A Strategic Agricultural Production Model with Risk and Return Considerations

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Decision support systems are generally geared to short-term tactical decision making. As an alternative, this paper develops a mathematical programming model to evaluate long-term strategic alternatives in the context of farm-level agricultural production where a broiler farm considers long-term implications of diversification into commercial aquaculture. The model considers a ten-year strategic planning horizon, incorporates financial risk and return considerations, and accommodates capacity variations. Results indicate that a diversification strategy significantly increases farm profitability over a strategic planning horizon while simultaneously maintaining financial risk below a predetermined tolerance level and return on investment above a predetermined level.

Organizations, facing the uncertain nature of the business environment, have implemented strategic management as a primary means of survival. Traditionally a task only for top management, changed circumstances have motivated the inclusion of numerous functional areas within the organization into the strategic planning process. Specifically, a change in priorities for planning, which gives more emphasis to the operations/production (O/P) function, is forcing a new relationship between strategic planning and the O/P function. Requirements in the O/P function are now being considered as major priorities with respect to strategic planning, as opposed to the strategic planning process forcing constraints on the O/P function (Helms; Adam and Swamidass).

The changing priorities over the role of the O/P function in the strategic planning process pose new demands for decision support tools tailored to address strategic issues. The O/P function has been a major beneficiary of advances in operations research methodologies; however, compatible to the traditional role of the O/P function in an organization, many of those methodologies were geared to short-term tactical and operational decisions. The integration of strategic planning and the O/P function requires availability of decision models covering longer time spans and having more versatility to reflect the unique features of long-term decisions. In a review of operations management literature and operations strategy, Adam and Swamidass made two points: (1) researchers have ignored the importance of operations management to strategic planning and (2) theory building in operations strategy is seemingly stalled by a lack of quality empirical research.

This article offers empirical research that demonstrates the importance of involving the O/P function in the overall strategic planning process. Specifically, this paper develops and applies an aggregate production planning-based mathematical decision model for strategic planning in farm-level agricultural production where an individual broiler farm considers diversification into commercial aquaculture. Typically, aggregate production planning models facilitate production planning decisions over medium-range planning horizons. In this paper, the aggregate planning model is augmented and transformed to produce a nonlinear mixed integer programming model that has the capability to evaluate production capacity variations and accommodate risk and return preferences. Because diversification can potentially increase risk and affect return on investment (ROI), measures of risk and return were essential inputs into the strategic planning model.

The Nature of the Problem

The Broiler and Aquaculture Industries

As a core industry in the Mid-Atlantic region's agricultural sector, broiler production has aided rural development by supporting farm income and creating employment. In specific states of the Mid-Atlantic region, broiler production contributes from 56% to 60% of rural household income (Taylor and Elterich). In the last decade, the broiler industry has experienced rapid expansion in both production and consumption due to better technologies and changes in consumer preference. Although the industry will continue expanding, the growth rate in the next decade is expected to be lower. In view of these changing circumstances, broiler growers face strategic decisions concerning diversification into alternative commodities as a method of creating an alternative income source and as a method of managing risk. An alternative commodity suggested for this purpose is commercial aquaculture (Gempesaw and Bacon).

Commercial aquaculture has several attractive features as a production alternative. Besides being a closely related product to broilers in terms of consumer product substitutability, future markets for aquaculture products are expected to expand significantly (Sandifer). In terms of production, commercial aquaculture has been one of the fastest growing agricultural commodities in the United States and is viewed as a future growth industry. Hybrid-striped bass (HSB) is an aquaculture product identified as having economic potential for farmers in the Mid-Atlantic region. New to the aquaculture product market, HSB commands a significantly higher price than broilers with producers expected to experience investment returns as high as 20% (Gempesaw et al.). Studies suggest HSB as a potential candidate for aquaculture in the Mid-Atlantic region (Hodson et al.) and indicate HSB as an alternative for broiler farmers considering product diversification (Gempesaw et al.). Although the adoption of aquaculture in developing countries as a supplement to poultry farming has been shown to be technically feasible (Schroeder, 1980), economic feasibility is determined by several other factors such as input prices, availability of natural resources, market conditions, investment costs and risk considerations.

