beginning inventory (200,000--Column 5), equaling a balance (137,941--Column 7). Since the balance is less than the reorder point (137,941--Column 7 is less than 169,900--Column 8), the reorder quantity is 200,000. The reOrder quantity is added to week 2 of month A (Column 5). In week 2 of month A the balance is greater than the Re-Order point trigering an order quantity of 0 (Column 9) to be added to the begining inventory of week 3 of month A. The cycle continues for the 12 week period.

Costs per week are calculated based on the defined billing system stipulations. For SPLIT MONTH billing, upper half of Figure 2, handling is charged as finished product is moved into the warehouse (Column 10). Storage is also accessed when the product is moved into the warehouse (Column 11). If the product moves into the warehouse between the 1st and 15th of the month, a full month's storage is applied. If product enters the warehouse between the 15th and the 30th, 1/2 month's storage is charged. Inbound and outbound charges are recorded as product moves in and out of the warehouse (Colums 13 & 14). Total cost and annual turn rate appears at the conclusion of the 12 week period.

ANNIVERSARY DATE billing is a slightly different situation. If finished product moves into the warehouse on the 15th of the month, billing for 1 month's storage applies to the following month on the 15th. Any inventory remaining past the 15th is rebilled for an additional months storage. Handling, Inbound & Outbound Transportation are calculated the same as the split month example.

Refering to the bottom half of Figure 2, product is charged one month storage (Column 1) as it moves into the warehouse. If the product does not turn from inventory in the course of a month, a rebill is charged equal to 1 months storage on the remaining quantity. The quantity to be rebilled is calculated by subtracting the most recent 4 weeks of demand from the inventory level recorded one month previous. If this calculation is negative, the product has turned from inventory. If it is positive, demand has not been high enough to turn the product from inventory in one months time and a rebill needs to be applied to the quantity remaining.

Column 15 contains the calculation of Inventory Carrying Costs. The formula employed is:

Inventory Carrying Cost = Interest Rate x Cost Per Pound x Inventory Level

Both Interest Rate and Cost Per Pound are inputed values. Inventory Level is referenced from Column 5 and represents the beginning of the week inventory for each of the 12 weeks included in the simulation.

The simulation for both billing systems was run fifty times with the help of a Macro Key Stroke [17]. The results of the fifty simulation runs were captured and recorded automatically. An average system cost for each billing type is calculated from the fifty runs and serves as the primary basis of comparison. Other descriptive statistics, appearing in Figure 6, were also calculated for potential future analysis and to highlight differences between the total costs of the two billing systems.

In order to check the validity of the simulation, 200 variates (mean = 100,000 pounds and standard deviation = 30,000 pounds) were generated using the Log and Trig formula and a Chi-square test was perfromed comparing the observed output of the formula to the expected output (see Figure 7). The results indicate output of the Log and Trig formula is distributed normally (alpha = .05). There has been some speculation that the pseudorandom numbers generated by the

IBM-AT are not uniformly distributed. Evidence presented would indicated that this is not a problem.

Finally, a great, fertile potential exists for further research regarding the simulation presented in this paper. It would be extremely interesting to examine the behavior of the two billing systems using different probability distributions; such as the Logrithmic of Poisson distributions. Perhaps a discrete probability distribution would more closely approximate the demand placed on a warehouse by a food distribution program for the poor.

NOTES

[1] Davis, Gordon, B., and Margrethe H. Olsen, MANAGEMENT INFORMATION SYSTEMS, McGraw-Hill, Inc. (1985), Page 168.

[2] Henry,Nicholas, H., PUBLIC ADMINISTRATION AND PUBLIC AFFAIRS, Prentice-Hall, Inc. (1980), Page 63.

[3] Ibid Page 69.

[4] Miles,Robert, H., MACRO ORGANIZATIONAL BEHAVIOR, Scott, Foresman and Company (1980), Page 199.

