APPLICATION OF ZERO-ONE PROGRAMMING

TO THE MAKE-OR-BUY DECISION

by 557

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CHAPTER I

INTRODUCTION

With the advent of technological changes, the scope of problems encountered in industrial firms has broadened and correspondingly presented management with more decisions of a higher degree of complexiety to be made. In this report a specific type of decision is studied. Usually when a firm enters into a contract with the government a tight money situation exists. That is, profits received tend to be low from the contracts for the performance of certain services for the government. It also implies that fiscal year budgeting is a difficult task. Typically the budgeting is established for the current budget period but is forecasted for future budget periods. Thus when making a decision on the feasiblity of producing a particular product it is necessary to evaluate what resources required to manufacture the product need to be budgeted for. Also it is necessary to note what effect the resource allocation to one product has on the total system. Perhaps there are one or two resources when considering the total system, which are critical resources, and, as a result, exert much influence on the total system.

Sometimes because of critical internal limitations of a particular resource it is necessary to make a decision to have a product manufactured at an external source. Thus in addition to budgeting for the allocation of resources required internally the situation of external buying can influence tremendously the decision making process and correspondingly the total system.

During the last few years two factors have effected significantly the operations of most industrial firms, including to some extent, the firm mentioned above. The two factors are: (1) a rapid technological change, and (2) an increase in competition between firms. As a result, each year considerable expenditures are made by firms on investments (for the manufacturing of products), each of which probably has some expected future rate of return. Because of the amount expended and the long period of time before a return on the investment is realized, it is obvious that planning and controlling the expenditures on such investments is necessary to attain goals set by the firm in accordance with the two factors mentioned above. The planning and controlling of these expenditures on investments is the capital budgeting problem. Capital allocation is a direct result of capital budgeting. In this report each investment represents the planning and production for a particular product. The expenditures for an investment for the capital budgeting problem is the amounts required (or the cost of capital) if the product is to be produced.

It is necessary for the acceptance or rejection decision of an investment to have available some method or criteria for making that decision. A final decision of accepting or rejecting a proposed investment obtained through the decision making process signifies whether a product should be invested in. Usually when considering the capital budgeting problem past analysis and methods of obtaining the decision have been restricted to decision making for internal operations of a firm.

When considering an acceptance or rejection criteria an additional problem exists at some industrial firms. This problem consists of obtaining the make-or-buy decision. The make decision represents the product(s) invested in to be made by internal operations of a firm, whereas the buy decision represents the investments on product(s) that are made external to the operations of the firm. The products bought from an external source are then resold to a customer. The make-or-buy decision for the firm is usually affected or influenced by some internally required resource which is constrained to its limit. Theoretically for the make-or-buy decision three solutions to the problem are available: The three solutions are: (1) make all of a product internally, (2) buy all of a product externally, or (3) make some and buy some. The fact that a product is new, modified, or a current product is not taken into consideration in this report.

The problem studied in this report thus is stated as follows. Given the proposed investments or a priority value assigned to each investment for n products and m parts in each product to be manufactured, consider the combination of a capital budgeting constraint and constraints on other resources required for make-or-buy decision making to maximize the present value (or priority value) of the parts and thus find the optimum part-mix and product-mix for purposes of obtaining a make-or-buy decision. The part (or product)-mix represents the mix of parts which should be bought and those which should be made. Consideration is given to single and multiple product cases where each product has m parts. In addition single and multiple budget periods are evaluated.

It should be noted that the capital budgeting problem is essentially a subproblem of the make-or-buy problem. That is, capital budgeting is only one factor among many which could influence the final make-or-buy decision.

1.1 Literature Survey

For this report three areas of literature have been searched. The three areas included articles pertaining to capital budgeting or capital allocation problems, make-or-buy decision problems, and zero-one integer programming. In recent years, various individuals [17,66,69] have applied zero-one programming to the capital budgeting and capital allocation problem. Zero-one programming presents a method of reaching the acceptance-rejection decision for each investment. To date literature pertaining to the make-or-buy decision have primarily used cost accounting as a means of solving the problem. One author [12] attempted to compare cost accounting procedures and linear programming procedures as methods of obtaining a solution to the make-or-buy problem.

The subject of capital budgeting has been the topic of many economic and technical papers in the last few years. In this report it serves as one of several factors for the mathematical formulations to be discussed. In his presentation of capital budgeting Dean [22] has attempted to remove deficiencies in procedures presented in previous literature. Emphasis has been placed on the economic viewpoint of investing. It has been recommended that an internal rate of return to be determined for each investment being considered by a firm. A procedure of ranking the rate of returns was proposed. This approach guarantees an optimal selection of investments when the following assumptions of economic theory were satisfied. The assumptions were: (1) perfect certainty, (2) perfect capital market, (3) projections of the rate of returns, and (4) independent investments of products. Lorie and Savage, and Weingartner [47, 69] have illustrated that Dean's approach [22] has its shortcomings because it is the usual case in business that one or more of the above assumptions cannot be met.

Lorie and Savage [47] have illustrated why and how the rate of return approach failed in certain cases. Dean's procedures [22] break down when the projects are not independent or when expenditures for an investment are budgeted for more than one budget period. Lorie and Savage then proposed that the present value of the investments being considered be maximized. In addition this approach assumed that cost of capital has been given and that the investments have been considered independent. The method of obtaining a solution to the problem has been first to rank the ratios of the present value to expenditures of a project. Then proceed to select investments with the highest ratios until the total capital budget funds have been exhausted. This approach has been applied to three problems of capital rationing: (1) one budget period case, (2) multiperiod budget case, and (3) the independency of investments. This method of approach of capital budgeting has its deficiencies also.