The existence of output and contract price agreements between poultry farmers and processors limits the variability of poultry farmers' earnings, making poultry farming a low-risk agricultural activity. Commercial aquaculture, however, is more risky. Aquaculture requires higher fixed overhead costs, causing more financial risk. An aquaculture farmer does not enjoy the contractual production arrangement characterizing poultry production; the farmer is directly exposed to price fluctuations in the product market. Although most aquaculture producers maintain one production cycle per year, farmers can expect to earn higher returns commensurate with the increased financial risk.

Because poultry farming is a relatively low-risk operation, diversification of a poultry farm into an integrated poultry-aquaculture farming system can potentially lower variable operating costs while simultaneously exposing the farmer to higher risk because poultry farming is relatively less risky. A primary benefit of poultry-aquaculture integration systems, as observed in developing countries, is the reduction in variable aquacultural production costs. These benefits are partially attributable to the fact that, in developing countries, poultry can be partially physically housed directly over aquaculture ponds, providing natural fertilization for plants, which finfish ultimately consume (Alsagoff, Clonts and Jolly; Schroeder, 1980). However, this type of primitive production (i.e., 100% of feed costs derived from animal manure) is not likely to exist in the United States. Another benefit of an integrated system is that the two production processes share certain fixed costs leading to economies of scope attributable to more efficient use of common resources.

Implementation of an integrated production plan under diversification should be preceded by a thorough evaluation of its economic feasibility to monitor the cost-benefit tradeoffs and to determine the optimal level of integration. This article provides a structured mechanism for such an evaluation by developing a mathematical decision model that serves two purposes: (1) evaluation of long-term economic benefits of diversification at an individual farm level and (2) establishment of optimal long-term production levels under diversification subject to financial risk and *ROI* considerations. The model provides an optimal strategy to pursue (i.e., diversify or not diversify), optimal production levels, optimal capacity requirements and optimal capacity utilization for the selected strategy.

Past Literature

Two major features distinguish the modelling approach of this paper from typical approaches to investment analysis (e.g., Barry (1984)). First, the model in this paper provides an optimization

framework in which constraints regarding risk and *ROI* can be externally imposed by the decision maker. Second, the model integrates long-term and medium-term planning by simultaneously considering risk, return, capacity variations, short-term costs and long-term costs.

Gempesaw and Bacon evaluated the economics of output specialization and diversification in the production of broilers, hybrid-striped bass and catfish using data for representative farms over a ten-year planning horizon. Their simulation study generated, among key output variables, risk and return information for various diversification scenarios. As opposed to simulation, this paper develops closed-form optimizing models to evaluate the economic feasibility and set appropriate levels of diversification subject to risk and *ROI* tolerances. In addition, the model developed in this paper provides an optimization framework in which constraints regarding risk and *ROI* can be externally imposed.

Previous works in the specific application of mathematical optimization models to aquaculture include Alsagoff, Clonts, and Jolly as well as Wilson, Shaftel, and Barefield. Alsagoff et al. analyzed long-term (ten years) economic viability of aquaculture farming, integrated with small wet-rice farms in Malaysia, by considering long-run biological, production, financial, and marketing constraints. The model focused on long-term policy implications rather than farm-level production decisions. Wilson et al. presented a medium-term planning model that enabled management of an aquaculture facility to develop optimal production schedules for a given technology, consistent with the requirement of economic feasibility. Their model determined medium-term production decisions of a pilot aquaculture facility that was not part of any integrated aquacultural system.

The model in this paper moves beyond previous works by integrating the strategic scope of Alsagoff et al. with the operational scope of Wilson et al. within an optimization framework. The strategic decision model in this article is based on an aggregate planning model. A traditional aggregate planning model is conceptually a short-term or medium-term planning and scheduling tool that lacks the capability to evaluate alternative courses of actions pertaining to strategic decisions. In this paper, an aggregate production planning model is used as the basis for structuring a strategic process involving the selection of an optimal farm-level diversification strategy in agricultural production where risk and return are essential long-term considerations.

Model Formulation

Measurement and Operationalization of Risk

In this paper, risk is defined as variability of expected earnings. A measure for risk is developed using three accounting concept of leverage: degree of operating leverage (*DOL*), degree of financial leverage (*DFL*) and degree of combined leverage (*DCL*). The concept of leverage deals with the effects of fixed operating and financial commitments on a firm's earnings. Variability of earnings is ascribed to a business' commitment to fixed obligations and its magnitude is a function of the level of fixed commitments and the scale of the production activity (Helfert). In the absence of fixed-cost obligations, a change in production volume translates into a proportional change in profit, leaving the rate of return unaffected. Existence of fixed commitments distorts this relationship. For example, with fixed-cost commitments, a 10% change in volume would cause more than a 10% change in earnings. Profit variability increases as fixed-cost commitments increase.