[5] Henry,Nicholas, H., PUBLIC ADMINISTRATION AND PUBLIC AFFAIRS, Prentice-Hall, Inc. (1980), Page 104.

[6] GH-501 PUBLIC POLICY PROCESS, Gannon University, Dr. Reinhard (Lecture Notes).

[7] Shortley, George, and Dudley Williams, ELEMENTS OF PHYSICS, Prentice-Hall,Inc. (1971), Page 337.

[8] Forrester, Jay, W., URBAN DYNAMICS, The M.I.T. Press (1969), Page 113.

[9] GH-501 PUBLIC POLICY PROCESS, Gannon University, Dr. Reinhard (Lecture Notes).

[10] THE PRACTICE OF LOCAL GOVERNMENT PLANNING, Published by the International City Management Association (1979), Page 104.

[11] Actual rates for a Kansas City refrigerated warehouse supplying the midwest. Frozen product is shipped into the warehouse from Lawton, Michigan.

[12] The Probability Distribution Parameters, Simulation Parameters and Inventory Carrying Costs remain constant, unless otherwise noted, for all simulations addressed by this paper. The default values are as follows:

PROBABILITY DISTRIBUTION PARAMETERS

Mean Demand = 100,000 lbs/week

Standard Deviation = 30,000 lbs/week

SIMULATION PARAMETERS

Re-Order Quantity = 2 weeks supply

Customer Service = 99%

INVENTORY CARRYING COSTS

Cost Per Pound = $0.50/LB

Interest Rate = 6%

[13] Annulized turns is defined as:

Annual Turn Rate = Total Throughput / Average Inventory,

Annual Turn Rate is a measure of the velocity of product movement through a warehouse. It is a very popular method of performance mersurement used throughout the warehousing industry.

[14] The geographical areas to be served include: New England, New York State, Philadelphia, Scranton, Delaware, Marland and Virginia.

[15] Mihram, G., Arther, SIMULATION: STATISTICAL FOUNDATIONS AND METHODOLOGY, Academic Press, Inc (1972), Page 130.

[16] Krupp, James, A., EFFECTIVE SAFETY STOCK PLANNING, Production and Inventory Management, Vol 23, Number 3 (1982), Page 35.

[17] Macro key strokes is a powerful command langue particular only to Symphony.

