3. Farm Planning - Theory and Practice

3.1 Introduction

This chapter examines the importance of planning in farm management. It relates this to the goals of the farm manager, of which profit is assumed to be a primary one. The theory underlying several of the available farm planning models are reviewed. Linear and multiperiod linear programming models receive particular attention as they are the basis of this study. A brief review of their use in a planning context at the farm level is provided.

3.2 Farm planning

The farm business has human, technical, economic and financial components. It is subject to seasonal, market and institutional influences which involve risk and uncertainties (Makeham and Malcolm 1993, p. 8. When considering change the farm manager must consider the unique combination of land, labour and capital available to the farm business, together with the goals, interests, skills and resources of the farm family.

A key consideration are the goals of the farm business and individual members of the farm management team. Patrick and Eisgruber (1986, p. 492) define an individual's goal as an objective or condition, not yet reached, that provides direction to their motivation and hence behaviour. They argue that individuals endeavour to attain a number of goals simultaneously, and that these goals may be competitive, complimentary, or independent. The goals of the farm firm are influenced by those of the individuals within the farm management team, those of other members of the farm family, those common to all families, and those unique to farm families. The overall satisfaction, or utility, that each member of the management team achieves is a function of the degree to which his/her goals are met. This will depend upon the quantity of resources purchased, the nature of resources and the way in which they are allocated amongst activities (Rae 1977, p. 8). The overall level of utility (U_j) for a given resource allocation by the jth individual is given by:

$$U_j = f_j(u_1, u_2, \ldots, u_n) \qquad (3.1)$$

where u_i, $i = 1,2,\ldots,n$, each refers to the utility attached to a specific goal.
The utility function is a personal one. It can be one-dimensional (dependent upon the achievement of a single goal such as profit maximisation) or multi-dimensional (where two or more goals are involved). The multi-dimensional nature of goals held by farm business managers was demonstrated by Patrick, Blake and Whitaker (1983, p. 317-9).

Goals form a multivariate objective function against which the expected outcomes of alternative farm plans are evaluated. In selecting a farm plan the farm manager chooses the farm plan that attains all the goals with an adequate level of satisfaction. This constrains the possibility of maximisation of a single goal at the expense of others (Patrick and Eisgruber 1986, p. 492). Imperfect knowledge of the future forces the team to allow for uncertainty in committing resources to a particular farm plan comprising activity combinations and inputs.

Decision making is a dynamic process. The key elements of the planning problem have been described by Dent et al. (1986, p. 2) as:

1. a set of goals;
2. a range of possible enterprises or activities; and
3. a set of limited resource supplies and other constraints.

They define the problem as how 'within an uncertain biological and economic environment, to allocate the available resources to the various activities in order to best achieve the farmer's objectives'.

3.3 Farm management economics

Production economics theory underlies the possible approaches to increasing operating profit available to the farm manager through farm management planning. The theory is based upon the existence of production functions relating the production of a commodity to the use of various resources or inputs.

These resources can be variable or fixed, depending upon the time frame being considered. In the short term many factors can be considered as fixed, and the costs associated with them are independent of output. In the longer term however, all factors can be considered variable. The production function is represented by:

$$Y = f(X_1, X_2, \ldots, X_k | X_{k+1}, \ldots, X_n) \qquad (3.2)$$

where Y is output, X_1 to X_k are variable resources and X_{k+1} to X_n are fixed resources.

To determine the most profitable level of use of resources in the production of a single product we introduce prices (P_i) and rewrite the operating profit (OP) as::

$$\text{OP} = P_Y Y - [P_{X_1} X_1 + \ldots + P_{X_k} X_k] - [P_{X_{k+1}} X_{k+1} + \ldots + P_{X_n} X_n] \qquad (3.3)$$

For a range of resource combinations it is possible to determine the level of profit from equation (3.3). Total revenue (TR) will vary from one resource combination to another as output varies. However, total fixed costs remain constant for all combinations of the variable resources. Thus the profit equation can be simplified to exclude fixed costs:

$$\begin{aligned} \Pi &= \text{TR - TVC} \\ &= P_Y Y - [P_{X_1} X_1 + P_{X_2} X_2 + \ldots + P_{X_k} X_k] \end{aligned} \qquad (3.4)$$

where TVC is total variable costs.

