

# Developments In Business Simulation & Experiential Exercises, Volume 17, 1990

## DEMAND EQUATIONS WHICH INCLUDE PRODUCT ATTRIBUTES

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### ABSTRACT

This paper presents a demand model which combines the normal economic factors such as price and advertising with a set of physical attributes of products in establishing the market share allocations as well as the aggregate levels of demand for business simulations. The usual assumptions of demand equations used in simulations, multiple firms producing homogeneous products and selling to a single market, are expanded to a more realistic representation of an actual market place. Multiple market segments exist, each with their own preference mapping. Different products may have different acts of physical attributes. Each product has its own set of attributes which are determined by the management team of the firm producing the product. In this model, buyers choose among alternative products, selecting from among those that best fit their needs and desires. If similar products are produced, the market cannibalizes one product for the other. If a product has only a few desirable characteristics, then the market will largely reject it. The poorer the product, in the eyes of the buyer, the fewer sales. Marketing pressures from price, promotion and sales force efforts, affect demand but do not need to dominate the product attributes. The relative importance among the economic and product attributes can be controlled by the simulation administrator.

### THE PROBLEM

Most business simulations make very simple assumptions regarding the market place. Both the buyers and the products are generally presumed to be homogeneous. The marketing variables, price, promotion, R&D, sales force, both number and compensation, determining the demand within a single market segment and its allocation among the products. If multiple market segments exist, they tend to be independent of one another.

There are a few simulations where product differentiation exists, but with only a single market. In these games, product attributes take on economic-like properties. That is, there is an optimum level or amount of each attribute and the demand is distributed according to some exponential function of the differences in the set of attributes from the existing products to the best or ideal product. The problem with this concept is that it assumes one ideal product, which dominates all others. This limits the number of possible firm strategies. Marketing in Action (Ness and Day, 1985) is an example of a popular marketing simulation using this concept.

There are also a few games that encompass market segments, but the segments are essentially independent of one another. That is, total demand expands when the new products are introduced and there is little or no cannibalism of existing products. The Executive Simulation (Keys and Leftwich, 1977) uses a scenario of one consumer type product and one industrial type product. Mansym IV (Schellenberger and Masters, 1986) varies the scenario for multiple product versions, but the markets for its products are independent of one another.

The model described in this paper will provide a method for multiple products to compete in a market place with many segments. When new products are introduced, they must fill an unmet need or take sales away from existing products; almost always a new product will do both. Product positioning is based upon product attributes and/or performance and each market segment may have different elasticities for each marketing variable.

### MARKET SEGMENTATION AND PRODUCT DIFFERENTIATION

Marketing texts have been expounding the market segmentation concept for many years. Daniel Yankelovich (1964) was an early writer on industrial market segmentation and Richard Johnson (1971) wrote on analytical methods to determine market segments. However, only a few games effectively utilize this fundamental concept. MARKSTRAT (Larache and Gatignon, 1977), developed in the 1970's, and its sister simulation, INDUSTRAT (Larache and Weinstein, 1988), are two simulations, which incorporate specific market segments in their demand structures. But, there are few others that have segmented demand functions that are easily controlled by the game administrator. This paper is an attempt to extend the development of a model introduced by Teach (1984) in which product attributes were used to allocate market share. The model developed in this paper utilizes multiple market segments, which can be controlled by the game administrator. The demand by segment can be controlled in a way that allows a product's characteristics to dominate, to equal, or to be subservient to any combination of the marketing variables of price, advertising, promotional expenditures, sales force, or any other variable the game designer may wish to include. The determination of the emphasis is controllable at the game administrator level. That is, an administrator has the capability to dramatically change the nature of competitive interaction any time he or she desires. (It would be best if most of these changes occurred only between games and not between plays during a game.)