FIGURE 1

DISTRIBUTION NETWORK

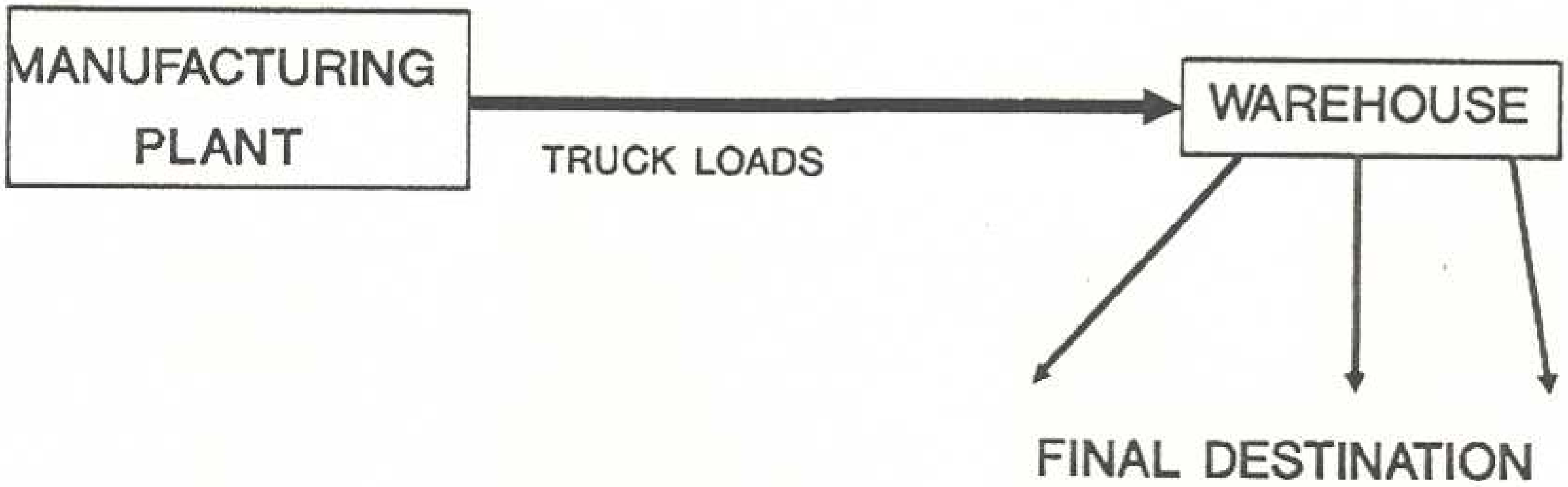

FIGURE 2

SPLIT MONTH BILLING

COLUMN #	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
				SPLIT MONTH BILLING						WAREHOUSE COSTS			TRANSPORTATION COSTS		
	U(1)	U(2)	Z	WEEK	INV	DEMAND	BALANCE	R.P.	QUANTITY	HANDLING	STORAGE		INBOUND	OUTBOUND	INVENTORY CARRYING COSTS
	0.4108	0.4485	-1.2647	1A	200000	62059	137941	169900	200000	$1,300	$1,680		$6,020	$2,091	$115
	0.8235	0.4309	-0.5653	2A	337941	83041	254900	169900	0	$0	$0		$0	$2,798	$195
	0.4359	0.6206	-0.9362	3A	254900	71913	182987	169900	0	$0	$0		$0	$2,423	$147
	0.5824	0.1004	0.8395	4A	182987	125186	57800	169900	200000	$1,300	$420		$6,020	$4,219	$106
	0.9114	0.6525	-0.2476	1B	257800	92572	165228	169900	200000	$1,300	$1,923		$6,020	$3,120	$149
	0.5828	0.8934	0.8148	2B	365228	124445	240783	169900	0	$0	$0		$0	$4,194	$211
	0.5603	0.3245	-0.4855	3B	240783	85434	155349	169900	200000	$1,300	$420		$6,020	$2,879	$139
	0.6468	0.1986	0.2960	4B	355349	108880	246469	169900	0	$0	$0		$0	$3,669	$205
	0.9466	0.8806	0.2423	1C	246469	107269	139200	169900	200000	$1,300	$1,875		$6,020	$3,615	$142
	0.2802	0.4237	-1.4151	2C	339200	57548	281652	169900	0	$0	$0		$0	$1,939	$196
	0.5347	0.4711	-1.1006	3C	281652	66982	214670	169900	0	$0	$0		$0	$2,257	$162
	0.3210	0.8728	1.0512	4C	214670	131536	83134	169900	200000	$1,300	$420		$6,020	$4,433	$124
				TOTAL DEMAND		1116866		TOTAL	1200000 LBS	$7,800	$6,738		$36,120	$37,638	$1,891