The value of Π in the profit equation (3.4) will exceed the operating profit by an amount equal to total fixed costs. However, the combination of resources that yield the greatest value of Π is equivalent to choosing that which maximises operating profit, because the optimal input mix (where Marginal Value Products = Marginal Factor Costs for each input) is independent of fixed costs.

The majority of farm operations have many different possible commodities that can be produced from the available resources. Rae (1977, p. 73) considers each available commodities as having a distinct production function. In representing the management problem he assumes there are a total of m commodities, Y_j , j = 1,2,...,m, that can be produced through the use of n production resources, X_i , i = 1,2,...,n , according to the production relationships:

$$\begin{aligned} Y_1 &= f_1(X_1, X_2, \ldots, X_n) \qquad (3.5) \\ Y_2 &= f_2(X_1, X_2, \ldots, X_n) \end{aligned}$$

$$\vdots$$

$$Y_m = f_m(X_1, X_2, \ldots, X_n)$$

This set of possible production functions assumes that any commodity Y_j can be produced independently of any other. The operating profit equation (3.3) for this situation can be written as:

$$\text{OP} = P_{Y_1}Y_1 + P_{Y_2}Y_2 + \ldots + P_{Y_m}Y_m - P_{X_1}X_1 - P_{X_2}X_2 - \ldots - P_{X_n}X_n$$

or

$$\text{OP} = \sum_{j=1}^{m} P_{Y_j}Y_j - \sum_{i=1}^{n} P_{X_i}X_i \qquad (3.6)$$

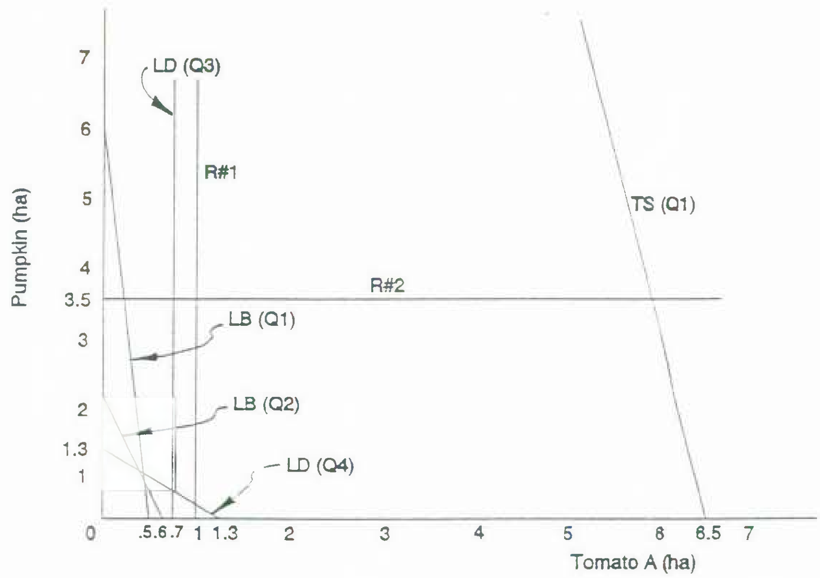
In achieving the stated objective of profit maximisation, the farm manager must allocate resources amongst possible commodities. Resources used in commodity production can be broadly classified as unlimited or limited according to Rae (1977, p. 76). An unlimited resource is one where the manager has both the time and money to purchase sufficient quantity to allow its use at the optimum level in the production of each commodity requiring its use. In this situation, the level of resource used in the production of a commodity is the level which equates its price to the value of its marginal product.

With a limited resource however, the optimum amount may not be available. Possible reasons for this include:

- the manager may be unable to purchase sufficient amount of the resource to enable its use at the optimal level (as a result of limited capital for example).
- the resource may be a fixed one such as land or an irrigation system. Within the production time period of the commodity in question, the manager may not have the time or capital available to expand the level of resource to the optimum.

The combination of products that can be produced within a given set of constraints can be represented by production possibility boundaries. Rae (1994, p. 65) provides an example of a production possibility boundary for the production of tomatoes and pumpkins. In this example there are fourteen identified constraints - land (LD), labour (LB) and tractor services (TS) within each of four quarters (Q1, Q2, Q3 and Q4), and crop rotational constraints (R1 and R2). When presented graphically in product-product space it can be seen that three of the constraints dominate all others (Figure 3.1) - labour required in Q2 and Q4, and available land in Q4. These constraints lie closest to the origin than all other constraints. They limit the possible production for pumpkins and tomatoes. The levels of redundant resources are in excess of those required by these activities.