### AN EXAMPLE USING PRODUCTS WITH ONLY TWO ATTRIBUTES

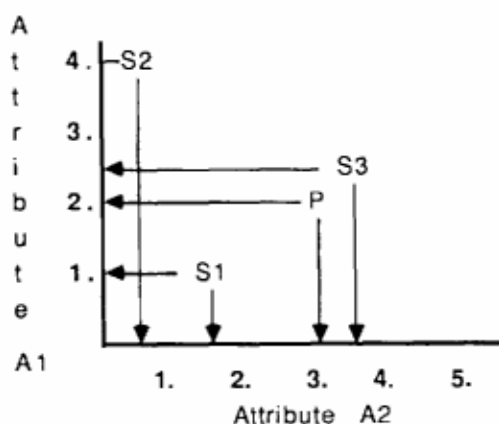
For illustrative purposes, assume a simulation of an industry where three firms each produce a common product ( $P_i$ ), and each product has two attributes,  $A_1$  and  $A_2$ . Let us further assume that there exists three market segments. While the market segments have preferences, they are willing to purchase any product. Segment One ( $S_1$ ) is made up of five hundred buyers from two-person households of young adults without children, and they can be characterized as preferring products with only small amounts of attributes 1 and 2. Segment Two ( $S_2$ ) is made up of two thousand buyers from households with teenaged children. These households desire products with a large amount of Attribute 1 but only a small amount of Attribute 2. Segment Three ( $S_3$ ) is made up of one thousand buyers from households with small children. In general, these buyers prefer products with a small amount of Attribute 1 but a mid-level amount of Attribute 2.

Figure 1 is a two-dimensional representation of the situation just described. The segments' ideal products are designated  $S_i$  and located at points (1.75,1.00), (0.50,4.00) and (3.50,2.50). The products that are being marketed are all identical and located at the point (3.00,2.00). Since all other firm level decisions are assumed to be equal and company histories are also assumed to be identical, the products have equal market shares.

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FIGURE 1

A TWO DIMENSIONAL SPACE CONFIGURATION OF THREE MARKET SEGMENTS AND A SET OF IDENTICAL PRODUCTS

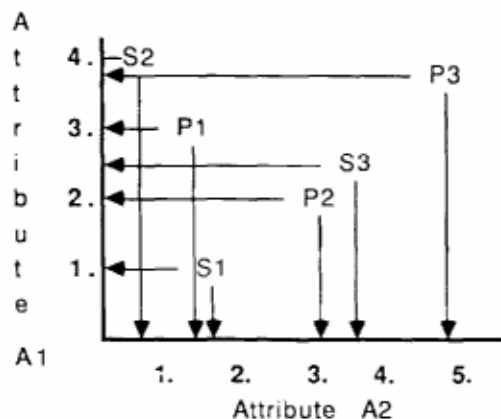


Let us now enrich the scenario. Assume the firms produce somewhat different products. Assume Firm One produces product P1 and these products are made up of 3.00 units of Attribute A1 and 1.50 units of Attribute A2. Firm Two produces product P2 and each of these assemblies are made up of 2.00 units of A1 and 3.00 units of A2. Firm Three produces yet a different product, and every P3 is composed of 3.75 units of A1 and 5.00 units of A2. Using the same market segments as shown on Figure 1 and replacing the 3 identical products P by the three now distinctively different products P1, and P3, a new competitive situation is created and shown in Figure 2.

Figure 2 can be viewed as a preference mapping produced by a multidimensional scaling routine. Segments tend to purchase the products nearest their "ideal point" but their preferences are not absolutes and they distribute their purchases across all of the available products inversely proportional to the distance the products are away from their ideal point. This inversely proportional to the distances model is called a *gravity flow model* and comes from the physical sciences where it is referred to as (the gravitational model: it is used in physics to measure (the gravitational pull between objects in space. In the simulation, it measures the degree of pull the buyers have upon products. The closer the product is to the buyers' preference, the greater the probability that the buyers will purchase that particular product.

FIGURE 2

A TWO DIMENSIONAL SPACE CONFIGURATION OF PRODUCTS AND MARKET SEGMENTS



In this example, product P1 is the nearest one to segment S2 and can expect to obtain the greatest proportion of S2's demand. Product P3 is the farthest way from segment S2 and will obtain the least share of segment S2's demand.

Assuming the axes are orthogonal (See endnotes for non-orthogonal comments), the distances between these buyer and product points in two-space are determined by equation (1). This equation can be generalized to n-space by adding new dimensions (attributes) to both the segments and the products and summing the differences across all axes before the square root is taken.

