

THE DESIGN OF A BUSINESS SIMULATION USING A SYSTEM-DYNAMICS-BASED APPROACH

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ABSTRACT

Research on business simulation design has been mostly on a sub-system level. Yet, the business environment is complex by nature, characterized by interconnected organizational elements with nonlinear feedback loops, and requires a systems approach to be modeled effectively. In this paper a system-dynamics based interactive model of a business enterprise simulation is developed, consisting of 18 equations. The model draws heavily upon the economic theory of the firm and the expansive body of prior research on the design of business simulations. The focus is on the linkages between the production, cost, revenues, profits and stock market value of the firm. A working model of the recommended system is tested and its empirical properties discussed.

INTRODUCTION AND PURPOSE

The design of business simulations is of high interest to the members of the Association of Business Simulations and Experiential Learning. Evidence of this interest is supported by a recent study by Peach and Platt (2002) titled "The ABSEL Research Heritage...". In this study the authors review the ten most frequently cited ABSEL papers over the past 28 years, calling them "classics", and conclude: "*the top papers seem to fall into two groups: those dealing with the construction of simulations and those dealing with learning and simulations.*" (p.261). This is not surprising as both users and developers of business simulations benefit from this type of research.

Primary interest in the design and construction of business simulations may be traced to the path breaking article by Kenneth Goosen (1981), in which he stated: "*The designing and developing of simulations at this time appears to be primarily an art form, a creative skill based on intuitive feel rather than acquired knowledge. There is a pressing need to construct a science of simulation design and development.*" (p.41).

A study by Gold and Pray (2001) found that since the Goosen (1981) article, about 50 studies were published on the algorithms used to model business simulations. Between 1982 and 1988, the algorithms centered on demand, marketing, and finance issues. In 1989 the focus shifted to the supply side, owing to the important work of Thavikulwat (1989), in which he pointed out that "*The*

problem of modeling supply...has tended to be neglected. Yet, the supply side of modeling presents issues that are at least as involved as those of the demand side." (p.37). The studies on the supply side focused on operations, quality, internal organization and human components of business simulation design. It was concluded by Gold and Pray (2001) that the open exchange, in which designers and users have shared their works, have resulted in improvements in newer simulations, such as: The Global Business Game (2000), and the Threshold Competitor (1999a & 1999b).

Still the design and modeling of business simulations needs to be an ongoing effort. Goosen, Jensen, and Wells (1999) point out a perplexing, and probably chronic, design problem, i.e. there are conflicting theories and alternative procedures that may be used to model business behavior in the areas of: accounting, economics, finance, marketing, and operations. Some examples of these conflicts were identified by: Garrison & Noreen (1997) in accounting and the treatment of fixed production costs; Goosen (1994) in finance and the valuation of stock market returns; and Cannon, McGolwan & Sung-Joon Yoon (1994) in marketing and the impact of advertising. Goosen, Jensen, and Wells (1999) outlined the current conflicts in these major functional areas of business with respect to the modeling of computerized business simulations. Certainly, as new business theories develop and evolve, it will be necessary to design and re-design business simulations.

SYSTEM-DYNAMICS BASED MODELING: THE NEXT FRONTIER

The design problems within the functional areas of business are exacerbated by the need for a systems-dynamics (SD) approach to modeling business simulations. The focus of business simulation design in the literature has been mostly on a sub-system level. Algorithms have been developed independently within the functional areas of marketing, accounting, finance, and operations without much attention to the system dynamics. However, Machuca (2000) argues, "*A systematic and holistic perception of the firm is basic for an understanding of its behavior.*" (p.231) It is pointed out that the business environment is characterized by interconnected organizational elements. Actions taken in one area may impact the performance in other areas. Sometimes the relationships have strong feedback loops and may be nonlinear in nature. There may

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be delays and inertia in the production, sales, and distribution of products. There may be interaction with the external environment that may alter the internal operations of the firm.