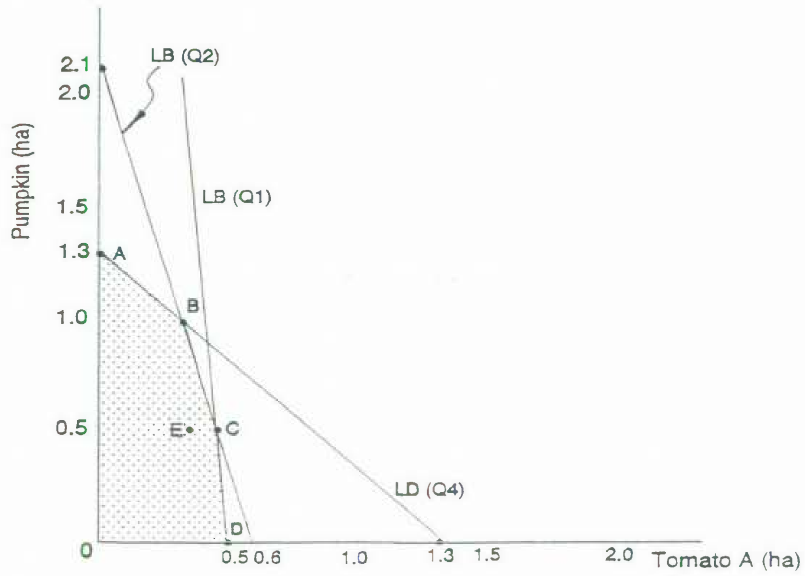
Figure 3.1: Production constraints for pumpkin and tomato production



Source: Rae, A.N. 1994

The three non-dominated constraints are redrawn in Figure 3.2. The line ABCD is the production-possibility boundary which indicates the combinations of pumpkin and tomato production activities which are physically possible as they do not violate the constraints. All points to the left of the production-possibility boundary (shown by the shaded portion of the figure) are feasible activity combinations. All points not on the boundary are technically inefficient, as it is possible to expand the level of one of the activities without decreasing the level of the other. For example, at point E it is possible to expand either or both areas of crops by moving to a point between B and C.

Figure 3.2: The production possibility boundary



Source: Rae, A.N. 1994

Although any combination on the production possibility boundary is technical efficient only one is the best in the sense of maximising profit (given the existence of the specified constraints). The combination of activities giving the highest revenue is found through the use of isorevenue lines. Total revenue for any combination of two products can be represented by the equation:

$$\mathrm{TR} = P_{Y_1}Y_1 + P_{Y_2}Y_2 \tag{3.7}$$

where P_{Y1} and P_{Y2} represent the price per unit for each product, and Y_1 and Y_2 represent the amount produced of each product from the specified activity combination used. For a given total revenue (TR^*) equation (3.7) can be rearranged to give an isorevenue line:

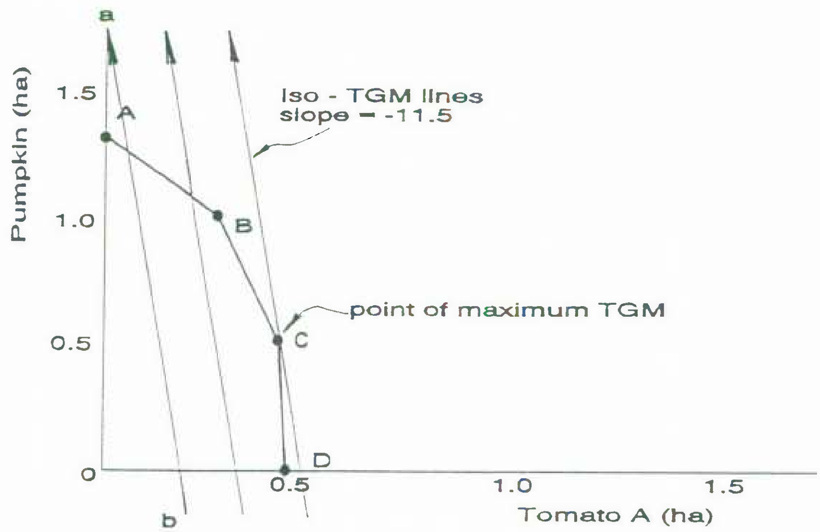
$$TR^* = P_{Y_1}Y_1 + P_{Y_2}Y_2$$

$$P_{Y_1}Y_1 = TR^* - P_{Y_2}Y_2$$

$$Y_1 = TR^*/P_{Y_1} - P_{Y_2}/P_{Y_1} . Y_2 \tag{3.8}$$

With output prices held constant, there is a family of isorevenue lines for each revenue level, all with a slope of $-P_{Y2}/P_{Y1}$. Profits will be greatest with the output combination returning the maximum total revenue. This point occurs where the isorevenue line is a tangent to the production possibility boundary. At this point the slope of the production possibility boundary (the marginal rate of product substitution) and the isorevenue line are equal. Figure 3.3 uses this approach to identify the most profitable combination of pumpkin and tomato areas as point C (Rae 1994, p. 73).

Figure 3.3: Maximising total gross margin



Source: Rae, A.N. 1994

In summary, production economics provides the theoretical base upon which the goal of profit maximisation can be attained by the farm manager. It shows that for each commodity that a farm can produce, there are optimal allocations of inputs that maximise profit. Similarly, within existing resource constraints it is possible to allocate resources to the production of alternative commodities with the aim of profit maximisation.

3.4 Farm planning models

The planning process is often an intuitive one where the farm manager initially makes assessments, weighs alternatives and then decides upon a course of action (Dent et al. 1986, p. 8). When more complex decisions are needed more formal planning procedures are required. These procedures can range from pencil-and-paper calculations through to the use of computers. Whatever approach is used requires the farm manager to develop a model of the farm business and use it to assess the course of action to follow and its likely outcome.

A model can be used to aid farm planning and decision making. By definition, a model is an abstraction and simplification of the real world. For it to be relevant for decision making, it must 'strive to portray realistically those features or characteristics of the real world which are relevant to the particular problem or it will fail to provide a sound basis for prediction and decision making' (Pearse 1973, p. 61). There are many types of models that can be used, ranging from informal 'mental' models to symbolic algebraic models (Dent et al. (1986, p. 9-10) The discussion that follows concentrates on three types of symbolic models - simulation, budgeting and programming models.

3.4.1 Simulation models

Simulation model development and use has been reviewed by Anderson (1974). He considered them to be the 'the most feasible, most workable and probably most potentially useful types of model' within the symbolic group of farm planning models. This view was based upon the belief that they were the most flexible and least confined of the symbolic models, readily allowing for the inclusion of stochastic variables not possible by other models.

Significant problems with simulation models identified by Anderson (1974, p. 33-4) were:

- the inclusion of components of the model where there is little data or logic supporting their use;
- the need for an efficient balance of the simulator's time between the various components of the model. The model is only as good as the poorest component within the model;
- the high cost of simulation; and
- the failure to include the real-world decision maker in the model development limiting its usefulness when finally developed.

Anderson is quick to point out, however, that these problems are not necessarily unique to simulation models, they can exist in all models developed to aid farm planning and decision making.

3.4.2 Budgeting models

Makeham and Malcolm (1993, p. 367) support the use of traditional budgeting techniques as the core of farm management analysis and decision making. These approaches are more likely to focus upon the key decisions that farm managers need to make in contrast to more elaborate quantitative approaches, such as systems simulation, mathematical programming and expected utility analysis

The manager must consider the technical, economic, financial, institutional and human factors that impinge on a particular decision. By its very nature the rigorous and logical basis of quantitative modelling often ignores the importance of the farm decision makers input into the analysis. This further prevents its use by farm managers. In contrast the traditional budgeting models which involve the manager in their development are more likely to be accepted as a useful decision tool.

There have been three primary budgeting models recommended to farm managers to aid in decision making - gross margin analysis, partial budgeting and whole farm budgeting. The choice of budget used is dependent upon the nature of the decision problem under consideration.