Weingartner [69] has treated Lorie and Savage's approach in a different and more efficient manner for the multiproject problem with either a single or multiple period budget. Initially a linear programming approach has been utilized to replace the Lorie and Savage approach. It has been formulated as follows.

Maximize

$$Z = c_j x_j, \qquad j = 1, 2, \ldots, n,$$

subject to

$$a_{tj}x_j \leq b_t, \qquad t = 1, 2, \ldots,$$

and

$$0 \leq x_j \leq 1,$$

where c_j is the present value of revenue and costs associated with individual projects. The coefficient, a_{tj}, is the cost of capital of project j in budget year t and b_t represents the budget ceiling for year t. The variable, x_j represents the fraction of project j undertaken. The problem of observing a combination of projects instead of just one project at a time is solved using the above formulation.

Weingartner also has obtained an exact solution using a zero-one programming algorithm. An important assumption of this approach was that x_j was expressed as a zero or one. This implied either a complete acceptance or rejection of a project. A general approach to capital budgeting has been dealt with by Weingartner in relation to that presented by Charnes, Cooper, and Miller [17]. Related problems discussed by Weingartner have been budget defferals, multiple budgets, parametric methods, horizon models, mutually exclusive projects contingent projects, and imperfect capital with or without being interdependent.

Birnberg, Pondy, and Davis [8] have conducted a study on voting rules which have established a capital budgeting committee for the allocation of resources. It has represented a behavioral approach to resource allocation. Fleischer [27] has discussed the two major issues associated with the rate of return method for capital allocation: (1) the ranking error, and (2) the preliminary selection. The ranking problem has excluded irreducibles or qualitative factors, thus the ranking error problem. The preliminary selection problem has represented the selection of alternatives preliminary to the preparation of the final capital budget. Fleischer has discussed further the proper approach to solving the problem. In addition Fleischer [26] has proposed a technique to be used to consider 'irreducibles' and monetary data together in determining mutually exclusive alternative investment proposals. The logic used has been discussed and a formal structure of a solution was presented.

Unger [66] has assumed that investment opportunities are indivisible in nature. He has proposed a model which maximized the discounted sum of dividends paid to its shareholders. Balas's zero-one algorithm [3] and partioning procedures have been combined for the allocation of a limited amount of capital among a specified set of investment opportunities.

Various algorithms have been proposed for the solution of an integer linear programming problem. Gomory [30] has initiated the integer programming proposals. An excellent exposition of integer programming has been introduced by Balinski [5] and Beale [7]. An enumerative approach has been developed by Hammer and Rudeanu [35] using branching and bounding processes subject to a set of rules. The rules are attributed to pseudo-Boolean functions. This approach has been coded in FORTRAN IV for the 360/50 computer by Char [14]. Salkin and Speilberg [62] and Lemke and Speilberg [63] have developed an Adaptive Binary Program. The computer program solves linear programming problems subject to an additional constraint that a variable must be either zero or one. In his thesis, Char [14] has compared both Hammer and Rudeanu's, and Salkin and Speilberg's algorithms using shop scheduling, line balancing, delivery, capital budgeting, traveling salesman, and fixed-charge problems. Because of the overall superiority of the Hammer and Rudeanu's program, it has been selected to be used in the solution of the make-or-buy problem discussed in this report.

The problem of make-or-buy has been discussed briefly in technical literature. Most literature on make-or-buy has been in the business and management fields. Culliton [20] and Gross [31] have been prominent in attempting to resolve the problem of make-or-buy.

Culliton [20] has proposed a group of principles which would aid management in the decision making process of the make-or-buy problem. In general, the following points are regarded as important: (1) determine the quality of product needed, (2) estimate quantity required, (3) compare the cost of making with the cost of buying, and (4) compare the cost to the firm as a whole. However, special emphasis has also been given to the following factors: (1) establish a time table of product duration, (2) select a method of estimating cost which will be most accurate, and (3) evaluate all factors affecting the make-or-buy decision when considering cost to the firm. The approach taken by Culliton has been to consider the theories and techniques of purchasing and the source of supply. He also has discussed in detail, cost, quality, and quantity of the product, production at the right time, and external factors on individual make-or-buy problems.

The evaluation of relevant data to the make-or-buy problem has been considered essential to the decision making process by Gross [31]. He has emphasized the development of principles for quantitative factors. For qualitative factors; however, it has been necessary that further evaluation by management take place. As in [20], Gross [31] also has attempted to develop principles to serve as a base for making the make-or-buy decision by management. He has listed the following principles as being important:

1. quality requirements for a product involved in a make-or-buy decision be established,
2. the quantity of the product required should be continually updated,
3. the cost should be compared for each of the alternatives
4. factors from financing related to cost need to be considered, and
5. whether the decision conform with circumstances and company policy.

It should be noted that the above five principles are similar to those discussed by Culliton [20].