Table 1 shows the derived distances and their inverses from the example used in Figure 2.

$$DP_iS_j = [(P_iA_1 - S_jA_1)^2 + (P_iA_2 - S_jA_2)^2]^{1/2} \quad (1)$$

Where:  $DP_iS_j$  is the distance between product  $P_i$  and segment  $S_j$ ,

$P_iA_1 - S_jA_1$  is the difference between product  $P_i$  and segment  $S_j$  on the  $A_1$  axis, and

$P_iA_2 - S_jA_2$  is the difference between product  $P_i$  and segment  $S_j$  on the  $A_2$  axis.

Assume that the industry level demand equation generated a demand of 35(y) units and the distribution of this demand was 15% in Segment One, 30% in segment Two and 55% in Segment Three.

TABLE 1

DISTANCES AND INVERSES BETWEEN PRODUCTS AND SEGMENTS

Segment	THE DISTANCES			THE INVERSES			Sum of Inverses
	Product P1	Product P2	Product P3	Product P1	Product P2	Product P3	
S1	2.02	1.60	4.26	0.50	0.63	0.24	1.37
S2	1.41	3.20	4.51	0.71	0.31	0.22	1.24
S3	2.06	0.71	1.94	0.49	1.41	0.51	2.41

Table 2 shows the resulting market shares and sales to each segment based upon the gravity flow model. As one would expect from a visual inspection of Figure 2, product P3 did not gather a very large share of the market. Product P3 was the most distant product from both segments S1 and S3 and almost equal distant with product P2 from market segment S2. Product P2 being very close to Segment S3 gets the lion's share of Segment S2's purchases.

TABLE 2

MARKET SHARES AND UNIT SALES BASED UPON THE PROPORTION OF THE DISTANCE INVERSE

Segment	MARKET SHARES			UNIT SALES			Units Demanded
	Product P1	Product P2	Product P3	Product P1	Product P2	Product P3	
S1	.37	.46	.17	192	242	91	525
S2	.57	.25	.18	598	264	188	1050
S3	.20	.59	.21	387	1,129	409	1925
Total Product Sales	1,177	1,635	688	3500			
Market shares for the total market	33.6%	46.7%	19.7%				

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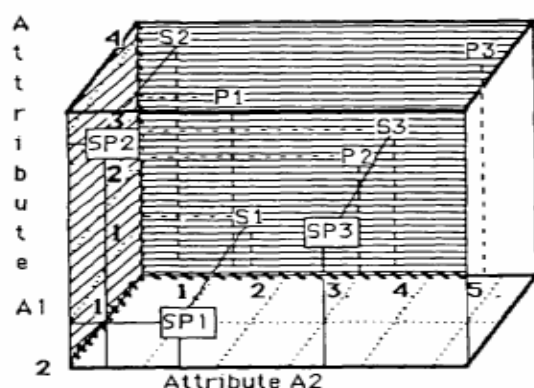
## ADDING NON-BUYERS AND SHADOW PRODUCTS

In mass markets, there are potential customers who are interested in a product class but they cannot find any product that fits their needs well enough to make a purchase. If new attributes were added or if the product were changed, some of these potential customers might then purchase the product. These potential customers represent the unfilled needs or niche in the market place.

In the current derivation of this model, all potential buyers purchase a product in each period. Let us abandon this assumption.

In order to create unfilled market niches, let us go back to the perceptual map in Figure 2 and add a set of 3 shadow products, one shadow product for each market segment. Each of the shadow product's locations will have the same co-ordinates as the market segment, but N units away, on an orthogonal axis, from the market segment. (The size of N should be game administrator selectable and it affects the portion of buyers whose needs are unmet during each round of the game.) For the purposes of this paper we will arbitrarily select N to be equal to 2. Graphically, this creates a third dimension, two units away from the original space for the illustrative example and is shown in Figure 3.

FIGURE 3  
A THREE DIMENSIONAL SPACE CONFIGURATION OF PRODUCTS AND MARKET SEGMENTS (INCLUDING THREE SHADOW PRODUCTS)



The market segments and their respective sizes remain the same. Now, calculate all the distances, their inverses and market shares including the three new shadow products shown on the perceptual map. Table 3 shows the results without all the intermediate steps.

