AN ABSTRACT OF THE THESIS OF

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A multi-phase methodology is proposed as an aid to resource planning and management activities in a high technology company faced with an uncertain marketing future. An attempt is made to incorporate both quantifiable and non-quantifiable factors.

The problem analysis phase of the proposed methodology employs Resource Planning and Management (RPM) network as a graphical representation of quantifiable relationships within the physical process operated by the company. Simple linear relationships between 100 resources and 92 processes lead to a linear programming (LP) model which was solved on a CDC-3300 computer. The results were compared against the actual production schedule for the period from which the

original data were obtained.

The decision analysis phase adapts the LP model to incorporate forecasted demands for the next production period. Information generated from the LP model is used to identify the potential resource bottlenecks.

The potential problem analysis phase considers the problem under uncertainty. A game theory payoff matrix is developed to estimate the effects of bottlenecks under a set of scenarios describing possible future conditions and for a given set of management alternatives.

Hurwicz, Savage, and Wald criteria from game theory and nine choice rules advocated by Easton are described. These techniques aid the management in bridging the gap between the quantified values in the payoff matrices and the subjective preferences imposed by the decision maker.

The proposed methodology is applied to the operation of a plant manufacturing accessories to precision doctrine instruments. Profitability, labor stabilization, and rate of return were used as three objectives evaluated under three marketing scenarios.

Resource Planning of a High Technology
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by

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RESOURCE PLANNING OF A HIGH TECHNOLOGY COMPANY UNDER RISK AND UNCERTAINTY

I. INTRODUCTION

The term "high-technology" is used in this thesis to describe a company that emphasizes Research and Development (R&D) activities, develops innovative products, implements their production within a short span of time.

When an innovative product is successfully introduced, the beginning portion of its product life cycle is expected to follow an S-shaped curve (Wasson, 1971; Kotler, 1971, p. 527). The curve is characterized by the slow increase in sales during the first phase (region OA on Figure 1-1) that is attributed to the "learning period" required for the market acceptance of the innovative product as well as for the manufacturer to reach its full production capability. Once a proper level of product awareness is reached, the sales begin to increase rapidly. The segment AB on Figure 1-1 represents the period during which the company enjoys a dominant market share due to the unique innovative features of its product. The point B denotes the beginning of the period when competitors start penetrating the market with similar products. Price competition begins and the product sales become more susceptible to environmental factors such as economy, political situations, and strategies employed by competitors. The qualitative description of the S-shaped

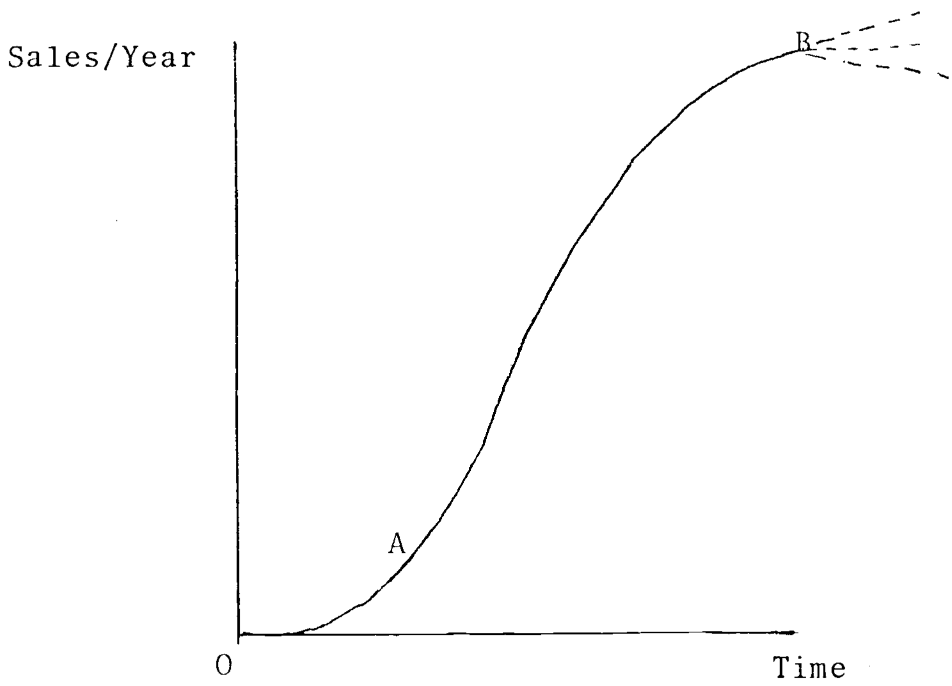


Figure 1-1. Sales Life Cycle of a Product

curve is supported by least-square regression analyses by Bass (1969), lognormal approximation model by Bain (1964), and epidemological model proposed by Coleman (1964).

The common characteristics of all diffusion models applied to innovative products is that they all describe the initial portion of the S-shaped curve (region OB) accurately but fail to prescribe the curve's behavior after point B. The problem of evaluating "risk" suddenly becomes a management decision problem to cope with many "uncertainties" associated with environmental factors. These environmental factors can be grouped together and called "nature". The shape of the curve beyond point B depends on the strategies selected by management in planning the company's resources and on the allocation of its marketing efforts. The resource planning process is made more difficult by the uncertainty associated with the future behavior of nature.

Aims and Objectives of the Study

The resource planning process consists of four phases of activities: (1) studying the problem and constructing a model, (2) carrying out the actual decision making, (3) considering potential problems and preventive measures, and (4) implementing the decisions. These phases are respectively known as: (1) Problem Analysis, (2) Decision Analysis, (3) Potential Problem Analysis and (4) Implementation.

The objective of the proposed study is to develop a methodology to aid management in the first three sets of activities.

A decision making model that deals with uncertainty must take into account the behavioral aspects of the decision maker.

Fox and Raiffa (Grayson, 1960, p.1) have stated:

> Any theory of "rational action" which does not bring in the subjective hunches and informal, noncodified information of "the man of experience" or fails to take account of the economic aspirations of the decision maker is doomed from start.

A lot of past experience and knowledge are reflected in decisions made by professional managers. Their subjective "hunches" must not be hampered if an operations research model is to be successfully implemented. The proposed methodology advocates the breakup of the resource planning process into small segments. This permits operations research techniques to generate objective and accurate information for the decision maker in a format that would enable him to use his subjective judgements in a systematic and productive manner.

Implementation of research results has been one of the major problems facing the operations researchers. The results of one survey (Ward, 1973) showed that only about 60% of the operations research projects are successfully implemented. This low rate of acceptance is mainly due to the difference in levels of understanding of the management and the research analysts. In the proposed study, an attempt has been made to facilitate better communication between the researcher and the management by using graphical operations research techniques.

Proposed Methodology

Game theory concepts can be applied in the planning activities discussed above; we consider the company to be the player and 'nature' to be the opponent. There have been a sufficient number of studies to show that decision makers adopt different management practices because they have different attitudes towards risk and uncertainty and that these attitudes can be measured and compared (Halter and Dean, p.246, 1971). The recommendations based on operations research study must, therefore, reflect the decision maker's attitude towards risk. Game theory has the unique capability of presenting information in a format that makes the risk elements explicitly apparent. Game theory, however, also has a limitation; as Thieraut and Grosse (1970, p.400) state:

> The basic limitation of game theory is the inability of the players to fill in accurate values for the payoff matrix rather than a lack of adequate methods to solve for strategies and game values. It is not difficult to establish that one outcome is preferable to another, but it is quite another thing to state exactly how much more.

Linear Programming and Resource Planning and Management System have been utilized in this study to overcome this limitation of game theory, i.e., to generate the information required for the payoff matrices.

Traditionally, game theory has dealt with only one objective at a time. But, in practice, decision makers are confronted with multiple objectives which have to be considered simultaneously. The various available methods to aid in multiple objective decision making have been grouped into four main categories by MacCrimmon (1973) as shown in Table 1-1. Some of the information required to show the interrelationships among the various methods is shown in Figure 1-2. The numbers in the circles refer to the methods mentioned

Table 1-1. Overview of Methods for Multiple Objective Decision Making

A. Weighting Methods
    1. Inferred preferences
        a. Linear regression
        b. Analysis of variance
        c. Quasi-linear regression
    2. Directly assessed preferences: general aggregation
        a. Trade-offs
        b. Simple additive weighting
        c. Hierarchical additive weighting
        d. Quasi-additive weighting
    3. Directly assessed preferences: specialized aggregation
        a. Maximin
        b. Maximax
B. Sequential Elimination Methods
    1. Alternative versus standard
        a. Disjunctive and conjunctive constraints
    2. Alternative versus alternative: comparison across attributes
        a. Dominance
    3. Alternative versus alternative: comparison across alternatives
        a. Lexicography
        b. Elimination by aspects
C. Mathematical Programming Methods
    1. Global objective function
        a. Linear programming
    2. Goals in constraints
        a. Goal programming
    3. Local objectives: interacti ve
        a. Interactive, multiple criterion programming
D. Spatial Proximity Methods
    1. Iso preference graphs
        a. Indifference maps
    2. Ideal points
        a. Multi-dimensional, nonmetric scaling
    3. Graphical preferences
        a. Graphical overlays

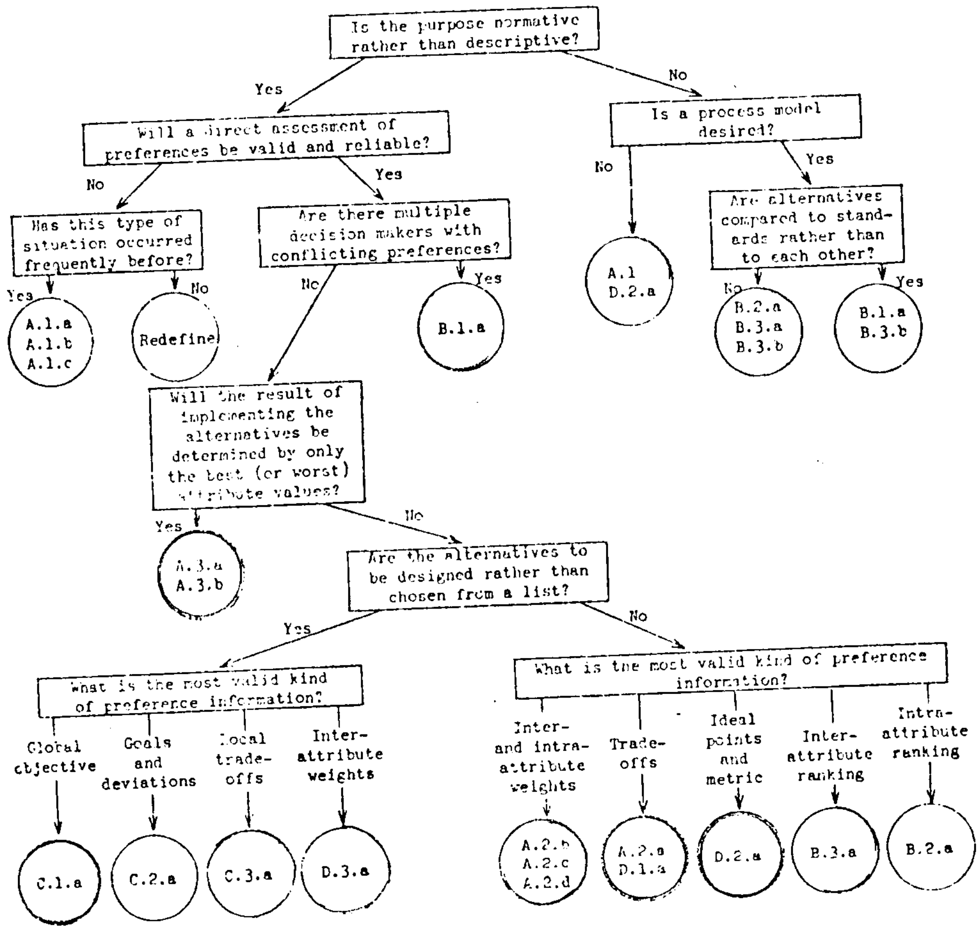


Figure 1-2. Method Specification Chart

above. In this thesis, a decision matrix approach has been adopted. This is essentially a conceptual integration of some of the above mentioned methods and is a convenient extension of the game theory approach; it utilizes the matrix format of game theory as its basis.

Data Source

Tektronix, Inc., is an Oregon based manufacturer specializing in the production of oscilloscopes and other electronic measurement instruments. A number of innovative cameras were introduced by Tektronix about 20 years ago to facilitate permanent recording of the displays of oscilloscopes and other visual devices. The Tektronix "camera shop," where all the cameras are assembled, was taken as an example of a company whose product is nearing the point B in its life cycle (Fig. 1-1). The data taken from this Tektronix camera shop have been utilized to construct models and to illustrate application of the proposed methodology.

Structure of the Thesis

Chapter 2 introduces and discusses the components, logical interrelationships, postulates and conventions practiced in the use of RPMS. Derivation of Linear Programming equations from the RPM networks is also described in this chapter.

In Chapter 3, a detailed discussion of the products and processes of the Tektronix Camera Shop is presented. A collection of data for the Tektronix model is briefly described and an example of Linear programming interpretation of RPM network is given.

Chapter 4 explains results of LP model of the camera shop and illustrates the use of these results to prepare and analyze the game theory payoff matrix with profit as a single objective. The approach discussed in this chapter is applicable whenever a single objective is considered to be significantly more important than the others.

Chapter 5 discusses preparation of the decision matrix along with the various choice rules that can be applied to identify the optimal alternatives. The Tektronix model has been used to illustrate the decision matrix approach, and its application to multiple objective situations.

A summary and mathematical interpretation of the complete methodology is given in chapter 6. This chapter also includes suggestions for future research and concluding comments.

II. RESOURCE PLANNING AND MANAGEMENT SYSTEM

Historical Sketch

The origin of network flow models, which constitutes a part of linear programming methodology, is obscure. Certain static minimal cost transportation models were independently studied by Hitchcock, Kantorovitch and Koopmans in the 1940's (Ford & Fulkerson, 1958). A few years later Dantzig (1953) showed how his general algorithm for solving linear programs, the simplex method, could be simplified and made more effective for the special case of transportation models. However, dismissing the optimizational aspects of the subject, and with the advantages of hindsight, one can go back a few years earlier to research of König, Egerrary and Menger (1936) on linear graphs, or Hall (1936) on systems of distinct representative for sets, and also relate this work in pure mathematics to the practically oriented subject of flows in networks. To carry the sketch another step back in time may lead one to Maxwell-Kichhoffs theory of current distribution in an electrical network. In fact, this problem may be viewed as a programming problem: one of minimizing a quadratic function subject to linear constraints (Ford and Fulkerson, 1962). A more general description of the problem of maximizing flow from one point to another in a capacity constrained network and a network methodology for solving the feasibility and combinational problems were developed by Ford and Fulkerson in their book (1962). A new version of these network methodologies is Resource Planning and Management System - developed by Inoue and Riggs in 1972 at Oregon State University. The unique feature of this methodology, as will become evident in the following discussion, is its ability to represent both the primal and dual flows on the same netowrk. This feature has been utilized in the proposed study to interpret optimal and sub-optimal solutions from their network format.

Resource Planning and Management (RPM) network was first proposed in 1972 as a graphical tool to model Linear Programming problems and their solutions. The input-output relationships were portrayed as a simplified cause and effect diagram and linked together to form a network. Subsequently it was noted that all primal and dual values could be portrayed on the same network (Inoue, 1974) and that non-linear models could also be represented (Chen, 1974). The use of this network has been extended to cover dynamic programming (Riggs and Inoue, 1975), quadratic programming (Inoue and Eslick, 1975) and other special cases of mathematical models.

A brief review of the Linear Programming problem will be presented in the next section followed by description of the notations and conventions of RPMS and its Linear Programming interpretation. The concepts discussed in this chapter will be illustrated later in this study by their application to the Tektronix model.

Linear Programming (LP) Problem

Any linear programming problem can be expressed in the following general conomical form.

$$\text{Maximize } Zx = \sum_{j=m+1}^{m+n} j \quad i \tag{2-1}$$

subject to the constraints

$$gi = \sum_{j=m+1}^{m+n} a_{ij} \; x_j \leqslant b_i \qquad 1 < i \leqslant m \tag{2-2}$$

$$x_i \geqslant 0 \qquad m+1 < j \leqslant n+m \tag{2-3}$$

where

a_{ij} , b_j and c_j are constants in a linear programming model.

x_j is called a primal variable.

The constants can be separated according to their positive and negative signs,

$$a_{ij} = a_{ij}^{+} - a_{ij}^{-} \tag{2-4}$$

$$b_j = b_j^{+} - b_j^{-} \tag{2-5}$$

$$c_j = c_j^{+} - c_j^{-} \tag{2-6}$$

1) $a_{ij}^{+} = a_{ij}$ if $a_{ij} < 0$ else $a_{ij}^{-} = 0$ (2-7)

2) $a_{ij}^{-} = a_{ij}$ if $a_{ij} < 0$ else $a_{ij}^{-} = 0$ (2-8)

3) $(a_{ij}^{+}) \cdot (a_{ij}^{-}) = 0$ (2-9)

4) $b_i^{-} = b_i$ if $b_i > 0$ else $b_i^{+} = 0$ (2-10)

5) $b_i^{-} = b_i$ if $b_i < 0$ else $b_i^{-} = 0$ (2-11)

6) $(b_i^{+}) \cdot (b_i^{-}) = 0$ (2-12)

7) $c_i^{+} = c_i$ if $c_i > 0$ (2-13)
else $c_i^{+} = 0$

8) $c_i^{-} = c_i$ if $c_i < 0$ else $c_i^{-} = 0$ (2-14)

9) $(c_i^{+}) \cdot (c_i^{-}) = 0$ (2-15)

The problem can now be stated as

$$\text{Maximize } Zx = \sum_{j=m+1}^{m+n} (c_j^{+} - c_j^{-})\, x_j \qquad (2\text{-}16)$$

subject to the constraints

$$\sum_{j=1+m}^{m+n} a_{ij}^{+} = a_{ij}^{-} \quad x_j \leqslant \quad b_i^{+} - b_i^{-} \quad 1 \leqslant i \leqslant m \qquad (2\text{-}17)$$

$$x_j \geqslant 0 \qquad\qquad m+1 \leqslant j \leqslant n+m \qquad (2\text{-}18)$$

An expansion of the above primal model gives a primal objective function:

$$\text{Maximize } Zx = \sum_{j=1+m}^{m+n} c_j^{+} x_j - \sum_{j=1+m}^{m+n} c_j^{-} x_i \tag{2-19}$$

subject to m resource constraints

$$\sum_{j=1+m}^{m+n} a_{ij} x_j^{-} + b_i^{+} \geq \sum_{j=1+m}^{m+n} a_{ij}^{+} x_j + b_i^{-} \tag{2-20}$$

$$1 \leq i \leq m$$

and the non negativity restrictions:

$$\begin{array}{lllll} x_j \geq 0 & a_{ij}^{+} > 0 & a_{ij}^{-} \geq 0 & b_i^{+} \leq 0 & b_i^{-} \geq 0 \\ c_i^{+} \geq 0 & c_i^{-} \geq 0 & 1 \leq i \leq m & & \\ & & m+1 \leq j \leq n+m & & \end{array} \tag{2-21}$$

The dual form of the general linear programming problem can be expressed as:

$$\text{Minimize } Zy = \sum_{i=1}^{m} b_i y_i \tag{2-22}$$

$$\text{subject to } \sum_{j=1+m}^{m+n} a_{ij}\ {}_{i} \geq c_j \qquad 1 \leq j \leq n \tag{2-23}$$

$$\text{and } y_i \geq 0 \qquad 1 \leq i \leq m \tag{2-24}$$

An expansion similar to the primal model transforms the above model into:

$$\text{Minimize } Zy = \sum_{i=1}^{m} b_i^+ y_i - \sum_{i=1}^{m} b_i^- y_i \tag{2-25}$$

Subject to n process constraints:

$$\sum_{i=1}^{m} a_{ij}^+ y_i + c_j^- \geq \sum_{i=1}^{m} a_{ij}^- y_i + c_i^+ \qquad 1 \leq j \leq m \tag{2-26}$$

$$\text{and} \qquad y_i \geq 0 \qquad 1 \leq i < m. \tag{2-27}$$

The n constraints are called "process constraints" since they convert endogenous $(\sum_{i=1}^{m} a_{ij}^+ y_i)$ and exogenous (c_j^-) resource flows into output resource flows $(\sum_{i=1}^{m} a_{ij}^- y_i + c_j^+)$. As y_i represents the shadow price of the resource i, and c_j^+ and c_j^- represent the per unit benefit and cost of the transformation, each process constraint implies that total value of input resource + cost of transformation is $\geq$ total value of output resource + benefits from the transformation process.