Fixed commitments arise due to the inherent characteristics of the underlying production process and the manner in which the production process is financed. The degree of operating leverage (*DOL*) is the extent to which a production operation is loaded by fixed operating costs and is theoretically defined as:

$$DOL = \frac{\%\Delta \; Earnings \; Before \; Tax \; and \; Interest}{\%\Delta \; Production \; Volume}$$

(1)

DOL is a measure of the elasticity of income before interest and tax (*EBIT*), with respect to volume, caused by the existence of fixed operating costs (Helfert).

In addition to operating costs, firms face fixed interest commitments due to opting for debt over equity as a financing source. The existence of fixed interest costs affects the variability of a firm's net earnings. In the absence of debt financing, any variation in operating income (*EBIT*) is translated directly into a proportional variation in net income. With fixed interest costs, a variation in operating income becomes magnified (or leveraged) into an exceedingly proportional change in net income. This effect, known as financial leverage, is measured by the degree of financial leverage (*DFL*) and is theoretically defined as (Helfert):

$$DFL = \frac{\%\Delta \ Earnings \ Before \ Tax}{\%\Delta \ Earnings \ Before \ Interest \ and \ Tax} \cdot$$

(2)

A firm faces both operating and financial leverage. The magnified variations in net income include the combined effects of fixed-cost production methods and fixed-cost financial arrangements. The combined effect, defined as the degree of combined leverage (*DCL*), is the product of *DOL* and *DFL*. To derive an operational measure of the degree of combined leverage, define Earnings Before Tax (*EBT*) as $EBT = (\alpha - \gamma)x - (F + I)$, where α is selling price per unit, γ is variable cost per unit, F is fixed operating costs, I is interest costs and x is production volume in units. Now,

$$DCL = \frac{\%\Delta \ EBT}{\%\Delta \ x} = \frac{d \ EBT}{dx} \frac{x}{EBT} = \frac{(\alpha - \gamma)x}{EBT}$$

(3)

where $(\alpha - \gamma)$ is total contribution margin (CM) (i.e., sales − variable costs). Dividing both sides by a constant CM ratio (CM/sales) yields

$$(4) \qquad DCL_S = \frac{1}{\dfrac{EBT}{\alpha x}} = \frac{1}{\lambda}$$

where λ, the profit margin ratio, is

$$\lambda = 1 - \frac{\gamma}{\alpha} - \frac{(F + I)}{\alpha x} =$$

(5) $\qquad f(\alpha, \gamma, (F + I), x).$

This surrogate measure of risk, λ, unveils the underlying determinants of risk. The parameters of α and γ are usually exogenously determined in the product and input markets, respectively. They may be considered as surrogates for the externally induced component of risk reflected in λ. γ may also be influenced by the efficiency with which inputs are utilized internally. Therefore, the internally induced component of risk in λ may be defined as a function of fixed commitments $(F + I)$ and the scale of production x. Other parameters constant, as $(F + I)$ increases, λ decreases resulting in DCL_s increasing, indicating higher risk. Similarly, as x increases, λ increases resulting in DCL_s decreasing, indicating lower risk.

Generally, the level of fixed commitments is dictated by and incidental to investment and financial decisions. Thus, one opportunity for attaining a desired level of risk lies in varying the scale of

production. Given $(F + I)$ implied by investment and financial decisions, the level of risk can be reduced by expanding the scale of production. Given a specified level of fixed operating and financial costs, to maximize λ (i.e., to reduce DCL_s), production volume should theoretically be infinitely large. However, as scale of production is increased, the reduction in risk is limited. As volume becomes arbitrarily large, DCL_s approaches $\alpha/(\alpha - \gamma)$. This result signifies the practical impossibility of a risk-free venture even with an infinite expansion in production.

In reality, scale of production cannot be infinitely large; practical factors force production levels to be within feasible ranges. If a lower bound is imposed on the profit margin, reflecting the maximum level of risk the entrepreneur is willing to tolerate, then a lower bound is implicitly imposed on production volume. Let L denote the minimum acceptable λ (i.e., maximum tolerable risk) for a given production operation. From equation (5), $\lambda \geq L$ imposes the following production volume constraint:

$$(6) \qquad x \geq \frac{(F + I)}{\alpha(1 - L) - \gamma} \cdot$$

Equation (6) can subsequently be used as a risk constraint in aggregate production planning models for strategic decisions in various production decision alternatives.