TOTAL COST FOR 3 MONTH SIMULATION $90,187
****

ANNUAL TURNS PER YEAR 16.4
***

ANNIVERSARY MONTH BILLING

COLUMN #	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
				ANNIVERSARY MONTH BILLING						WAREHOUSE COSTS			TRANSPORTATION COSTS		
				WEEK	INV	DEMAND	BALANCE	R.P.	QUANTITY	HANDLING	STORAGE	REBILL	INBOUND	OUTBOUND	INVENTORY CARRYING COSTS
				1A	200000	62059	137941	169900	220000	$1,430	$1,764		$6,622	$2,091	$115
				2A	357941	83041	274900	169900	0	$0	$0		$0	$2,798	$207
				3A	274900	71913	202987	169900	0	$0	$0		$0	$2,423	$159
				4A	202987	125186	77800	169900	220000	$1,430	$924		$6,622	$4,219	$117
				1B	297800	92572	205228	169900	0	$0	$0	$327	$0	$3,120	$172
				2B	205228	124445	80783	169900	220000	$1,430	$924	$0	$6,622	$4,194	$118
				3B	300783	85434	215349	169900	0	$0	$0	$0	$0	$2,879	$174
				4B	215349	108880	106469	169900	220000	$1,430	$924	$0	$6,622	$3,669	$124
				1C	326469	107269	219200	169900	0	$0	$0	$0	$0	$3,615	$188
				2C	219200	57548	161652	169900	220000	$1,430	$924	$0	$6,622	$1,939	$126
				3C	381652	66982	314670	169900	0	$0	$0	$0	$0	$2,257	$220
				4C	314670	131536	183134	169900	0	$0	$0	$398	$0	$4,433	$182
				TOTAL DEMAND		1116866		TOTAL	1100000 LBS	$7,150	$5,460	$724	$33,110	$37,638	$1,902

TOTAL COST FOR 3 MONTH SIMULATION $85,985
****

ANNUAL TURNS PER YEAR 16.3
***

FIGURE 3

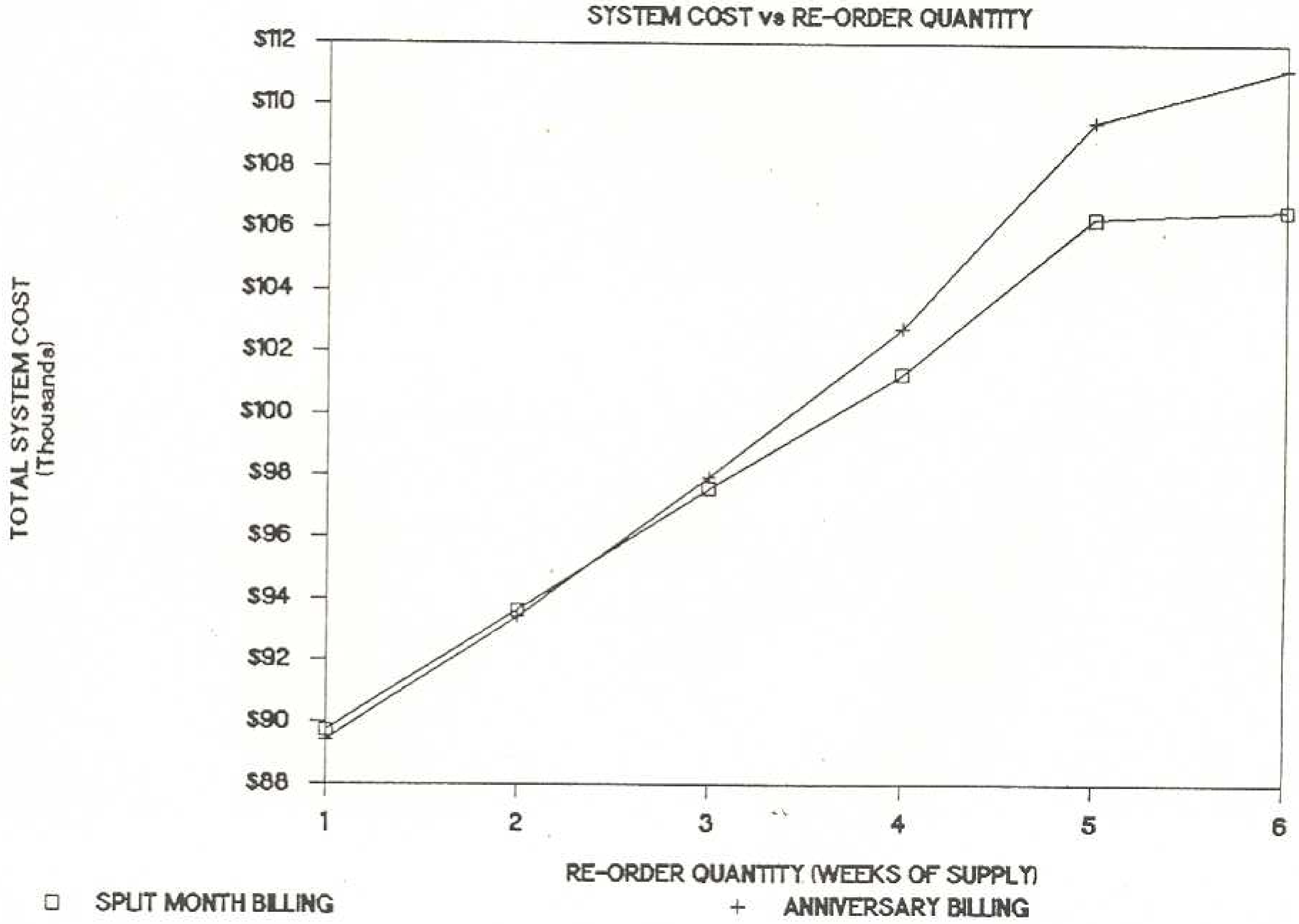
SYSTEM COST vs RE-ORDER QUANTITY
TOTAL SYSTEM COST
(Thousands)
$112
$110
$108
$106
$104
$102
$100
$98
$96
$94
$92
$90
$88
1
2
3
4
5
6
RE-ORDER QUANTITY (WEEKS OF SUPPLY)
□ SPLIT MONTH BILLING
+ ANNIVERSARY BILLING