Components and Conventions of RPMS for Representing a LP Problem

The basic elements of RPM network are described below and their significance in representing a mathematical model is noted.

Resource Node (R)

A resource is taken to mean anything that can place a limitation on the attainment of a level of activity and is represented by a circle on the RPM network. This circle is divided into four cells (see Figure 1-a). The dual variable, y_i, is entered into the top cell quater and can be interpreted in the following ways:

1. The shadow price or the imputed value of the resource.

2. The value of the Lagrangian multiplier associated with the resource constraint computed by the simplex algorithm (Inoue, 1974).

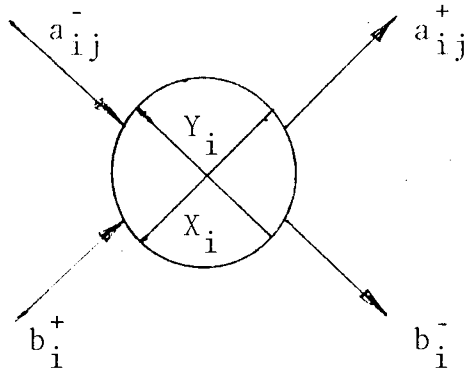
The slack value of the resource, x_i, is entered into the bottom cell and it represents amount of the resource that is left over.

The left cell and the right cell are optionally used to tally the total inflow ($\sum a_{ij}^- x_j + b_i^+$) and the total outflow ($\sum a_{ij} + x_i + b_i^-$).

The application of the first postulate of RPMS (inflows $\geq$ outflows), stated later in this chapter, leads to the following constraint of the primal mode of the LP problem:

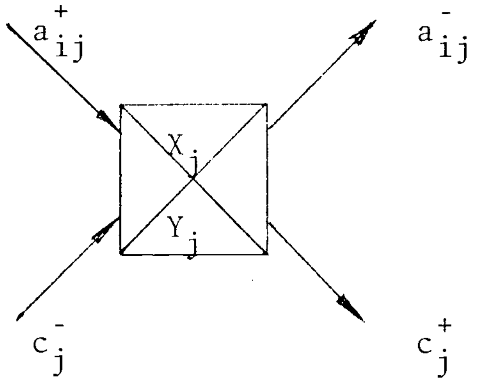
$$\sum_{j=1}^{n} a_{ij}^- x_j + b_i^+ \geq \sum_{j=1}^{n} a_{ij}^+ x_j + b_i^- \qquad (2\text{-}20)$$

A modification of the Resource node is an equality node that represents an equality constraint and is denoted by a double circle (see Figure 4-1). In this special case, x_i is always equal to zero and y_i is free to take a positive, zero or a negative value. The direction of the arrows



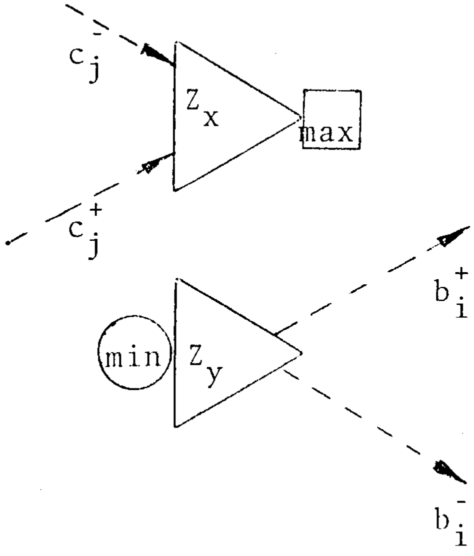
$$\sum_{j=1}^{n} a_{ij}^{-} x_j + b_i^{+} \geq \sum_{j=1}^{n} a_{ij}^{+} x_j + b_i^{-}$$

(a) Resource Node



$$\sum_{i=1}^{m} a_{ij}^{+} y_i + c_j^{-} \geq \sum_{i=1}^{m} a_{ij}^{-} y_i + c_j^{+}$$

(b) Process Node



Maximize $Z_x = \sum_{j=1}^{n} c_j^{+} x_j - \sum_{j=1}^{n} c_j^{-} x_j$

Minimize $Z_y = \sum_{i=1}^{m} b_i^{+} y_i - \sum_{i=1}^{m} b_i^{-} y_i$

(c) Maximizing and Minimizing Nodes

Figure 2-1. RPMS Nodal Conventions

representing inflows and outflows can be reversed in this case without changing the constraint.

Process Node (p)

A process is interpreted as a decision activity which is actually representative of the action taken in order to achieve an end result. A process node is denoted by a square divided into four cells (see Figure 2-1-b). The primal decision variable, x_j, of LP problem is entered into the top cell and represents "the level of activity."

The opportunity cost, y_j, is entered into the bottom cell and it can also be interpreted as the Lagrangian multiplier associated with the non-negativity constraint imposed upon the primal variable x_j (Inoue, 1974).

As in the case of the resource node, the left and the right cells can be optionally used for tallying the total inflows and the total outflows respectively.

Applying the first postulate of RPMS to the process node leads to the following equiations of LP:

$$\sum_{i=1}^{m} a_{ij}^{+} \quad y_i + c_j^{-} \geq \sum_{i=1}^{m} a_{ij}^{-} y_i + c_j^{+} \qquad (2\text{-}26)$$

or

$$y_i = \left\{ \sum_{i=1}^{m} a_{ij}^{+} y_i + c_j^{-} \right\} - \left\{ \sum_{i=1}^{m} a_{ij}^{-} y_i + c_j^{+} \right\} \qquad (2\text{-}28)$$

The relationship between a resource y_i and a primal decision variable x_j, is established by using a solid line with an arrowhead to connect the corresponding circle and square. The solid arrow has a transmittance value of a_{ij} and the direction of the arrowhead is selected so as to make the transmittance value appear positive; reversing the direction of an arrowhead has the same effect as of multiplying the transmittance by -1.

Minimizing and Maximizing Nodes (M): Each optimization model will have one minimizing "source" and one maximizing "sink." In the case of a primal maximization problem, the primal objective function, $-Z_x-$ is represented by a triangle sink node with the word "Max" denoted within a box and attached to the point of the triangle. This is connected to all the process nodes--representing primal decision variables included in the objective function--with dashed arrows. The value of the objective function is written inside the triangle.

The dual model will then have a minimizing source node which is represented on the RPM network by a triangle pointing towards right (see Fig. 2-1-c). The word "Min" inside a circle identifies the dual objective function to be minimizing. All the resource nodes representing variables included in the dual objective function are connected to the triangle by dashed arrows.

A minimizing primal problem will have a primal source node and a maximizing dual sink node.

RMPS Conventions

Following conventions as stated by Riggs and Inoue (1975, p. 152) must be observed while constructing a RPM network:

1. Never connect a circle to another circle or a square to another square directly.

2. Use solid arrows for internal flows and dotted arrows for exogenous or endogenous flows.

3. All squares are explicitly or implicitly (with zero objective-function value) connected to one terminal, and all circles are explicitly or implicitly connected to the other terminal; no mixing of terminals is allowed.

4. The dimension of the arrow coefficient is always resource-unit/process-unit regardless of the direction of the flow.

5. A resource node implies an OR relationship among flows; none, any, or all flows may be realized at the same time and all must have the same resource unit of measurement.

6. A process node implies an AND relationship among flows; all flows must be realized when the process is basic primal. If one input is missing, the process cannot be realized; and if the process is realized, all outputs will be generated. The units of these flows may be in different measurement units since the function of a process is to convert a set of input resources into a more useful set of output resources.

7. It is advisable to set the RPM network in a more or less chronological order, flowing from left to right or from top to bottom, and label the date whenever possible. A resource at one time is different from the same resource at another time.

8. The dimensional units of resources and processes may be changed to suit the convenience of the analyst and/ or user. (The details of scaling are discussed in Chapter 9, Section 9-2.)

9. The double circle implies an equality constraint where residue must be zero. The dual value of the resource may then be either positive or negative, and the dual variable is said to be "free" while the connected process may be "frozen" because of the equality.

10. A double square may be used in a similar manner to imply a free decision (primal) variable, which may be either positive or negative but which will always be basic (i.e., no residual value). Such a process can always be represented by two parallel processes with opposing arrows.

RPMS Postulates

The following intuitively appealing rules were formulated as postulates to incorporate Kuhn Tucker conditions and the concavity criterion into the RPM system (Inoue, 1974):

(R). Resource Conservation Postulate: The total inflow at a process or resource node cannot be less than the total outflow from the same node.

Equations (2-20) and (2-26) are examples of application of this postulate to a resource and process node respectively.

(P). Positive or Zero Requirement: A primal entry must be positive or zero for the solution to be feasible; a dual entry must be positive or zero for the solution to be optimal (equality nodes excepted). Moreover, either or both entries in any resource or process node must be zero.

This postulate is a combination of the non-negativity condition of the LP variables and the complementary slackness requirement.

(M). Maximizing and Minimizing Objectives: If the primal objective function is to maximize, then the dual objective function should be minimizing. If the primal objective function is to minimize, then the dual objective should be maximizing.

(S). Solution Criteria: If all the entries on RPM network are positive or zero, this indicates an optimal and feasible solution (see Figure 2-2).

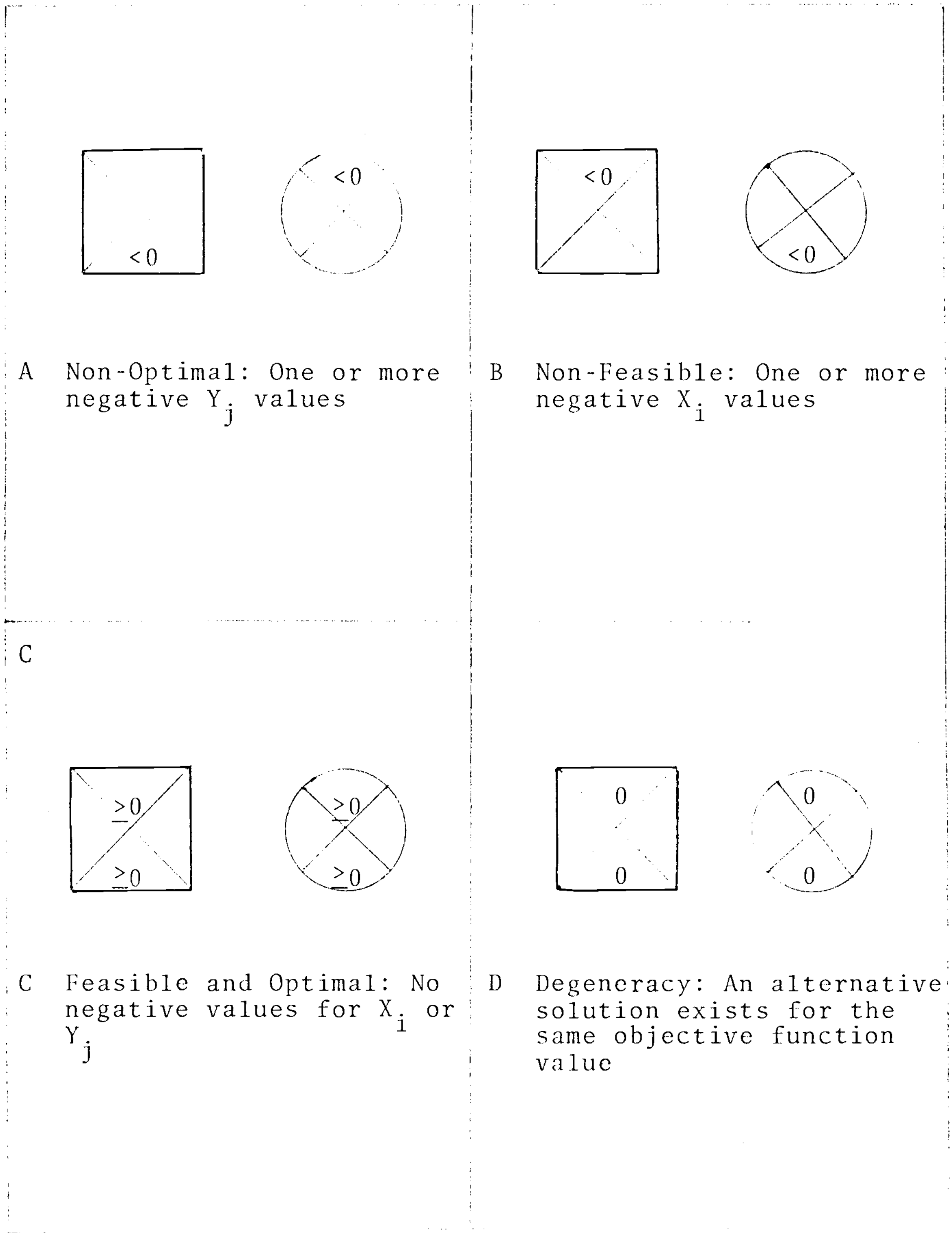


Figure 2-2. RPMS Feasibility and Optimality Conditions

III. THE TEKTRONIX MODEL

Brief Description of Tektronix

Tektronix was started in 1946 by a group of five men manufacturing one instrument type. The company now employs 12000 people building hundreds of instruments and accessories (Tektronix, 1975). Engineering offices have been established by Tektronix all over the U.S.A. and a few foreign countries. Tektronix instruments are being used in virtually every country of the world. The headquarters and plants occupy a 300-acre industrial park near Beaverton, Oregon and another 265 acres near Wilsonville, Oregon were added in 1975 to cope with the anticipated growth.

The Tektronix 1975 catalogue states:

> Our business is measurement instrumentation. Any phenomenon that can be converted to an electrical impulse can be measured by a Tektronix instrument. The electronic measurement tool must be more advanced than the circuit or device it examines. Tektronix then, must both extend the state of art in science and technology, and keep running a few paces ahead of it.

Besides the measurement instrumentation, the extensive services that go along with these high technology products can be viewed as the other set of products offered by Tektronix. The nature of the product necessitates a policy of high degree of technology innovation, and research orientation in Tektronix. Also, the market of Tektronix which largely consists of the research and production related fields, is extremely sensitive to changes in its technological environment. This explains for the great breadth of Tektronix product lines which is necessary to meet the specific research and industrial requirements in precision instrumentation. The technological superiority of the products enabled Tektronix to maintain a dominant market share in the industry. However, due to the effects of changes in the economic environment and attempts of the potential competitors to penetrate the market, a need was felt by Tektronix to plan its resources more carefully.

The Tektronix Camera Shop

The camera shop is a small subdivision of Tektronix presently employing nineteen full-time workers. A description of its products and processes is given in the following discussion.

A. The Products.

The products of the Tektronix camera shop is a specialized set of cameras which were developed to facilitate permanent recording of cathode ray tube display and to enable the users of oscilloscopes to accurately study the high transient phenomena. These cameras are essentially sold as accessories to oscilloscopes and some other visual display devices. Each camera is designed to complement a specific group of the Tektronix oscilloscopes and is identified by its main electrical, optical and mechanical characteristics. A list of some such characteristics is given below (compiled from the Tektronix catalogue of 1975 products).

1. Camera Mounting and Use: By using optional adapters, most cameras can be mounted on a wide variety of instruments, but they must of course be optically compatible to produce useful photos.
2. Lens Speed: Most of the cameras have a different relative lens speed. For photogaphing a stored or recurrent stable cathode ray tube display, a slow or medium speed lens is suitable and economical. For recording a high speed, single sweep trace the fastest lens available may be needed.
3. Field of View: Cameras are made for the cathode ray tube display that range in size from 6x8 cm. to 10.2 and 12.7 cm. The field of view of each camera is different in its capability of fully recording the entire display on a given film size.
4. Lens Magnification: Every camera has a different lens magnification which affects the size of the photo image.
5. Film Backs: It may be deisrable to interchange different types of film backs to allow use of different film types, picture sizes and emulsion

speeds. Except for the C-5 camera, all Tektronix cameras have changeable film backs.

6. Multiple Images: It may also be desirable to record more than one CRT display on a single photo. The C-12 and C-27 cameras have rotatable, indexed sliding backs that allow recording multiple images on one photo.
7. Films: The different types of cameras have different types of film backs available which can only accomodate certain types of films.
8. Viewing: Most Tektronix cameras allow viewing the display while photographing it; but some compact cameras do not have a viewing point.
9. Shutters: Some cameras have a shutter operable by remote electrical control while some have manually operable shutters.
10. Camera Power: Finally, some of the C-50 series cameras are electrically operated from a supply of +15 volts while some others would require a battery pack.