The message from the systems dynamics literature is clear. The business environment is complex by nature and requires a systems approach if it is to be modeled adequately. Machuca (2000) argues that real progress in management education will occur only when the use of SD (system-dynamics) becomes widespread. But the task is not simple. Davidsen (2000) states, "...the most fundamental challenge of all is that the field of system dynamics has yet to develop a consistent mathematical theory linking the behavior modes exhibited by a nonlinear feedback system to the underlying system structure."

The objective of this paper is to begin to develop a system-dynamics based interactive model for a business enterprise simulation. The model will draw heavily upon the economic theory of the firm and the expansive body of

research on the design of business simulations. The focus will be on the linkages between the production, cost, revenues, and profits of the firm. Generally accepted economic principles on the relationships between these factors will be outlined. A working model of the recommended system will be tested as an illustrative example and its empirical properties discussed. The working model will draw upon algorithms developed in prior studies.

THE BUSINESS SYSTEM-DYNAMICS MODEL

A system-dynamic model is developed by drawing upon the fundamental market and firm relationships supported by economic theory. The market system is the starting point as shown in Figure 1.

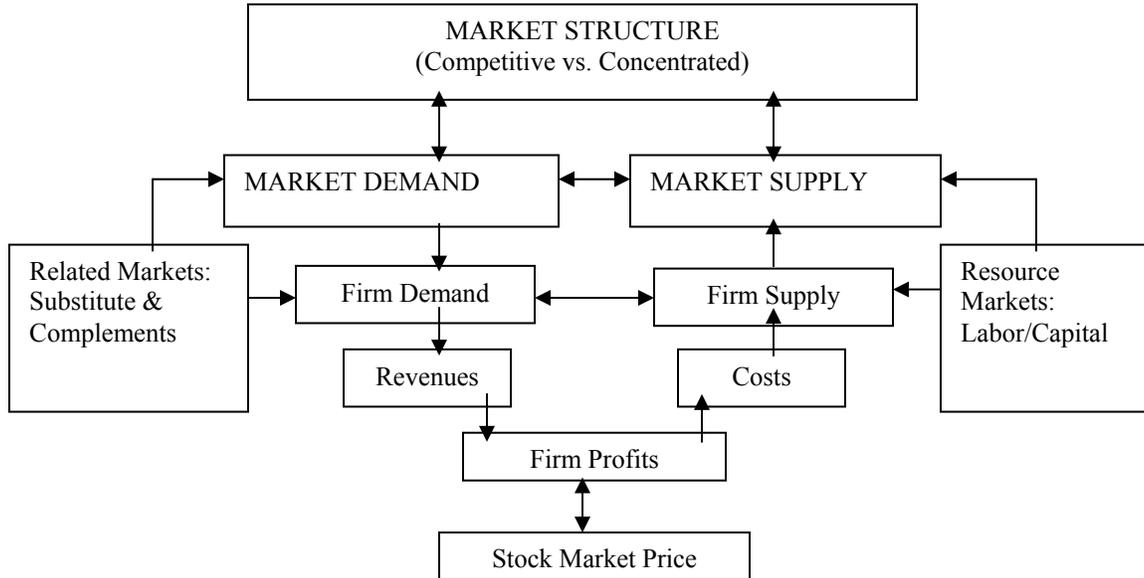


FIGURE 1: Market System Model

The initial market structure establishes the competitive nature of the market and the degree of mutual interdependence. Typical characteristics include: number of firms in the market, concentration ratios, degree of product differentiation, and market segmentation. The market demand depends on the total number of customers. The number of customers is affected by factors such as: population, demographics, income, and the markets for substitute and complement goods or services. Firm demand is influenced by several key factors, like: relative price, advertising, product quality and service. Revenues of the firm are based on demand, and add to profits. Profits affect the stock market value of the firm.