TABLE 3  
UNIT SALES

Segment	Units Demanded	Products Sold			Units Sold	Un-met Demand
		P1	P2	P3		
S1	525	107	134	50	291	234
S2	1050	329	145	103	577	473
S3	1925	267	779	282	1,328	597
Unit Sales by Product		702	1,058	436	2,196	1,304
Total Market Shares		32.0%	48.2%	19.8%		

Table 3 shows that, based upon physical attributes only, that is, assuming no differences in marketing and any other variables,

Product One would have sold 702 units, Product Two would have sold 1,058 units and Product Three would have sold 436 units. The total sales would have been 2,196 out of a theoretical 3,500 unit potential demand. By altering the physical attributes  $A_1$  and  $A_2$ , the unit sales will vary. The closer the products  $P_i$  are to the buyers or segment's "ideal products  $S_j$ , the greater the total sales. Also, if the shadow products are positioned closer to the market segments by the game administrator, under ceteris paribus conditions, the total unmet needs will be greater, and if the shadow products are more distant from the market segments, the unmet needs will be smaller. For instance, if N had been set equal to 3.0 instead of 2.0, the unmet needs would have been 1,093. If N had been set equal to 1.0, the unmet needs would have totaled 1,671 units. This functional relationship between unmet needs and the value of N is asymptotic to 0 as N gets large and asymptotic to as N approaches zero. One could also let the value of N to vary between segments. If N were small for one segment, it would simulate very "picky" potential buyers. Ones who's needs must be met very closely or they would not purchase. If N were large, the segment would be willing to freely purchase from among all of the substitutable products on the market.

## SOME PROBLEMS WITH THIS SYSTEM

There is an inherent problem with this system of allocation, based upon the inverse of the distance, but it is easily overcome. If a firm specifies the exact same levels of the attributes that the market segment desires, the distance is zero and the inverse is undefined. This difficulty can easily be solved by shifting the position of the market segments along the axis created for the shadow products. Using this one axis, place all the market segments at the value 1.0 on this axis. This simply forces the minimum distance between any product and any market segment to be equal to 1.0, thus the distance always has a defined inverse.

There is a minor problem that can easily be overcome. The example being used has all the physical characteristics defined on a simple scale of one to five. In some cases, it may be desirable to use a scale, which represents real values rather than relative ones. If there are costs associated with the amount of each characteristic incorporated into the product, a weighting scheme could transform the data prior to its use in the equations described in this paper.

## MAKING THE MARKET PLACE DYNAMIC

Since a segment preferred product is defined as a point in space, a dynamic market for products can be simulated. An initial starting point and the desired ending position for each market segment can easily be selected by the game administrator on each of the product attribute axes. The administrator then estimates the number of periods the simulation is expected to run and the paths of the market segments are defined. If nonlinear paths are desired, the problem is a little more difficult but still manageable. (This change would not be done by the typical simulation administrator.)

## REPLACING PRODUCT ATTRIBUTES WITH ECONOMIC VARIABLES

Using the hypothesis that economic variables such as price, advertising, sales promotion, R&D, the size of the sales force, etc. affect demand, a similar model can be constructed using the economic variables instead of the product attributes. Since economic variables affect each segment independently, the solution can be applied to each segment, one at a time. Using this hypothesis, each market segment is considered to be at the origin for these calculations. The advantage of solving the allocations one segment at a time is that each segment may now be assigned unique marginal propensities to purchases based upon the economic variables. Thus, one segment may be highly price sensitive, another may be sensitive to promotion expenditures and a third sensitive to the number in the sales force.

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Assume a three-competitor game, where each firm produces a single product and only two economic variables, price and advertising, are used in the simulation with only one market segment. (An unlimited number of market segments can be added because in the economic part of this model, the market segments are independent and as many economic variables may be incorporated as one desires. The general model is capable of accommodating any number of competitors, products, economic variables and market segments.) Let us assume Company One's product has been priced at \$8.00 and the firm advertised at a rate of 800 thousand dollars per period. Firm Two's price has been set at \$7.25 and its advertising budget was only 700 thousand dollars. Firm Three has set its price at \$9.45 but has an advertising budget of 850 thousand dollars.

### The price variable

It would be possible to directly use price as the variable in this model, but the game administrator could not alter the price elasticities. Also, if the simulation was to be used for either more or less expensive products, the resulting price elasticities might not be appropriate. To remedy the problem, a transformation of the data is performed to control the price elasticity (or the elasticities of any other of the marketing variables used in the model).