B. The Processes

The camera shop of Tektronix is essentially an assembly shop. Various components and materials that are bought

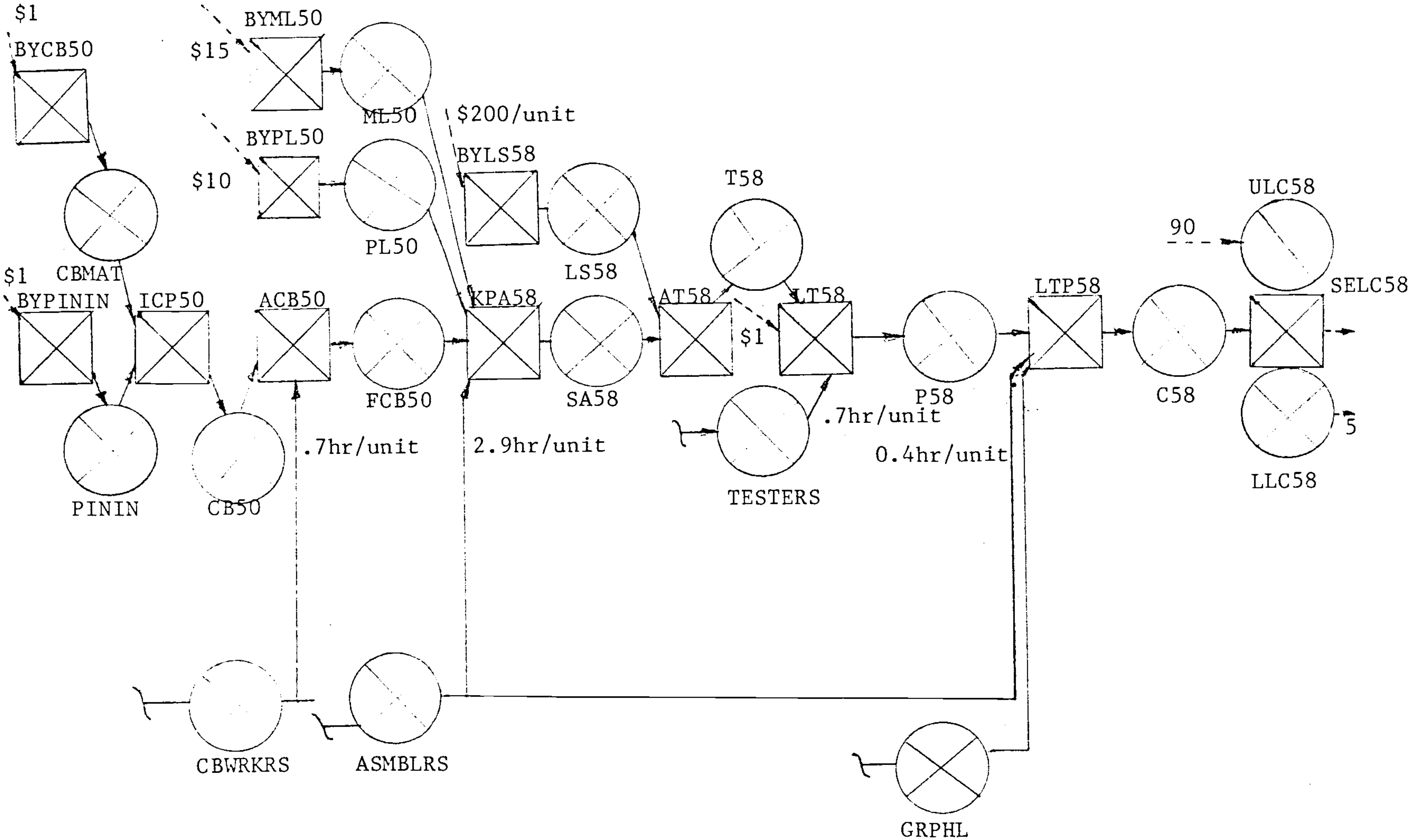


Figure 3-1. Segment of RPM Showing Assembly of A Camera.

from outside or manufactured in other plants of Tektronix, are assembled in the camera shop. There are no separate product lines for the different cameras. Only one worker is assigned to each work station. The operations involved in the assembly of different cameras are similar; although the manhours consumed for different cameras are not the same.

The assembly operations of a typical camera are shown in Figure 3-1 and briefly explained in the following discussion.

Assembly of a Camera

The first step in the assembly process is of inserting the pins into the circuit boards. These circuit boards form the basic framework on which the assembly is built. The circuit boards are, however, used only for the C-50 series of cameras (not shown in Figure 3-1).

The finished circuit boards are then passed on to the next operation which is called kit preparation and assembly. This operation involves assembling the structural parts of the cameras which can be classified into metal parts and plastic parts. These parts are purchased from the market and their costs depend on the type of camera they are used for.

The unfinished camera then goes to another assembly operation where lens and shutters are fitted onto the camera. The type of lens and shutter and their costs vary with the type of camera they are used for.

The assembled unit is then sent for the "live test." This test consists of actually taking a picture with the camera.

The camera then goes for a test called "light test." This test is used to check the electrical system of the camera. The camera is then packed with its respective 'back.' The back is an accessory of the camera. There are four different types of backs. Each back itself has to go through a small assembly operation in the camera shop. Backs are also sold independently. Another accessory is a viewing hood used for cameras C59, C50, C51 and C52.

A copy of the RPM network for the camera shop is attached to this thesis. This network shows the assembly of all the cameras.

There are two types of workers employed by the camera shop - grade 5 and grade 8. Grade 8 workers are high skilled workers and they only perform certain types of testing activities. Grade 8 workers are referred to on the RPM network as TESTER. Grade 5 workers perform the rest of the assembly operations and have been referred to as ASMBLRS on the RPM network. The term "ranges" are sometimes preferred over the word "grades" by Tektronix management.

Data Collection

The first step in the collection of data was to prepare a rough logical structure of the RPM network to represent the assembly processes as described by the management. This network was then used as a communicational tool for the dual purpose of (1) developing the understanding of the processes and their interrelationships and (2) validating the data by obtaining feedback from the management.

The data collection can be classified and described as follows:

a. Cost Data: They include various costs associated with buying the components and materials and paying for the labor. Such data are confidential and not disclosed in this study.

b. Sales Data: The sales data was gathered for one production period; where one accounting period consists of thirteen production periods and a production period is of four weeks' duration. Expected figures for the maximum and minimum sales of the different cameras and backs were obtained by interviewing the manager of the camera shop. The actual sales figures for a past accounting period were also obtained to carry out the test run. The sales data for the camera shop are given in Table 4-1.

c. Manhour Requirement Data: The standard times for each activity or operation were obtained. The manhour requirements of various activities are given in Appendix A along with a brief description of each activity.

d. Constraints Data: Supply of various components and materials was assumed to be unlimited. The maximum available manhours of Grade 5 and Grade 8 workers were obtained by multiplying the number of workers available with the number of hours in a production period.

e. The Price Data: The catalogue prices of all the products were used in the model.

Linear Programming Model of the Camera Shop

A master RPM network was prepared by validating the original RPM network. Deriving the linear programming constraints from the RPM network was done as shown in chapter 2. In order to derive the constraints for the primal LP problem, the first postulate of RPMS was applied to each resource node. The following example shows the derivation of LP problem for the segment of RPM network given in Figure 3-1.

Due to the problems of dimensionality, abbreviations were used for identifying all the process and resource nodes. A list of all these abbreviations is given in Appendix A along with a brief description.

Example 3-1: {Max.} Profit = 755 SLC58 - 1 LT58 - 200 BYL558 -15 BYML50 - 10 BYPL50

s.t.	@ ML50	KPA58 $\leq$ BYML50
	@ PL50	KPA58 $\leq$ BYPL50
	@ ASMBLRS	2.9 KPA58 + 0.4 LTP 58 $\leq$ PWRAS
	@ SA58	AT58 $\leq$ KPA58
	@ LS58	AT58 $\leq$ BYL558
	@ T58	LT58 $\leq$ AT58
	@ TESTERS	0.7 LT58 $\leq$ HSTGR8
	@ P58	LTP58 $\leq$ LT58
	@ C58	SLC58 $\leq$ LTP58
	@ ULC58	SLC58 $\leq$ 90
	@ LLC58	5 $\leq$ SLC58

All Variables ≥ 0

Preparation of the Computer Input Data File

The program used for solving the LP problem was *REXY which was developed by H. Lynn Scheurman (1975) at Oregon State University. This program is compatible with IBM's SHARE standard software (LPS, MPS AND MPSX) for solving LP problems.

In order to use *REXY, an input data file has to be prepared which consists of three sections ROWS, COLUMNS and RHS.

In the ROWS section, the objective function is identified by a $ symbol in front of it. This is followed by identification of all the resource nodes on the RPM network. Each of these is preceded by a symbol which shows the nature of the corresponding constraint viz. <is used to represent a less than or equal to constraint, >is used to represent a greater than or equal to constraint and = is used for an equality constraint.

In each line of the column section, first a process node is identified and then its interrelationships with the resource nodes and the objective function are shown.

Finally, the RHS section of the input data file provides a description of any exogenous or endogenous flows from a resource node.

An example[1] of the input data file for the segment of RPM shown in Figure 3-1 is seen in Table 3-1.

---

[1]The *REXY output files for the problem being discussed in this study are shown in Appendix B along with their interpretation.

Table 3-1. Example of *REXY Input Data File

```
ROWS <
$ PROFIT < ML50 < PL50 < ASSMBLRS < LS58 < FCB50
<T58 < P58 < C58 < ULC58 < LLC58

COLUMNS
BYML50    PROFIT - 15  ML50 - 1
BYPL50    PROFIT - 10  PL50 - 1
BYLS58    PROFIT - 200 L558 - 1
KPA58     ML50 1  PL50 1  FCB50 1  ASMBLRS 2.9
KPA58     SA58 - 1
AT58      SA58 1  LS58 1  T58 - 1
LT58      PROFIT - 1  T58 1  TESTERS 0.7  P58 - 1
LTP58     P58 1  GRPHL 1  ASMBLRS 0.4  C58 - 1
SLC58     PROFIT 755  C58 1  ULC58 1  LLC58 - 1
BYPININ   PROFIT - 1  PININ - 1
ACB50     FCB50 - 1  CBWRKRS 0.7  CB50 1
ICP50     CB50 - 1  CBMAT 1  PININ 1
BYCB50    PROFIT - 1  CBMAT - 1
RHJ
RESOURCE ULC58  90  LLC58 - 5
EOF
```

IV. A METHODOLOGY TO AID IN RESOURCE PLANNING WITH A SINGLE OBJECTIVE

The theoretical aspects of linear programming and RPM were discussed in chapter two. A methodology utilizing these operations research tools and game theory will be discussed in this chapter. The objective of this methodology is to aid the resource planning activities under uncertainty and risk conditions. The concepts presented in this chapter will be illustrated by their applications to the Tektronix camera shop model which was described in chapter three. An extension of this methodology to deal with multiple conflicting objectives will be discussed in the next chapter.

The Proposed Methodology

The proposed methodology is divided into three phases.

Phase 1: Proposed Analysis: A preliminary RPM network is first prepared to represent interrelationships among resources and activities in the system. The draft copy of this RPM network for the Tektronix model was prepared as the camera shop was described by the higher level management personnel in a meeting. This draft copy of RPM network was then used as a communicational tool to study the system and to obtain detailed information from the operating management. After the RPM

Table 4-1. Tektronix Camera Production Facility Study Summary

MODELS	min units	max units	price $	(A) PERIOD 513 quantity units	(A) PERIOD 513 shadow price($)	(B) OPTIMIZED AS IS quantity units	(B) OPTIMIZED AS IS shadow price($)	(C) OVERTIME GR5 quantity units	(C) OVERTIME GR5 shadow price($)
C5A	75	400	$ 235	0	+146	326	0	400	+138
C12	10	60	750	35	+427	10	-45	60	+401
C27	5	175	690	40	+367	5	-105	175	+341
C12E	2	12	1090	0	+617	12	+145	12	+591
C27E	2	12	1030	0	+557	12	+85	12	+531
C30	50	100	650	63	+375	50	-17	100	+355
C31-32	0	10	770	6	+476	10	+83	10	+455
C58	5	90	755	2	+475	90	+49	90	+449
C53	35	75	1000	14	+868	35	-52	75	+815
C59	40	85	615	18	+453	40	-181	85	+416
C50	35	75	990	7	+842	35	-140	75	+785
C51	22	55	1260	22	+975	22	-7	55	+918
C52	3	20	1290	4	+1019	20	-36	20	+962
C Special	4	8	1430	0	+1067	4	-84	8	+1001
Plastic Back	10	25	70	25	+41	10	-15	25	+38
Metal Back	10	25	100	25	+55	10	-57	25	+49
Roll Back	10	25	135	25	+86	25	+30	25	+83
Graflok Back	10	25	70	25	+36	10	-20	25	+33

	(A) PERIOD 513	(B) OPTIMIZED AS IS	(C) OVERTIME GR5
PROFIT CONTRIBUTION	21.28	52.17	100
Grade 5 Regular hrs	2720	2720	2720
Grade 5 Overtime hrs	NA	NA	2453
Grade 5 2nd Shift hrs	NA	NA	NA
Grade 5 Idle hrs	1268	0	0
Grade 5 Shadow Price (WRKRS)	$0	$112.30	$61.2
Grade 8 Regular hrs	320	320	320
Grade 8 Overtime hrs	NA	0	0
Grade 8 Transferred hrs	NA	NA	33.9
Grade 8 Idle hrs	275	142	0
Grade 8 Shadow price (TESTERS)	$0	$0	$6.12

network had been validated to the extent where it represented the system sufficiently accurately; a 'test run' was conducted. This test run consisted of making a LP computer run using the actual sales figures of a previous period. Results of this run were compared with actual results obtained in the period to test whether the model realistically reflected the system or not. A summary of results of the test run conducted for the Tektronix model is shown in Table 4-1 under PERIOD 513. Validation of the preliminary RPM network is followed by preparation of a master RPM network.

Phase 2: Decision Analysis. The LP model represented by the master RPM network is then optimized using the forecasted demand figures for the next study period. Derivation of the input computer file from the RPM network was explained in chapter three. The output computer files obtained for the Tektronix model are given in Appendix B along with a brief description of their interpretation. The LP model can be modified by incorporating the pre-emptive goals, if any, as constraints in the model.

A summary of the results of the LP run made for the Tektronix model is also given in Table 4-1 under the heading "OPTIMIZED AS IS". Optimization of the LP model results into various important findings, such as:

1. An optimal solution for the study period. An optimal product mix for the next production period was obtained in case of the Tektronix model;

2. An input computer file which serves as a data base for the researcher or the decision maker to do sensitivity or adaptivity analysis as and when required. The input computer file for the Tektronix model is also given in Appendix B;

3. Information for decisions such as the "make-or-buy" and the "hire-or-fire" decisions. If shadow price of certain resource is found to be lower than its unit cost, the decision maker should consider other posibilities of acquiring this resource including the one of producing the resource himself. The shadow prices listed in Table 4-1 correspond to the upper and lower limits imposed on sales of different products. In case of the Tektronix model, therefore, the products could be classified in the order of their profitability using the values of their shadow prices. This could provide the marketing department with useful information for deciding on allocation of its marketing efforts;

4. Identification of resource bottlenecks. This is done by seeking out the resources that show unreasonably high shadow prices. In case of the Tektronix model, availability of grade 5 manhours showed a shadow price of

$112.30. A manhour of grade 5 workers costs only $4.19. Availability of this resource was therefore identified as a potential bottleneck in the camera shop.

<u>Phase 3: Potential Problem Analysis</u>. The resources identified as bottlenecks in phase 2 are selected as the decision areas for long term resource planning. In the Tektronix camera shop uncertainty is associated only with the demands. If the decision maker could assume, with sufficient accuracy, a probability distribution governing the future demands, stochastic programming techniques (Hadley, 1964, p. 158-181) would be applicable to the design of optimal strategies. Also, with some modifications in the constraints, it could help the management select the optimal alternative from a given set of alternatives. When probability distributions could not be assumed by the decision maker, however, pertinent information must be generated so that the risk elements -- involved with making a long term decision under uncertainty -- are made explicitly apparent to him. The game theory format has been selected in this study to serve this purpose. A major limitation of game theory, as was mentioned in chapter one, is the inability of the players to fill in accurate values in the payoff matrix. In the following discussion, application of linear programming to generate accurate information for the payoff matrix will

be described. One other reason for selecting the game theory approach was the fact that it could be easily extended to deal with multiple objective situations, as will be shown in chapter five.

A game theory classification of decision problems based on variables in decision maker's utility function not subject to his choice is given by Irving H. Lavalle (1967, p. 68) as follows:

1. A disinterested 'nature' whose choice of values of variables is performed without the decision maker's knowledge of the governing law (the uncertainty problem);

2. A disinterested opponent of known characteristics called 'nature' choice of variables is performed under known probability (the risk problem);

3. An interested opponent, whose choice of variables is in some fashion affected with consideration of decision maker's possible choices (the certainty problem).

The first two classes of problems can be further classified as follows:

a. Problems or situations where utility function is derived by using deterministic or subjective approaches (strategic models);

b. Situations where the utility function is derived by using probabilistic theorems, for example, the Bayesian Theorem (probabilistic models).

The discussion in this study will be restricted to problems classified as 1 and 2 in the first classification, and as 'a' in the second classification.

Preparation of The Game Theory Matrices

A game theory matrix is developed for each of the decision areas selected for the long term resource planning. A planning horizon of one accounting period that is 52 weeks was chosen for the Tektronix model. Development of the payoff matrices mainly consists of three steps which are described in the following discussion.

A. Developing Alternatives.

Quality of the final decision depends on the best of the alternatives considered or, where applicable, the mix of some of the alternatives considered. This implies the necessity of being extremely careful and comprehensive in identifying all the promising alternatives.

D. J. White (1975) has suggested two ways in which the alternatives can be specified:

(i) the allowable set is made explicit, and we have to evaluate each alternative in this set. For example, it may be asked whether or not a product should be inspected;

(ii) the set of alternatives is defined via constraints and the decision maker has to search for feasible solutions.

In case of the Tektronix model, the set of alternatives was defined as any number of manhours less than or equal to 70,720 manhours which is equivalent to maintaining two regular shifts of grade 5 workers for one accounting period. From this set, the management selected the following four feasible alternatives:

1. Second Shift: Implementing a second shift meant doubling the present workforce with the workers in the second shift to be paid 10% more than the workers in the first shift.

2. Overtime (A_O): Allowing the grade-5 workers to work overtime. The maximum overtime that can be allowed to a worker in the camera shop is limited to half of his regular working hours.

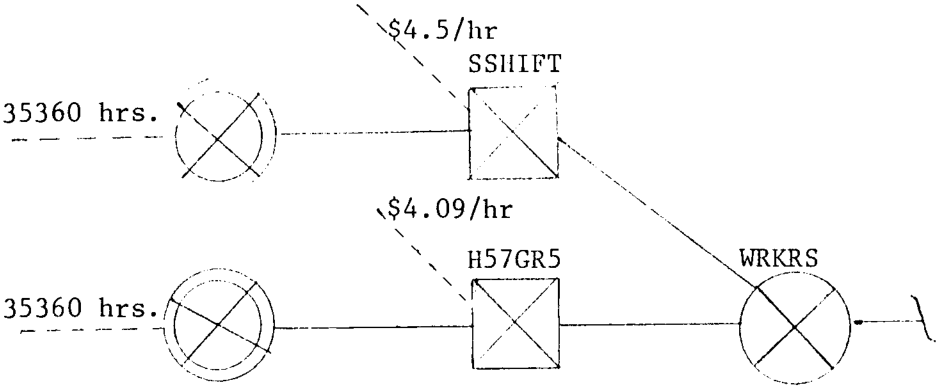
3. Regular Time (A_R): Maintaining the present work force without allowing any overtime. This alternative implied availability of manhours of grade 5 workers = 35360 manhours.

4. 5 Extra Work Stations: Expanding the capacity of the camera shop to accomodate five more work stations. This also meant hiring five more grade-5 workers since one worker is assigned to each work station in the camera shop.