Measurement and Operationalization of Return

Return is defined as a return on investment (*ROI*) over a planning horizon and can be measured as $ROI = $ Total Before Tax Profit/Total Investment.

Let $T = $ number of operating periods in the planning horizon,

$\mu = $ capacity in production units of a production facility,

$\gamma_t = $ variable cost per unit in period t,

$\delta_t = $ contribution margin per unit in period t,

$\theta_t = $ operating costs of a facility in period t,

$\phi = $ capital costs traceable to a production facility including those nontraceable to the product type,

$\psi = $ nontraceable capital costs,

$x_t = $ production volume in period t,

$k_t = $ number of production facilities in use in period t,

$m = $ number of production facilities available in the planning horizon.

ROI can be expressed as:

ROI =

$$
(7) \quad \frac{\sum_{t=1}^{T} \delta_t x_t - \left(\sum_{t=1}^{T} \theta_t k_t + \Phi m + \Psi \right)}{\sum_{t=1}^{T} \gamma_t x_t + \sum_{t=1}^{T} \theta_t k_t + \Phi m + \Psi}.
$$

Assuming a sold-out market, an optimal production strategy, one that maximizes total profit, requires (1) full capacity utilization of a production facility in an operating period, and (2) full utilization of all facilities available over the planning horizon in each operating cycle. Utilization of a facility below its capacity causes an inefficient use of the fixed operating costs. Full capacity utilization spreads the operating costs over a larger volume resulting in more profitability. Likewise, deployment of facilities below the number available in a planning horizon would be an inefficient use of fixed traceable capital costs associated with the facilities available.

Thus, given the cost structure of a firm, and the prevailing prices and costs in the planning horizon, the optimal *ROI* (ρ) can be defined as:

$$
(8) \quad \rho = \frac{\sum_{t=1}^{T} \delta_t(\mu m) - \left(\sum_{t=1}^{T} \theta_t m + \Phi m + \Psi \right)}{\sum_{t=1}^{T} \gamma_t(\mu m) + \sum_{t=1}^{T} \theta_t m + \Phi m + \Psi}.
$$

Letting

$$
\Gamma = \mu \Sigma \gamma_t,
$$
$$
\Delta = \mu \Sigma \delta_t,
$$
$$
\Theta = \Sigma \theta_t,
$$

equation (8) can be written as

$$
(9) \quad \rho = \frac{\Delta m - (\Theta m + \Phi m + \Psi)}{\Gamma m + \Theta m + \Phi m + \Psi}.
$$

Equation (9) defines the optimal *ROI* as a function of *m* which, in turn, is a function of the scale of production (*x*). The higher the scale of production, the higher ρ due to a more efficient utilization of fixed resources. There is, however, an upper bound on ρ when the scale of production is expanded. Allowing *m* to approach infinity,

$$
(10) \quad lim_{m \to \infty} \rho = \frac{\Delta - (\Theta + \Phi)}{\Gamma + \Theta + \Phi}.
$$

Equation (10) provides the theoretical maximum optimal *ROI*, given the cost structure of a firm. In reality, *m* cannot be infinitely large. Practical factors, particularly demand, force *m* to be within a feasible range. Increasing *m* within a feasible range improves ρ. Imposing a lower bound on ρ, reflecting the minimum desired *ROI*, forces a lower bound on *m*. Let *r* be the minimum desired *ROI*. From equation (9), $\rho \geq r$ imposes the following constraint on *m*:

$$
(11) \quad m \geq \frac{-(1 + r)\Psi}{[\Gamma r + (1 + r)(\Theta + \Phi) - \Delta]}.
$$

Equation (11) may be used to determine the size of a firm to attain a specified *ROI* over a long term planning horizon. However, before applying equation (11), it might be necessary to check if the specified *ROI* level (i.e., the *r* value) is indeed attainable by evaluating equation (10).

The Model

The model evaluates the economic benefits of a broiler grower diversifying into aquaculturally produced hybrid-striped bass (HSB). The model assumes each of these two products can be produced in non-diversified systems (i.e., a system that produces only broilers or only HSB) and all contribution margins and costs incurred in a non-diversified production system are known. Diversification of a broiler farm into an integrated broiler/HSB facility has two potential economic advantages over non-diversified production systems: (1) certain fixed costs are shared between the two types of production systems and (2) a diversified system generates a small per-unit variable production cost savings in HSB due to the potential of poultry by-products to provide natural fertilization for pond system plants, which serve as partial fish feed.

