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TWO ALGORITHMS FOR REDISTRIBUTION OF STOCKOUTS IN COMPUTERIZED BUSINESS SIMULATIONS

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ABSTRACT

This paper is concerned with the design and development of computerized business simulations which are competitive and interactive in nature. Specifically, it deals with the modeling of loss sales (i.e. stockouts) and their impact on game play.

The paper reviews how stockouts are modeled in a number of commercially available computerized and interactive business games. In some of the simulations reviewed, stockouts, either small or excessive in magnitude, are lost forever - returning neither to the firm nor to the competing firms. Other designers penalize the firm for having excess demand potential by reducing their actual sales potential in the current and future periods. Other simulations redistributed (i.e. by forces of supply and demand) excessive loss sales to the other firms. In all of these stockout routines, the design was to represent, in some fashion, how lost goodwill, lost sales, and their redistribution might occur in the "real world."

Extreme care, however, should be taken in the adjustment and redistribution of stockouts. Carelessly prepared stockout routines can lead to unrealistic strategies in game play, such as: "It pays to stockout this period for the stockouts return next period. We will raise our price in the next period and make a real killing", or "Since the semester is near completion and since we cannot possibly win this game, let's destroy it for the rest of the firms. Let's raise our advertising and cut our price to $.l0 and capture the entire market."

To avoid such distortion problems TWO algorithms for the redistribution of excessive stockouts are presented. Both algorithms check to ascertain if excessive stockouts have occurred, and if they have, they are redistributed in the same period to other competing firms via the forces of supply and demand. The strengths and weaknesses of each routine are presented along with a brief discussion concerning altering the routines encompassing other lost sales issues.

INTRODUCTION

Over the past three years, ABSEL conferences have had papers and discussions dealing with design issues for simulation games. For example, Goosen (1), Pray and Gold (2), and Gold and Pray (3) have all addressed the need by ABSEL members to be more open about the design and the internal workings of ongoing interactive business simulations. Some questions such as: What are the steps (macro) to be followed in designing a simulation?; and, How does one model demand in an effective manner?, have been brought forth by simulation designers and have been the basis for discussion of designing new games and modifying existing ones. Hopefully, such design- oriented discussions will be useful for both new designers and users of simulations.

This paper continues the discussion of design issues for computerized interactive- business simulations. Specifically, the paper addresses a question that was raised at the Oklahoma Conference.

The question dealt with the modeling of demand and handling of excessive firm-level demand (i.e. stockouts). The question was: "Where do the stockouts go?"

PURPOSE

The purpose of the paper is threefold:

(i) to briefly review how twelve different interactive-business simulations dealt with the issue of excess demand and loss sales at the firm level. The simulations reviewed (4) through (15) include general management/ business, marketing, production, operations, microeconomic and multinational games.

(ii) propose two different algorithms for stockout reallocation that allow decision variable flexibility, and correct for market distortion.

(iii) to discuss the pros and cons of the reallocation schemes including how these algorithms may be easily modified to encompass a number of the desirable stockout issues found in (i).

A REVIEW OF STOCKOUT ROUTINES

Twelve different simulations were selected to illustrate the diversity of methods for handling stockouts. The selection of games included six general business/management simulations (4, 6, 8, 9, 12, and 13), three marketing simulations (5, 7, and 11), one production/operations simulation (14), one microeconomics (15), one collection of "micro" games, and multinational game (10).

The simulations addressed the issue of excessive demand in a number of different manners. Four of the simulations stated that either the excessive demand was lost, or went to the competitors. Interestingly, two games opted not to have stockouts, but rather to meet demand through overtime and at a higher cost of production. One game explicitly penalized (i.e. $/unit lost sale) the firms for failing to meet their demand potential. Three of the games backordered the excessive demand in some fashion. Most, however, only allowed a fixed or variable (i.e., random) percentage to be backordered. A few games did not mention how the issues of lost sales were to be handled. Table l, summarizes the general findings.