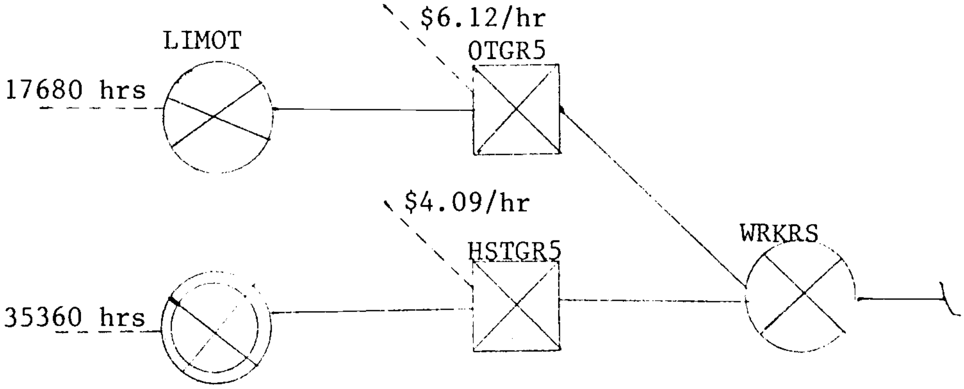
Thus the 1st step in preparation of the game theory matrix is to identify all the feasible alternatives affecting availability of each of the bottleneck resources.

B. Developing the States of Nature.

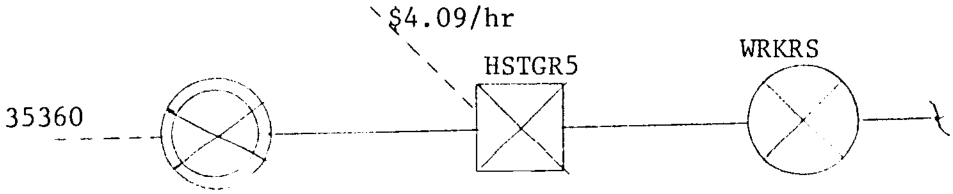
The management is then asked to identify all the possible states of nature that he expects to occur in the planning period. In cases of absolute uncertainty, the management is asked to identify the 'worst' and the 'best' that can happen in the planning period. For example, in



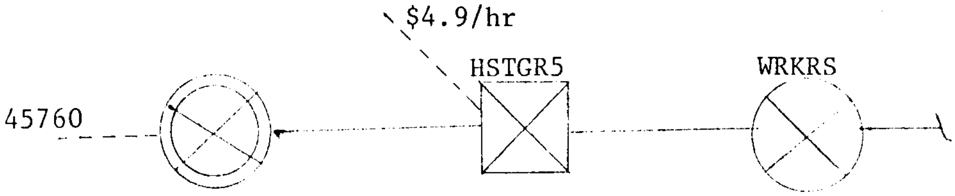
(i) For Alternative A_s



(ii) For Alternative A_o



(iii) For Alternative A_R



(iv) For Alternative A_E

Figure 4-1. The Changes Made in the RPM for Each Alternative.

case of the Tektronix camera shop the three states of nature identified were:

a) demand of each product doubles up,

b) demands of different cameras (DUP) remain the same as they are at present and (DASIS),

c) demand of each camera goes down to the minimum that the company is committed to sell at present (DDWN)

An LP run is then made corresponding to each combination of state of nature and alternative since each alternative reflects a change in availability of the resource, it can be incorporated as a constraint in the LP model. Fig. 4-1 shows the changes made on the RPM network corresponding to each alternative developed for the Tektronix model. Twelve different LP runs were made to develop the game theory matrix where the payoff figures represent the profits made in different LP runs. The profit figure in the matrix shown below have been converted to a 0 to 100 scale, since the actual profit figures are confidential.

Analysis of the Payoff Matrices

The purpose of presenting the management or the decision maker with the payoff matrices is to provide him with information in a format that would make the risk and uncertainty elements explicitly apparent. The management

Decision Maker \ Nature	S=1 Demand up (DUP)	S=2 Demand as it is (DASIS)	S=3 Demand down (DDWN)
k = 1 Second Shift	100	87·16	22·95
k = 2 Overtime	73·5	70·4	23·44
k = 3 Regular Time	47·0	45·9	24·97
k = 4 5 Extra Work Stations	63·4	60·81	24·34

can then decide on one of the alternatives with exact knowledge of the gains or losses that would not occur if he had chosen some other alternative. A number of game theory criteria are available which can be applied to the payoff matrices to identify the optimal alternative or the optimal mix of alternatives. Applications of these criteria to the profit matrix shown above will now be presented.

A. Wald's Maximin Criterion: This criterion is based on the minimax theorem which was first introudced by Von Neuman in his papers published in 1928 and 1937 (Luce and Raiffa, 1957). The basic assumption of this criterion is that the opponent will select the "worst possible" strategy for the player.

The optimal alternative corresponds to

$$\max_{k} \left\{ \min_{s} (Z_{ks}) \right\}$$

Where there are k alternatives (k = 1, 2, 3 ...) and s states of nature (s = 1, 2, 3 ...). Z_{ks} represents the payoff resulting from k^{th} alternative under s^{th} state of nature.

Application of this criterion to the Tektronix model profit matrix gives k = 3 (Regular Time) as the optimal alternative.

Z_{ks}^* is said to be the "saddle point" if

$$Z_{ks}^* = \max_k \left\{ \min_s \; (Z_{ks}) \right\} = \min_s \left\{ \max_k \; (Z_{ks}) \right\} \qquad (4\text{-}1)$$

Whenever there exists a saddle point in the payoff matrix, this criterion will give one alternative (i.e., a pure strategy) as the optimal alternative; a mix of alternatives (i.e., a mixed strategy) will be given as the optimal strategy otherwise. Interpretation of a mix of alternatives is explained later in this chapter.

Wald's maximin criterion assumes that nature would try to do the worst possible to the company's profit. This assumption leads to a very conservative or pessimistic solution. This criterion, however, can be useful in providing the management with a lower bound on the expected payoff.

B. Laplace's Criterion: This criterion, based on the so called "Laplace's Principle of Insufficient Reason," assumes that if absolutely nothing is known about the probability distribution of the states of nature, they can all assumed to be equally likely. Let the probability distribution associated with the states of nature be given by set X. Where,

$$X = (x_s \mid \sum_s x_s = 1) \qquad (4\text{-}2)$$

Laplace's criterion assumes all the elements of the above set to be equal. For the Tektronix camera shop profit matrix, therefore, $x_1 = x_2 = x_3 = 1/3$. The expected payoff from the k^{th} alternative is given by,

$$\Sigma\ E\ (k) = \sum_s Z_{ks} \cdot X_s \qquad (4\text{-}3)$$

The highest expected payoff, for the profit matrix, is obtained from the alternative k = 1 (second shift). Second shift is therefore taken as the optimal alternative.

C. Optimism - Pessimism Criterion: This criterion was proposed by Hurwicz in 1951 (p. 140). An optimism index is selected where $0 \leq \delta \leq 1$. A column vector (W_k) is prepared such that

$$W_k = (\delta)\ \{\max_k (Z_{ks})\} + (1-\delta)\ \{\min_k (Z_{ks})\} \qquad (4\text{-}4)$$

The optimal alternative corresponds to $\max_k (W_k)$.

Selection of a realistic optimism index for the Tektronix model was found to be extremely difficult. In order to illustrate application of this criterion, an arbitrary value of 0.8 was taken. This criterion also gave second shift to be the optimal alternative. Another drawback of this criterion was found to be the fact that it only considers the extreme values of the payoffs in each row. This may lead to rejection of an alternative with higher expected payoff but lower values of the minimum and maximum payoffs.

D. Minimum Regret Criterion: This criterion was proposed by Savage (1951, p.57) to enable the decision maker to take advantage of the opportunity that may be created due to the selection of a "favorable" state by nature.

A regret matrix $\{\delta_{ks}\}$ is created from the payoff matrix using the following equation:

$$\delta_{ks} = \{ Z_{ks} - \max_{s} (Z_{ks})\} \text{ for all k and s} \qquad (4\text{-}5)$$

The optimal alternative corresponds to

$$\max_{k} (\min_{s} Z_{ks})$$

Application of this criterion to the profit matrix gave second shift to be the optimal alternative.

E. Excess Benefit Criterion: This criterion was developed by Agrawal and Heady (1972, p.152) to blend the overly optimistic criterion of minimum regret and the extremely pessimistic maximin criterion.

A benefit matrix $\{b_{ks}\}$ is derived using the following equation:

$$b_{ks} = \{ Z_{ks} - \min_{k} (Z_{ks}) \} \qquad (4\text{-}6)$$

Optimal alternative then corresponds to

$$\max_{k} (\min_{s} b_{ks})$$

Application of this criterion to the profit matrix gave k = 4 (5 Extra Work Stations) to be the optimal alternative.

A further analysis of the payoff matrix based on Savage's Subjective Probability Theorem can be carried out as shown below:

Consider the two cases that can exist at the time of decision making for the Tektronix model:

Case 1. Probability of demand going down is zero.

let P(DUP) = x

P(DASIS) = 1-x

$$E\ (A_s) = 87{\cdot}6\ (1-x) + 100\ x \qquad (4\text{-}7)$$

$$E\ (A_o) = 70{\cdot}4\ (1-x) + 73{\cdot}4\ x \qquad (4\text{-}8)$$

$$E\ (A_r) = 45\ (1-x) + 47\ x \tag{4-9}$$

$$E\ (A_e) = 60 \cdot 45\ (1-x) + 63 \cdot 4\ x \tag{4-10}$$

From the above equations it is seen that the expected payoff of alternative A_s is higher than that of other alternatives for all values of x. This implies that no matter how low are the chances of demands going up; it is advisable to implement the second shift option for this case.

Case 2. Probability of demands going up is zero.

let P(DASIS) = 1-x

P(DDWN) = x

$$E\ (A_s) = 87 \cdot 6\ (1-x) + 23\ x \tag{4-11}$$

$$E\ (A_o) = 70 \cdot 4\ (1-x) + 23 \cdot 44\ x \tag{4-12}$$

$$E\ (A_r) = 45\ (1-x) + 23\ x \tag{4-13}$$

$$E\ (A_s) = 60 \cdot 45\ (1-x) + 24 \cdot 34\ x \tag{4-14}$$

A paired companion of the alternatives can now be carried out using their expected payoffs. For example, the expected payoff from alternative A_s will be greater than that of alternative A_r if

$$E\ (A_s) > E\ (A_r)$$

$$\text{i.e., } x < 95 \cdot 36\%$$

This means that if chances of demand going down are not less than 5%, the second shift option will be more profitable than that of maintaining the regular work force.

Table 4-2. Results of Application of Game Theory Criteria

Game Theory Criterion	Optimal Alternative
Wald's Maximin	Regular time
Laplace's criterion	Second shift
Hurwicz's criterion (optimism index = 0.8)	Second shift
The regret criterion	Second shift
Excess benefit criterion	5 Extra work stations

The approach based on Savage's subjective probability distribution showed that Second shift will be profitable even if chances of demand going down are as high as 95% (assuming chances of demand going up are 0%.

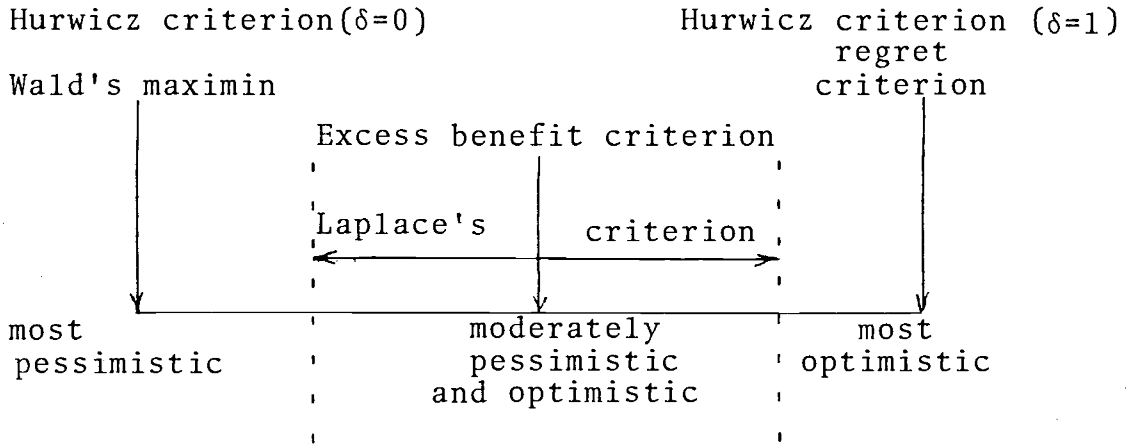


Figure 4-2. Selection of a Criterion.

This analysis will obviously become very tedious if number of alternatives and states of nature is very large.

A summary of the results of application of different criteria is given in Table 4-2.

Selection of Criterion

Though the Tektronix managers preferred to work directly with the payoff matrix containing the actual profit figures, the application of game theory criteria enables the researcher to interpret the decision maker's motives and some features of his 'utility function'. The concepts of utility function are discussed in the next chapter.

As is seen in Table 4-2, different criteria lead to different optimal solutions. Selection of a criterion is determined by the decision maker's attitude towards taking risk or the degree of optimism or pessimism desired by him. An approximate placement of different criteria on an optimism-pessimism scale is shown in Fig. 4-3. In the cases where it is difficult to define the management's attitude towards taking risk, the game theory model can be used as a descriptive model. After presenting the management with the payoff matrix, his decision can be compared with the optimal decisions given by the different criteria and the management can be told how pessimistic or optimistic his decision is.

Interpretation of Mixed Strategies

The results given by application of the game theory criteria take into account the possibility that nature can mix its strategies. Thus the optimal alternatives given by the different criteria, will remain optimal for any linear combination of the states of nature.

As was mentioned earlier in this chapter, Wald's maximin and minimum regret criteria may give a mixed strategy, as the optimal strategy for the decision maker. A possible interpretation of this mixed strategy for the management will be explained by the following example:

Example 4-1:

Suppose application of Wald's minimax criterion to the camera shop profit matrix gave the following optimal strategy: "Play second shift with a probability of 0.3 and overtime with a probability of 0.7":

In order to implement the above strategy, the management can be presented with 10 labeled cards; three of which say second shift and 7 of which say overtime. The management can then be asked to randomly select a card and choose the alternative suggested by it.

In the analysis of the profit matrix discussed in this chapter, the alternatives were evaluated only in terms of their profitability. An approach to take into account other factors such as effects on labor stabilization and fixed costs of implementing the alternatives is discussed in the next chapter.

V. EXTENSION OF THE METHODOLOGY TO AID IN MULTIPLE OBJECTIVE DECISION MAKING

In most resource planning and management problems, more than one conflicting objectives are involved.

> The objectives of a decision are a set of prescriptive and constraining conditions adopted by the decision maker to permit him to achieve a reasonable compromise of the immediate and potential demands made on him (in his personal or organizational roles by his direct and indirect claimants (Allan Easton, 1973).

One popular approach for dealing with multiple objective situations is the use of goal programming first proposed by Charnes and Cooper (1960). In order to make goal programming applicable, however, the problem must have certain special features such as:

1. The goals (objectives) must be pre-emptive and constraining in nature and should be ranked in an ordinal scale. One or more of the goals have absolute priority over other goals;

2. Possible interactions of goals at different priority levels must be ignored. Goal programming considers one objective at a time with the optimum satisfaction of the higher priority goals being taken as constraints in satisfying lower priority goals;

3. Goal programming specifies the values of decision variables for an optimal solution. The real situation may call for the selection of a plan out of several alternatives.

A problem that meets the above requirements can be portrayed by the proposed methodology through the application of goal programming to the RPM network model. In essence, this is equivalent to optimizing the linear programming model using each goal as its objective function. The highest priority goal is optimized first, and this objective function is converted into a constraint with the constraint set to the optimized value. The next priority goal is then used as the new objective function and the process is repeated for all goals (Lee, 1972).

While goal programming, linear programming, and other continuous models are effective in formulating each individual alternative plan, the top management of the corporation must eventually be presented with a finite set of concrete alternatives. It is likely that each of the alternatives have merits and comparative advantages and disadvantages that depend largely upon environmental factors (nature) and no obviously superior alternative exists for all foreseeable future conditions.

The main objective of the present chapter is to present a decision matrix approach that extends the previously discussed methodologies. Each step of this proposed approach will be described and then applied to the Tektronix camera shop model to illustrate its application.

Defining the Multiple Objective Problem

The long term goals and policies of the organization must first be considered in defining multiple objectives.

The primary objective for the Tektronix camera shop model was identified to be profit maximization. The camera shop operates as an independent profit center which is accountable for its own revenues and expenses.

Besides the primary objective of profit maximization, two other objectives are considered in comparing new alternatives against the present management plan.

1. Maximize labor stabilization within the camera shop.
2. Maximize rate of return of investment required for switching to new alternatives.

Developing The Outcome Matrices

An LP run is conducted corresponding to each combination of alternative and state of nature. A payoff matrix is then prepared in terms of each objective using the information generated from LP runs. The alternative defined as Regular Time is the present practice at the Tektronix camera shop. The methodology discussed in this chapter is applied to the Tektronix model to show its usefulness in evaluating the relative worth of the alternatives with respect to the present plan -- Regular Time.

Preparation of the Outcome Matrices for the Tektronix Model

A. Profit Matrix: The preparation of the profit matrix was discussed in Chapter IV. A payoff matrix $\{p_{ks}\}$ was derived from this matrix:

$$p_{ks} = Z_{ks} - Z_{3s} \text{ (k = 3 represents the Regular Time Option)} \quad (5\text{-}1)$$

The matrix so obtained is shown below:

	(s=1) DASIS	(s=2) DUP	(s=3) DDWN
(k = 1) Second Shift	41·7	53·1	-2·02
(k = 2) Overtime	24·94	27	-1·53
(k = 4) 5 Extra Work Stations	15·35	16·1	-·57

B. Labor Stabilization Matrix: A manhours matrix, W, was first prepared by taking the optimal number of manhours of grade 5 workers utilized from each of the K x S = 12 runs made for the profit matrix. Thus element, W_{ks}, of the matrix W correspond to the manhours of grade 5 workers in the basic LP solution for Z_{ks} where,

$$W_{4s} = \{\text{ HSTGR5 - residue of WRKRS }\},$$

$$W_{2s} = \{HSTGR5 + OTGR5 - \text{residue of } WRKRS\},$$

and

$$W_{1s} = \{HSTGR5 + SSHIFT - \text{residue of } WRKRS\}$$

for $S = 1$, 2 and 3.

The resulting matrix obtained is shown below:

	s=1 DASIS	s=2 DUP	s=3 DDWN
(k = 1) Second Shift	70720	70720	23339
(k = 2) Overtime	53235	53235	23339
(k = 4) 5 Extra Work Stations	45760	45760	2339

From this matrix, the following matrix W was derived:

k \ s	DASIS	DUP	DDWN
(k = 1) Second Shift	+35360	+35360	+35360 -47381
(k = 2) Overtime	+17875	+17875	-12021
(k = 4) 5 Extra Work Stations	+10400	+10400	+10400 -22421

A positive W'ks for k 2, represents the extra manhours that need to be hired for going to k^{th} alternative from the regular time alternative under 5th state of nature.

A positive W'ks for $k = 2$, represents the manhours that have to be put on overtime and

A negative W'ks represents the number of idle manhours.

Hiring, firing and overtime are all undesirable activities for the management because of the extra costs associated with these activities and other subjective factors. Overtime causes fatigue in the workers and may adversely affect the quality of the product. Hiring involves increased responsibilities for the supervisory staff and firing or laying off the workers may affect the image of the company of a "reliable employer." In order to prepare the labor stabilization matrix, it is necessary to quantify the relative undesirability of these activities.