However, diversification also generates increased financial risk. The increased risk associated with diversification into aquaculture stems from three sources: a) noncontractual production, thereby exposing the farmer directly to market variability, b) higher operating commitments, thereby increasing operating risk, and c) higher investment needs requiring debt financing, thereby increasing financial risk.

The model evaluates the economic benefits of a diversified system versus non-diversified production systems. If diversification is economically

beneficial and feasible with respect to risk tolerance, the model simultaneously determines the optimal level of diversification (i.e., how many ponds should be built?) and the corresponding period production quantities for both broilers and HSB. If diversification is not economically beneficial or not feasible with respect to risk tolerance, the model determines optimal period production quantities for broilers and sets period production quantities for HSB to zero. The mathematical programming formulation is as follows:

δ_{it} = contribution margin per unit of product i in period t,

μ_i = per period capacity of the production facility used to produce product i (i.e., a type i production facility),

D_{it} = demand for product i in period t,

$\Delta_i = \mu_i \sum\limits_t \delta_{it}$

$\Gamma_i = \mu_i \sum\limits_t \gamma_{it}$

Φ_i = capital costs of a type i production facility,

ϕ_{it} = traceable capital costs allocated to period t, for a type i facility,

$$(12) \quad MAX \sum_{t=1}^{T_1} [\delta_{1t} (D_{1t} - s_{1t}) - \theta_{1t} k_{1t}] - \Phi_1 m_1 - \Psi_1$$

$$+ \left[w \sum_{t=1}^{T_2} ((\delta_{2t} + v_t) (D_{2t} - s_{2t}) - \theta_{2t} k_{2t}) - \Phi_2 m_2 - \Psi_2 \right] - \Omega$$

subject to:

$$(13) \quad D_{it} - \mu_i k_{it} = s_{it} \quad \forall \quad i, t$$

$$(14) \quad k_{1t} \le m_1 \quad t = 1, \ldots, T_1$$

$$(15) \quad k_{2t} \le w \, m_2 \quad t = 1, \ldots, T_2$$

$$(16) \quad \mu_2 \, k_{2t} \ge \frac{w(\theta_{2t} k_{2t} + \phi_{2t} m_{2t} + \Psi_{2t})}{\alpha_{2t} (1 - L) - \gamma_{2t}}$$

$$t = 1, \ldots, T_2$$

$$(17) \quad m_2 \ge \frac{-(1 + r) (\Psi_2 + \Omega)}{\Gamma_2 r + (1 + r) \left(\sum\limits_{t=1}^{T_2} \theta_{2t} + \Phi_2 \right) - \Delta_2}$$

$$s_{it} \ge 0; \, k_{it}, \, m_{it}$$

≥ 0 and general integer, w integer 0/1

where

i = product index; $i = 1$ denotes the broiler product, $i = 2$ denotes the HSB product,

T_i = number of production periods associated with product i during the strategic planning horizon,

α_{it} = selling price per unit of product i in period t,

γ_{it} = variable cost per unit of product i in period t,

v_t = variable per unit cost savings in HSB in period t attributable to HSB being produced in an integrated broiler/HSB system,

Ψ_i = capital costs traceable to product i but nontraceable to the type i production facility,

Ω = capital costs nontraceable to product type or to the production facility,

Ψ_{it} = capital costs, traceable to product i and nontraceable, allocated to period t,

θ_{it} = operating costs of a type i facility in period t,

L = desired profit margin from HSB production,

r = minimum desired return on investment from HSB production.

s_{it} = production shortage of product i in period t,

k_{it} = number of type i production facilities used in period t,

m_i = number of type i production facilities available for use during the planning horizon,

w = strategic 0/1 variable; $w = 1$ if diversification into the HSB product, 0 otherwise.

Equation (12) represents total contribution to profit less all operating and capital costs (shared and non-shared) plus variable cost savings in HSB production if diversification occurs. Equation (13) defines, for both product types, production and shortages in terms of production capacity each period. Equation (14) restricts the number of broiler houses in use each period (8.5 weeks) to be no more than the number available over the entire planning horizon. Equation (15) restricts the num-

ber of ponds in use each period (one year) to be no more than the number available over the entire planning horizon. Equation (16) is the application of the risk constraint of equation (6). Equation (16) forces annual production of HSB to a minimum level so that the financial risk associated with HSB production does not exceed the pre-specified maximum tolerable level. Equation (17) forces the number of ponds available for use over the planning horizon to a minimum level so that the *ROI* associated with HSB production exceeds a pre-specified minimum tolerance level.