FIGURE 4

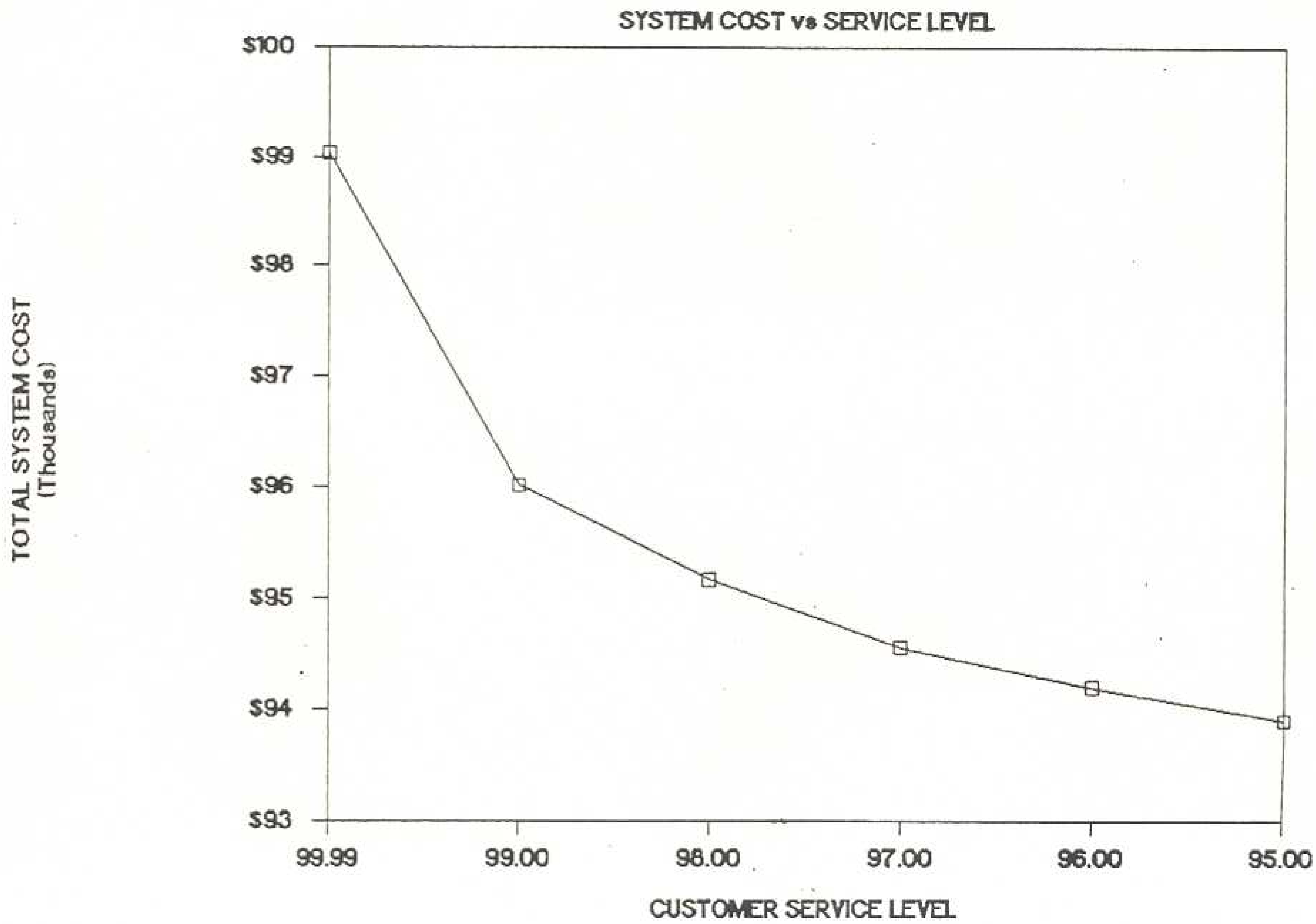
SYSTEM COST vs SERVICE LEVEL
TOTAL SYSTEM COST
(Thousands)
$100
$99
$98
$97
$96
$95
$94
$93
99.99
99.00
98.00
97.00
96.00
95.00
CUSTOMER SERVICE LEVEL