Costs take away profits and are based on the firm's supply of goods and services. The resource market determines the availability and costs of labor and capital. The ability to attract and retain workers is influenced by the firm's HR policies with respect to wages and benefits, including training and management development. Production costs are affected by the productivity of the firm. Productivity is affected by the HR decisions of the firm as well as research in new technologies and capital investment in plant and equipment.

Demand and supply on both the firm and market levels are mutually interdependent. Firm demand and supply will affect the competitive nature of the market. Relative

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market shares and concentration ratios will change. In the long-run, the entire market is affected which feeds back to the firm's performance and strategies.

The business market is a highly interactive and complex systems-dynamics model and is clearly a challenge to simulate. The methodology used in this paper is to break down the system into its major components and provide the linkages between the components. The major components include: market demand, firm demand, costs, production, profits, and stock market value. The algorithms for each component will draw upon models developed in previous studies.

MARKET DEMAND ALGORITHM

The recommended demand algorithm combines the product attribute gravity flow model developed by Teach (1990) and later modified to fit the multiplicative demand function by Gold and Pray (1999). The equation set is listed below and briefly summarized.

The market is divided into segments (j). For illustrative purposes, two demand factors (price and marketing expenditures) are included. Also, the difference (D) or gap between the attributes of the products offered for sale and the ideal product attributes desired by consumers is included as a demand factor. For a complete explanation of the product attribute variable see Teach (1990).

The total market demand for each segment is:

$$Q_j = g_1 P_j^{-(g_2 + g_3 P_j)} M_j^{+(g_4 + g_5 M_j)} D_j^{-(g_6 + g_7 D_j)} \quad (1)$$

Where the variable definitions are:

- Q_j = market demand for the segment j.
- P_j = average price of all products in segment j (harmonic mean used)
- M_j = average marketing expenditures in segment j
- D_j = average difference (d) or gap between the actual product attributes from the ideal product attributes based on customer preferences in segment j.

FIRM DEMAND ALGORITHM

The demand of firm i in market segment j (q_{ij}) is based on its market share and the size of the total market segment (Q_j).

$$q_{ij} = S_{ij} Q_j \quad (2)$$

The market share of each firm i in segment j (S_{ij}) depends on its relative price, relative marketing expenditures, and products attributes compared to the competition.

$$S_{ij} = \frac{w_{ij}}{\sum w_{ij}} \quad (3)$$

$$w_{ij} = k_1 p_{ij}^{-(k_2 + k_3 p_{ij})} m_{ij}^{+(k_4 + k_5 M_{ij})} d_{ij}^{-(k_6 + k_7 D_{ij})} \quad (4)$$

Where the variable definitions are:

- w_{ij} = weight used to calculate market share of firm i in segment j.
- $\sum w_{ij}$ = summation of weights (w) of all firms i in segment j.
- p_{ij} = price of firm i product in segment j (harmonic mean used)
- m_{ij} = marketing expenditures in of firm i in segment j
- d_{ij} = difference (d) between the actual product attributes from the ideal product attributes of firm i based in segment j

An explanation of how to solve for the parameters of the market and firm demand equations (g₁..g₇; k₁...k₇) are given in Gold and Pray (1984).

COST AND PRODUCTION ALGORITHMS

A cost and production function, consistent with the economic principles of duality theory was derived using Sheppard's lemma by Gold (1992) and is used in this model. The cost function possesses the desired properties of increasing and diminishing returns to the factors of production, economies and diseconomies of scale, and maintains a consistent relationship between production and costs. Non-separability is achieved between the variable and fixed factors, making variable costs dependent on the level of the fixed input. The cost function possesses the important duality property that maximum average (or marginal) production efficiency for each input corresponds to the point of minimum average (or marginal) cost.