TABLE 1
Stockout Summary of Simulations Reviewed

	Lost or Go to Competitor	Not Lost-Increased Production Cost	Dollar Penalty Charge	Backorder-% Lost	No Mention
Game(s)					
[4]	x		x		
[5]		x			
[6]					x
[7]					x
[8]				x	
[9]	x				
[10]	x				
[11]		x			
[12]				x	
[13]				x	
[14]	x				
[15]	x				

In each simulation the designers modeled and explained a situation that they thought was reasonable for the scenario that they had decided to simulate. In most cases, restrictions were placed on key demand variables such as marketing, price and R&D. These restrictions were needed to prevent the game play from being distorted by unrealistic decisions. Market distortion generally occurs when a firm opts to place an exorbitant amount of money in R&D or marketing, or cust the price by say 50%. These type of unrealistic decisions result1 in one firm capturing an excessive share[1] of the market, and then not being able to meet their demand.

Prior to discussing two different ways to handle excessive stockouts without placing artificial restrictions on key demand decisions, a brief review of demand theory is presented.

MARKET AND FIRM LEVEL DEMAND FUNDAMENTALS

In most interactive-type simulations, the total market demand is determined by a functional relationship such as equation (1) in which the total demand for the industry is a function of a number of predictive variables such as: price, marketing, R&D, economic and seasonal forces, and the number of competing firms in the industry.

$$Q = f(P,M,R,S,N) \qquad (1)$$

Where: Q = total demand for the industry
P = average industry price
M = average industry marketing expenditure
R = average industry research and development
S = seasonal/economic index or factor
N = number of firms in the industry

After the market demand is calculated, it must then be allocated to the competing firms in the industry. This is often accomplished through the use of a weighting function. This function assigns a value or weight to each firm. This weight then becomes the numerator in the share ratio, and thus serves as the basis for the firm's share of the "pie". This weighting routine for the above demand equation is functionally represented as equation (2). It is often based on the firm's price position, relative to industry average price, and relative expenditure patterns for the other demand predictor variables.

$$W_i = f(P_i, m_i, r_i) \qquad (2)$$

Where: W_i is the weight for firm i
P_i. is firm's relative price
(i.e. price/ave. price)
m_i is firm's relative marketing expenditure
r_i is firm's relative R&D expenditures

After each firm has been assigned a weight, then equation (3) can be used to normalize the weights which then become the firm's share of the total market demand. Individual firm demand is then found by multiplying Q by

$$S_i = \frac{W_i}{\sum_i^n W} \qquad (3)$$

Where: S_i is the firm's share
W_i is the firm's weight
n = number of firms
and $\sum_i^n S_i = 1.00$

MARKET DISTORTION CONCERNS

One of the fundamental problems that occurs in some simulations is the case where the total market is distorted because of one firm's actions. To prevent such distortion a number of safeguards are often modeled. Two commonly used ones are: (i) restricting the amount of change of the demand variables such as restricting price changes to a maximum of, say, 10% per period and (ii) removal of "outlier" decisions from the calculation of the average price, or average marketing expenditure, etc.

Another alternative, which we advocate, is not to restrict the range or percentage change for key decision variables (such as price), but set up a mechanism that permits flexibility in decisions and eliminates market distortion. This alternative incorporates removal of outlier decisions and then corrects for market distortion by reallocating excessive stockouts to the competing firms.

While we advocate flexibility, there are certain cases where decisions should be constrained or removed. For instance, in the case of a simulation designed for a small number of competing firms, say, less than 6, it is wise to remove the "outlier" decision(s) from determining the market average for that demand variable. Then, let the share equation deal with the allocation in a normal fashion, and reallocate excessive stockouts to the other firms in the same decision period. A numerical example demonstrates the first aspect - the need for outlier removal.

A DEMAND ILLUSTRATION

The following simplified example assumes that there are only four firms in the simulation

[1] In nearly all cases, the firms modeled demand by first calculating the market demand and then distributing it via share routines to the competing firms in the industry.

and the system of equations that were developed to determine total industry demand and firm share are driven by price.[2] The demand system is detailed in equations (4) and (5).

$$Q = n*5000*(\text{P-bar})^{-2.0} \quad (4)$$

Where: P-bar = average price
n = 4; number of firms
* denotes multiplication

$$W_i = \left[\frac{\text{P-bar}}{P_i}\right]^3 \quad (5)$$

Where: P_i is the firm's price

$$S_i = \frac{W_i}{\sum_i^n W_i} \quad (6)$$

$$D_i = S_i * Q \quad (7)$$

Equation (4) is a power-type industry demand function which has been scaled (i.e. 5000) so that the firm-level demand will average 50 units when the average price is $10. The industry-level price elasticity is constant at 2. The weighting equation (5) is a simple ratio of firm price to average price raised to the third power. 3The power is the firm-level price elasticity.[3]