There are several deficiencies in each of the budgeting approaches to farm planning. For gross margin analysis these include:

- the exclusion of fixed costs from the analysis limits activity comparison to those which can be undertaken within the existing resource structure of the farm.
- where activities exhibit either competitive, complementary or supplementary relationships, this analysis is inadequate.
- the linearity assumption that implies constant extra product and returns with increasing scale of an activity may be unrealistic, as there may be diminishing returns at the margin.

The chief limitations of partial budgets identified by Makeham and Malcolm (1993, p. 314-15) are:

- being partial in nature, they cannot fully represent the complex interactions that can exist between activities and resources of the farm.
- they only indicate the net gain or loss of proposed changes. They do not show if a given change is the best alternative, as they do not identify the return on all the capital involved in the activity

The obvious limitation of whole farm budgeting is the amount of time involved in drawing up of the budgets for all possible alternative plans. This can limit the number of alternative plans evaluated. Without comparing whole-farm budgets for alternative plans this process cannot be considered a planning tool (Dent et al. 1986, p. 11).

3.4.3 Linear Programming

Linear programming (LP) was developed during the 1940s for use in military operations. Subsequently applications for use in managerial decision analysis in business were developed. The technique is suited to a wide range of problems with the following features:

1. a range of possible activities from which the manager can choose;
2. a number of constraints that limit free selection from the available activities; and
3. the choice of activity mix is related to some measure of the managers utility function (for example, profit) for each activity (Dent et al. 1986, p. 33).

The LP model can be written as:

$$\text{maximise } Z_p = \sum_{j=1}^{n} c_j X_j \qquad (3.9)$$

subject to

$$\sum_{j=1}^{n} a_{ij} X_j \le b_j, \qquad \text{all } i = 1 \text{ to } m \qquad (3.10)$$

$$X_j \ge 0, \qquad \text{all } j = 1 \text{ to } n \qquad (3.11)$$

where

Z_p = the objective function, such as total gross margin

X_j = the level of the jth farm activity, such as the area of a crop grown

c_j = the expected gross margin of a unit of the jth activity (e.g. dollars per hectare)

a_{ij} = the quantity of the ith resource (e.g. hectares of land or hours of labour) required to produce one unit of the jth activity

b_i = the amount of the ith resource available (e.g. hectares of land or hours of labour)

n = the number of possible activities

m = the number of resources

This problem is referred to as the primal LP problem.

This model aims to identify the farm plan (defined by the set of activity levels X_j, j = 1 to n) that has the largest possible gross margin Z, which does not violate any of the fixed resource constraints (equation (3.10)) or involve any negative activity levels (equation (3.11)) (Hazell and Norton 1986, p. 11). LP can also be used in the minimisation of an objective function. The LP model can be represented as a matrix of coefficients organised into a 'tableau'. The tableau for this problem is shown in Table 3.1

Table 3.1: The linear programming tableau

	Columns				
Row name	X_1	X_2	…	X_n	RHS
Objective function	c_1	c_2	…	c_n	Maximise
Resource constraints:					
1	a_{11}	a_{12}	…	a_{1n}	$\leq b_1$
2	a_{21}	a_{22}	…	a_{2n}	$\leq b_2$
⋮	⋰	⋰	…	⋰	⋮
m	a_{m1}	a_{m2}	…	a_{mn}	$\leq b_m$

Source: Hazell, P.B.R. and Norton, R.D. 1986

Limitations and criticisms of the use of LP in addressing the decision problem of resource allocation include:

- the lack of adequate data on input-output coefficients, and on price and yield expectations.
- the restrictive nature of the linearity assumption which excludes the existence of diminishing marginal returns in farm production
- the high cost of linear planning applications and availability of adequate computing facilities

- the difficulty of extending the applicability of a farm plan from a case study farm to a wider group owing to resource heterogeneity (Dent et al. 1986, p. 198)

The first of these criticisms is equally applicable to all planning techniques except that data demands may be greater because a more comprehensive analysis is performed (Beneke and Winterboer 1973, p. 8; Dent et al. 1986, p. 197). Imaginative specification of the model can be used to overcome the problem of linearity as demonstrated by Pomerada (1978) in formulating irrigation production functions using a modified separable LP model. The increased availability of computer hardware and software in recent years has overcome the problem of cost and availability of adequate computing facilities and software.