The equation set for the cost function developed by Gold (1992) is listed below and briefly summarized. For illustrative purposes, two input variables (labor and materials) and one fixed input (capital) are used to specify the cost function.

$$TVC_{ij} = a_1 P_1^{a_2} P_m^{a_3} Q_{ij}^{(a_4 + a_5 Q - a_6 K)} K_{ij}^{a_7} \quad (5)$$

$$TVC_{ij} = P_1 L_{ij} + P_m M_{ij} \quad (6)$$

Where the variable definitions are:

- TVC_{ij} = total variable costs of firm i in segment j
- P_1 = price of labor
- P_m = price of materials
- Q_{ij} = quantity produced of firm i.
- K_{ij} = capital equipment and facilities of firm i.
- a_i = parameters of system
- L_{ij} = Labor of firm i for segment j product
- M_{ij} = Materials of firm i for segment j product

Equation 5 shows total variable costs to be a non-linear multiplicative function of the level of output, the level of the fixed input, and the prices of the factor inputs. Equation 6

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follows by definition. Total variable cost is the sum of the price of each input times the quantity of each input used.

A homogeneity restriction of degree one must be imposed with respect to equation 5.

$$a_2 + a_3 = 1.0 \quad (7)$$

The capital input, K, is fixed in the short-run. Fixed costs are:

$$TFC_{ij} = P_k K_{ij} \quad (8)$$

Total costs of firm i in segment j (TC_{ij}) are the sum of fixed and variable costs.

$$TVC_{ij} = TVC_{ij} + TFC_{ij} \quad (9)$$

This guarantees that if factor prices (labor & materials) increase by, say 10%, then total variable costs (TVC) will increase by 10%. This forces a consistent relationship between equations 5 and 6.

The levels of labor (L) and material (M) inputs can be derived from the cost function, as demonstrated by Gold (1992).

$$L_{ij} = a_2 TVC / P_l \quad (10)$$

$$M_{ij} = a_3 TVC / P_m \quad (11)$$

PROFIT AND STOCK MARKET VALUE ALGORITHM

Most business enterprise simulations measure student performance (success) by the increase in profits and stock market value. Surprisingly very limited research on the modeling of stock market valuation has been done with respect to business simulations. The one major work in this area is by Goosen, Foote & Terry (1994), who state: "*How simulation designers model the complex cost of capital issues is a well kept secret.*" (p.63).

The authors present a detailed financial valuation model based on modern cost of capital and capital structure principles. The major equations used to determine stock market value are presented below and used in this study. For a more detailed description and illustration of the functioning of this sub-system see the paper by Goosen, Foote & Terry (1994).

Profit is the starting point. Profit before interest expense is referred to as net operating income (NOI) and is the difference between total revenues and total variable costs (TVC).

$$NOI = \text{Total Revenue} - TVC \quad (12)$$

Subtracting interest expense (IE) and adjusting for tax rates we get net income after tax (NIAT). Dividing by the number of shares (NS) gives the net income per share after tax (NIPS).

$$NIAT = (NOI - IE)(1.0 - T) \quad (13)$$

$$NIPS = NIAT / NS \quad (14)$$

The future value of the net income per share (NIPSF) depends on the expected growth rate in net income (GR) and the number of future periods (FP). The expected growth rate is based on the historical growth in net income of the firm.

$$NIPSF = NIPS(1+GR)^{FP} \quad (15)$$

The market value per share (MVPS) is based on the current net income per share plus the discounted value of the incremental net income per share (DINIPS).

$$INIPS = NIPSF - NIPS \quad (16)$$

$$DINIPS = INIPS / (1.0 + ECC)^{FP} \quad (17)$$

$$MVPS = (NIPS + DINIPS) / ECC \quad (18)$$

It is suggested that the NIPS used in the Goosen, Foote & Terry (1994) model be an exponentially smoothed average. This is needed to stabilize the system, since a one time significant drop in NIPS would have an unrealistic effect on the MVPS. It would also minimize large fluctuation in the MVPS.