Robert T. Eckenrode (1965) performed a set of experiments in his paper to compare the reliability or consistency and time efficiency of six different methods of putting relative weights on different outcomes according to their desirability or undesirability. The six methods used by him were:

1. Subjective Ranking
2. Subjective Rating
3. Partial Paired Comparisons I
4. Partial Paired Comparisons II
5. Complete Paired Comparisons
6. Successive Comparisons - same as the so called Churchman and Achoff method (Eckenrode, 1965, p.2)

In his study he concluded that there were no significant differences in the sets of criterion weights derived from collecting the judgement data by any of the methods, but that ranking was by far the most efficient method and

and rating came next.

In the present study the weights for hiring, firing and overtime were assumed to be 0·6 and 0·3 respectively.

An arbitrary maximum of 20,000 can be taken to correspond to most stable states of labor (i.e., no hiring, firing and overtime). Now let every manhour hired, fired or put on overtime be equivalent to taking off 0·2, ·6 and 0·3 points from the maximum of 40,000. Using this condition, the following final labor stabilization matrix is derived from the matrix W^1.

	DAIS	DUP	DDWN
Second Shift	32928	32928	4500
Overtime Shift	34637	34637	32787
5 Extra Work Stations	37920	37920	24467

In constructing the above matrix, simple linear relationships between undesirability and the three activities (hiring, firing and overtime) were assumed.

C. The Rate of Return Matrix: The fixed costs, variable costs and the profit obtained by adopting each alternative under the three given states of nature were used to calculate the rate of return by applying the following annuity equation:

$$A = P \left\{ \frac{i(1+i)^n}{(1+i)^n - 1} \right\} \tag{5-2}$$

where, i is the rate of return in fraction,

n is the number of accounting periods,

P is the fixed present cost

and A represents the individual amount received in a uniform series continuing for the n coming periods, the entire series being equivalent to P at interest rate i.

For the Tektronix model, n was taken to be one accounting period and "annual" rates of return for different combinations of k and s were calculated. The resulting matrix obtained is shown below; the payoff figures of this matrix have been converted to a 0 to 100 scale since the actual figures are confidential.

	DAIS	DUP	DDWN
Second Shift	30·8	39·3	-1·8
Overtime	93	100	-5·9
5 Extra Work Stations	5	6	-·48

Conversion of Outcome Scores Into Utility Points

Utility of an outcome score is essentially a measure of its contribution to the final objective.

> Synonyms for utility are desirability, attractiveness, worth and positive valuation. The fact that efficient, explicit, precise or easily understood methods for measuring utility are yet not available for guiding the decision maker in this task may be temporarily distressing, particularly if he has a passion for rationality and for orderly, logical thought. But in the absence of good and rigorous methods, he must do with whatever methods can be devised, however imperfect they may be (Easton, 1973).

In the proposed methodology, conversion of outcome scores into utility points is optional. This is, however, recommended for the following two reasons:

1. The utility points are derived from the utility function for the decision maker. The utility function approximately, but explicitly, represents the decision maker's attitude towards risk. Therefore, utility points instead of the payoff figures, should be used if the researcher wants his recommendations to reflect the behavioral pattern of the decision maker.

2. Some of the choice rules, discussed later, are not applicable if the payoff figures of the different matrices are expressed in non-commensurate units.

The first step in converting the outcome scores into utility points is to understand and express their relationship as a mathematical expression. "Fortunately there exists a class of cases in which maximizing expected monetary value is identical with maximizing utility and can therefore be substituted without an error as a choice indicator" (Halter and Dean, 1971, p. 32). In case of the Tektronix model, conversion of the payoff figures of the profit matrix and the labor stabilization matrix to utility points was assumed to belong to the above mentioned class of cases. Conversion of these matrices to corresponding utility matrices was performed by simply converting their payoff figures to a scale of 0 to 100.

A. Profit Matrix	DAIS	DUP	DDWN
Second Shift	78·7	100	0
Overtime	48·6	52·2	·87
5 Extra Work Stations	31·2	32·6	2·6

B. Labor Stabilization Matrix	DAIS	DUP	DDWN
Second Shift	86·8	86·8	12
Overtime	91	91	86·5
5 Extra Work Stations	100	100	64·5

Danniel Bernoulli was one of the first to present "the general idea of introducing subjective values of dollars into expectation calculations rather than dollars

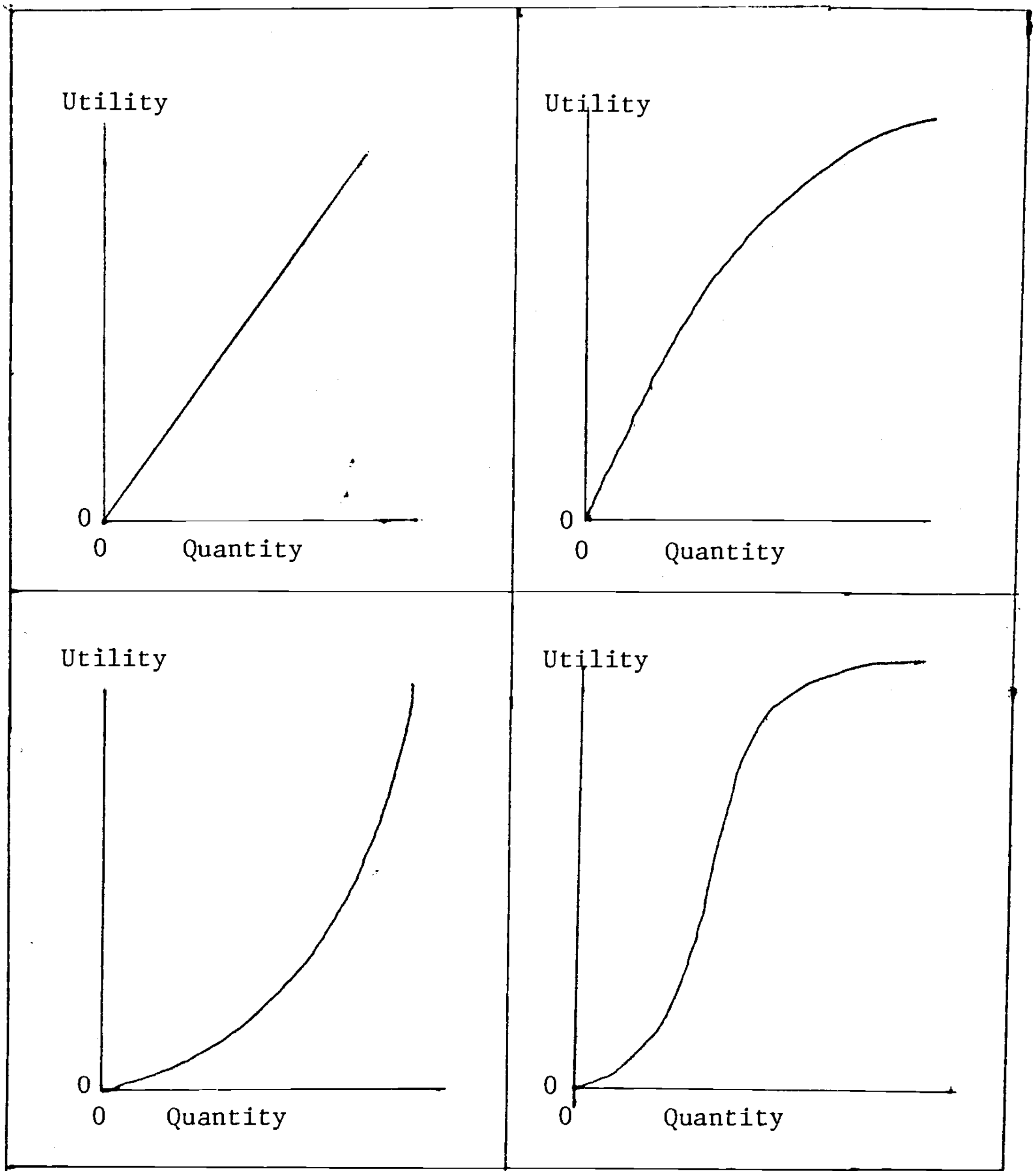


Figure 5-1. Some Typical Shapes of Utility Functions.

themselves" (Grayson, 1960, p. 279). He proposed that dollars be converted to utility value by means of a logarithmic curve, now known as "diminishing marginal utility curve." Von Neumann and Mogenstern (1964) expanded the utility concept and proposed a system for determining an individual's utility function. Some more typical shapes of utility functions are shown in Fig. 5-1.

An experimental approach for deriving the utility function was proposed by Halter and Dean (1971, p. 36-41). The following example illustrates the procedure.

Example 5-1: Suppose that it is required to develop a utility function for converting the payoff figures of the rate of return matrix into utility points. A maximum of 100 utility points is arbitrarily attached to the highest payoff figure in the matrix and a minimum of zero utility point is attached to the lowest rate of return (Viz. -5·9) in the matrix.

The decision maker is then presented with the following two alternatives:

Alternative A: Having a rate of return of 100% with porbability π and a rate of return of -5.9% with a probability of $1-\pi$.

Alternative B: Having a rate of return of R with certainty.

Various values of R are selected and for each value of

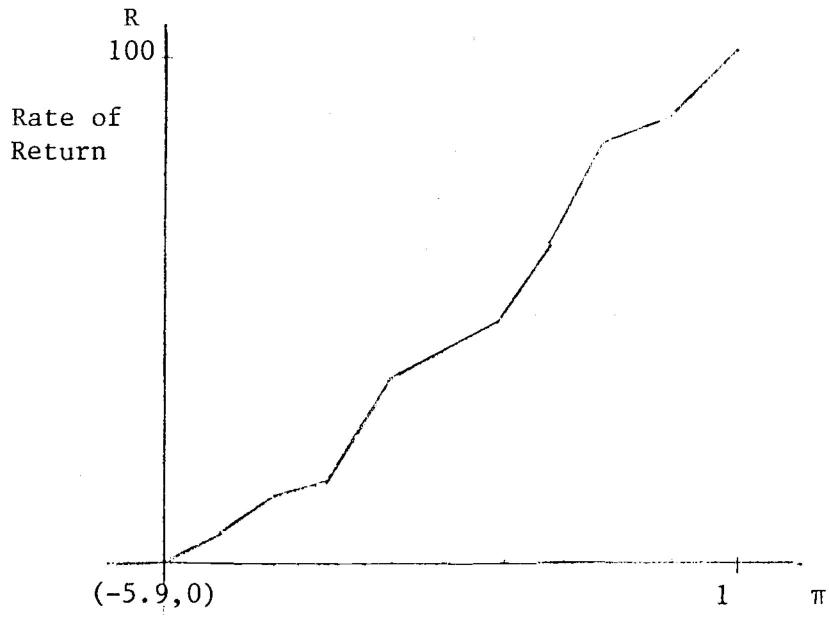


Figure 5-2(a). The Indifference Map.

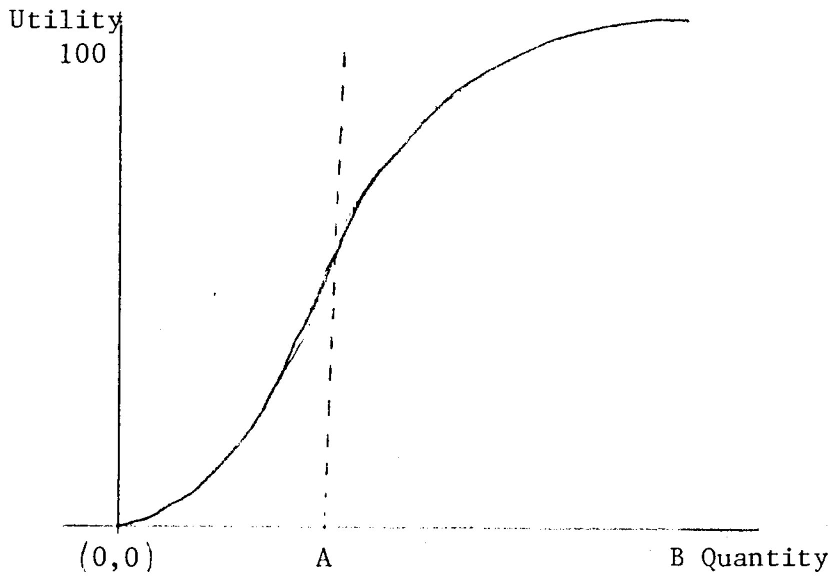


Figure 5-2(b). The S Shaped Utility Function.

R, the decision maker is given the two alternatives with different values of π (0·1, 0·2, 0·3, etc.). The value of π for which the decision maker is indifferent to the two alternatives is found out. The values of R are chosen around and in between 100% and -5·9%.

This experiment leads us to a graph -- called "Indifference Map" as shown in Fig. 5·2(a).

Besides the two assumed points (100, 100) and (0, -5·9), additional intermediate points are needed to plot the utility function. This is done by using the following equation:

$$U(X) = U(100)\,\pi + U(-5{\cdot}9)\,(1-\pi) \qquad (5\text{-}3)$$

Where X is an intermediate value of the rate of return and, π is the corresponding probability from the indifference map. The result is often an S shaped curve (see Fig. 5-2(b)).

No such actual experiment was carried out for the Tektronix model. In order to further illustrate concepts of this study, the following S shaped utility function was assumed for the rate of return of the Tektronix model.

$$\text{utility} = 100\,\{1+e^{3\cdot 10 - \cdot 08\,(\text{rate of return})}\}^{-1} \qquad (5\text{-}4)$$

The utility matrix obtained for rate of return is shown below;

	DAIS	DUP	DDWN
Second Shift	7·84	51·2	3·75
Overtime	99	99	2·73
5 Extra Work Stations	6·3	6·78	4·15

Developing the Decision Matrix

In the foregoing discussion, an approach for developing an individual matrix in terms of each objective was described. This leads to a situation schematically represented by Figure 5-3.

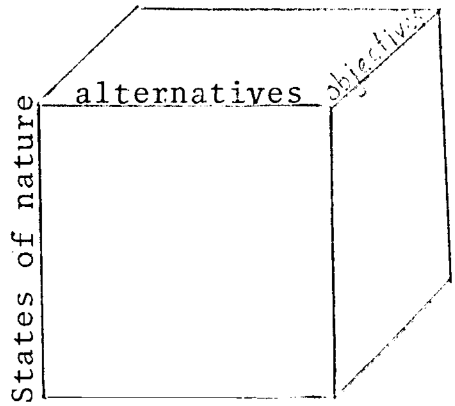


Figure 5-3. Schematic Representation of the Three Dimensional (k x p x s) Matrix

The decision matrix d_{kp} is derived by reducing this three dimensional (k x p x s) matrix to a two dimensional (k x p) matrix. Derivation of the decision matrix -- for different cases that may prevail at the time of decision making -- will be now discussed.

Case 1: Case of Uncertainty About the Behavior of Nature:

The Laplace's and Hurwicz's criteria of game theory, discussed in Chapter Four, can be applied to each of the matrices in order to calculate the expected payoffs of different alternatives under different objectives. These expected payoffs are then used to form a K x P matrix which is called the decision matrix.

Example 5-2: Derivation of the decision matrix, for the Tektronix model, using Laplace's criterion is shown below:

1. Profit Matrix

	DAIS	DUP	DDWN	
Second Shift (k=1)	78·7	100	0	$E_1(U_{1s})=59{\cdot}56$
Overtime (k=2)	48·	52·2	·87	$E_1(U_{2s})=33{\cdot}90$
5 Extra Work Stations (k=4)	31·	32·6	2·6	$E_1(U_{4s})=22{\cdot}13$

2. Labor Stabilization Matrix

	DAIS	DUP	DDWN	
Second Shift (k=1)	86·8	86·8	12	$E_2(U_{1s})=61\cdot8$
Overtime (k=2)	91	91	86·5	$E_2(U_{2s})=89\cdot5$
5 Extra Work Stations (k=4)	100	100	64·5	$E_3(U_{3s})=88\cdot2$

3. Rate of Return Matrix

	DAIS	DUP	DDWN	
Second Shift (k=1)	7·84	51·2	3·75	$E_3(U_{1s})=20\cdot93$
Overtime (k=2)	99	99	2·73	$E_3(U_{2s})=66\cdot9$
5 Extra Work Stations (k=4)	6·3	6·78	4·15	$E_3(U_{4s})=17\cdot23$

The decision matrix is then obtained as shown below:

	(p=1) PROFIT	(p=2) LABOR STAB(LS)	(p=3) RATE OF RETURN(RR)
Second Shift (k=1)	59·56	61·8	20·9
Overtime (k=2)	33·90	89·5	66·9
5 Extra Work Stations (k=3)	22·13	88·2	17·23

Case 2: Decision Making Under Risk: If at the time of decision making, it is possible to estimate a realistic probability distribution of the states of nature, the decision matrix can again be formed by calculating expected utility of each alternative

Finding the Best Alternative (or Merit Ordering the Alternatives

The first step towards merit ordering[1] the alternatives is to place relative weights on all the objectives or criterions of decision making.

Suppose in the Tektronix model example the weights assigned to Profit, L.S., and RR are ·25, ·5 and ·25 respectively.

In the following discussion, choice rules (Easton, 1973, p. 183-355) available for merit ordering the alternatives will be discussed and illustrated with Tektronix model using the decision matrix derived by Laplace's criterion.

[1]Tektronix preferred to utilize matrices containing dollar figures. However, it has requested that such figures be not revealed in this thesis. The utility values used in matrices are substitute data that are assumed to possess the same cardinal measure and are therefore committable from one matrix to another.

Choice Rule No. 1: This is essentially a go-no go type of rule which consists of setting up standards of acceptability for each criterion and then eliminating the alternatives with scores that fail to meet or exceed standards. If only one alternative survives the test it is obviously the best one. If none survives the test, there are two possible things that can be done,

1. Search for more alternatives until one that passes is found,

or 2. Progressively relax the standards by small increments until one alternative falls into the modified acceptance region.

If two or more alternatives survive the test, the standards should be progressively raised till only one alternative survives. The standards for the higher weight criteria can be raised more rapidly than the lower weight criteria.

This rule should work fine if the number of alternatives is not too large and if it is possible at the time of decision making to easily and accurately form the standards.

Example 5-4. In the Tek model let the standards set for PROFIT, LS and RR be 30, 70 and 60 respectively. The decision matrix is as shown below:

	PROFIT	LS	RR
A_s	59·56	61·8	20·9
A_o	33·9	89·5	66·9
A_e	22·13	88·2	17·23

Since only A_o meets these standards, it is selected as the optimal alternative.

Choice Rule No. 2: As in rule 1, standards are set on all criteria. If scores on more than one alternatives meet or exceed the standards, the alternative that has the highest score on the most important criterion is selected.

Example 5-5: As in example 5-4, if we had to select between alternatives A_s and A_o, we would select A_o since it has the higher score on the most important objective LS.

Choice Rule Number 3: This rule is based on finding the weighted sum of scores for each alternative using the criteria weights and then ranking the alternative with the highest weighted sum as the best, the next highest as the second best and so on.

Example 5-6. In our Tektronix model, the weighted sum for

A_s is $59{\cdot}56(\cdot25)+61{\cdot}8(\cdot5)+20{\cdot}9(\cdot25)=51{\cdot}015$

A_o is $33{\cdot}9(\cdot25)+89{\cdot}5(\cdot5)+66{\cdot}9(\cdot25)=69{\cdot}3$

A_E is $22{\cdot}13({\cdot}25)+88{\cdot}2({\cdot}5)+17{\cdot}23({\cdot}25)=70{\cdot}78$

Therefore A_E is the best alternative, A_o is the second best and A_s is the third best.