The share for each firm, from (6), is their weight from (5) divided by the sum of the weights. Each firm would then receive D. as their total demand potential. 1

OUTLIER IDENTIFICATION AND REMOVAL

For simplicity of calculations, it is assumed that each of the four firms were planning on setting the same price of $10. Equation (4) would then set the total market demand at 200 units and the weight and share equations would have evenly distributed 50 to each firm. If, however, one of these firms had entered a $1 price, either by accident or with the intent to disrupt the entire market, then the average industry price would have fallen from $10 to $7.76. This, in turn, would induce the total industry demand to increase to 332, or a 66% increase. Such a sharp increase in the total demand potential induced by one firm "cutting" its price, is difficult to justify and rationalize. Some designers have eliminated this particular problem by removing the "outlier" price from the industry average. The question that arises, however, is, "When is a decision an outlier?"

One way to identify outliers is to calculate the standard deviation along with the average price. If any of the prices fall beyond or below 3 standard deviations of the average, they should be removed from the industry average calculation. Such a check would eliminate outliers and prevent the total market demand from being distorted.

[2] To simplify calculations, we omitted the other predictive variables and have not employed any intertemporal smoothing techniques.

[3] For stability, the firm-level elasticity must exceed the industry-level elasticity.

EXCESSIVE STOCKOUTS

A potential problem still exists, however, and this deals with the share determination. Since the firm-level price elasticity is relatively high (i.e. 3), this $1 price will distort the distribution within the market. The calculations presented in Table 2 illustrate this problem.

TABLE 2
Share and Firm-Level Demand Distortion

Firm #	Pi ($/unit)	W_i	S_i	D (units)
1	10	1	.001000	.19
2	10	1	.001000	.19
3	10	1	.001000	.19
4	1	1000	.997000	199.43
Sum	31	1003	1.000000	200.00

P-bar = 10 (after removing the outlier)
Q = 200 (after removing the outlier)

Even with the removal of the outlier decision, the market would be distorted by permitting total flexibility in pricing. If it is assumed that each firm had the same total number of goods available for sale (from production and finished goods inventory), say, 50 units, then Firm #4 would have stocked out by approximately 150 units and the other firms would have had virtually no sales what- so-ever. Thus, Firm #4 has distorted the entire market with their $1 price.

IDENTIFICATION OF EXCESSIVE STOCKOUTS

In this illustration it is clear that Firm #4 has incurred excessive demand potential, but what are the general conditions for excessive stockouts and market distortion?

From our experience, we have found the following two step procedure to work well in identifying: (i) when stockouts are excessive, and (ii) when the market is or will be distorted. The procedure involves ascertaining whether the calculated share, S., is out of line statistically, and then determining if the "flagged" firm will incur a significant number of loss sales. The two steps are described below:

Step 1 - The Share Check

The methodology used comes from statistical quality control procedures and is based on a "p-chart". While in quality control, P is the proportion defectives, in the stockout case, P is defined as 1 divided by the number of firms (or the starting share for each firm). Equation (8) establishes the upper LIMIT.

$$\text{LIMIT} = P_r + 3\sqrt{\frac{P_r[1-P_r]}{n}} \quad (8)$$

where: $P_r = 1/n$

n = number of firms

If the firm's calculated share, Sj, from equation (6), is greater than LIM±T (three standard deviations above the P), then this firm is "flagged" and concern is raised over the potential for market distortion.

The SHARE CHECK is precautionary in nature and its purpose is to ascertain if there will be market distortion. However, an additional check is needed because it is possible for a firm, through effective planning, to capture a large percentage or share of the market demand.

Step 2 - Supply Check

The SUPPLY CHECK's purpose is to see if a firm can supply its demand potential and is used when a firm has been "flagged" by the first check. The check, illustrated in equation (9), compares the firm's product availability (from production and inventory) with their assigned demand from equation (7). If the firm incurs excessive stockouts and its share is too large, then redistribution is in order.

$$STOUT_i = D_i - C * AVAIL_i$$

Where: AVAIL is the sum of current production and finished goods inventory for firm i.
i is firm number.
C is a positive constant.