Implementation and Results

Data Construction

Input parameters for the model were constructed from data on initial prices, production costs and production capacity for representative broiler and HSB farms, reflecting current characteristics, as used in the simulation model of Gempesaw and Bacon. Forecasted annual growth rates of broiler prices, agricultural production expenses and broiler production in the United States, over the years 1991–2000 were obtained from a recent WEFA report.

Tables 1 and 2 present cost estimates constructed from the simulated data of Gempesaw and Bacon. Variable and fixed operating costs for both

Table 1. Cost Estimates for Broiler Production

Type of Cost	Item	Cost
Variable	labor	$0.008 per pound
Fixed Operating	utilities	$600
	maintenance	100
	other	320
		$1,020
		per house per period
Fixed Capital		
Traceable	house	$50,000
	land	1,895
	interest on capital	25,474
	property tax	1,905
		$79,274
		per house over
		planning horizon
Nontraceable	tractors	$59,375
	trucks	18,750
	all-terraine vehicle	8,750
	interest on capital	17,375
	property tax	1,300
		$105,550
		over planning horizon

Table 2. Cost Estimates for HSB Production

Type of Cost	Item	Cost
Variable	labor	$0.128/lb
	fingerlings	0.750
	feed	0.500
	harvesting/hauling	0.050
		$1.428/lb
Fixed Operating	utilities	$2,888
	maintenance	656
	other	682
		$4,226
		per pond per period
Fixed Capital		
Traceable	pond	$20,839
	wells	6,250
	land	9,475
	aerators	5,500
	interest on capital	9,829
	property tax	735
		$52,628
		per pond over
		planning horizon
Nontraceable	tractors	$59,375
	trucks	18,750
	all-terraine vehicle	8,750
	boat	4,000
	feeder	5,000
	testing devices	3,600
	backup aerators	2,000
	building	10,000
	shed/lab	10,000
	interest on capital	24,200
	property tax	1,810
		$147,485
		over planning horizon

poultry and HSB were allowed to increase at the forecasted growth rates of agricultural production expenses over the years 1991–2000 (i.e., a ten-year planning horizon) provided by WEFA. Decisions concerning capacity allocations are made at the beginning of the planning horizon so that capital costs remain constant throughout the planning horizon. A production facility for broiler production is a broiler house. In computing capital costs for the broiler farm, it was assumed that the broiler grower finances half of the required investment using external debt. An interest cost of 5% and a 0.187% annual property tax were assumed. A production facility for an HSB production is a five-acre fish pond. In constructing capital costs for HSB production, an interest rate of 5%, an annual property tax of 0.187% and debt-financing equivalent to half of the total capital investment requirements were assumed.

A typical broiler production cycle is approximately two months (8.5 weeks), generating approximately six discrete production periods per

year and sixty discrete periods over a ten-year planning horizon. The 1991 output prices for broilers averaged $0.034 per pound (Gempesaw and Bacon). The initial price was allowed to increase at the forecasted annual growth rates in broiler prices over the years 1991–2000 (i.e., a ten-year planning horizon). To develop demand forecasts over the planning horizon, it was assumed that current capacity reflects existing demand and this figure was allowed to increase at the forecasted growth rates in broiler production over the years 1991–2000.

HSB fingerlings are stocked once per year, generating one production period a year for a total of ten periods over a ten-year planning horizon. The 1991 wholesale market prices for HSB averaged $2.35 per pound (Maryland Department of Agriculture). This price was allowed to increase at the forecasted annual growth rates in broiler prices over the period 1991–2000. Because commercial aquaculture is a relatively small sector in U.S. agriculture, data on sectoral characteristics, let alone farm-level data, are scarce. In the absence of such data, price forecasts for HSB were developed using the forecasted annual growth rates in broiler prices. The justification lies in the fact that the two product types are related in that major determinants of their price dynamics, such as consumer taste and income, influence their prices in a similar fashion. To develop demand forecasts, it was assumed that current capacity reflected existing demand. Given growth rates in demand for fish products over the past decade, initial demand was allowed to increase by an annual growth rate of 2.5%.