FIGURE 5
COMPETING ALTERNATIVES
WAREHOUSE LOCATION

ORIGIN	STORAGE	DESTINATION
ERIE, PA. (ALT 1)	SYRACUSE	NEW YORK CITY
ERIE, PA. (ALT 2)	NEW YORK CITY	NEW YORK CITY

FIGURE 6
DESCRIPTIVE STATISTICS

- COUNT
- AVERAGE
- STANDARD DEVIATION
- COEFFICIENT OF VARIATION
- MAXIMUM
- MINIMUM
- RANGE

FIGURE 7

OBSERVED

INTERVAL: LOW	HIGH	BIN	FREQ	PROB	PER 100	f(o)
		0	0			
0	10000	10000	0	0.0000	0.0000	0.0000
10000	20000	20000	1	0.0050	0.5000	0.5000
20000	30000	30000	0	0.0000	0.0000	0.0000
30000	40000	40000	5	0.0250	2.5000	2.5000
40000	50000	50000	4	0.0200	2.0000	2.0000
50000	60000	60000	11	0.0550	5.5000	5.5000
60000	70000	70000	17	0.0850	8.5000	8.5000
70000	80000	80000	21	0.1050	10.5000	10.5000
80000	90000	90000	22	0.1100	11.0000	11.0000
90000	100000	100000	20	0.1000	10.0000	10.0000
100000	110000	110000	25	0.1250	12.5000	12.5000
110000	120000	120000	21	0.1050	10.5000	10.5000
120000	130000	130000	21	0.1050	10.5000	10.5000
130000	140000	140000	13	0.0650	6.5000	6.5000
140000	150000	150000	9	0.0450	4.5000	4.5000
150000	160000	160000	3	0.0150	1.5000	1.5000
160000	170000	170000	4	0.0200	2.0000	2.0000
170000	180000	180000	1	0.0050	0.5000	0.5000
180000	190000	190000	1	0.0050	0.5000	0.5000
190000	200000	200000	1	0.0050	0.5000	0.5000
			0			