Variable definitions in the finance algorithm equations are:

| | |
|--------|--|
| NOI | = Net Operating Income |
| IE | = Interest Expense |
| T | = Tax rate |
| NS | = Number of shares of stock |
| NIAT | = Net Income After Tax |
| NIPS | = Net Income Per Share after tax (exponentially smoothed average) |
| NIPSF | = Future value of increase in net income per share |
| GR | = expected Growth Rate (based on historical growth in net income) |
| FP | = number of Future Periods |
| INIPS | = Incremental Net Income Per Share |
| ECC | = Cost of Equity Capital |
| DINIPS | = Discounted Incremental Net Income Per Share |
| MVPS | = Market Value Per Share |

It is pointed out by Goosen, Foote, & Terry (1994) that the dividend payout rate is not included. The authors argue that this is consistent with the branch of theory that dividend payout has no effect on the cost of capital and therefore the market value per share of stock.

TESTING THE SYSTEM

Numerous scenarios could be used to test the dynamic behavior of the proposed system of equations. But only one scenario is simulated for sake of brevity. The objective in this study is to highlight and demonstrate: (1) the

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functioning of the components of the system (i.e. demand, cost, production, profits and stock market value), (2) the interaction between the components of the system and (3) the system-based dynamics.

The model developed to test the system is an oligopoly market composed of 6 firms. The parameters of the system were designed to be consistent with the characteristics of the

standard oligopoly market as described by economic theory. The selected scenario is that one of the firms in the market lowers price and increases production to meet demand, holding other decisions constant (i.e. the prices of the other rival firms, marketing expenditures, product attributes, capital investment, etc.). The results of this scenario on the simulated system are show in Table 1.

Table 1: Impact of a Firm Lowering Price and Increasing Production

| Price (\$/unit) | Sales Units (thousands) | Market Share (%) | Total Revenue (thou.\$) | Total Costs (thou.\$) | Net Income After Tax (thou.\$) | Stock Price (\$/Share) |
|-----------------|-------------------------|------------------|-------------------------|-----------------------|--------------------------------|------------------------|
| \$12.25 | 171 | 8.22 | \$2,098 | \$1,760 | \$203 | \$24.49 |
| \$12.00 | 185 | 8.83 | \$2,220 | \$1,871 | \$209 | \$25.04 |
| \$11.75 | 200 | 9.50 | \$2,350 | \$1,993 | \$215 | \$25.49 |
| \$11.50 | 216 | 10.21 | \$2,488 | \$2,124 | \$218 | \$25.81 |
| \$11.25 | 234 | 10.97 | \$2,634 | \$2,267 | \$220 | \$25.96 |
| \$11.00 | 253 | 11.79 | \$2,788 | \$2,422 | \$219 | \$25.91 |
| \$10.75 | 273 | 12.63 | \$2,937 | \$2,581 | \$214 | \$25.43 |
| \$10.50 | 294 | 13.47 | \$3,083 | \$2,744 | \$204 | \$24.56 |
| \$10.25 | 316 | 14.37 | \$3,236 | \$2,920 | \$190 | \$23.44 |
| \$10.00 | 339 | 15.32 | \$3,394 | \$3,115 | \$168 | \$21.80 |
| \$9.75 | 365 | 16.33 | \$3,558 | \$3,395 | \$98 | \$17.55 |
| \$9.50 | 392 | 17.39 | \$3,728 | \$3,901 | -\$104 | \$10.29 |
| \$9.25 | 422 | 18.70 | \$3,903 | \$4,675 | -\$463 | \$4.23 |