An attempt has been made by Burton and Holzer [12] to compare cost accounting and a proposed linear programming approach for the make-or-buy problem. It has been shown that for more than two products, cost accounting technique of decision making becomes laborious. In addition it has been stated that linear programming presents a much easier and faster approach for decision making purposes. The possibility of considering capital equipment has not been considered, thus capital budgeting did not enter into the mathematical formulation. As a result the problem has been only to minimize total cost per unit subject to demand requirements and production constraints. The decision of making all, buying all, and making some and buying some has been considered.

Others which have contributed somewhat to make-or-buy theory are Fabrychy [24], Higgins [38], and Hubler [40]. Fabrychy has approached the make-or-buy problem for a procurement and inventory study. Other literature has presented no technical and mathematical approaches other than cost accounting.

A similar type of problem considered quite frequent in industry is the lease-buy problem which has been discussed by Weekes, Chambers, and Mallick [68]. They have primarily discussed a method for deriving optimal implementation schedules and cost evaluations for such a problem. Basic characteristics of lease-buy situations have been introduced.

1.2 Proposed Research

This report studies the make-or-buy problem with capital budgeting as one of the influential factors. The approach used for obtaining the make-or-buy decision is the zero-one programming algorithm developed by Hammer and Rudeanu [34] and coded by Char [14]. A mathematical model is developed with a certain objective function and restrictions which pertain to an industrial firm.

The objective function introduced utilizes the assignment of priority values for purposes of influencing the make or buy decision. In particular, the priority values method is proposed to provide a method of including and evaluating both quantitative and qualitative factors.

The constraints proposed in the model are established with special consideration of an industrial firm. Five stages of product flow are also included in the mathematical development. The fundamental concepts of capital budgeting and make-or-buy are discussed in Chapter II. The problem is then developed in mathematical terms for solution by zero-one programming. A sample problem is presented which illustrates the mathematical development for the make-or-buy problem. This sample problem is set up for a single product, multiple parts, and single budget period model.

Computational results for problems of various formulations which pertain to the industrial firm mentioned above are discussed in Chapter III. The first problem discussed is a multiple product, multiple parts, and single budget period problem where all parts are independent. In the second problem, two parts in different products are assumed to be identical for a multiple product, multiple parts, and single budget period. The third problem takes into consideration a multiple budget period in addition to multiple products, and multiple parts. This problem assumes that all parts are independent. The fourth problem is identical to the third one except that a part which is used in different products is considered. Conclusions and Summary on the report are stated in Chapter IV.

CHAPTER II

DEVELOPMENT OF A MAKE-BUY DECISION MODEL

In this chapter, four sections are included. Section 2.1 discusses the nature of the make-or-buy problem. Briefly, the industrial firm requiring a solution to such a problem is discussed. Section 2.2 analyzes the make-or-buy decision. Factors which have some influence on the final decision are mentioned. In addition, the capital budgeting problem is discussed to serve as a base for the mathematical formulation. The mathematical formulation is developed in Section 2.3 in the form of zero-one integer programming. Three variations of the objective function are proposed. The constraints are set up for five stages of product flow. Stage 1 represents the concepts stage. Development of the production processes and fabrication of a prototype consist of stage 2. The initial production is established in stage 3. Stage 4 includes full production activities. Inventory storage or shipping to the customer represents stage 5. A sample problem is presented for the illustration of the mathematical development in Section 2.4.

2.1 Nature of the Problem

In discussing the make-or-buy problem it is desirable to limit the type of organizations to which the discussion pertains. This report intends to discuss only those manufacturing firms which produce products for government utilization. It is a type of manufacturing concern which stresses the production of high quality products. The products to be manufactured, usually require special labor skills, sometimes state-of-the-art technological know-how, and facilities with an extensive range on the types of machinery. The products manufactured represent a diversified range from those machined, to rubber and plastics, and to electrical and electronic devices.

At such manufacturing firms whenever an external source is contracted to fabricate a product, that product is being bought. Correspondingly, whenever a product is scheduled to be fabricated internally, that product is being made. Hence, when a product is bought externally, a decision to buy and not to make has been established. In addition, when an internal schedule has been established for a product, the decision has been to make and not to buy. This type of decision making is an end result of studying, weighing, and evaluating many internal and external factors which could effect the final decision. It means that before the final decision to make or buy is made, some method or process of interrelating factors is required. Even before this stage, it is necessary to collect the proper information and data. In addition, it is helpful if guidelines are available for use by managers making the final decisions.

The information on factors leading to a final decision are supplied by many divisions within the industrial firm. These divisions typically perform a function which helps attain the firms' goals. The decisions, however, cannot be the responsibility of just one division, except when the final decision is being considered. The divisions are Accounting, Computer Science, Engineering, Manufacturing, Planning, and Quality Control.

The concept of the make-or-buy decision making has continually produced problems for most managers where this type of decision making is necessary. The most prevalent problem is how the different factors should be related, and what influence each factor should have on the final decision. Decision making for one product at a time has typically been carried on at the industrial firm. Even when one product is considered, the decision making process is difficult. When it is decided to expand the decision making process to more than one product simultaneously the complexity of the problem increases: especially when the same resource is allocated to more than one product. It is usually difficult to make the decision, because of the many quantitative and qualitative factors that could enter the decision making process. Based on a broad view, the main factors are the three resources: land, labor, and capital. However, it is the usual case that factors are in much finer detail than the three main resources. In addition, the qualitative factors are not considered resources. They could be factors such as design stability, quality level or technological know-how. To evaluate these factors, it is necessary that a method of analysis provide a path for a more efficient decision-making process to reach the optimal product-mix. It is necessary to eliminate or make assumptions about these factors which cannot be measured in quantitative terms. An end result is the possible improvement of the performance of a firm and the optimal allocation of resources among investments.