Choice Rule No. 4: This rule uses the weighted product of the scores of each alternative as the criterion for merit ordering the alternatives.

If W_p where p = 1, 2, 3 -- q denotes the weights assigned to the criteria, the weighted product for an alternative K is simply given as

$$P_k = \prod_{p=1}^{q} (d_{k\ p})^{W_p} \tag{5-5}$$

The alternative with the largest P_k is the best, the alternative with the next highest, the second best and so on.

Example 5-7. For the Tektronix model.

Alternative	P_k	Merit Ordering
A_s	2404·0	2
A_o	6343·0	1
A_E	1050·95	3

Choice Rule Number 5: A dummy alternative is established with worst possible scores for each criterion. The deviation of each alternative from this dummy alternative is computed -- the higher is this deviation, the better is the alternative.

If the scores for the dummy variable is zero for each criterion, the deviation for an alternative K can be computed as follows:

$$D_k = \{ \sum_{p=1}^{q} (W_p \; d_{kp})^2 \}^{\frac{1}{2}} \qquad (5\text{-}6)$$

W_p is defined as in Choice Rule Number 4.

Example 5-8. In the Tektronix model

Alternative	D_i	Merit Ordering
A_s	34·69	3
A_o	48·51	1
A_E	44·65	2

<u>Choice Rule No. 6</u>: A dummy variable is established with the best possible scores for each criterion. The deviation of each alternative from this dummy alternative is computed -- the lower is the deviation, the better is the corresponding alternative.

If the score for the dummy variable is 100 for each criterion, the deviation of alternative k can be computed as follows

$$D_k = \{ \sum_{p=1}^{q} W_p^2 \; (100-d_{kp})^2 \}^{\frac{1}{2}} \qquad (5\text{-}7)$$

Example 5-9. For the Tektronix model,

Alternative	D_k	Merit Ordering
A_s	29·29	3
A_o	25·74	1
A_E	29·0	2

Choice Rule No. 7: This rule is the same as rule 6 except that instead of a dummy variable with the best possible scores, a dummy variable with the 'most desired' or 'target scores' is established and the deviation of each alternative is measured with respect to the target dummy alternative.

Example 5-10. Suppose the target scores for the Tektronix model are (100, 100 or 100), then the example is solved in the same way as Example 5-9.

Choice Rule No. 8: This rule involves a pair by pair comparison of the alternatives. Let any two alternatives being compared be k=1 and k=5, then for p=1, if $d_{11} > d_{51}$, replace d_{11} by 1 and d_{51} by 0 and if $d_{11} < d_{51}$, replace d_{11} by 0 and d_{51} by 1.

This is done for all p and by doing this we finally get a score set for each alternative containing only ones and zeroes. The alternative with greater numbers of ones is selected and compared with the next alternative. This process is repeated till all but one alternative is left and that is the best one.

Example 5-11. In the Tektronix model, in comparing A_s with A_o we get

$$A_s = (1 \quad 0 \quad 0)$$
$$A_o = (0 \quad 1 \quad 1)$$

A_o is selected and compared with A_E, which gives

$$A_o = (1 \quad 1 \quad 1)$$
$$A_E = (0 \quad 0 \quad 0)$$

A_o is the best alternative.

Choice Rule No. 9: After having obtained score sets of one and zero for the alternatives being compared, weighted sum of scores for each alternative is found. The alternative with the highest weighted sum is selected for comparison with the next alternative.

Example 5-12. From Example 5-11, weighted sum for A_s = $0{\cdot}25$ and weighted sum for $A_o = 0{\cdot}75$

A_o is selected and compared with A_E. Now weighted sum for $A_o = 1$, and weighted sum for $A_E = 0$.

A_o is the best alternative.

Selection of a Choice Rule

Results of application of the choice rules to the Tektronix model example are summarized in Table 5-1. As is

Table 5-1. Results of Application of Choice Rules

Choice Rule	A_s	A_o	A_E
1	-	1	-
2	-	1	-
3	3	2	1
4	2	1	3
5	3	1	2
6	3	1	2
7	3	1	2
8	-	1	-
9	-	1	-

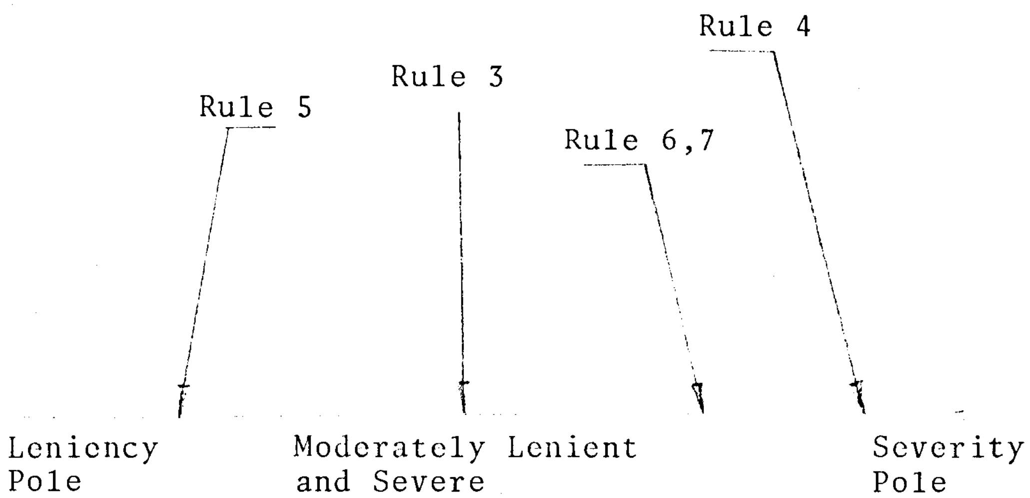


Figure 5-4. Approximate Placement of Choice Rules on a Leniency-Severity Axis

seen in Table 5-1, the choice rules give different solutions when applied to the same decision matrix. This fact should not be very distressing if selection of the choice rule is based on a proper understanding of the characteristics of various choice rules. A brief description of these characteristics will now be presented.

Units and scales of measurements of the payoff figures in the decision matrix are an important factor that helps in the selection of a choice rule. If the circumstances dictate the use of natural, heterogenous units for measuring scores of alternatives on multiple criteria, only few of the rules that are compatible with them can be used (choice rules one, two and four).

To illustrate this limitation, consider an alternative whose numerical scores for three different criteria are

α manhours,

β dollars of cost,

and γ space in feet.

It will make no sense to amalgamate these three scores by a weighted sum. Multiplication and division, however, are for mathematical operations, that are permissable. For example, $\frac{\beta}{\gamma \cdot \alpha}$ can be taken as a criterion in units of dollar of cost/manhour-feet.

In case of the Tektronix model, this limitation was overcome by converting all the outcome scores to utility points.

One distinguishing characteristic of the choice rules is the weights that they attach to the low and high scores of an alternative. A choice rule is said to be 'lenient' if it attaches a relatively greater weight to the high scores of an alternative. On the other hand, a choice rule is said to 'severe' if it attaches a relatively greater weight to the low scores of an alternative. An approximate placement of some of the choice rules on a liniency-severity scale is shown in Figure 5-4. In case of the Tektronix model, choice rule 4, which is the most severe, identifies A_S to be superior to A_E whereas choice rule 5 finds A_E preferable over A_S.

If the company's policy and long term goals require selection of safe and conservative alternatives, the relatively severe choice rules should be selected. Whereas if it is desired to take advantage of better opportunities at the cost of taking some risk, the relatively lenient rules should be considered.

Choice rules 8 and 9 are based on sequential elimination procedure and should be recommended when the number of alternatives is not too large (as in case of the Tektronix model).

Choice rules 1 and 2 can only be applied if it is possible to accurately quantify the acceptable levels of accomplishment of different criteria.

Concluding Remarks

The major objective of the approach discussed in this chapter is to present the decision maker with the decision matrix which provides him with a simultaneous evaluation of his alternatives in terms of the multiple objectives. The decision maker can then identify the optimal alternative by utilizing his personal judgement or by applying one of the choice rules. The major shortcoming associated with the use of a choice rule is the difficulty in selecting an appropriate choice rule. A number of factors affecting the selection of a choice rule are listed in the next chapter.

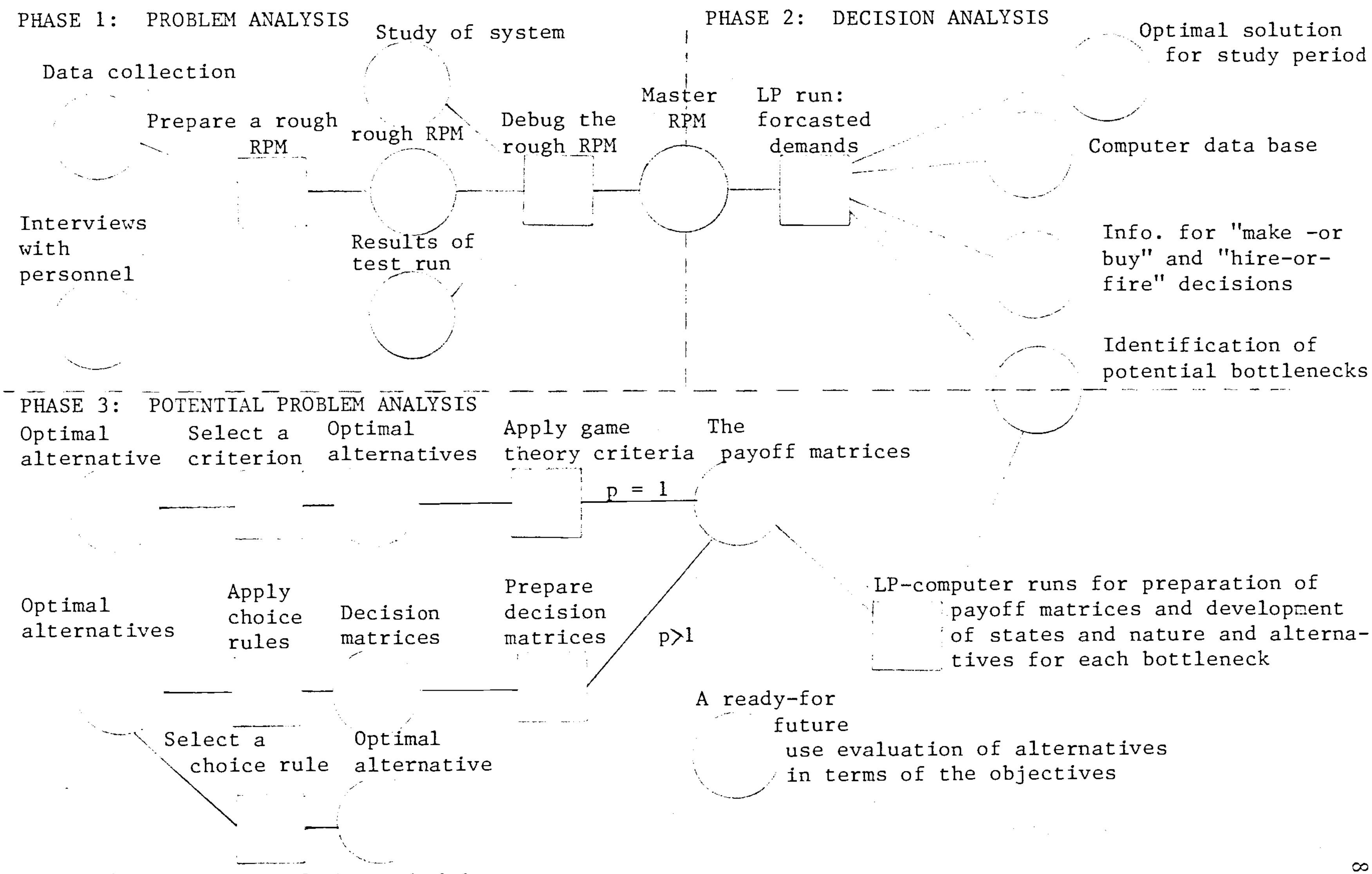


Figure 6-1. Summary of the Methodology.

VI. CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

This chapter presents the summary of the methodology, discusses its mathematical interpretation, presents some observations, and suggests topics for future research work.

Summary of the Methodology

The multiphase methodology discussed in this study is schematically represented by Figure 6-1. Each square represents an activity to be performed and is identified as a stage of the model. Endogenous flows into the square represent the inputs required at the corresponding stage and exogenous flows from the square represent the outcomes or findings of that stage.

Each phase of the methodology and the stage within it, will now be summarized.

Phase 1: Problem Analysis

Stage 1: This is the initial stage where the researcher proceeds to familiarize himself with the system by collecting data on various operations, processes, etc. Based on this preliminary information, a rough RPM network is prepared.

Stage 2: The initial RPM network obtained rarely turns out to be a correct one. The lack of understanding of the system on the part of the researchers and misinterpretation of the information given are just two of the many possible causes. However, the rough RPM network enables the researcher to obtain feedbacks from the people involved and makes it easier for him to study the system properly. After the corrections are made, a test run is conducted using the historical data and the results are verified to see whether the model realistically reflects the system or not. After all the corrections are made, a master RPM network is prepared.

Both of the above stages require co-operation and input from people involved with the system at various levels. In preparing the model for Tektronix, RPM significantly helped attain the necessary level of communication.

Phase 2: Decision Analysis

Stage 3: The corresponding LP equations are derived from the master RPM as shown in chapter 2. A computer run is made using the forecasted values for the study period. This stage leads to many valuable findings viz.:

1. Optimal solution for the study period. The optimmal product schedule for a given accounting period was identified in the Tektronix model;

2. An input computer file which serves as the data base for the researcher or the decision maker to do sensitivity and adaptivity analysis on the system.

3. Both the primal and dual solutions of LP model are

simultaneously represented on RPM network. This provides information in a convenient form for decisions such as the "make-or-buy" decisions and the hire-or-fire" decisions. Also, shadow prices of the products enable the decision maker to classify the products in the order of their profitability. This can be valuable information for the marketing department in deciding on the allocation of marketing efforts.

4. Identification of bottlenecks by seeking out unreasonably high shadow prices on resources as shown in chapter 4.

Phase 3: Potential Problem Analysis

Stage 4: Having identified the bottlenecks or the critical areas that require careful planning, the next step is to develop alternatives and hypothesize a series of expected states of nature. This is also discussed in chapter 4. A computer run is then made for various combinations of the alternatives and states of nature. This provides information required for preparation of payoff matrices in terms of the various objectives (see chapter 5). These payoff matrices provide information that can help the decision maker evaluate the alternatives in terms of the objectives and the states of nature.

Stage 5A: If, at the time of decision making, any one of the objectives is found to be significantly more important than others, various game theory criteria discussed in chapter 4 can now be applied to the corresponding matrix to aid the management in finding the optimal alternative.

Stage 5B: If it is importnat to consider more than one objective simultaneously, a decision matrix can be prepared as shown in chapter 5.

Stage 6: In order to identify the optimal alternative or to merit order the alternatives, the various choice rules discussed in chapter 5 can be applied.

Mathematical Interpretation of the Methodology

The methodology summarized above can be mathematically interpreted as follows:

$$Z_{pks} = \sum_j C_{pjs} \overset{*}{x}_{1jks} \quad \ldots\ldots\ldots\ldots \quad (6\text{-}1)$$

$$\text{s.t.}\ \overset{*}{Z}_{1ks} = \max(Z_{1ks}) = \max(\sum_j C_{1js}x^*_{1jks}) \quad \ldots\ldots\ldots\ldots \quad (6\text{-}2)$$

$$\text{and, } \sum_j a_{ij}x_{ijks} = b_{iks} \quad \ldots\ldots\ldots\ldots \quad (6\text{-}3)$$

$$\text{and, } \quad x_{ijks} \geq 0 \text{ for all } i,j,k,s \quad \ldots\ldots\ldots\ldots \quad (6\text{-}4)$$

where, subscript

i corresponds to i^{th} resource node,

p corresponds to the p^{th} objective,

j corresponds to the j^{th} process or LP primal variable k corresponds to k^{th} alternative,

s corresponds to s^{th} state of nature.

A variable with a star (*) represents the optimal value of the variable. a_{ij} and b_{iks} may include constants resulting from prior imposition of pre-emptive goals.

$x^*_{1jks} = x_{pks}$ where p = 1: identifies the value of the x_{jks} variable in the optimal solution with respect to the objective functions Z_{iks}.

Incorporation of different alternatives and states of nature into the LP model results in different values of the constants of LP. For example, b_{123} would represent value of the constraint constant corresponding to the resource node y_1, the second alternative, and third state of nature. The above equations represent a set of different LP problems corresponding to different states of nature which was, for example, profit in case of the Tektronix model. In our notations, this objective is denoted by p = 1.

Z_{pks} represents values of the payoff matrices in terms of the p different objectives.

Case 1: A single objective (p=1) is significantly the most important one.

Let the various game theory criteria be denoted by T_r, where r=1,2,...etc. The set of optimal alternatives obtained by applying the game theory criteria is given by the following equation:

$$R = T_r\ (Z^*_{1ks})\ \ldots\ldots\ldots\ldots\ldots \quad (6\text{-}5)$$

The optimal alternative (h^*) can be found using the following equation:

$$h^* = H_1\ \{\ T_r(Z^*_{1ks})\ \}\ \ldots\ldots\ldots\ldots\ldots \quad (6\text{-}6)$$

Where H_1 represents the subjective choice of a game theory criterion.

Case 2: Multiple Conflicting Objectives ($p > 1$)

Let the utility function corresponding to the p^{th} objective be denoted by $U_p(m)$. Substituting for m in this function, the payoff figures can be converted into utility points and denoted by $U_p\ (Z_{pks})$. Formation of the pxk decision matrix can be represented by the following equation

$$E\ \{\ U_p(Z_{pks})\ \} = \int_s f(s)\cdot U_p(Z_{pks})ds\ \ldots\ldots\ldots\ldots \quad (6\text{-}7)$$

Where, f(s) is the probability distribution associated with the states of nature. f(s) is either assumed or derived by using a game theory criterion. Let the various choice rules be denoted by T_q, where 1 = 1,2,3,.... etc. The expected utility of the alternatives after applying the various choice rules is given by the following expression:

$$T_q\ \{\ E\ \{\ U_p(Z^*_{pks})\ \}\}\ \ldots\ldots\ldots\ldots\ldots \quad (6\text{-}8)$$

The optimal alternative (h^*) can be found using the following equation:

$$h^* = H_2\ \{\ T_1\ \{\ E(U_p(Z^*_{pks}))\ \}\}\ \ldots\ldots\ldots\ldots\ldots \quad (6\text{-}9)$$

where H_2 represents the subjective selection of a choice rule.

Comments and Suggestions for Future Research

The methodology discussed above utilizes objective, quantitative operations research techniques such as LP and game theory. This results in a decision matrix which is subjected to various quantitative methods of identifying optimal alternatives in a multiple objective situation. A list of the different methods is reproduced in Fig. 6-2(a) from chapter 1. Fig. 6-2(b) shows the conceptual relationships among the methods and the choice rules discussed in chapter six.