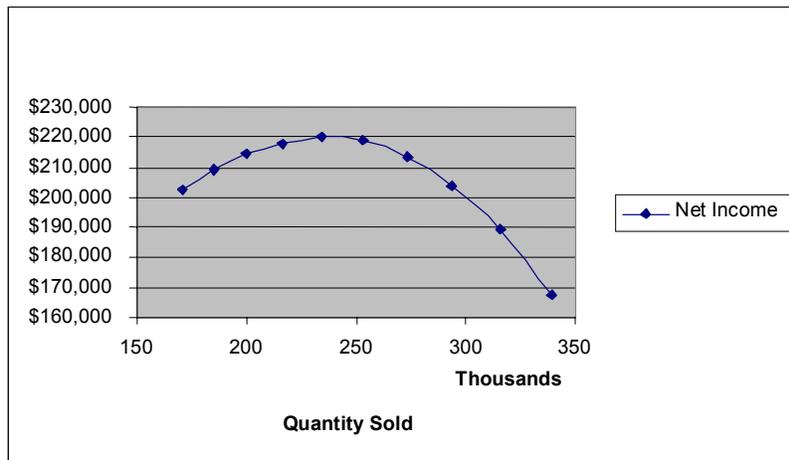


FIGURE 2: Impact of Sales on Profits (Net Income)

DISCUSSION OF RESULTS

It can be seen that as price is lowered by only one firm in the market, there is a continuous increase in sales, market share, and total revenues. However, net income after tax (NIAT) and stock price increase up to a point (at a sales

level of 273 units) and then decline. The relationship between NIAT and sales is shown in Figure 2.

The interesting question is why net income (NIAT) declines after a point. To understand the behavior of the system, we look at each of the components, starting with the demand function.

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DEMAND FUNCTION

As price is lowered, the firm's weight in equation 4 is increased. This will increase market share in equation 3 and firm demand in equation 2. Firm demand is market share multiplied by industry demand. The factors affecting industry demand are held constant except for the average industry price, which declines slightly, causing industry demand to increase (equation 1). The extend of the increase in demand, and firm revenues, is based on the price

elasticity, which depends on the selected parameter values (g_i and k_i). Figure 3 shows the demand function with the corresponding marginal revenue schedule. The marginal revenues decline as price is lowered and quantity demanded increases. This means that although total revenues increase with sales, the incremental (marginal) gains in revenues to the firm are lowered each time price is lowered to increase sales. In part, this begins to explain the reason firm profit declines after a point. But the cost structure of the firm must be examined as well.

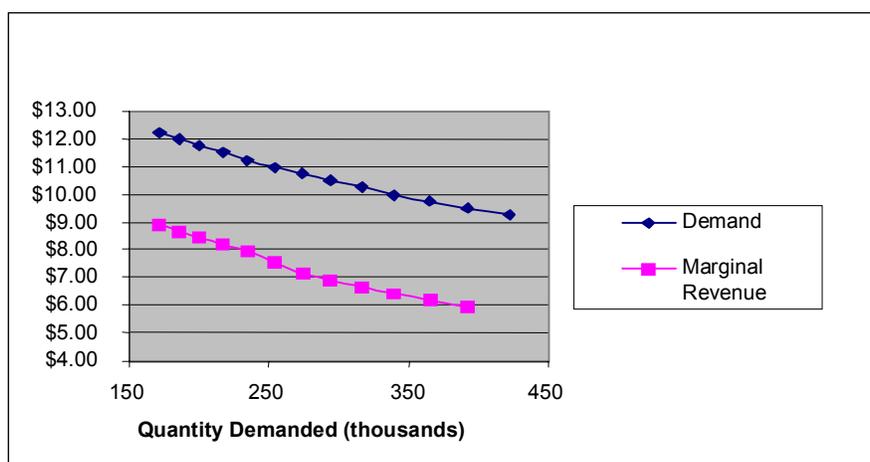


FIGURE 3: Demand and Marginal Revenues

TABLE 2: Average and Marginal Costs

| Production (thousands) | Total Costs (thou.\$) | ATC | MC |
|------------------------|-----------------------|-------|-------|
| 171 | \$1,760 | 9.33 | xxx |
| 185 | \$1,871 | 9.23 | 8.10 |
| 200 | \$1,993 | 9.15 | 8.08 |
| 216 | \$2,124 | 9.07 | 8.06 |
| 234 | \$2,267 | 8.99 | 8.04 |
| 253 | \$2,422 | 8.92 | 8.03 |
| 273 | \$2,581 | 8.85 | 8.01 |
| 294 | \$2,744 | 8.79 | 7.99 |
| 316 | \$2,920 | 8.73 | 7.97 |
| 339 | \$3,115 | 8.70 | 8.22 |
| 365 | \$3,395 | 8.86 | 10.98 |
| 392 | \$3,901 | 9.52 | 18.39 |
| 422 | \$4,675 | 10.69 | 26.17 |