When considering the make-or-buy problem the manager has at his discretion three possible solutions: (1) make all of a product internally, (2) buy all of a product externally, and (3) make some internally and buy some externally.

2.2 Analysis of the Problem

Extensive studies of the capital budgeting problem influences further research of the make-or-buy problem. In addition, an assumption by Burton and Holzer [12] that the capital budgeting problem be ignored in their formulation of the make-or-buy problem created the fact that one of the more important influencing factors was ignored. It should be emphasized that capital budgeting is only one of many factors in the make-or-buy decision. However, because of the emphasis in past years on this subject, it serves as an excellent base for establishing a make-or-buy model.

Capital budgeting consists of the planning and control of expenditures for assets with an expected resulting return. This return need not be in terms of monetary value. At least four elements are generally required when establishing a capital budget for expenditures: (1) a demand for capital should exist, (2) a supply of capital must be available, (3) the timing or the use of the cost of capital to obtain demanded capital is important, and (4) a method of ranking, appraising or selecting investments is required.

The concept of the cost of capital has been subject to much controversy in literature. It is defined as the cost of capital equipment which is required as a condition for undertaking the manufacturing of a product with a minimum rate of return on the investment. This cost can also be considered an opportunity cost, since there is the opportunity to demand a lower cost for capital equipment obtained, and consequently to produce a higher rate of return and additional revenue intake.

Thus, to have a capital budget there should be a demand for something which is being invested in. The demand must be determined using some analysis or marketing procedure. Corresponding to the demand there has to be sources for the supply of what is demanded. In order to determine if supply is available to satisfy demand and what the sources of supply are, some analytical or premarketing procedure must be established.

It is obvious that when more than one investment is considered in a capital budget, the problem of selecting the investments which generate the higher rate of returns increases in complexity. As a result, the problem of satisfying the demand becomes quite complex when more than one investment is considered at the same time.

When the capital budget is established for a firm in the manufacturing industry, using the generally required information mentioned above, additional elements must be considered. The first element is the generation or introduction of a possible new investment or modification of an existing investment. Included in this stage are the initial plans, sketches or prints of the product which is being invested in. Also, it is necessary to determine the demand of capital in case it is decided that an investment should be made on the product. The second element is the evaluation of the product. Measures should be established for the estimation of benefits and costs of the product. After this is completed, a determination is made if the benefits of investment and cost are of a reasonable value. The third element represents the selection of those investments which benefit the manufacturing firm the most. This stage is the stage of critical decision-making for making or not making the investment in a product. Important to this stage is the manufacturing, if necessary, of a prototype of the product in demand, to further justify the feasibility of investing in the product. The last element is the execution stage or that stage which provides manufacturing facilities, or replacement of existing internal facilities. It is also possible that, because the demand for a product and the overloading of internal facilities, the product must be produced at an external source.

In this report, it is assumed that the capital budgeting is utilized to control (or allocate) the expenditures on investments. In order to control the expenditures and to determine optimally what products should be invested in, various mathematical approaches have been established [17, 53, 69]. A mathematical formulation is established below for the general capital budgeting problem described previously. It is assumed that the total demand for each investment is known, regardless of the way it is determined, that is, by a marketing survey, contract, or estimation. Further, it is assumed that the availability of supply from various sources is known and that the supply satisfies the demand.

The capital budgeting problem for a firm in the manufacturing industry is generally stated as follows. Consider simultaneously from a multiple number of products the demand desired, the supply availability, the cost of capital during specific time periods, and the present value or the rate of return. It is desired to maximize the present value or the rate of return when the total cost of capital available for all investments (or products) is known. It is possible to make either the product internally or not to make it at all.

The general problem is initially stated mathematically as a linear programming problem to obtain an approximate solution for one budget period.

Maximize

$$Z = CX \tag{1}$$

subject to

$$AX \leq P_0 \tag{2}$$

and

$$0 \leq X \leq 1 \tag{3}$$

where

C vector representing the present value

X vector representing the amount invested

A matrix representing the cost of capital

P_0 vector representing total capital dollars available

An extension to the above formulation is the restriction that each components in the vector X is either 0 or 1. This implies that an exact solution of either investing or not investing is obtained. This type of restriction has been utilized in studies by Weingartner [69] and Petersen [53]. In addition, a formulation for more than one budget period has been considered. It is stated as follows.

Maximize

$$Z = CX \tag{4}$$

subject to

$$AX \leq P_0 \tag{5}$$

and

$$X = 0 \text{ or } 1 \tag{6}$$

where all notation is defined as above.

The capital budgeting mathematical formulations to date have been restricted to the option of either investing or not investing internally in a product. Because of competition between firms and technological advances, a third option is becoming important to the manufacturing industry. The third option is that of buying a product externally for resale. This creates the make-or-buy decision. The decision for make-or-buy is important for purposes of cost reduction, profit increase, product-quality improvement, and optimal allocation of resources.