Let us use the following equation to represent the demand-price relationship for Market Segment I - This form of price-volume relationship has been previously considered by Gold and Pray (1983).

The elasticity is defined as the first derivative of the price-volume

$$E_p = z_1 P^{(k_1 + k_2 P)} \quad (2)$$

Where:  $E_p$  is the price effect used in the gravity flow model,  
 $P$  is the price,  
 $k_1$  is the set of constants which control the elasticities,  
 $z_1$  is a scaling factor that affects the absolute value of the distances, but not their relative positions.

function (2). In this case it is:

$$e_p = k_1 + k_2 P(1 + \ln P) \quad (3)$$

where  $e_p$  is the price elasticity.

By defining two points with both a price and, a corresponding elasticity for a market segment, a pair of equations can be set up using equation (3) to determine  $k_1$  and  $k_2$  for the general equation (2).

For the purposes of the example, let us select a price of \$10.00 and assign an elasticity of 1.0 to it. For the price of \$5.00 let us assign an elasticity of 0.5. The pair of equations would be:

$$k_1 + k_2 \cdot (10) \cdot (1 + \ln(10)) = 1.0 \quad (4)$$

$$k_1 + k_2 \cdot (5) \cdot (1 + \ln(5)) = 0.5 \quad (5)$$

Solving for  $k_1$  and  $k_2$  yield:  $k_1 = 0.17347$   
 and  $k_2 = 0.025$

Figure 3 shows the demand curve derived by using these two point elasticities.

Using these two constants,  $k_1$  and  $k_2$ , and assigning  $Z_1$  a value of 1.0 for equation (2) and using the example data of three competitors prices, yields the following values shown in Table 5.

FIGURE 3

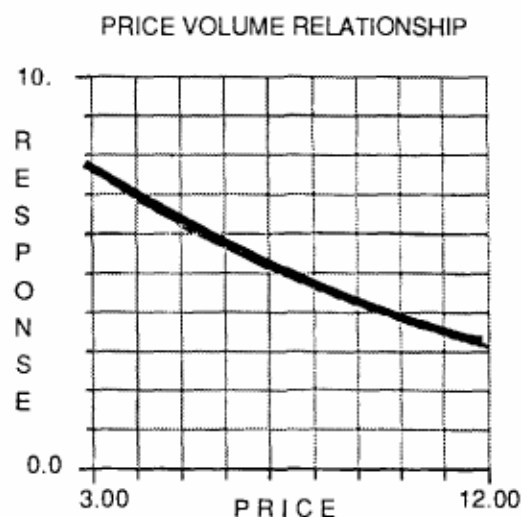


TABLE 5

### PRODUCT PRICES AND THEIR ASSOCIATED VALUES

Product	Price	$E_p$	Inverse	Market Share
1	8.00	2.174	.46	33.8%
2	7.25	2.019	.50	36.8%
3	9.45	2.510	.40	29.4%
Sum			1.36	

### The advertising variable

In a similar fashion, the advertising variable may be incorporated to define the advertising effect. The case of advertising and other economic variables where higher values are presumed to increase demand, the actual values are used to determine the share allocations, not their inverses. (When prices were used, a higher value was less desirable.) The advertising effects transformation can be shown as:

$$E_A = z_2 A^{(k_3 - k_4 A)} \quad (6)$$

This time, the elasticity  $e_A$  is defined as the first derivative of the advertising-volume function and is:

$$e_A = k_3 - k_4 A(1 + \ln(A)) \quad (7)$$

Again, for the purposes the example, for Market Segment 1, let us arbitrarily select an advertising budget of 100 thousand dollars and assign an elasticity of 20 to it. For an advertising budget of 1,000 thousand dollars (one million, but the values are calculated in thousands.) let us assign an elasticity of 1.0. Other segments could have different elasticities. The pair of equations are:

$$2.0 = k_3 - k_4 \cdot (100) \cdot (1 + \ln(100)) \quad (8)$$

$$1.0 = k_3 - k_4 \cdot (1,000) \cdot (1 + \ln(1,000)) \quad (9)$$

Solving for  $k_3$  and  $k_4$  yield:  $k_3 = 2.07634$  and  
 $k_4 = 1.36 \cdot 10^{-4}$

Using the two constants,  $k_3$  and  $k_4$ , and assigning a value of .0001 (0  $z_2$  in equation (6), and using the previous example data of the three competitors advertising budgets yields the values shown in Table 6.