The methodology also allows for subjective judgments mainly when answering the following questions:

1. What is the utility or disutility of a certain outcome in the payoff matrix?

2. Which game theory criterion should be applied to the payoff matrix in order to identify the optimal alternative?

3. Which choice rule should be selected to find the best alternative from the decision matrix?

The answer to the first two questions will reflect the attitude of the decision maker towards taking risk and can be obtained by developing a utility function for the

- A. Weighting Methods
    - 1. Inferred preferences
        - a. Linear regression
        - b. Analysis of variance
        - c. Quasi-linear regression
    - 2. Directly assessed preferences: general aggregation
        - a. Trade-offs
        - b. Simple additive weighting
        - c. Hierarchical additive weighting
        - d. Quasi-additive weighting
    - 3. Directly assessed preferences: specialized aggregation
        - a. Maximin
        - b. Maximax
- B. Sequential Elimination Methods
    - 1. Alternative versus standard
        - a. Disjunctive and conjunctive constraints
    - 2. Alternative versus alternative: comparison across attributes
        - a. Dominance
    - 3. Alternative versus alternative: comparison across alternatives
        - a. Lexicography
        - b. Elimination by aspects
- C. Mathematical Programming Methods
    - 1. Global objective function
        - a. Linear programming
    - 2. Goals in constraints
        - a. Goal programming
    - 3. Local objectives: alternatives
        - a. Interactive, multiple criterion programming
- D. Spatial Proximity Methods
    - 1. Iso preference graphs
        - a. Indifference maps
    - 2. Ideal points
        - a. Multi-dimensional, nonmetric scaling
    - 3. Graphical preferences
        - a. Graphical overlays

Figure 6-2(a). Overview of Methods for Multiple Objective Decision Making.

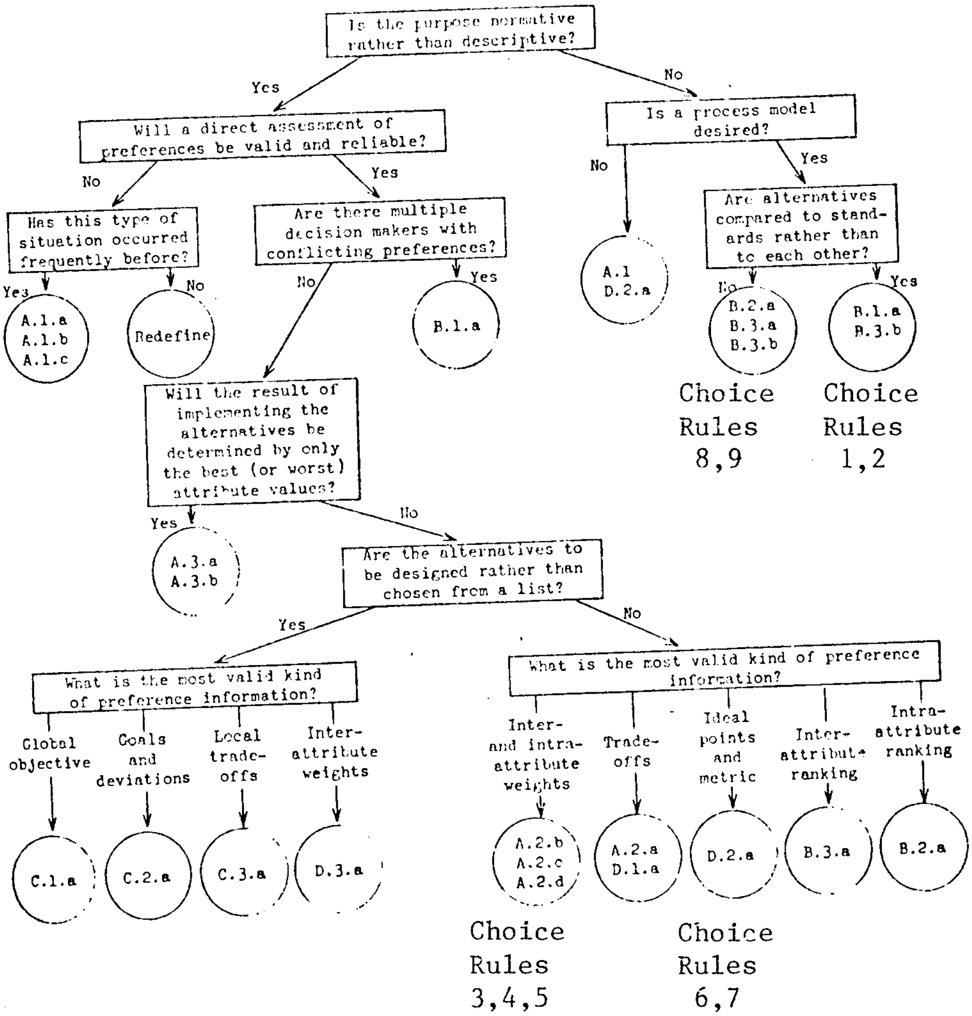


Figure 6-2(b). Method Specification Chart.

decision maker. In the case of a group recommendation, the researcher should use a group utility function as an aid in arriving at his recommendations.

In a study reported by Officer, Halter and Dean (1967) two different methods of deriving group utility functions were used and an assessment of the errors between the group recommendation based on the group utility function and the decision maker's actual decision was made.

One easy method of deriving a group utility function is to take the average of the individual's utility functions, that is, average the coefficients of the individual functions. Another method is to take the median of the individual utility function as the group function. Both of these methods have been applied to five farmers' utility functions by Halter and Dean (1971, p. 60-80), who also state:

> The use of a utility function for making group decisions does not overcome problems of interpersonal comparisons of utility. The shortcomings in using group utility functions must be balanced against the economic benefits of making a group recommendation. Although this approach is open to misinterpretations, it is concluded that this essentially behavioral approach is generally superior to alternative approaches of maximizing expected monetary outcomes or simply consulting a conjurer. Obviously further research work is required before a definite statement can be made on the use of group utility functions.

The answer to the third question on selection of the choice rule is in itself a multiple criteria decision making problem. According to Allan Easton (1973), a rule should be sought that:

> a. is reasonably easy to explain and justify to the decisions' probable critics;
> b. involves reasonable computational expense;
> c. reflects the proper degree of conservatism or daring (severity or tolerance of weakness) in relation to the special circumstances (e.g. consequences of a bad choice of alternatives);
> d. have reasonably good efficiency (does not reject good alternatives and accept bad ones)
> e. is appropriate for the kinds of scales and units used to score alternatives on criteria;
> f. produces a satisfying decision.

Developing techniques to answer the three questions more objectively and accurately constitute a field that remains open for future research work. Another such field consists of techniques to quantify the essentially qualitative feelings, for example, assigning weights to different critiera and putting probability figures on expected future behavior of nature. A special case of deriving posterior probabilities of future events may be treated by the Bayesian Theorem when prior and conditional probabilities are known (Halter and Dean, 1971); this concept has been extended to deal with multiple objective situations (Frederick, 1973).

Another promising area for future research work is coupling simulation with game theory. Thierauf and Grosse (1970, p. 401) have predicted:

> Game theory has not yet reached its potential at this writing. The utilization of computers to simulate the operations of the firm is also in

> its infant state. When these two basics - game theory and simulation - of operations research are brought together to solve periodic problems for a firm, game theory will be an important tool for quantitative managerial decision making.

These authors ignore earlier work by Grayson (1960) who applied the game theory and simulation technqiues to the problem of drilling oil wells for investment. However, more research is needed in this area.

A missing part of our methodology is a validation system which provides ways of testing the effectiveness of the strategies selected by game theory application under simulated operating conditions. This has been partially accomplished by using RPMS in this study. Conklin (1975) states:

> One of the most useful contributions made by the RPMS methodology is its ability to validate a programming model which would otherwise be hidden behind the veil of complex mathematical notations.

Simulation can be used to provide this validation system. Incorporating simulation in the model can also increase the credibility of the results and make it easier to implement them. Simulation can also provide the decision maker, and the people responsible for implementing them, with some actual experience with the new ideas and strategies when subjected to variable operating conditions. Before accepting new ideas, managers would like to be convinced of their viability. Simulation is usually the only economical way to do this. While RPM network and LP were used in this study, no attempt has been made to simulate stochasticity of coefficients.

A Final Warning

What Halter and Dean (1971) have said in their book applies readily to our study:

"If the decision makers use the framework of this book, all of their decisions will be good in the sense of maximizing expected utility. Unfortunately, we are still dealing with uncertainty, and a carefully reasoned decision might still have a bad outcome in any particular instance. We do not guarantee good outcomes, just good decisions!"

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Table A-1: (Continued)

Resource Name	Description
CBWRKRS	Manhours utilized in assembly of circuit boards
PL5A	Plastic materials for C5A
LS5A	Lens and shutters for C5A
PL1227	Plastic parts for C12 and C27
ML1227	Metal parts for C12 and C27
PL30	Plastic parts for C30
ML30	Metal parts for C30
LS30	Lens and shutters for C30
PL50	Plastic parts for C50
ML50	Metal parts for C50
ASMBLRS	Manhours of grade 5 workers for assembly of cameras
SA58	Partially assembled C58
SA59	Partially assembled C59
SA50	Partially assembled C50
LS53	Lens and shutters for C53
LS50	Lens and shutters for C50
LS51	Lens and shutters for C51
LS52	Lens and shutters for C52
LS58	Lens and shutters for C58
METAL	Metal parts for C50, C51, C52 and C53
CLS53	C53 with lens and shutters assembled

Table A-1: (Continued)

Resource Name	Description
CLS50	C50 with lens and shutters assembled
CLS51	C51 with lens and shutters assembled
CLS52	C52 with lens and shutters assembled
T58	C58 ready for testing
T53	C53 ready for testing
T50	C50 ready for testing
T51	C51 ready for testing
T52	C52 ready for testing
LS59	Lens and shutters for C59
P5A	C5A ready to be packed
P1227	C1227 ready to be packed
P30	C30 ready to be packed
P58	C58 ready to be packed
P53	C53 ready to be packed
P59	C59 ready to be packed
P50	C50 ready to be packed
P51	C51 ready to be packed
PLBK	Plastic parts for backs
PPBKML	Materials for pack backs
MPBKML	Materials for metal backs
RLBKML	Materials for roll backs
GLBKML	Materials for graphlok backs

Table A-1: (Continued)

Resource Name	Description
HDML	Materials for the viewing hoods
PLKBK	Assembled pack backs
MTLBK	Assembled metal backs
RLLBK	Assembled roll backs
GRPHL	Assembled graphlok backs
LS1227	Lens and shutters for C12 and C27
SPCOM	Speed computers
P52	C52 ready to be packed
HOOD	Assembled viewing hoods
CLT5A	C5A ready for light test
C1227	Assembled units of C12 & C27
C5A	Assembled units of C5A
C1227E	Assembled units of C12 and C27 (electrical)
C30	Assembled units of C30
C3132	Assembled units of C31 and C32
C58	Assembled units of C58
C53	Assembled units of C53
C59	Assembled units of C59
C50	Assembled units of C50
C51	Assembled units of C51
C52	Assembled units of C52
CSP	Assembled units of C-special

Table A-1: (Continued)

Resource Name	Description
ULPLKBK	Upper sales limit on pack backs
LLPLKBK	Lower sales limit on pack backs
ULMTLBK	Upper sales limit on metal backs
LLMTLBK	Lower sales limit on metal backs
ULRLLBK	Upper sales limit on roll backs
LLRLLBK	Lower sales limit on roll backs
ULGRFL	Upper sales limit on graphlok back
LLGRFL	Lower sales limit on graphlok back
ULC5A	Upper sales limit on C5A
LSLC5A	Lower sales limit on C5A
ULC12	Upper sales limit on C12
LLC12	Lower sales limit on C12
ULC27	Upper sales limit on C27
LLC27	Lower sales limit on C27
ULC12E	Upper sales limit on C12 (electrical)
LLC12E	Lower sales limit on C12 (electrical)
ULC27E	Upper sales limit on C27 (electrical)
LLC27E	Lower sales limit on C27 (electrical)
ULC30	Upper sales limit on C30
LLC30	Lower sales limit on C30
ULC3132	Upper sales limit on C31 & C32
LLC3132	Lower sales limit on C31 & C32

Table A-1: (Continued)

Resource Name	Description
ULC58	Upper sales limit on C58
LLC58	Lower sales limit on C58
ULC53	Upper sales limit on C53
LLC53	Lower sales limit on C53
ULC59	Upper sales limit on C59
LLC59	Lower sales limit on C59
ULC50	Upper sales limit on C50
LLC50	Lower sales limit on C50
ULC51	Upper sales limit on C51
LLC51	Lower sales limit on C51
ULC52	Upper sales limit on C52
LLC52	Lower sales limit on C52
ULCSP	Upper sales limit on C-special
LLCSP	Lower sales limit on C-special
BKWRKRS	Manhours of grade-5 worker for back-assembly
GRADE5	Limiting constraint on manhours of grade 5 workers

Table A-2: Activity-Descriptions

Activity Names	Description
BYCB50	Buy circuit boards for C50's
BYPININ	Buy pins
HSTGR5	Hire grade 5 workers
HSTGR8	Hire grade 8 workers
BYCB5A	Buy circuit boards for C5A's
ICP50	Insert pins in C50's
SSHIFT	Hire workers for second shift
OTGR5	Assign overtime to grade 5 workers
PWRCB	Provide circuit board workers
PWRAS	Provide assemblers
PWRBK	Provide back workers
ACB5A	Assemble circuit boards for C5A
ACB50	Assemble circuit boards for C50
BYML1227	Buy metal parts for C12 & C27
BYML30	Buy metal parts for C30
BYML50	Buy metal parts for C50
BYPL5A	Buy plastic parts for C5A
BYLS5A	Buy lens & shutters for C5A
BYPL1227	Buy plastic parts for C12 & C27
BYLS30	Buy lens & shutters for C30
BYPL50	Buy plastic parts for C50
KPA5A	Kit preparation and assembly for C5A

Table A-2: (Continued)

Activity Name	Description
KPA1227	Kit preparation and assembly for C12 & C27
KPA30	Kit preparation and assembly for C30
KPA58	Kit preparation and assembly for C58

APPENDIX B

THE COMPUTER FILES FOR THE TEKTRONIX MODEL

Description of Computer Output:

The *REXY computer listing and output are included in this appendix. The actual construction of the input data file followed the logic discussed in chapter three. The output data of the computer model is included in two sections, 'Rows" and 'Columns."

Rows:

This section of the *REXY output lists the optimal values (both primal and dual) given for the resources and constraints used by the linear programming model.

The 1st column lists names of the various resources and constraints used in the LP model. Each of these names corresponds to a circle node on the RPM network.

The next column provides an indication of the status of the resource or constraint in the solution. Table B-1 lists the various codes and a description of their meanings.

The third column gives the value at which the resource is satisfied. The fourth column supplies the solution value of each of the resources or constraints in the study.

Table B-1: Resource Status Indications (Scheurman, 1970)

Code Letter	Description
B	Slack or logical variable in the basis
F	Equality constraint
L	Inequality constraint satisfied at lower limit
N	Free constraint with slack or logical non-basic
U	Inequality constraint satisfied at upper limit
Z	Objective function

These values represent 'residues' which are entered into the bottom of each circle in the RPM network.

The next two columns give the lower limits and the upper limits of the values at which the resource or constraint may be satisfied.

The final column provides the dual variable for the corresponding constraint or resource. This value is put into the top of its respective circle node in the RPM network.

Columns:

This section of the *REXY output provides the optimal values for the primal (process) nodes of the RPM network.

The 1st column lists the names of each activity in the study. These activities are represented by the square nodes in the RPM network.

The next column indicates the status of the activity in the solution. Table B-2 shows a description of each of the code letters that may appear in this column.

Table B-2: Activity Status Indications (Scheurman, 1970)

Code Letter	Description
A	Artificial row variable. This indicates that a row specified is redundant.
B	Activity is basic
F	Activity is fixed to take certain numerical value
L	Activity is non basic at the lower limit
N	Activity is free variable which is non basic
U	Activity is non basic at upper limit

The third column from left provides the optimal primal level of activity which is entered into the top cell of the corresponding square in the RPM network.

The fourth column lists the values indicating the effective objective function value for the particular activity.

The next two columns give the smallest and largest values which the activity can assume and still remain feasible.