The use of LP in a decision-support role with farmer groups has resulted in benefits to farmers in their decision making processes and for modellers in respecification of the model, as demonstrated by use of the Purdue Top Farmer Cropping Model "B" (McCarl, Candler, Doster and Robbins 1977) This improved the applicability of LP at the farm level and its cost effectiveness.

There have been several modifications made to the traditional LP model to make it more realistic. The need to allow for real world dynamics, uncertainty, variability and the multiplicity of decision-makers objectives have led to the development of models such as:

- parametric LP (variable price programming and variable resource programming discussed by Throsby (1962, 120-1));
- multiperiod LP (MLP);
- stochastic LP (Separable LP, Marginal Risk Constrained LP, and MOTAD); and
- multiple-objective LP (Goal Programming).

Makeham and Malcolm (1993, p. 359) consider these approaches to be 'not operational or economical enough to be tools for farm management'. The MLP model, however, does have application to the problem being investigated here as investment in longterm activities such as grapes and redclaw production need to be considered in developing an optimal farm plan.

3.5 Long term planning

3.5.1 Development planning

By definition, the planning process is a longterm one. Decisions made in one time period are often the result of past decisions and experiences, together with expectations about future farm performance. One of the differences between the choice of alternative farm plans over time and that in the short-term is the greater flexibility in available farm resources. They can no longer be considered fixed.

In long-term planning the problem becomes one of choosing between alternative plans which will maximise the utility function of the management team over the planning period. Dent et al. (1986, p. 171) describe the problem as being one of development planning. Reinvestment which leads to modification of the resource structure of the farm depends upon surplus cash flow to the business from previous years following withdrawls for consumption expenditure and taxation. This surplus cash can be used to modify the resource base and activity mix. Choices have to be made as to what investments are made and at what time, consistent with the long-term goals of the farming business. Consideration also needs to be given to the acceptable level of financial borrowings in order to implement long-term plans.

As with short-term planning, there are a number of possible modelling approaches to aid farm managers in the longterm investment decision. Traditionally these approaches have focussed upon the discounted cash flow budgeting (DCF) techniques of net present value (NPV), the internal rate of return (IRR) and benefit-cost ratios (B:C) for evaluating alternative investment projects (Makeham and Malcolm 1993, p. 316-22).

These investment choice criteria should be used with caution as they are only as accurate as the information used to develop the project cash flows in the first place. The risks associated with the key variables used in drawing up the project cash flows need also to be considered. Stamp and Peacock (1972) recommend the use of Monte Carlo simulation of these key variables together with decision tree analysis to assist managers choose between alternative investment projects.

3.5.2 Multiperiod Linear Programming

Rae (1970, p. 39) considers traditional investment decision tools based on DCF as inapplicable when choosing between possible investment projects if they:

- are interdependent so that complementary and competitive relationships exist between them;
- complement each other with respect to cash supplies;
- have multiple uses.

MLP can be used to overcome these problems. The use of MLP to develop an optimal farm plan over time is more complex than that for static LP. In the static LP model, the plan with the highest gross margin before allowance for fixed costs such as consumption expenditure, debt servicing and taxation is generally the optimal one (Dent et al. 1986, p. 172). As a result fixed costs are generally ignored in model development. With long-term planning these costs must be included as they affect the cash flows from year to year and hence the opportunity to expand the resource base. MLP models must:

- include inventories of materials and money to be transferred from one time period to the next;
- allow for purchase of capital items and short-term resources; and
- account for income tax, debt servicing and consumption expenditure.

The MLP model can be written as:

$$\text{maximise } Z_p = \sum_{j=1}^{n} c_{j1} X_{j1} + \sum_{j=1}^{n} c_{j2} X_{j2} + \ldots + \sum_{j=1}^{n} c_{jT} X_{jT} \tag{3.12}$$

subject to

$$\begin{array}{llll}
\sum_{j=1}^{n} a_{ij1} X_{j1} & & \le b_{i1}^{*}, & i = k+1, k+2, \ldots, m \\
\sum_{j=1}^{n} a_{ij2} X_{j1} + \sum_{j=1}^{n} a_{ij2} X_{j2} & & \le b_{i2}^{*} & \\
\vdots \qquad \vdots \qquad \ddots & & \vdots & \\
\sum_{j=1}^{n} a_{ijT} X_{j1} + \sum_{j=1}^{n} a_{ijT} X_{j2} + \ldots + \sum_{j=1}^{n} a_{ijT} X_{jT} & & \le b_{iT}^{*} & \\
 & X_{jt} & \ge 0, & j = 1, 2, \ldots, n;
\end{array}$$

$$t = 1, 2, \ldots, T$$

where

$Z_p =$ the objective function

$X_{jt} =$ the level at which activity X_j is initiated in period t

$c_{jt} =$ the forecast gross margin per unit of activity X_j initiated in period t