To reiterate, the decision to manufacture or make a product in the firm's plant, which is the internal source, is the make decision. Whereas, the decision to obtain a product from an external source is the buy decision. A possible third decision is to make some internally and buy some externally. In their article [12], Burton and Holzer has studied this possibility using linear programming. The following solutions are considered in this report: (1) Make all of a product internally, and (2) buy all of a product externally. This restriction is established because the products being fabricated required, in most cases, special technical know-how and specified types of capital equipment. It is possible that a product is neither made nor bought by using special mathematical restrictions. This avenue of solution is mentioned in the formulation of the problem.

When studying the make-or-buy decision, it is necessary to establish what factors effect such a decision. If only one product and one budget period is being considered, the decision is usually easier to reach because of no interrelationships with factors of another product. This is similiar to the one product capital budget problem, except for additional constraints that are included. When more than one product and more than one budget period are considered, the complexity of the decision-making task increases quite rapidly because of interrelationships between factors of various products. As a result some approach is required to interrelate the resources being considered for individual products as compared to total resources available.

Thus, the important elements for make-or-buy decision making are as follows: (1) establish exactly what type of decisions are desired; and (2) establish and identify those factors which influence the make-or-buy decision in some manner, whether the factors are quantitative or qualitative. In this report, the broad definition of resources of land, labor, capital and ownership are considered the quantitative factors. Sometimes one or more of these resources are detailed further. When considering labor, for example, it is possible to have administrative, technical, direct, and indirect labor. This type of approach is considered in the mathematical formulations in Section 2.3. When considering qualitative factors, it is difficult to express in mathematical terms those which could be influential in the final make-or-buy decision. An attempt is made to establish a mathematical equation for consideration of qualitative factors only.

If the decision is to make everything, then the final product is usually a product of high quality and resultantly has a high monetary value. When this type of decision is to make, then production equipment, factory labor, technical personnel, facilities (including space), materials and management are required internally. A control on the quality of a product can be established more easily. In addition, the delivery time to inventory storage or shipping to a vendor is shortened. Work can be supplied to idle capital equipment and factory labor to reduce opportunity cost. The make decision allows for a greater flexibility in the design of a product and requires experimentation on products which cannot be produced at an external source. Usually the cost for a product made internally is less. Perhaps the most important factor is that a make decision keeps information on a product internal to the firms operations for purposes of security requirements.

When the buy decision is made, a little or no investment in internal facility is needed. The factory labor force can be smaller and can be reduced in the required flexibility of special labor skill capabilities. When a steady labor force is desired the make-or-buy decision could have significant results on keeping labor at the desired level. The buy decision allows for buying standardized items externally and making specialized products internally. This type of decision allows for a lower inventory of products. In addition competitive bidding for subcontracts allows for the selection of a lower cost from the external source and utilizes in some cases the valuable technical experience of the subcontractor.

Initial assumptions for the formulation are given below. A product is defined to be the final assembly ready for shipment, or storage and then ship later. Any subassembly which makes up a part of the final assembly is defined as a part. It is assumed that the products are independent in the initial formulation. Provisions are made in the additional special constraints to allow for dependency among products and correspondingly, parts. This represents the fact that a part in one product is also a part in one or more other products. An assumption is also made that the parts are indivisible in nature, that is, a part is either made or bought but not both. If it is desired that the possibility of making some and buying the remainder be considered, then linear programming is utilized. This case is not considered in our formulation. Unused funds from one budget period are not carried over to a future budget period. It is possible to formulate a problem where carry over funds are taken into account. An additional assumption is that the technical know-how is developed internally during a special development of manufacturing processes period and assumed to be adequate for the desired quality level of a part. Competitive position with other firms is not accounted for in the first objective function proposed. A special forced decision making objective function is proposed to consider any qualitative factors such as competitive position. The stability of a part or product performance criterion, that is, quality control, is established during the research and development stage. For manpower, a stable labor force is desired with little fluctuations in the number available.

The budgets for the current period are set. Budgets for future budgets period are forecasted over several budget periods based on estimates of engineering studies. In the mathematical development the cost of capital constraint of capital budgeting problems is included with constraints representing the resources of land and facilities, or labor influencing the make-or-buy decision.

2.3 Formulation of the Problem

The section on the analysis of the problem places emphasis on many factors which enter the decision making process. To some degree the formulation below considers these factors in the form of mathematical formulation. Specifically, the formulation is established for a zero-one integer program. Special constraints are established when parts are utilized for more than one product. In addition, a special objective function is stated for application to the industrial firm being considered. The formulation is set up to handle a multiple number of parts for each product, a multiple number of products, and a multiple number of budget periods. Information for the current budget period is known with certainty because of budget appropriations allocated by the government. Future budgets are forecasted usually with uncertainty.

The formulation below includes data and information for the external source in the objective function only, except for cases where internal resources are required for the buy decision. An example of this is the administrative personnel and their time spent on decision making for the make proposal and the buy proposal. In addition, when the buy decision is possible, only a present value of subcontracting is known. Further breakdown of cost is generally not required. The formulation for making the make-or-buy decision is as follows.

Objective function. For the initial formulation the objective function is stated such that

Maximize

$$Z = \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ijM} X_{ijM} + \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ijB} X_{ijB} \tag{7}$$

where C_{ijM} (or C_{ijB}) is the present value of part j in product i for the make (or buy) decision. Also, X_{ijM} (or X_{ijB}) is equal to 0 or 1 for part j in product i for the make (or buy) decision. The decision of either make or buy is made for all budget periods at one time based on the present value of each product.