The last column corresponds to the 'opportunity cost' or expected loss. This dual value is put into the bottom of the respective square activity in the RPM network.

```
0209 0209 0209 0209 0209 0209 0209 11/14/75 14:45:15 0209 0209 0209 0209 0209 0209 0209

TEK                    LIMOT DU

ROWS
$PROFIT <CBMAT <PININ =GRADES <CB5A <CB50 <WRKRS
<TESTERS <FCB5A <FCB50 <CBWRKRS <PL5A <LS5A <PL1227 <ML1227
<PL30 <ML30 <LS30 <PL50 <ML50 <ASMBLRS <SA58 <SA59 <SA50
<LS58 <LS50 <LS51 <LS52 <METAL <LS53 <CLS53 <CLS50 <CLS51
<CLS52 <T58 <T53 <T50 <T51 <T52 <LS59 <P5A <P1227 <P30 <P58
<P53 <P59 <P50 <P51 <PLBK <PPBKML <MPBKML <RLBKML <GLBKML
<HOML <PLKBK <MTLBK <PLLBK <GRPHL <LS1227 <SPCOM <P52 <HOOD
<CLT5A <C1227 <C5A <C1227E <C30 <C3132 <C58 <C53 <C59 <C50
<C51 <C52 <CSP <ULPLKBK <LLPLKBK <ULMTLBK <LLMTLBK
<ULPLLBK <LLPLLBK <ULGRFL <LLGRFL <ULC5A <LSLC5A
<ULC12 <LLC12 <ULC27 <LLC27 <ULC12E <LLC12E <ULC27E
<LLC27E <ULC30 <LLC30 <ULC3132 <LLC3132 <ULC58
<LLC58 <ULC53 <LLC53 <ULC59 <LLC59 <ULC50 <LLC50
<ULC51 <LLC51 <ULC52 <LLC52 <ULCSP <LLCSP
<BKWRKRS <LLC5A
=GRADES
=LIMOT
COLUMNS
CB5AS PROFIT -6.12 WRKRS -1 LIMOT 1
BYCB50 PROFIT CBMAT -1
BYPININ PROFIT PININ -3600
HITGDS GRADES 1 PROFIT -4.09 WRKRS -1
LOTGDS GRADES 1 PROFIT -5.14 TESTERS -1
BYCB5A PROFIT CB5A -1
MKCB50 CBMAT 1 PININ 15 CB50 -1
PRWCB WRKRS 1 CBWRKRS -1
PRASB WRKRS 1 ASMBLRS -1
PRBKW WRKRS 1 BKWRKRS -1
ACB5A CB5A 1 CBWRKRS .4 FCB5A -1
ACB50 CB50 1 CBWRKRS 0.7 FCB50 -1
BYML1227 PROFIT ML1227 -1
BYML30 PROFIT ML30 -1
BYML50 PROFIT ML50 -1
BYPL5A PROFIT PL5A -1
BYLS5A PROFIT LS5A -1
BYPL1227 PROFIT PL1227 -1
BYPL30 PROFIT PL30 -1
BYLS30 PROFIT LS30 -1
BYPL50 PROFIT PL50 -1
KP5A FCB5A 1 PL5A 1 LS5A 1 ASMBLRS 0.3 P5A -1
KP1227 PL1227 1 ML1227 1 ASMBLRS 2.6 P1227 -1
KP30 PL30 1 ML30 1 LS30 1 ASMBLRS 2.6 P30 -1
KPSA58 FCB50 1 PL50 1 ML50 1 ASMBLRS 2.2 SA58 -1
KPSA59 PL50 1 ML50 1 FCB50 1 ASMBLPS 4 SA59 -1
KPSA50 PL50 1 ML50 1 FCB50 1 ASMBLRS 7.1 SA50 -1
BYLS58 PROFIT LS58 -1
BYLS53 PROFIT LS53 -1
BYLS50 PROFIT LS50 -1
BYLS51 PROFIT LS51 -1
BYLS52 PROFIT LS52 -1
BYMETAL PROFIT METAL -1
ALS53 LS53 1 METAL 1 CLS53 -1
ALS50 LS50 1 METAL 1 CLS50 -1
ALS51 LS51 1 METAL 1 CLS51 -1
ALS52 LS52 1 METAL 1 CLS52 -1
AT58 LS58 1 SA58 1 T58 -1
AT53 CLS53 1 SA50 1 T53 -1
AT50 CLS50 1 SA50 1 T50 -1
AT52 CLS52 1 SA50 1 T52 -1
AT51 CLS51 1 SA50 1 T51 -1
BYLS59 PROFIT -33 LS59 -1
LT58 PROFIT -1 T58 1 P58 -1 TESTERS .3
LT53 PROFIT -1 T53 1 TESTERS 0.7 P53 -1
LT59 LS59 1 PROFIT -1 SA59 1 TESTERS 0.6 P59 -1
LT50 PROFIT -1 T50 1 TESTERS 0.7 P50 -1
LT51 PROFIT -1 T51 1 TESTERS 0.7 P51 -1
LT52 PROFIT -1 T52 1 TESTERS 0.7 P52 -1
BYPPBK PROFIT PPBKML -1
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BYPLBK PROFIT     PLBK -1
BYMPBK PROFIT      MPBKML -1
BYPLBK PROFIT      PLBKML -1
BYGLBK PROFIT      GLBKML -1
BYHD50 PROFIT     HDML -1
APPBK PLBK 1 PPBKML 1 BKWRKRS 0.5 PLKBK -1
AMPBK MPBKML 1 BKWFKRS 1 MTLBK -1
APLBK PLBK 1 PLBKML 1 BKWRKPS 0.5 RLLBK -1
AGLBK PLBK 1 GLBKML 1 BKWRKRS 0.5 GRPHL -1
BYLC127 PROFIT       LS1227 -1
BYSPCOM PROFIT       SPCOM -1
AHD50 HDML 1 BKWRKRS .05 HOOD -1
LT5A P5A 1 PLKBK 1 ASMBLRS .05 CLT5A -1
LTP1227 LS1227 1 ASMBLRS .6 P1227 1 MTLBK 1 C1227 -1
LTP1227E LS1227 1 P1227 1 ASMBLRS 0.6 MTLBK 1 SPCOM 1 C1227E -1
LTP30 ASMBLRS 0.4 P30 1 PLKBK 1 C30 -1
LTP3132 P30 1 ASMBLRS 0.4 RLLBK 1 C3132 -1
LTP58 ASMBLRS 0.4 P58 1 GRPHL 1 C58 -1
LTP53 P53 1 C53 -1 ASMBLRS .4
LTP59 ASMBLRS 0.4 P59 1 PLKBK 1 HOOD 1 C59 -1
LTP50 ASMBLRS 0.4 P50 1 PLKBK 1 HOOD 1 C50 -1
LTP51 ASMBLRS 0.4 P51 1 RLLBK 1 HOOD 1 C51 -1
LTP52 ASMBLRS 0.4 P52 1 GRPHL 1 HOOD 1 C52 -1
LTPSP ASMBLRS 0.4 P51 1 HOOD 1 MTLBK 1 RLLBK 1 GRPHL 1 CSP -1
P5A CLT5A 1 ASMBLRS .05 C5A -1
SLC5A C5A 1 PROFIT     ULC5A 1 LLC5A -1
SLC12 C1227 1 PROFIT     ULC12 1 LLC12 -1
SLC27 C1227 1 PROFIT     ULC27 1 LLC27 -1
SLC12E C1227E 1 PROFIT     ULC12E 1 LLC12E -1
SLC27E C1227E 1 PROFIT     ULC27E 1 LLC27E -1
SLC30 C30 1 PROFIT    ULC30 1 LLC30 -1
SLC3132 C3132 1 PROFIT     ULC3132 1 LLC3132 -1
SLC58 C58 1 PROFIT 755 ULC58 1 LLC58 -1
SLC53 C53 1 PROFIT 1000 ULC53 1 LLC53 -1
SLC59 C59 1 PROFIT 615 ULC59 1 LLC59 -1
SLC50 C50 1 PROFIT 990 ULC50 1 LLC50 -1
SLC51 C51 1 PROFIT 1260 ULC51 1 LLC51 -1
SLC52 C52 1 PROFIT 1290 ULC52 1 LLC52 -1
SLCSP CSP 1 PROFIT 1430 ULCSP 1 LLCSP -1
SLPLKBK PLKBK 1 PROFIT 70 ULPLKBK 1 LLPLKBK -1
SLMTLBK MTLBK 1 PROFIT 100 ULMTLBK 1 LLMTLBK -1
SLRLLBK RLLBK 1 PROFIT 135 ULRLLBK 1 LLRLLBK -1
SLGRFL GRPHL 1 PROFIT 70 ULGRFL 1 LLGRFL -1
RHS
RESOURCE WRKRS -320 ULC5A 800 LLC5A -75 ULC12 120 LLC12 -10
RESOURCE ULC27 350 LLC27 -5 ULC12E 24 LLC12E -2 ULC30 200
RESOURCE LLC30 -50 ULC3132 20 LLC3132 0 ULC58 180 LLC58 -5
RESOURCE ULC53 150 LLC53 -35 ULC50 150 LLC50 -35 ULC59 170
RESOURCE LLC59 -40 ULC51 110 LLC51 -22 ULC52 40 LLC52 -3
RESOURCE ULCSP 15 LLCSP -4 ULPLKBK 50 LLPLKBK -10
RESOURCE ULMTLBK 50 LLMTLBK -10 ULRLLBK 50 LLRLLBK -10
RESOURCE ULGRFL 50 LLGRFL -10
RESOURCE ULC27F 24 LLC27E -2
RESOURCE  GRADE8 320
RESOURCE GRADE5 2720
RESOURCE LIMOT 1375
EOF
```

TITLE
OBJ = PROFIT
RHS = RESOURCE
MAXIMUM =
ROWS

PROFIT	Z			MINF	PINF	-1.000000
CBMAT	U	0	0	MINF	0	13.000000
PININ	U	0	0	MINF	0	.001250
GRADE8	F	320.000000	0	320.000000	320.000000	-5.140000
CBSA	U	0	0	MINF	0	11.000000
CBS0	U	0	0	MINF	0	13.018750
WRKRS	U	-320.000000	0	MINF	-320.000000	111.540714
TESTERS	B	-49.308000	49.308000	MINF	0	0
FO85A	U	0	0	MINF	0	55.616286
FO950	U	0	0	MINF	0	91.097250
CBWRKRS	U	0	0	MINF	0	111.540714
PL5A	U	0	0	MINF	0	4.000000
LS5A	U	0	0	MINF	0	45.000000
PL1227	U	0	0	MINF	0	10.000000
ML1227	U	0	0	MINF	0	140.000000
PL30	U	0	0	MINF	0	5.000000
ML30	U	0	0	MINF	0	120.000000
LS30	U	0	0	MINF	0	120.000000
PL50	U	0	0	MINF	0	10.000000
ML50	U	0	0	MINF	0	15.000000
ASMBLRS	U	0	0	MINF	0	111.540714
SA58	U	0	0	MINF	0	351.486821
SA59	U	0	0	MINF	0	562.260107
SA50	U	0	0	MINF	0	908.036321
LS53	U	0	0	MINF	0	83.000000
LS50	U	0	0	MINF	0	71.500000
LS51	U	0	0	MINF	0	188.000000
LS52	U	0	0	MINF	0	190.000000
METAL	U	0	0	MINF	0	3.000000
LS58	U	0	0	MINF	0	205.000000
CLS53	U	0	0	MINF	0	92.000000
CLS50	U	0	0	MINF	0	74.500000
CLS51	U	0	0	MINF	0	191.000000
CLS52	U	0	0	MINF	0	193.000000
T58	U	0	0	MINF	0	567.486821
T53	U	0	0	MINF	0	1000.036321
T50	U	0	0	MINF	0	982.536321
T51	U	0	0	MINF	0	1099.036321
T52	U	0	0	MINF	0	1101.036321
LS59	U	0	0	MINF	0	89.000000
P5A	U	0	0	MINF	0	138.078500
P1227	U	0	0	MINF	0	440.005857
P30	U	0	0	MINF	0	535.005857
P58	U	0	0	MINF	0	568.485821
P53	U	0	0	MINF	0	1001.036321
P59	U	0	0	MINF	0	651.260107
P50	U	0	0	MINF	0	983.535321
P51	U	0	0	MINF	0	1100.036321
PLBK	U	0	0	MINF	0	4.000000
PBBKML	U	0	0	MINF	0	25.000000
MPBKML	U	0	0	MINF	0	45.000000
RLBKML	U	0	0	MINF	0	45.000000
GLBKML	U	0	0	MINF	0	30.000000
MTML	U	0	0	MINF	0	5.000000
PLKPK	U	0	0	MINF	0	84.770357
MTLBK	U	0	0	MINF	0	156.540714
RLLBK	U	0	0	MINF	0	104.770357
GRPML	U	0	0	MINF	0	89.770357
LS1227	U	0	0	MINF	0	128.000000
SPCOM	U	0	0	MINF	0	150.000000
P52	U	0	0	MINF	0	1102.036321
M000	U	0	0	MINF	0	10.577036
CLT5A	U	0	0	MINF	0	228.425893
C1227	U	0	0	MINF	0	791.471000
C5A	U	0	0	MINF	0	234.002929
C1227E	U	0	0	MINF	0	941.471000
C30	U	0	0	MINF	0	664.392500
C3132	U	0	0	MINF	0	684.392500
C58	U	0	0	MINF	0	702.873464
C53	U	0	0	MINF	0	1045.652607
C59	U	0	0	MINF	0	791.223786
C50	U	0	0	MINF	0	1123.500000
C51	U	0	0	MINF	0	1260.000000
C52	U	0	0	MINF	0	1247.000000
CSP	U	0	0	MINF	0	1566.311071
ULPLK9K	B	10.000000	40.000000	MINF	50.000000	0
LLPLK9K	U	-10.000000	0	MINF	-10.000000	14.770357
ULMTLBK	B	10.000000	40.000000	MINF	50.000000	0

LT5C	B	35.000000	-1.000000	0	PINF	0
LT51	B	36.702857	-1.000000	0	PINF	0
LT52	B	40.000000	-1.000000	0	PINF	0
BYPPBK	B	935.000000	-25.000000	0	PINF	0
BYPLBK	B	1275.702857	-4.000000	0	PINF	0
BYMPBK	B	77.000000	-45.000000	0	PINF	0
BYPLBK	B	106.702857	-45.000000	0	PINF	0
BYGLBK	B	234.000000	-30.000000	0	PINF	0
BYH050	B	151.702857	-5.000000	0	PINF	0
APPBK	B	935.000000	0	0	PINF	0
AMPBK	B	77.000000	0	0	PINF	0
APLBK	B	106.702857	0	0	PINF	0
AGLBK	B	234.000000	0	0	PINF	0
BYLS127	B	67.000000	-128.000000	0	PINF	0
BYSPCOM	B	48.000000	-150.000000	0	PINF	0
AH050	B	151.702857	0	0	PINF	0
LT5A	B	800.000000	0	0	PINF	0
LTP1227	B	15.000000	0	0	PINF	-0.000000
LTP127E	B	43.000000	0	0	PINF	-0.000000
LTP30	B	50.000000	0	0	PINF	-0.000000
LTP3132	B	20.000000	0	0	PINF	-0.000000
LTP58	B	180.000000	0	0	PINF	-0.000000
LTP53	B	35.000000	0	0	PINF	-0.000000
LTP59	B	40.000000	0	0	PINF	0
LTP50	B	35.000000	0	0	PINF	-0.000000
LTP51	B	32.702857	0	0	PINF	.000000
LTP52	B	40.000000	0	0	PINF	0
LTPSP	B	4.000000	0	0	PINF	0
P5A	B	800.000000	0	0	PINF	0
SLC5A	B	800.000000	235.000000	0	PINF	0
SLC12	B	10.000000	750.000000	0	PINF	0
SLC27	B	5.000000	690.000000	0	PINF	0
SLC12E	B	24.000000	1090.000000	0	PINF	0
SLC27E	B	24.000000	1030.000000	0	PINF	0
SLC30	B	50.000000	650.000000	0	PINF	0
SLC3132	B	20.000000	770.000000	0	PINF	0
SLC58	B	180.000000	755.000000	0	PINF	0
SLC53	B	35.000000	1000.000000	0	PINF	0
SLC59	B	40.000000	615.000000	0	PINF	0
SLC50	B	35.000000	990.000000	0	PINF	0
SLC51	B	32.702857	1260.000000	0	PINF	0
SLC52	B	40.000000	1290.000000	0	PINF	0
SLCSP	B	4.000000	1430.000000	0	PINF	0
SLPLKBK	B	10.000000	70.000000	0	PINF	0
SLMTLBK	B	10.000000	100.000000	0	PINF	0
SLRLLBK	B	50.000000	135.000000	0	PINF	0
SLGRFL	B	10.000000	70.000000	0	PINF	0

EOF

LLMTLBK	U	-10.000000	0	MINF	-10.000000	56.540714
ULPLLBK	U	50.000000	0	MINF	50.000000	30.229643
LLPLLBK	B	-50.000000	40.000000	MINF	-10.000000	0
ULGPFL	B	10.000000	40.000000	MINF	50.000000	0
LLGPFL	U	-10.000000	0	MINF	-10.000000	19.770357
ULC5A	U	800.000000	0	MINF	800.000000	.997071
LSLC5A	B	0	0	MINF	0	0
ULC12	B	10.000000	110.000000	MINF	120.000000	0
LLC12	U	-10.000000	0	MINF	-10.000000	41.471000
ULC27	B	5.000000	345.000000	MINF	350.000000	0
LLC27	U	-5.000000	0	MINF	-5.000000	101.471000
ULC12E	U	24.000000	0	MINF	24.000000	148.529000
LLC12E	B	-24.000000	22.000000	MINF	-2.000000	0
ULC27E	U	24.000000	0	MINF	24.000000	88.529000
LLC27E	B	-24.000000	22.000000	MINF	-2.000000	0
ULC30	B	50.000000	150.000000	MINF	200.000000	0
LLC30	U	-50.000000	0	MINF	-50.000000	14.392500
ULC3132	U	20.000000	0	MINF	20.000000	85.607500
LLC3132	B	-20.000000	20.000000	MINF	0	0
ULC58	U	180.000000	0	MINF	180.000000	52.126536
LLC58	B	-180.000000	175.000000	MINF	-5.000000	0
ULC53	B	35.000000	115.000000	MINF	150.000000	0
LLC53	U	-35.000000	0	MINF	-35.000000	45.652607
ULC59	B	40.000000	130.000000	MINF	170.000000	0
LLC59	U	-40.000000	0	MINF	-40.000000	176.223786
ULC50	B	35.000000	115.000000	MINF	150.000000	0
LLC50	U	-35.000000	0	MINF	-35.000000	133.500000
ULC51	B	32.702857	77.297143	MINF	110.000000	0
LLC51	B	-32.702857	10.702857	MINF	-22.000000	0
ULC52	U	40.000000	0	MINF	40.000000	43.000000
LLC52	B	-40.000000	37.000000	MINF	-3.000000	0
ULCSP	B	4.000000	12.000000	MINF	16.000000	0
LLCSP	U	-4.000000	0	MINF	-4.000000	76.311071
BKWPKRS	U	0	0	MINF	0	111.540714
LLC5A	B	-800.000000	725.000000	MINF	-75.000000	0
GPHDES	F	2720.000000	0	2720.000000	2720.000000	107.450714
LIMOT	F	1375.000000	0	1375.000000	1375.000000	105.420714

COLUMNS

OTGP5	B	1375.000000	-6.120000	0	PINF	0
BYCP50	B	366.702857	-13.000000	0	PINF	0
BYPININ	B	1.527929	-4.500000	0	PINF	0
HSTGP5	B	2720.000000	-4.090000	0	PINF	0
HSTGP8	B	320.000000	-5.140000	0	PINF	0
BYCP5A	B	800.000000	-11.000000	0	PINF	0
ICP50	B	366.702857	0	0	PINF	0
PWPCB	B	576.692000	0	0	PINF	0
PWPAS	B	2475.571429	0	0	PINF	0
PWPPK	B	722.428571	0	0	PINF	0
ACB5A	B	800.000000	0	0	PINF	0
ACB50	B	355.702857	0	0	PINF	0
BYHL1227	B	63.000000	-140.000000	0	PINF	0
BYHL30	B	70.000000	-120.000000	0	PINF	0
BYHL50	B	366.702857	-15.000000	0	PINF	0
BYPL5A	B	800.000000	-4.000000	0	PINF	0
BYLS5A	B	800.000000	-45.000000	0	PINF	0
BYPL1227	B	63.000000	-10.000000	0	PINF	0
BYPL30	B	70.000000	-5.000000	0	PINF	0
BYLS30	B	70.000000	-120.000000	0	PINF	0
BYPL50	B	366.702857	-10.000000	0	PINF	0
KPA5A	B	800.000000	0	0	PINF	0
KPA1227	B	63.000000	0	0	PINF	0
KPA30	B	70.000000	0	0	PINF	0
KPA58	B	180.000000	0	0	PINF	0
KPA59	B	40.000000	0	0	PINF	-0.000000
KPA50	B	146.702857	0	0	PINF	-0.000000
BYLS58	B	180.000000	-206.000000	0	PINF	0
BYLS53	B	35.000000	-89.000000	0	PINF	0
BYLS50	B	35.000000	-71.500000	0	PINF	0
BYLS51	B	36.702857	-188.000000	0	PINF	0
BYLS52	B	40.000000	-190.000000	0	PINF	0
BYMETAL	B	146.702857	-3.000000	0	PINF	0
ALS53	B	35.000000	0	0	PINF	0
ALS50	B	35.000000	0	0	PINF	0
ALS51	B	36.702857	0	0	PINF	0
ALS52	B	40.000000	0	0	PINF	0
AT58	B	180.000000	0	0	PINF	-0.000000
AT53	B	35.000000	0	0	PINF	0
AT50	B	35.000000	0	0	PINF	0
AT52	B	40.000000	0	0	PINF	0
AT51	B	36.702857	0	0	PINF	0
BYLS59	B	40.000000	-88.000000	0	PINF	0
LT58	B	180.000000	-1.000000	0	PINF	0
LT53	B	35.000000	-1.000000	0	PINF	0
LT59	B	40.000000	-1.000000	0	PINF	0