$a_{ijt} =$ the quantity of the ith resource required to produce one unit of the activity X_j in period t

$b^*_{it} =$ the amount of the ith resource available in period t

$n =$ the number of possible activities

$m =$ the number of resources

The objective function (3.12) shows that maximisation is to be applied to the present value of gross margins for each activity summed over the planning period. Restraints are specified in each time period. The resources available in any time period, must be allocated to activities initiated within that period, and those initiated in any prior time period.

The objective function for a MLP model can be specified in many different ways. Examples reported by Rae (1970, p. 39) include:

- maximising the present value of future income over some planning period.
- maximising income at the end of the planning period (and including a bank activity which reinvests surplus cash throughout the life of the project).
- maximising the net worth of the farm business over the planning period.

He proposes that multi-dimensional objectives be included in programming models based upon the utility function represented in (3.13). This utility function has a linear combination of appropriately-weighted objectives and those that must be satisfied in all solutions:

$$U = f(\alpha_1 G_1, \ldots, \alpha_n G_n \mid L_1, \ldots L_m) \qquad (3.13)$$

where

$\alpha_1 \ldots \alpha_2$ are weights applied to the objectives $G_1 \ldots G_n$

$L_1 \ldots L_m$ are a compulsory set of objectives

Pearse (1973 p. 61) listed the following features necessary for an ideal MLP model:

1. sources of external finance should be made available, used and secured under realistic conditions
2. the time of committing funds to a secondary development expenditure should be flexible
3. provision must be made for the following demands upon income:
    - variable and fixed farm costs
    - minimum family consumption expenditure
    - income tax payments
    - principal repayments
    - personal requirements for savings; and
    - capital expenditure.
4. the risk associated with alternative plans must be incorporated within the model, or at least evaluated.

Practical considerations of matrix size may however limit the development of such an ideal MLP model for all investment problems.

There are a number of reported difficulties in the literature in relation to the specification and use of MLP models. The first of these relates to difficulties in the prediction of activity performance in the future. Two causes for this are suggested by Dent et al. (1986, p. 189):

- the use of performance figures from existing activities to estimate those for future activities operating at a different scale; and
- future technological advances and changing economic conditions affecting yields and prices for products and resources

This problem is not unique to MLP analysis; it occurs with all planning procedures.

Secondly, the size of the MLP tableau is dependent upon the number of activities and constraints considered, and the planning horizon adopted. The length of the planning horizon is important as each additional year adds substantially to the final tableau. It is possible for the tableau to become unmanageable because of its size. The time for development also increases. This increases the likelihood of problems such as infeasibility, unboundedness and degeneracy, often as a result of simple errors of omission or inconsistencies within the MLP tableau (Dent et al. 1986, p. 191).

The problem of large matrix size and available computing facilities was raised as an issue with MLP analysis by Gunn and Hardaker (1967, p. 277). They also discussed the problem of non-linearity in a long-term planning context. It was felt both these factors limited the usefulness of MLP in actually solving long-term planning problems. More recently, Makeham and Malcolm (1993, p. 359), while acknowledging that MLP results in better decisions about the first period of a plan (compared with static LP analysis), they consider the marginal gain to compare unfavourably with the marginal cost of its use.

3.6 The application of Linear Programming models

The literature contains many examples of farm level LP models used to determine optimum activity mixes and evaluate alternative farming systems. These include work by Musgrave and Bird (1966); Rickards and McConnell (1967); Powell and Hardaker (1968) and Wrigley and Sturgess (1969) among others. These studies used single year multi-period models, containing transfer activities designed to shift resources between different time periods within the same year. They used a "hypothetical" or "typical" farm as the basis of the model. Several different approaches have been used in specifying the input-output coefficients of a "typical" or "hypothetical" farm:

- data from published surveys (Musgrave and Bird 1966)
- use of actual data from a case study farm (Rickards and McConnell 1967)
- normalisation of data from an actual farm (Powell and Hardaker 1968)
- field studies of farms within a study area (Wrigley and Sturgess 1969)

In the Powell and Hardaker (1968) study the model developed was further modified following discussions with farmers within the study area. For any model to be relevant at a farm level, the input of the farm manager is important. This has been demonstrated with the Purdue Top Farmer Cropping Model B in the United States (McCarl et al. 1977).