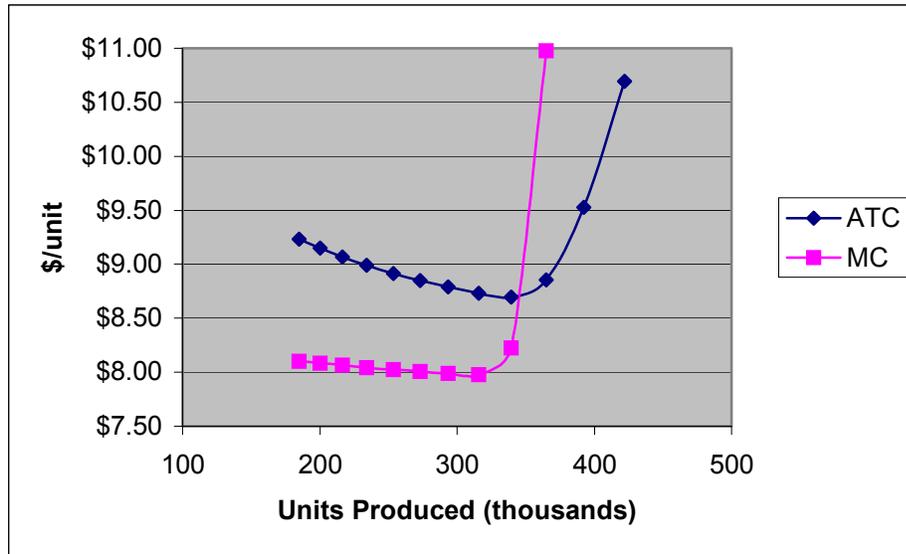


FIGURE 4: Average and Marginal Costs

COST FUNCTION

Table 1 shows that total costs increase with production, but the relationship is not linear. From equation 6 we can see that as production (Q) rises, a point will be reached where total variable costs (TVC) increase at an increasing rate. To understand the impact of production on costs, it is useful to derive the average and marginal costs. Table 2 shows that average total costs (ATC) initially declines, but after a point begin to increase, owing to the rise in marginal costs. This is shown graphically in Figure 4.

The rise in total costs is another contributing factor to the eventual decline in profits. The rise in average and marginal costs can be explained by the production function of the firm.

PRODUCTION FUNCTION

The cost function is based on the production relationship of the firm. Equations 10 and 11 show the required levels of inputs (labor and materials) needed to produce a given level of output. The level of output determines the level of variable costs (TVC), based on equation 5.

Table 3 shows the required level of labor, derived from equation 10, for each production level. From the labor hours, the average product of labor (APL) and the marginal product of labor (MPL) are calculated. Average product of labor initially rises, but after a point declines. This is shown graphically in Figure 5. The decline in the productivity of

TABLE 3: Average and Marginal Productivity of Labor

| Production (thousands) | Labor hours (thousands) | APL | MPL |
|------------------------|-------------------------|------|------|
| 171 | 183 | 0.93 | xxx |
| 185 | 196 | 0.94 | 1.08 |
| 200 | 210 | 0.95 | 1.09 |
| 216 | 225 | 0.96 | 1.10 |
| 234 | 241 | 0.97 | 1.11 |
| 253 | 258 | 0.98 | 1.12 |
| 273 | 275 | 0.99 | 1.14 |
| 294 | 293 | 1.00 | 1.15 |
| 316 | 312 | 1.01 | 1.16 |
| 339 | 333 | 1.02 | 1.12 |
| 365 | 366 | 1.00 | 0.77 |
| 392 | 433 | 0.91 | 0.41 |
| 422 | 568 | 0.74 | 0.22 |