The objective function as stated above maximizes the present value of the n products to be invested in, taking into consideration that each product has up to m parts, where m may or may not be the same for each product. If $m = 1$, all parts of product i are included in one coefficient. In addition, the present value, C_{ijM} is not necessarily equal to the present value, C_{ijB} because of different cost allocations. The present value approach has been used previously by Weingartner [69] for the capital budgeting problem.

A second proposal for the objective function may be stated as follows: Maximize

$$Z = \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ijM} X_{ijM} + \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ijB} X_{ijB} \tag{8}$$

where C_{ijM}(or C_{ijB}) is the priority value assigned to part j in product i for the make (or buy) decision. Also, X_{ijM}(or X_{ijB}) is equal to 0 or 1 for part j in product i for the make (or buy) decision. Because of the assigned priority values, the coefficients of this objective function present a flexible planning and control guide for managers. In this type of formulation, the qualitative factors may be considered also. For example, if the technical know-how of internal capability is much greater than the external capability, a high priority value could be assigned to C_{ijM} and a low priority value to C_{ijB}, considering that all other qualitative factors as equal for make or buy. In addition, a forced solution is possible when the assumption, make as many parts as internal resources allow, is required. Assignment of high priority values to C_{ijM} produces the forced make decision until the constraints begin to reach their limits, assuming also that the objective function is maximized. The forced decision then occurs when a constraint has reached its limits, that is, the remaining parts are bought from an external source. Assuming that a forced decision for make is desired, the coefficients C_{ijM} are set for each part from a scale which ranges as some integer from a minimum of 1 to an upper limit. For this case, the coefficients, C_{ijB}, are equal to 1.

For the first two formulations the decision of make or buy is made only once for all budget periods. If it is desired to consider a priority value, for instance, for each of the k budget periods in the objective function the equation is stated as follows:

Maximize

$$Z = \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{\ell} C_{ijkM} X_{ijkM} + \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{\ell} C_{ijkB} X_{ijkB} \tag{9}$$

where C_{ijkM} (or C_{ijkB}) is the priority value assigned to part j in product i during budget period k. Also, X_{ijkM} (or X_{ijkB}) is equal to 0 or 1 indicating whether a part j is either made or not made (or whether part j is either bought or not bought). This type of formulation is used for the remainder of the model development.

Constraints. The constraints set up in the following paragraphs are established for the flow of a product or part from the concepts stage to the inventory storage or shipping stage. A listing of the five stages are as follows:

Stage 1: Concepts or idea stage

Stage 2: Process Development stage

Stage 3: Initial Production stage

Stage 4: Full Production stage

Stage 5: Storage or shipping stage

As stated previously, the initial formulation assumes independency of parts in each product. The state of dependency is taken into account with special constraints.

1. Concepts stage. The initial stage of the product (and part) cycle is designed to include the area for development of concepts and ideas about investments into new products and remodifications of current products. This requires that a general purpose of the product be established or re-evaluated, its specific function stated, and the potential quantity demanded by a buyer. All activities occuring in stage 1 are expressed in terms of a pre-marketing cost. The cost includes administrative and staff type functions. The constraint is expressed such that

$$D_{11ijkM}X_{ijkM} + D_{11ijkB}X_{ijkB} \leq B_{11k} \tag{10}$$

where $k = 1, 2, \ldots, \ell$. The coefficients D_{11ijkM} (or D_{11ijkB}) represents the costs of concepts (constraint 1) incurred during stage 1 for part j in product i and during budget period k for the make (or buy) decision. Also, B_{11k} is the total dollars budgeted during budget period k for use in constraint 1 in stage 1.

2. Process development stage. After stage 1 has been completed and the general concepts of the products are established, it is necessary to next develop the technical skill to produce the new part (or product)

or remodify the current part. This stage which may be referred to as research and development stage, includes determination of, through testing, the feasibility of using any new or special materials. In addition, a level of quality control is established here. Another important facet of this stage is the development of processes required to produce a product. The cost of technical and direct labor, materials, and some equipment and facilities are also required. In addition, during stage 2, advance planning of resource needs for full production is accomplished. Thus, stage 2 serves as a research and development stage for the fabrication of prototypes of the products to be produced during the production stage. The constraint for this stage is formulated such that

$$E_{21ijkM}X_{ijkM} + E_{21ijkB}X_{ijkB} \leq B_{21k} \tag{11}$$

where the coefficient E_{21ijkM} (or E_{21ijkB}) is the total dollars required for constraint 1 in stage 2 for part j in product i during budget period k. Also, B_{21k} represents the total dollars available for constraint 1 in stage 2 during budget period k. Equation (11) represents the allocation of the total dollars available for the development of production processes during budget period k for all products in this stage of flow.

3. Initial production stage. After production processes have been developed in stage 2, where a product of the required quality level can be produced, stage 3 begins. This stage establishes the initial production stage. This period represents the time when the initial critical resource allocation is encountered. The resources of land and facilities, capital equipment, and labor are treated as separate entities and must be allocated

to the production of various parts. They are treated in this manner because of generally higher cost encountered during stage 3.

Following are a number of constraints considered important during stage 3. During this stage it is intended that the production system is debugged to ensure smooth flow of work during full production and to maintain a consistent quality level for products.

