SIMULATING WAREHOUSE COSTS: A SPREADSHEET APPLICATION

TONY CANELLA
ED SCHUSTER
Welch Foods Inc., Westfield, NY 14787

The activity to be simulated is best visualized as a pull distribution system with flow of a single commodity originating from the manufacturer, moving through a forward refrigerated warehouse, to the eventual consumer. Products that require low temperature storage often have high distribution costs due to the expense of refrigerated warehouse operation and refrigerated transportation. For this reason the simulation presented has great application in the refrigerated foods or pharmaceutical industries where distribution cost is a main consideration and must be aggressively controlled.

Truckload quantities of product are shipped to a refrigerated warehouse for storage, while smaller quantities of product are shipped from the refrigerated warehouse to final consumers. This fanning-out distribution arrangement is an efficient method to deal with small customer orders, production lead times, and demand uncertainty.

Common to the entire distribution network is the CWT unit of measure (1 CWT = 100 lb). 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 equally spaced time intervals and assessing the proper charges.

A final characteristic of simulating warehousing costs is demand uncertainty. The major simulation assumption is that weekly demand patterns for outbound shipments from a forward refrigerated warehouse can be expressed as a normal distribution. It is reasonable that the aggregate demand behavior of numerous customers placing small orders on a central refrigerated warehouse will approximate a normal distribution with a stationary mean and variance.

PUBLIC REFRIGERATED WAREHOUSE COSTS

Refrigerated warehouse costs consist of the following:

- Handling
- Storage
- Inbound transportation
- 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.

STORAGE is charged on a monthly basis for product that resides in the facility. Two types of billing systems dominate the refrigerated 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 ½ 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 manufacturers into truckload quantities.

With complex billing systems and uncertain demand, it becomes difficult to evaluate the cost of competing public refrigerated warehouses. To cope with this intricate problem, a simulation programmed on a microcomputer can be a valuable tool.

PARAMETERS OF THE SIMULATION

Several parameters must be inputted into the microcomputer prior to running the simulation, including:

Warehousing Costs
- Handling ($/CWT)
- Storage ($/CWT)
- Inbound transportation ($/CWT)
- Outbound transportation ($/CWT)

Probability Distribution Parameters
- Mean demand (lb/wk)
- Standard deviation (lb/wk)

Simulation Parameters
- Reorder quantity (weeks supply)
- Customer service (% level)

Inventory Carrying Costs
- Cost per pound ($/lb)
- Carrying cost (annual %)

Warehousing Costs are obtained directly 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 demand is considered probabilistic, a small standard deviation will cluster demands, generated by the simulation, close to the mean, while a large standard deviation will result in demands widely dispersed from the mean. Historical demand data for a particular geographical area serve as a valid guide on which to base the mean and standard deviation.

Simulation parameters define the flow rate of product from the manufacturer through the refrigerated warehouse to the final consumer. Reorder quantity indicates the supply of product to be shipped from the manufacturer to the warehouse when an order is placed to restock the warehouse. Customer service refers to the probability that stock will be available at the warehouse for shipment to final consumers.

Finally, *Inventory Carrying Cost* allows for financial analysis of inventory value based on the estimated cost per pound and established carrying cost.

APPLICATIONS OF THE SIMULATION

Though there are numerous uses for the simulation: one powerful application involves cost evaluation of competing public refrigerated warehouses serving the same distribution area. There are frequent real situations which are complicated by such compexities as bimodal or multi-commodity problems, or dynamic data which is cyclical or trended. The example used in this article to demonstrate the technique is an extremely simple one which is actually steady state and hence subject to a closed form solution; the direction of the answer is even evident from inspection.

If an analyst has to determine the cheapest way to distribute product manufactured in Erie, Pennsylvania, to final destinations in Eastern metropolitan areas, where should the refrigerated warehouse be located to store the goods? Common sense dictates that the cheapest alternative would be a location close to population centers, but it is often difficult to evaluate quotes from several warehouses with different locations and billing systems. For example, two candidate warehouses list their charges for serving an 11-state Eastern metropolitan area from Erie, Pennsylvania:

	Alternative 1 Syracuse, NY	Alternative 2 Secaucus, NJ
HANDLING	0.70/CWT	0.86/CWT
STORAGE	0.40/CWT	0.60/CWT
INBOUND	1.57/CWT	2.19/CWT
OUTBOUND	3.55/CWT	3.29/CWT
BILLING SYSTEM	Split month	Anniversary

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, billing is on a split-month basis. Inbound transportation is cheaper between Erie and Syracuse, but outbound transportation is cheaper from Secaucus.