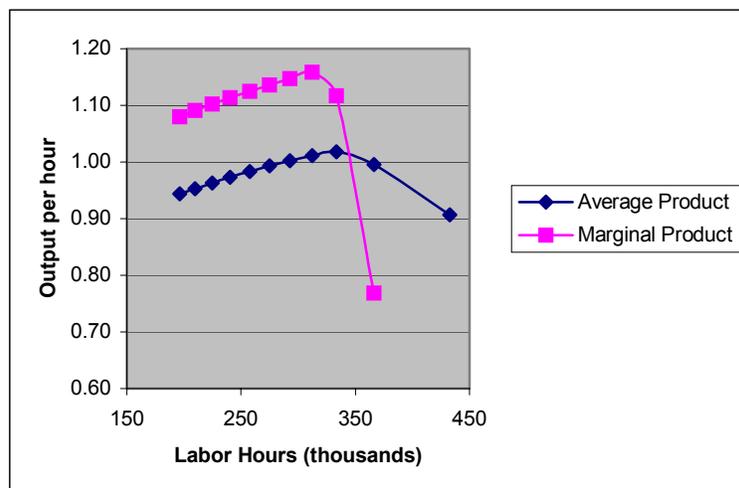


FIGURE 5: Labor Productivity

labor accounts for the rise in average and marginal costs, and is consistent with the duality theory in economics. This further explains the decline in profits as production increases to meet demand.

PROFITS AND STOCK MARKET VALUE

The change in the stock market value of the firm is directly related to the profits of the firm or net income after taxes (NIAT). As profits decline, the expected growth rate (GR) and expected future net income per share after tax (NIPSF) declines (see equation 15).

CONCLUSIONS

The design of computerized business simulations has focused on the development of its subsystems, such as: demand, marketing, operations, accounting and finance. However, it is clear from the system-dynamics literature that a more holistic approach is needed.

The business environment is a highly interactive system. Decisions in one area, like marketing and sales, will affect the other functional areas of the business. Complex feedback loops exist and may give rise to unexpected results that are difficult to understand and interpret. Users of business simulations, both students and faculty, are often perplexed concerning the outcomes associated with particular simulations. For these reasons it is important, from a management education perspective, to model and view the business system as a whole.

In this study, a system-dynamics based interactive model of a business enterprise simulation was developed and tested. The model utilized several algorithms of subsystems (demand, operations, costs, etc.) that were developed in prior studies. The purpose was to show the

linkage and interactions between the subsystems previously developed.

A relatively simple example was simulated to illustrate and explain the behavior of the system. In the example, a change in price and production created a non-linear profit function that initially increased, reached a maximum, and then declined. Profits declined despite the fact that sales and revenues continued to increase. The system results were explained by examining the interactive effects between the demand, revenue, production and cost functions of the firm. After a point, it was shown that productivity declined, causing unit costs to increase more than revenues, and bring about the decline in profits. The example shows that a holistic perception of the firm is needed to truly understand and explain the outcome of the business system. This supports the conclusion by Machuca (2000) that *“management education will make real progress both in effectiveness and scope only when the use of SD (system-dynamics) becomes widespread.”* (p.233)

To continue to advance the state of business simulation design and use, and management education, it is critical to open the “black box” and debate the equations and algorithms used to model the business system. Clearly, more research emphasis needs to be placed on the system level rather than the subsystem, but both need to be addressed in a coordinated effort. Goosen, Jensen, and Wells (1999) point out that in the core business disciplines, conflicting theories exist that may require the simulation designer to make difficult choices concerning how to model a particular subsystem. The algorithms selected in this study to model the business system should be viewed as part of an ongoing effort to further develop the state of business simulation design. Further scrutiny of the system in this paper is encouraged, along with the development of more advanced business systems.

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