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TABLE 6

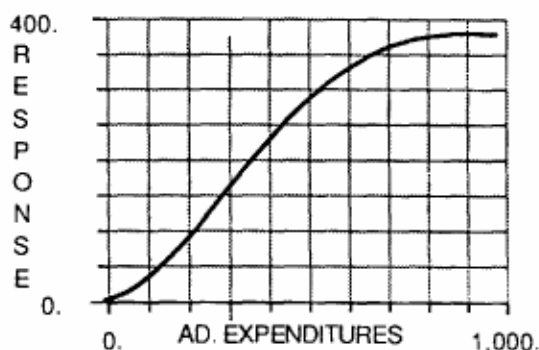
MARKET SHARES BASES UPON PRODUCT ADVERTISING BUDGETS

Product	Advertising	$E_A$	Market Share
1	800	5.150	34.3%
2	700	4.329	28.8%
3	850	5.543	36.9%

Figure 4 shows the response to varying advertising expenditures.

FIGURE 4

RESPONSE TO ADVERTISING EXPENDITURES



## Combining the price and advertising functions into a single effect

Since the values of  $E_p$  and  $E_A$  yield values of different magnitude, they are not directly comparable and can not be directly plotted on axes to determine the joint effect of advertising and price. However, these functions yield market share allocations for each variable under ceteris paribus conditions. If the inverse of these functions yields market share allocations, then the inverse of market share produces a pseudo distance function. But, the inverse of the market shares all have the same domain, and thus can be plotted on different axes in a common space without differentially weighting a variable. Each of the variables then are equally weighted (assuming orthogonal axes).

Figure 5 shows the two-dimension plot of the inverses of both sets of market share data and Table 7 shows the market share allocations as determined by advertising alone and by prices alone for Market Segment 1.

FIGURE 5

TWO DIMENSIONAL CONFIGURATION SHOWING PRICE AND ADVERTISING RELATIONSHIPS (FOR MARKET SEGMENT 1)

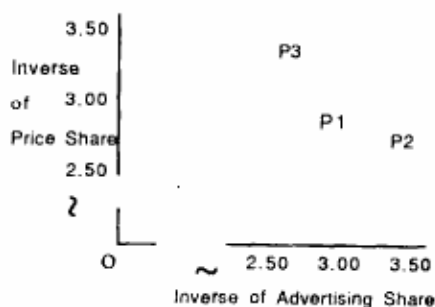


TABLE 7

MARKET SHARES AND THEIR INVERSES (FOR MARKET SEGMENT 1)

Product	Share based on price	Inverse	Share based on advertising	Inverse
P1	33.8%	2.96	34.3%	2.92
P2	36.8%	2.72	28.8%	3.47
P3	29.4%	3.40	36.9%	2.70

The distances from the origin to each product is 4.158, 4.409, and 4.342. The combined effects of price and advertising then produces market shares of 0.345, 0.325 and 0.330 for products P1, P2 and P3 respectively.

## COMBINING THE EFFECTS OF ECONOMIC VARIABLES WITH THE EFFECTS OF PRODUCT ATTRIBUTES

Using the same logic that combined the effects of the different economic variables, the effects of the economic variables can be combined with the effects of the product attributes to determine market share allocation. As an example, the market share data of Segment One resulting from product differences, as shown in Table 2, and the combined advertising, price effects as described in the previous section, has been selected. Their final market shares resulting from the combination of these two effects have been determined and is shown in Table 8.

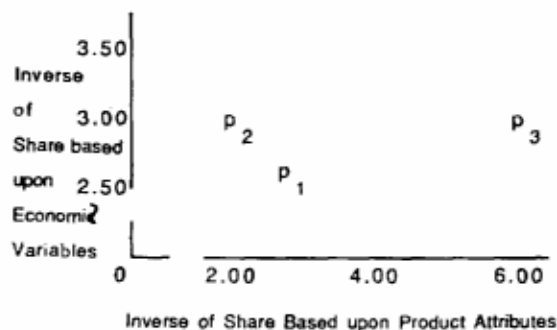
TABLE 8

MARKET SHARES RESULTING FROM ECONOMIC AND ATTRIBUTE VARIABLES (FOR MARKET SEGMENT 1)