To allow for a reasonable amount of error in forecasting sales, "C" should be set at a value greater than one, possibly at values such as 2 or 3. If STOUT is a positive number and the first check indicated a share problem then the firm's excessive demand should be reallocated to the other firms during the same period of play.

Table 3 presents the calculation for the example and notes that Firm 4 was "flagged" in both checks:

TABLE 3
Identification of Excessive Stockouts

Firm #	S_i	FLAG1	D_i (units)	$STOUT_i$ (units)	FLAG2
1	.001000		.19	-99.81	
2	.001000		.19	-99.81	
3	.001000		.19	-99.81	
4	.997000	X	199.43	99.43	X
Sum	1.00000		200.00		

LIMIT = .25 + .6495 = .8995
AVAIL = ASSUMED TO BE THE SAME FOR ALL FIRMS AT 50
C = 2
X = INDICATES FLAGGED BY THE CHECKS

TWO PROPOSED ALGORITHMS FOR REALLOCATION

The two proposed methods of handling market distortion, such as in our example, and the reallocation of the excessive stockouts use the forces of supply and demand. The first method uses the shares determined by equation (6), normalizes them, and then distributes the excessive demand potential to the competing firms. The second method identifies the problems with the two step procedure, and then removes the "flagged firm(s)" and recalculates and distributes the demand to the remaining firms using the full set of equations.

Share Normalization

In this method, after a firm has been identified by the two checks, the excessive demand (i.e. Di - AVAILi) is calculated and distributed by normalizing the shares of the remaining firms. Table 4 demonstrates how Firm 4 would be removed, the new normalized shares determined, and the revised demand potential calculated for the remaining three firms:

Table 4
The Share Normalization Algorithm

Firm #	Old Share	New Share	Distributed Demand (units)	Old Demand (units)	Total Demand (units)
1	.001000	.333	49.81	.19	50
2	.001000	.333	49.81	.19	50
3	.001000	.333	49.81	.19	50
Sum	.003000	1.000	149.43		

Excessive demand: 149.43
Firm four removed

With this approach, the new shares are found by taking each old share and dividing it by the sum of the "non-flagged" firm shares (for our example, the sum is .002991). The excess demand (149.43 units) is redistributed to the remaining three firms in the industry.

Some advantages of this method include:

- Uses the Forces of Supply and Demand: No arbitrary decision rule has to be imposed on the reallocation because the share weights implicitly have the forces of supply and demand modeled in them.
- Ease in Implementation: Since most interactive computerized simulations use the share method of distribution, the method has the advantage of being relatively easy to model and implement.
- Multiple Outliers: If the firm-level price elasticity is large and there is a large number of firms in the market (say, more than 9), it is possible for more than one firm to be considered an outlier. This approach will handle more than one firm being removed simultaneously.
- Iterative Reallocation: With a highly sensitive price elasticity and a large number of competing firms in the industry, it is quite likely for the redistribution to cause other firms to be "flagged". Therefore, the algorithm has to check the two step procedure to see if market distortion has occurred as a result of the reallocation. In a nearly perfect competitive market situation, it is possible for most, if not all of the firms to be iteratively "flagged" via the reallocation process.

There are, however, a number of shortcomings of the use of the share normalization approach.

These include:

- Double Precision Requirements: Large price elasticity, combined with a large number of firms, may cause the non-normalized shares to be extremely small in magnitude. On some computers this may cause errors in calculations and require the programmer/designer to use double precision.

- Unrealistic Results: There are special cases where the algorithm may report some results that are inconsistent with standard microeconomic theory. For instance, if the market demand greatly exceeds what all the firms can supply ,[4] and a series of firms are "flagged", the algorithm will distribute the excess demand in its iterative fashion. The end result can be a situation where the last firm receives a larger total demand potential (because so much is left over!) than a firm with a lower price.

Demand Shift Method

With the demand shift method, an outlier firm is identified with the two step check routine. It is then removed, the average industry price is recalculated, and the new total market demand is established for the n-1 firms. The industry demand is distributed to n-1 firms through the weight and share equations. The process is iterative, checking after each new demand calculation to see if any of the firms are "outliers". If they are, they are removed, the industry demand is calculated, and then distributed to the remaining firms. For our example, the routine would involve two passes and work as shown in Table 5.