Implementation Results

The model was implemented using simulated data from a three-house broiler farm for the purpose of evaluating the economic benefits of diversifying into HSB aquacultural production. Input parameters for the model for the first year of the planning horizon are provided in Table 3. One of the major benefits of diversification relates to the reduction in the variable costs of HSB production. For the purpose of this study, a $0.05/lb savings in variable cost of HSB (i.e., 3.5% of variable costs) was assumed. Given a $0.05 savings in HSB variable cost from diversification, the optimal production structure calls for integrating broiler farming with HSB production. Optimal activity levels within the integrated system amount to full utilization of three broiler houses and partial use of five ponds. Table 4 presents the optimal production structure.

The optimal plan involves incurring production

Table 3. Parameter Estimates for Year 1—Diversified Production

| Broiler Production | | HSB Production | |
Parameter	Estimate	Parameter	Estimate
δ_{11}	0.026	δ_{21}	0.922
γ_{11}	0.008	γ_{21}	1.428
—	—	ν_1	0.0500
Γ_1	72,000	Γ_2	419,029
Δ_1	206,483	Δ_2	212,573
D_{11}	400,005	D_{21}	105,000
μ_1	133,335	μ_1	26,250
θ_{11}	1,020	θ_{21}	4,226
Φ_1	79,274	Φ_2	52,628
ϕ_{11}	4,316	ψ_{21}	14,750
Ψ_1	0	Ψ_2	41,935
Ω	105,500	L	10%
		r	15%

shortages of 145,000 per period in broilers and over 26,000 pounds per period in HSB by year 10 of the planning horizon. Nonetheless, these shortages are economically meaningful in that the additional operating and capital cost requirements do not justify the forgone benefits associated with the unmet demand. Given the assumed variable cost savings, the optimal diversified production structure generates a total before-tax profit of $548,432 (PV = $390,691 at a discount rate of 5%) over a ten-year planning horizon.

A nondiversified three-house broiler production system would generate a total before-tax profit of $70,876 (PV = $29,554 at a discount rate of 5%) over the ten-year planning horizon. A nondiversified five-pond HSB production system would generate a total before-tax profit of $306,010 (PV = $213,436 at a discount rate of 5%) over the ten-year planning horizon. Thus, a diversified broiler/HSB production system generates an additional $171,546 before-tax profit over the ten-year planning horizon than the combined profits of two separate nondiversified broiler and HSB farms. Table 5 presents a projected profit and loss statement for each of these production scenarios during the plan-

Table 4. Optimal Yearly Production Levels Under Diversification

# Broiler Houses to be Built	3
Annual Broiler Production (lbs)	400,005
# Ponds to be built	5
# Ponds Used Annually	5 (with the exception of year 1)
Total Before-Tax Profit	$548,432 over planning horizon
PV of Before-Tax Profit	$390,691 over planning horizon

Table 5.   An Enterprise Budget Under Diversification

	Broiler Farm (3 houses)	HSB Farm (5 ponds)	Diversified Farm
Sales	835,448	2,836,229	3,671,677
Variable costs	216,000	1,887,675	2,037,679
Operating costs	205,200	231,919	437,119
Traceable fixed cost	237,822	263,140	500,962
Nontraceable fixed costs	105,550	147,485	147,485
Profit (before-tax)	70,876	306,010	548,432

ning horizon. The significant boost in earnings of the diversified plan stems primarily from the efficient utilization of resources which the two separate farms could potentially share. Direct savings in the variable costs of the HSB production accounted for about 40% of the increased profits of the diversified system.

The diversified plan satisfies the annual risk constraints which force the profit margin, associated with HSB production, to be at least 10% in each year of the planning horizon. Also, the optimal diversified plan generates an *ROI*, associated with HSB production, of 19.1% over the entire planning horizon. This *ROI* value is consistent with previous simulated *ROI* projections (Gempesaw et al.). Because an *ROI* value of 19.1% exceeds the minimum desired level of $L = 15\%$ for HSB production, the return constraint associated with HSB production is nonbinding at the optimal solution.