The first constraint is stated such that

$$F_{31ijkM}X_{ijkM} + F_{31ijkB}X_{ijkB} \leq B_{31k} \qquad (12)$$

where F_{31ijkM} (or F_{31ijkB}) represents the cost of capital equipment (constraint 1 during stage 3) for part j in product i during budget period k for the make (or buy) decision. Also, B_{31k} is the total dollars available for capital equipment during budget period k. Equation (12) represents the allocation of dollars for procurement of capital equipment to fabricate part j in product i. The cost included in this equation is the cost of capital as utilized in previous capital budgeting formulations.

The next constraint considered during stage 3 is such that

$$F_{32ijkM}X_{ijkM} + F_{32ijkB}X_{ijkB} \leq B_{32k} \qquad (13)$$

where the coefficient F_{32ijkM} (or F_{32ijkB}) is the cost of facilities for part j in product i during budget period k for the make (or buy) decision. The right hand side coefficient, B_{32k}, is the total dollars available for facilities during budget period k. Equation (13) represents the cost of facilities expansion (or contraction) or remodification requirement. The dollars are considered for allocation to each part. The minimum requirement, B_{32k}, for the current budget period is set. However, for future budget periods B_{32k}, is usually forecasted.

Corresponding to Equation (13), a special resource which is a critical resource in some cases is that of internal area (ft^2) available for the manufacturing facilities. The constraint formulation is stated such that

$$F_{33ijkM}X_{ijkM} + F_{33ijkB}X_{ijkB} \leq B_{33k} \tag{14}$$

where F_{33ijkM} (or F_{33ijkB}) is the area requirements for part j in product i during budget period k for the make (or buy) decision and B_{33k} is the total area (ft^2) available during budget period k. This constraint is utilized when the floor area is considered critical. If it is constrained to its limit then it is obvious that either the manufacturing area should be increased or the remaining parts should be bought externally. This constraint isn't necessarily redundant with Equation (13), which is the constraint of facilities cost.

Another constraint which is a factor in producing a product is manpower. A general constraint for the resource labor can be formulated mathematically. However, because of the make-or-buy decision being studied, a division of labor would make mathematical formulation for the products more meaningful.

In this report, manpower is divided into the administrative, technical, direct, and indirect labor types. Additional types of labor can be established, however, in this report the formulations are restricted to the four mentioned. The division of labor is required because of administrative and technical labor necessary for influencing the buy decision. Internal direct and indirect labor usually does not effect the buy decision for a part. Technical personnel consist of various types of professional engineering manpower. Technical advisement comes from this group when the decision must be made. Administrative personnel, which represents the management level, are usually people who make the final make or buy decision. Direct labor are those personnel who actually produce the part. Indirect labor consist of personnel who indirectly contribute to the production of parts.

The constraint for administrative manpower in terms of manpower hours is such that

$$F_{34ijkM} X_{ijkM} + F_{34ijkB} X_{ijkB} \leq B_{34k} \tag{15}$$

where the coefficient F_{34ijkM} (or F_{34ijkB}) is the administrative hours required for part j in product i during budget period k for the make (or buy) decision and B_{34k} is the total number of administrative hours available during budget period k.

The constraint for technical personnel is such that

$$F_{35ijkM} X_{ijkM} + F_{35ijkB} X_{ijkB} \leq B_{35k} \tag{16}$$

where F_{35ijkM} (or F_{35ijkB}) is the coefficient which represents the technical personnel (constraint 5 in stage 3) required for part j in product i during budget period k for the make (or buy) decision. Technical manpower during stage 3 is generally at a higher level than other stages because of the debugging required for capital equipment set up.

The constraint for direct labor is formulated such that

$$F_{36ijkM} X_{ijkM} + F_{36ijkB} X_{ijkB} \leq B_{36k} \tag{17}$$

where the coefficient F_{36ijkM} (or F_{36ijkB}) represents the standard hours of work (constraint 6 in stage 3) required for part j in product i during budget period k for the make (or buy) decision. Also B_{36k} is the total number of standard hours of work available for direct labor during budget period k.

The constraint for indirect labor is formulated such that

$$F_{37ijkM}X_{ijkM} + F_{37ijkB}X_{ijkB} \leq B_{37k} \tag{18}$$

where F_{37ijkM} (or F_{37ijkB}) represents the indirect standard hours required for part j in product i during budget period k for the make (or buy) decision and B_{37k} is the total standard hours of work for indirect labor available during budget period k. The direct and indirect labor could also be expressed in terms of actual manpower or as a cost of manpower.

The last constraint (number 8) set up for stage 3 is concerned with the cost of materials required for the fabrication of a product. Because of the research and development stage (stage 2) the material composites of a product are established in terms of cost of material. The constraint for materials cost is such that

$$F_{38ijkM}X_{ijkM} + F_{38ijkB}X_{ijkB} \leq B_{38k} \tag{19}$$

where F_{38ijkM} (or F_{38ijkB}) is the cost of material required for part j in product i during budget period k for the make (or buy) decision and B_{38k} is the total material dollars available during budget period k. It is possible that additional constraints could be added. However the constraints that have been considered above for stage 3 presents constraints on the general resources of land and facilities, labor, and capital. At this point stage 4 will be considered.