Product	Share based on Economic Variables	Inverse	Share based on Product Attributes	Inverse
1	.34	2.94	.37	2.70
2	.33	3.03	.46	2.17
3	.33	3.03	.17	5.88

FIGURE 6

TWO DIMENSIONAL CONFIGURATION SHOWING ECONOMIC AND PRODUCT ATTRIBUTE RELATIONSHIPS (FOR MARKET SEGMENT 1)



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The market shares in Market Segment 1, of products P1, P2 and P3 resulting from the distances displayed in Figure 6 are 0.37, 0.40 and 0.23, respectively. This assumes equal weighting of the economic variables (price and advertising) and the product attribute variables. In some situations, the game administrator may wish to differentially weight these two effects, in order to emphasize a particular point. The two axes may be stretched or reduced by a simple transformation. If non-equal weighing is desired, (then a weighting function needs to be defined. Equation 11 defines such a function.

$$P_i = (w_E \cdot 1/X_i), (w_P \cdot 1/Y_i) \quad (11)$$

Where:  $P_i$  is the point in two-space of product  $i$ .

$X_i$  is the market share of product  $i$  based upon economic variables,

$Y_i$  is the market share of product  $i$  based upon product attributes,

$w_E$  is a weight  $0 < w_E < 1$ . It is associated with the relative importance of the economic variables, and

$w_P$  is a weight equal to  $(1 - w_E)$  and is associated with the relative importance of product attributes.

If no weight is to be given to the product attributes, then only economic variables are used in the simulation, and  $w_E$  is set at 1.0. A value less than 1.0 begins to utilize product attributes as a determinate of market share. If  $w_E$  is set at 0.0 then only product attributes effect the market shares.

### MODELING AGGREGATE DEMAND

Simulation models have used many different equations to generate total, or industry, demand. Some simply determine demand at the firm level and then sum across firms to establish industry demand. However, to be even remotely realistic, care must be taken in determining the elasticities of all the variables used to ascertain demand. All of the elasticities at the industry level must be less than at the firm level. As simple as this economic principle seems, many games do not follow this premise.

A model adapted from Gold and Pray (1983) is used to determine total or aggregate demand and shown as equation (12):

$$Q = z_1 \exp^{-c(D-s)} P^{-(k_1+k_2P)} A^{(k_3-k_4A)} O^{(k_5-k_6O)} \quad (12)$$

Where;  $Q$  is the quantity of inherent demand for a period. This demand includes unmet needs as defined in Table 3.

$D$  is an average of the distances between all products and all market segments. Thus, as products in the market place are more like the products preferred by the buyers, the demand grows. As the product offerings stray from the buyers preferences, demand falls.

$P$  is the harmonic mean of the firms' prices.

$A$  is the arithmetic mean of all exponentially smoothed advertising expenditures.

$O$  is the arithmetic mean of any other desired variable. It is included here to indicate that the model could be expanded to include as many continuous, economic variables as the designer wished to include.

$z_1$  is a scaling factor which controls the overall magnitude of demand and has no bearing on the elasticities of the marketing variables,

$c$  is a value which controls the sensitivity of demand to degree of fit between what attributes the market segments desire and the attributes of the products supplied by the simulation participant teams. This value can be selected by the simulation administrator,

$s$  is the amount of shift on the axis between products and Market Segments ideal points and which prevents an undefined inverse. In the example given in this paper, this value was set equal to 1.0 for all products.

$k_i$  is a set of constants that control the elasticities of the marketing variables and need to be determined by the simulation administrator, and  $\exp$  is the natural logarithm base.

### END NOTES

All of the previous derivations assumed the variables and their associated axes were statistically independent of one another. However, the mathematical statement:

$$"2(P_1A_1 - S_1A_1)(P_1A_2 - S_1A_2) \cos \theta"$$

defines the correction term for the case when the two axes are not orthogonal. The degree of association, or correlation, between any pair of variables can be expressed as a function of the angle  $\theta$ . Thus, with the careful selection of, the game administrator may represent competition where the response to advertising is correlated with the prices. Or, where the one physical characteristic (maybe weight) is associated with another (say, size). Any degree of association can be modeled with the careful selection of the angles  $\theta$ . However, the derivation of this fact will be left to another paper.

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