To answer this question, a simulation was run to determine the least-cost alternative. The results indicate that for a five-month period, total cost equals $126,400 for Syracuse and $144,600 for Secaucus. By using Syracuse rather than Secaucus, $18,200 can be saved.

TECHNICAL ASPECTS OF THE SIMULATION

The first step in simulating warehouse costs is to develop a method of generating patterns of weekly demand based on a predetermined probability distribution. 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, demand will more closely reflect actual week-to-week fluctuations experienced by a warehouse.

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 "log and trig" method of generating normally distributed Z values was employed. The formula is expressed as [2]:

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

where U(1) and U(2) are independent, uniformly distributed random variables (shown in Table 1, the sample spreadsheet, under "Split-month Billing").

As a value of Z is calculated it is translated into product demand using the relation

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

where

μ is the mean
σ is the standard deviation.

Solving for X:

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

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, randomly generated from a normal distribution specified by inputted mean and standard deviation values.

Demand is calculated by a cell formula that references the inputted mean and standard deviation as well as the calculated Z value. The common demand patterns were used for both simulations so that fair comparison of the two billing systems can be made.

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

INV(n) − DEMAND (n) = BALANCE(n)
IF BALANCE < REORDER POINT, THEN REORDER QUANTITY + INV(n+1)
IF BALANCE > R.P., THEN 0 + INV(n+1)
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:

$$R.P. = ut + SS,$$

where

u is demand per week
t is lead time
SS (safety stock) = $K\sigma$.

Since the lead time is one week, the first part of the above formula is equal to the average demand per week as inputted into the simulation. The amount of safety stock is dependent on the desired service level [1] which is also an inputted value.

As an example of the weekly replenishment cycle, in Table 1 the demand for week 1 of month A, 78,630, is subtracted from the beginning inventory 200,000, giving a balance of 121,370. Since the balance is less than the reorder point (121,370 less than 169,900), the reorder quantity, 200,000 is added to week 2 of month A. In week 2 of month A, the balance is greater than the reorder point, triggering an order quantity of 0 to be added to the beginning inventory of week 3 of month A. The cycle continues for the 24-week period.

Costs per week are calculated based on the defined billing system stipulations. For SPLIT MONTH billing, handling is charged as finished product is moved into the warehouse. Storage is also assessed when the product is moved into the warehouse. If the product moves into the warehouse between the 1st and 15th of the month, a full month's storage is applied. If the product enters the warehouse between the 15th and the 30th, one-half month's storage is charged. Inbound and outbound charges are recorded as product moves in and out of the warehouse. Total cost and annual turn rate appear 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 month's storage. Handling and inbound and outbound transportation are calculated the same as the split month example. Product is charged one month of storage 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 one month's storage on the remaining quantity. The quantity to be rebilled is calculated by subtracting the most recent four weeks of demand from the inventory level recorded one month previously. 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 month's time, and a rebill needs to be applied to the quantity remaining.

TABLE 1: **Twenty-four-week Simulation of Split-month and Anniversary-month Billing. Reorder Point is 169,900 lb.**