Sensitivity Analysis

As expected, the optimal objective function value increases with increases in the variable cost savings. The amount of savings in variable cost of the HSB production depends primarily on the quality of pond management. It has been observed from experimental station ponds in Israel that, with the use of animal manure alone, a cost saving of as much as the full feed cost is possible (Schroeder, 1979). However, given the sensitivity of HSB to environmental factors and government restrictions on feed inputs, it is doubtful if HSB could sustain solely on manure feed. To raise the fish to its full market size, some form of supplemental feed would be necessary. The assumed 3.5% cost savings in the variable costs, for the purpose of the model, is a reasonable benchmark figure for a new farm with no experience in aquaculture. Higher savings are expected from sources other than feed cost, as the farmer becomes more experienced. Thus, the reported optimal value should be inter-

preted as a minimum based on conservative estimates for variable production cost savings in HSB.

Given that all other model inputs remain constant, the optimal level of diversification is relatively insensitive to changes in variable cost savings. The optimal level of diversification is also relatively insensitive to drastic surges in demand. As stated earlier, the capital investments required for HSB production make construction of new ponds (to meet surging demand) uneconomical. As a result, the optimal production plan generates an annual production shortage of over 26,000 pounds of HSB by year ten. Given the high capital investments of HSB production, the optimal level of diversification is not affected by either moderate (10%–15%) underestimations or overestimations in demand forecasting.

If in any given year, fish production were to be affected by off-flavor disease problems or related disease problems, production capacity would essentially be reduced for that year. Such a scenario can be modeled by examining the effects on net profit of decreased fish production capacity (i.e., reduction of the parameter μ_2) in any given year. Sensitivity results indicated that a decrease in production capacity in year 10 would generate the greatest loss in profits, a decrease in production capacity in year 1 would generate the minimal loss in profits. These results are expected because annual demand for fish is assumed to increase throughout the planning horizon. Figure 1 illustrates the minimum and maximum profit loss (as a percentage of projected profit) for various percentage decreases in annual production capacity.

Conclusions

In this paper, a decision support model for strategic planning was developed. The model was geared to decisions involving long-term planning horizons and incorporated considerations of financial risk, return on investment and capacity variations, three essential ingredients of long-term strategic decisions. The model was implemented to evaluate an agricultural diversification decision in which a broiler farm considers diversification into commercial aquaculture. Results indicated that a diversification plan significantly increases the profitability of the farm while keeping the potential financial risk from HSB production within a desired tolerable limit and *ROI* from HSB production at an acceptable level.

Moreover, the findings indicate that due to its cost structure, operating the broiler farm separately is a less attractive venture in comparison to an
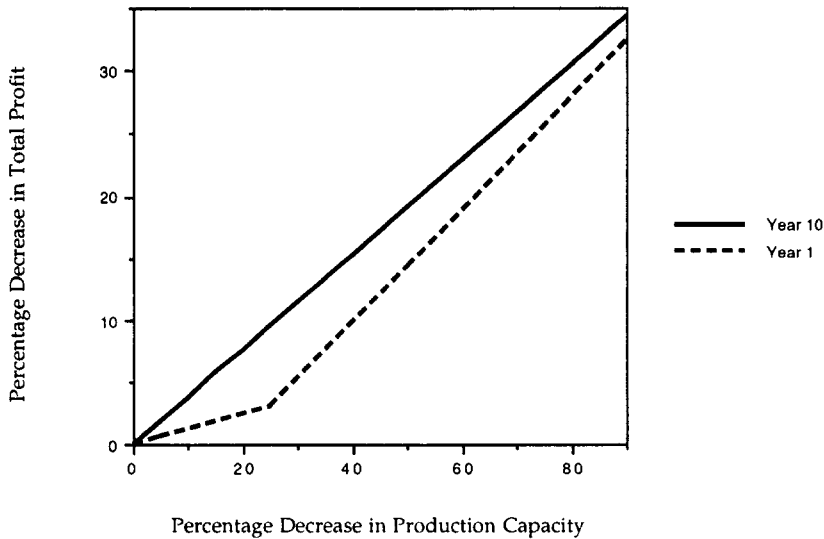
Figure 1.   **Minimum and Maximum Percentage Profit Loss Under Reduced Production Capacity.**

aquaculture HSB farm. The present value of be-fore-tax profits for the representative broiler farm over a ten-year planning horizon was found to be relatively lower. This figure did not significantly improve when evaluated at a higher scale of pro-duction. On the other hand, the HSB farm gener-ated higher discounted total profit even at a lower scale of production where huge fixed costs could affect profitability. As indicated in Table 5, the significant boost in earnings of the diversified plan stems primarily from the efficient utilization of re-sources which the two separate farms could poten-tially share. Direct savings in the variable costs of the HSB production accounted for only about 40% of the increased profits of the diversified system.

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