Table 5
The Demand Shift Method

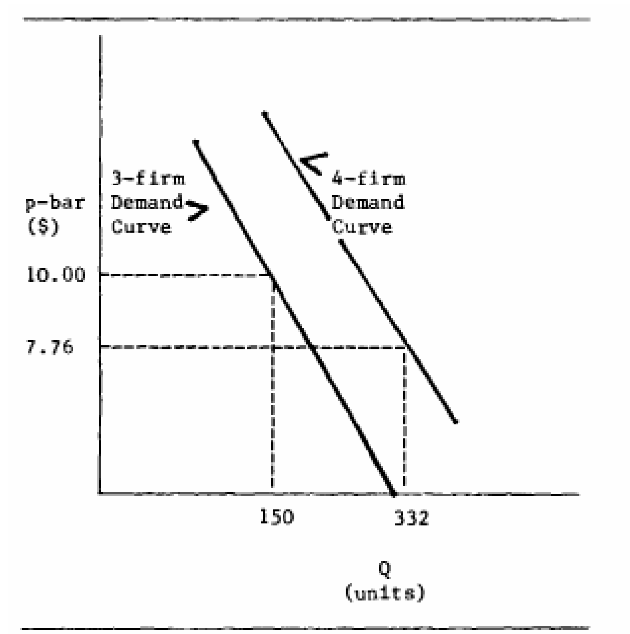
First Pass	Second Pass
n = 4	n = 3
Q = 332	Q = 150
p-bar = $7.76	p-bar = $10.00
	Total demand distributed with S_i
Firm 4 flags on both checks	

Reported Firm	Demand D_i	Potential	Reported Firm	Demand D_i	Potential
4	331		1	50	
			2	50	
			3	50	

In the first pass using equations (4)-(6), the average price would have been $7.76 and the total industry demand would have been 332 units. From Table 2, Firm 4 would have received .997 of the total market and would have been caught by the two step check routine. In the second pass, Firm 4 would be removed from the demand calculations and the average price would have risen to $10.00 and the total demand for the 3-firm industry would have been 150 units. The weight and share equation would have evenly distributed the 150 units to each firm. The reported demand to each firm could be 50 each to the three firms and excessive demand to the outlier firm.

Like the share method, the process is iterative with checks after each pass and outlier firms being removed. This method ensures that the average industry price will increase with the removal of the outlier firm. This, in turn, causes the total "pie" to decrease with each iteration. Figure 1 demonstrates the concept using a conventional supply and demand diagram.

Figure 1
The Shifting Demand Curve



The advantages of this approach include:

- Economically-based Reallocation Scheme: The model is not dependent on normalizing shares, rather it works directly with the demand function. The "shifting demand concept" has a stronger appeal from an economic theory standpoint.

- Unrealistic Results Minimized: Simulation testing of the second routine indicates that it is not as likely to generate unrealistic results such as in the case where the market demand is "too" large for the number of firms.

- Multiple Outliers and Iterative in Nature: As in the first model, it is both iterative process, and it will catch multiple outliers.

- Double Precision Not Required: Because it shifts the demand curve it is not dependent upon the shares for reallocation. Therefore, the need for double precision arithmetic is no longer required.

This method has the following disadvantages:

- More Difficult to Model or Modify: It may be more difficult to model because of inter- temporal smoothing methods often found in industry demand calculations.

[4] This can easily occur if an instructor-controlled parameter such as S in equation (1) is set too high.

• Greater Memory and Time Requirements: Exponential smoothing techniques might require the use of both temporary and permanent subscripted variables. Additionally, the iterative recalculation of industry demand may substantially increase CPU processing time.

SUMMARY AND CONCLUSION

This paper represents an on-going attempt to encourage open discussion concerning the design and development of computerized business simulations. To encourage an open discussion about modeling, the paper addresses the issue of excessive demand in computerized- interactive business simulations. It reviews a number of different commercially available simulations pointing out the method used to handle excessive demand potential for individual firms.

The paper went on to describe two different algorithms which may be used to redistribute excessive demand to the other firms in the same period of play. This prevents unrealistic market or industry results from occurring, if a firm (or set of firms) makes irrational decisions, or data input errors occur.

Additionally, either algorithm lends itself to modification such as to penalize firms for excessive demand either in current or future periods, or only permitting a percentage of loss sales to return in future periods.

With the use of either the normalization of share approach or the demand shift method, designers of simulations can permit greater flexibility of demand-related decisions, and thus place more realism into the simulation.

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