EXPECTED

INTERVAL: LOW (Z)	HIGH (Z)	LOW P	HIGH P	DIFF	PER 100	f(e)
-3.3	-3.0	0.5000	0.4987	0.0013	0.1300	0.1300
-3.0	-2.7	0.4987	0.4965	0.0022	0.2200	0.2200
-2.7	-2.3	0.4965	0.4893	0.0072	0.7200	0.7200
-2.3	-2.0	0.4893	0.4772	0.0121	1.2100	1.2100
-2.0	-1.7	0.4772	0.4554	0.0218	2.1800	2.1800
-1.7	-1.3	0.4554	0.4032	0.0522	5.2200	5.2200
-1.3	-1.0	0.4032	0.3414	0.0618	6.1800	6.1800
-1.0	-0.7	0.3414	0.2580	0.0834	8.3400	8.3400
-0.7	-0.3	0.2580	0.1179	0.1401	14.0100	14.0100
-0.3	0.0	0.1179	0.0000	0.1179	11.7900	11.7900
0.0	0.3	0.0000	0.1179	0.1179	11.7900	11.7900
0.3	0.7	0.1179	0.2580	0.1401	14.0100	14.0100
0.7	1.0	0.2580	0.3413	0.0833	8.3300	8.3300
1.0	1.3	0.3413	0.4023	0.0610	6.1000	6.1000
1.3	1.7	0.4023	0.4554	0.0531	5.3100	5.3100
1.7	2.0	0.4554	0.4772	0.0218	2.1800	2.1800
2.0	2.3	0.4772	0.4893	0.0121	1.2100	1.2100
2.3	2.7	0.4893	0.4965	0.0072	0.7200	0.7200
2.7	3.0	0.4965	0.4987	0.0022	0.2200	0.2200
3.0	3.3	0.4987	0.5000	0.0013	0.1300	0.1300

INTERVAL: LOW	HIGH	f(o)	f(e)	f(o)-f(e)	[f(o)-f(e)]^2	[f(o)-f(e)]^2/f(e)
0	10000	0.0000	0.1300	-0.1300	0.0169	0.1300
10000	20000	0.5000	0.2200	0.2800	0.0784	0.3564
20000	30000	0.0000	0.7200	-0.7200	0.5184	0.7200
30000	40000	2.5000	1.2100	1.2900	1.6641	1.3753
40000	50000	2.0000	2.1800	-0.1800	0.0324	0.0149
50000	60000	5.5000	5.2200	0.2800	0.0784	0.0150
60000	70000	8.5000	6.1800	2.3200	5.3824	0.8709
70000	80000	10.5000	8.3400	2.1600	4.6656	0.5594
80000	90000	11.0000	14.0100	-3.0100	9.0601	0.6467
90000	100000	10.0000	11.7900	-1.7900	3.2041	0.2718
100000	110000	12.5000	11.7900	0.7100	0.5041	0.0428
110000	120000	10.5000	14.0100	-3.5100	12.3201	0.8794
120000	130000	10.5000	8.3300	2.1700	4.7089	0.5653
130000	140000	6.5000	6.1000	0.4000	0.1600	0.0262
140000	150000	4.5000	5.3100	-0.8100	0.6561	0.1236
150000	160000	1.5000	2.1800	-0.6800	0.4624	0.2121
160000	170000	2.0000	1.2100	0.7900	0.6241	0.5158
170000	180000	0.5000	0.7200	-0.2200	0.0484	0.0672
180000	190000	0.5000	0.2200	0.2800	0.0784	0.3564
190000	200000	0.5000	0.1300	0.3700	0.1369	1.0531

CHI-SQUARE 8.8021

AT 19 d.f., ALPHA = .05; 30.144