					Transportation Costs ($)		*Inventory ($)*	*Split-month Billing*						*Anniversary-month Billing*	
								Warehouse Costs ($)	*Warehouse Costs ($)*					*Warehouse Costs ($)*	
wk/mo	*Inv (lb/wk)*	*Dem (lb/wk)*	*Bal (lb/wk)*	*Quantity (lb/wk)*	*Inbound*	*Outbound*	*Carrying Costs*	*Handling*	*Storage*	*U(1)*	*U(2)*	*Z*		*Storage*	*Rebill*
1A	200000	78630	121370	200000	$0	$0	$0	$0	$0	0.3950	0.6625	−0.7123		$0	
2A	321370	92145	229225	0	$0	$0	$0	$0	$0	0.2351	0.2746	−0.2618		$0	
3A	229225	107162	122063	200000	$0	$0	$0	$0	$0	0.4373	0.2203	0.2387		$0	
4A	322063	160461	161602	200000	$0	$0	$0	$0	$0	0.0744	0.0774	2.0154		$0	
1B	361602	127500	234103	0	$0	$4,526	$209	$0	$1,446	0.6570	0.9990	0.9167		$0	$0
2B	234103	127707	106396	200000	$3,140	$4,534	$135	$1,400	$800	0.6237	0.9497	0.9236		$800	$0
3B	306396	117624	188772	0	$0	$4,176	$177	$0	$0	0.6620	0.8619	0.5875		$0	$0
4B	188772	82952	105820	200000	$3,140	$2,945	$109	$1,400	$400	0.5951	0.6558	−0.5683		$800	$0
1C	305820	116016	189804	0	$0	$4,119	$176	$0	$1,223	0.2733	0.8038	0.5339		$0	$0
2C	189804	75487	114318	200000	$3,140	$2,680	$110	$1,400	$800	0.6982	0.5428	−0.8171		$800	$0
3C	314318	98251	216067	0	$0	$3,488	$181	$0	$0	0.0490	0.7462	−0.0583		$0	$0
4C	216067	115944	100122	200000	$3,140	$4,116	$125	$1,400	$400	0.4244	0.1835	0.5315		$800	$64
1D	300122	104324	195799	0	$0	$3,703	$173	$0	$0	0.5440	0.2292	0.1441		$0	$0
2D	195799	77095	118703	200000	$3,140	$2,737	$113	$1,400	$400	0.4029	0.3458	−0.7635		$800	$0
3D	318703	83766	234938	0	$0	$2,974	$184	$0	$0	0.5396	0.6690	−0.5411		$0	$0
4D	234938	147483	87454	200000	$3,140	$5,236	$136	$1,400	$400	0.1874	0.0837	1.5828		$800	$140
1E	287454	118778	168676	200000	$3,140	$4,217	$166	$1,400	$400	0.7270	0.1066	0.6259		$800	$0
2E	368676	131180	237496	0	$0	$4,657	$213	$0	$0	0.5826	0.9970	1.0393		$0	$0
3E	237496	76609	160887	200000	$3,140	$2,720	$137	$1,400	$400	0.5793	0.6159	−0.7797		$800	$0
4E	360887	115259	245627	0	$0	$4,092	$208	$0	$0	0.8701	0.9574	0.5086		$0	$0
1F	245627	111677	133950	200000	$3,140	$3,965	$142	$1,400	$400	0.3961	0.7962	0.3892		$800	$183
2F	333950	118878	215072	0	$0	$4,220	$193	$0	$0	0.5437	0.8465	0.6293		$0	$0
3F	215072	122289	92783	200000	$3,140	$4,341	$124	$1,400	$400	0.7560	0.0183	0.7430		$800	$60
4F	292783	131678	161105	200000	$3,140	$4,675	$169	$1,400	$400	0.4114	0.1044	1.0559		$800	$0
Total		2638895		2800000	$34,540	$78,118	$3,178	$15,400	$7,870					$8,800	$447
									Total Cost (for 24-wk simulation)			$139,105	Total Cost (for 24-wk simulation)		$140,482
									Turns per Year			19.2	Turns per Year		19.2

The formula employed for calculation of inventory carrying costs is:

Inventory carrying cost

$$= \text{Carrying cost} \times \text{Cost per pound} \times \text{Inventory.}$$

Both carrying cost and cost per pound are inputted values. Inventory represents the beginning of the week inventory for each of the 12 weeks included in the simulation.

Even though the duration of the simulation is 24 weeks, costs (warehouse, transportation, and inventory) are not calculated for the first four weeks of data (Month A). This is to allow the simulation to achieve a steady state condition before costs are assessed.

The simulation was run 50 times with the help of a Macro Key Stroke (Symphony command language). Results of the 50 simulation runs are captured and recorded automatically. An average system cost for each billing type is calculated from the 50 runs and serves as the primary basis of comparison.

As a check of simulation validity, a two-tailed large sample test was performed on two sample means of 50 simulation runs to determine if the means were statistically equal. The test results indicate that the two means were equal (alpha = 0.05). This demonstrates that the output of the simulation, under identical parameter settings, can be duplicated in successive runs with a high statistical confidence level.

ACKNOWLEDGMENTS

The authors wish to thank Professors Giauque of Brigham Young University and Kliorys and Wellington of Gannon University for their help and comments regarding the preparation of this paper.

REFERENCES

1. Krupp, James A. G., "Effective Safety Stock Planning," *Production and Inventory Management*, Vol. 23, No. 3 (1982), p. 35.
2. Mihram, G., Arthur, *Simulation: Statistical Foundations and Methodology*, Academic Press, Inc., NY (1972), p. 130.

ABOUT THE AUTHORS—

TONY CANELLA is manager of warehousing at Welch Foods Inc., located in Westfield, NY. Tony has spent 30 years in various transportation/distribution management positions at Welch Foods and is an active member of the Warehouse Research Council.

ED SCHUSTER is an inventory analyst at Welch Foods. Previously, Ed worked for Oscar Mayer, Inc., and has served as a production supervisor at Welch's North East, PA plant. An active member of APICS, Ed serves on the Process Industry Steering Committee and as President of the Erie, PA Chapter.