Linear programming has also been used in a number of economic and agronomic studies related to irrigation. At a regional level it has been used to determine the short run responsiveness to changes in water price of the demand for irrigation water in the Murrumbidgee Valley (Briggs Clark, Menz, Collins and Firth 1986) and the Murray Valley (Chewings and Pascoe 1988). At a farm level, LP has been used to optimise the on-farm allocation of water across a large number of crops and paddocks within the limits of available water and labour (Trava, Heermann and Labadie 1977). The economic implications of allocating irrigation amongst alternative crops with differing response functions to irrigation water was examined by Pomereda (1978), who approximated the response functions by use of linear segments which enabled optimal crop selection and irrigation strategies to be determined.

Bryant, Buffier and Verdich (1984) used an LP model to evaluate the profitability of planting decision rules by irrigators experiencing a limited supply of irrigation water. This study examined the impact of applying a planting decision rule for cotton on a farm with varying resource constraints over a 21 year period.

Poulter, Hall and Greer (1993) presented a bioeconomic model which used recursive MLP to study representative farms within the West Berriquin Irrigation District. This model examined the profitability of types of irrigated and non-irrigated farms over a 20 year period, allowing for the effect of increasing salinity and waterlogging resulting from irrigation accessions to groundwater. The model enabled the likely impact of installing drainage on each farm and increasing the delivery cost of water to farmers to be assessed.

There are several examples of MLP models developed to determine optimal investment plans (Throsby 1962; Jensen, 1968; Rae 1970; Pearse 1973; Hansen and Krause 1989; Mallawaarachchi, Hall and Phillips 1992). In outlining the concept of dynamic MLP modelling, Throsby (1962) used an example of an area of unimproved land on an actual farm. The objective of the manager was the optimal allocation of this land between wheat, improved pasture and unimproved pasture over a four year planning cycle. This paper examined in detail some of the important constraints that need to be included when evaluating an investment proposal. The model was again used in evaluating the profitability of sown pasture development by Jensen (1968) and Pearse (1973).

Rae (1970) applied MLP to horticultural crops. He studied the replacement of areas of annual horticultural crops with perennials in a six year planning period. This study accounted for the existence a multi-dimensional objective function by farm managers. Of particular interest was the allowance made within the model for different, and sometimes conflicting, management objectives.

More recently, MLP was used to determine the optimum cereal/grazing mix for mixed farms within South Australia by Hansen and Krause (1989). Their model allowed crop and pasture rotations to be developed endogenously, enabling the identification of the most profitable mix of livestock and cropping activities in a medium term farm plan.

Mallawaarachchi et al. (1992) developed a MLP model which examined the adoption of water saving technology within a 20 year planning horizon. The model used average farm data for a "typical" farm growing only oranges and grapes. It included activities for investment in drip irrigation, the replanting of new varieties and off-farm investment, as well as constraints related to capital investment, taxation and consumption expenditure.

There have been several approaches to dealing with uncertainty in the use of LP models. Nuthall and Moffatt (1975) used deterministic LP analysis to develop a payoff matrix of alternative farm plans to aid planning under risk at the farm level. Other approaches have included Target MOTAD models, such as that used by Prevatt et al. (1992) in evaluating the adoption of drip irrigation on vegetable farms, and discrete stochastic programming models, such as MUDAS, which has been used to identify optimal tactical adjustments to climate for wheat-sheep farms in Western Australia (Kingwell, Pannell and Robinson 1993). The inclusion of risk into MLP analysis increases the complexity of finding an optimal solution according to Hansen and Krause (1989). In their study risk was included by formulating a series of alternative plans containing varied input coefficients. This allowed a subjective assessment of the optimal plan's sensitivity to variations in these coefficients. A similar approach was used by Mallawaarachchi et al. (1992).