4. <u>Full production stage</u>. Stage 4 consists of the full production stage. At this stage it is assumed that all manufacturing processes are debugged,

all capital equipment and facilities are completed and a complete production cycle of a product is possible. Constraints during this stage are similar to those for manpower during stage 3. The four constraints for administrative, technical, direct, and indirect labor are stated as follows.

The administrative personnel, constraint is such that

$$G_{41ijkM}X_{ijkM} + G_{41ijkB}X_{ijkB} \leq B_{41k} \tag{20}$$

where the coefficient G_{41ijkM} (or G_{41ijkB}) represents the administrative hours (constraint 1 in stage 4) required for part j in product i during budget period k for the make (or buy) decision. Also, B_{41k} is the total administrative hours available during stage 4 for budget period k. The technical personnel constraint is such that

$$G_{42ijkM}X_{ijkM} + G_{42ijkB}X_{ijkB} \leq B_{42k} \tag{21}$$

where G_{42ijkM} (or G_{42ijkB}) is the number of technical personnel required for stage 4 for part j in product i during budget period k for the make (or buy) decision and B_{42k} is the total number of technical personnel available during budget period k. The direct labor constraint is

$$G_{43ijkM}X_{ijkM} + G_{43ijkB}X_{ijkB} \leq B_{43k} \tag{22}$$

where the coefficient G_{43ijkM} (or G_{43ijkB}) is the standard hours of work available for direct labor for part j in product i during budget period k for the make (or buy) decision and B_{43k} is the total standard hours of work allowable during budget period k. The indirect labor constraint is such that

$$G_{44ijkM}X_{ijkM} + G_{44ijkB}X_{ijkB} \leq B_{44k} \tag{23}$$

where G_{44ijkM} (or G_{44ijkB}) is the standard hours of work for indirect labor for part j in product i during budget period k for the make (or buy) decision. Also, B_{44k} is the total standard hours for indirect labor available during budget period k.

The scaling of labor for stage 4 as compared to stage 3 shows that the direct and indirect labor increases as stage 4 begins. This is due to the increase in production rate. Typically technical personnel level is steady for stages 3 and 4.

A constraint for equipment utilization is established for idle machine hours, which is an opportunity cost, such that

$$G_{45ijkM}X_{ijkM} + G_{45ijkB}X_{ijkB} \leq B_{45k} \tag{24}$$

where G_{45ijkM} (or G_{45ijkB}) is the cost of downtime for part j in product i during budget period k for the make (or buy) decision and B_{45k} is the total cost of downtime during budget period k.

The last resource of importance to be considered during stage 4 is the cost of material. It is basically the same as stage 3 except that a higher cost is incurred because of the full production period. The constraint for the cost of material is such that

$$G_{46ijkM}X_{ijkM} + G_{46ijkB}X_{ijkB} \leq B_{46k} \tag{25}$$

where G_{46ijkM} (or G_{46ijkB}) is the cost of material for part j in product i during the budget period k for the make (or buy) decision and B_{46k} is the total cost of material available during budget period k.

5. Inventory or shipping stage. After the production of a part is completed, the possibility of either storing the part and then shipping or shipping the product immediately to the customer is considered. If the part is stored some inventory carry over cost is encountered. It is expressed in the following constraints:

$$H_{51ijkM}X_{ijkM} + H_{51ijkB}X_{ijkB} \leq B_{51k} \tag{26}$$

where the coefficient H_{51ijkM} (or H_{51ijkB}) is the storage carrying cost of part j in product i during budget period k for the make (or buy) decision and B_{51k} is the total storage cost which can be encountered during budget period k.

If instead of storing a part or product, it is shipped immediately to the customer then only shipping cost need be considered. The shipping cost constraint is expressed such that

$$H_{52ijkM}X_{ijkM} + H_{52ijkB}X_{ijkB} \leq B_{52k} \tag{27}$$

where the coefficient H_{52ijkM} (or H_{52ijkB}) is the shipping cost of part j in product i during budget period k for the make (or buy) decision.

For a problem where products and their respective parts are assumed to be independent the following constraint is necessary for each part.

$$X_{ijkM} + X_{ijkB} = 1 \tag{28}$$

where

$$X_{ijkM} = \begin{cases} 1, & \text{if part j of product i is made during budget period k} \\ 0, & \text{otherwise} \end{cases}$$

and

$$X_{ijkB} = \begin{cases} 1, & \text{if part j of product i is bought during budget period k} \\ 0, & \text{otherwise} \end{cases}$$

A direct result of this is that the make-or-buy decision is such that each part must either be made internally or bought externally. This constraint is necessary in the mathematical development to distinguish between the make decision or the buy decision.

If it is desired that a third possibility, that of neither make nor buy existing, the constraint is stated such that

$$X_{ijkM} + X_{ijkB} \leq 1 \tag{29}$$

where X_{ijkM} (or X_{ijkB}) is defined as in Equation (28). Equation (29) besides the possibility of a part being made or a product being bought also presents the possibility that the product is neither made nor bought.

Further versatility in developing the make-or-buy decision model is established when it is assumed that some of the products are not independent. This assumption means that it is possible for part j in product i to be identical to part t in product s during the same budget period k. In other words the same part is used in two products. This is often a frequent occurrence in the manufacturing industry.

For a part used in two products the following constraint is required in addition to Equation (28).

$$X_{ijkM} + X_{stkB} = 1 \tag{30}$$

where

$$X_{ijkM} = \begin{cases} 1, & \text{if part j in product i during budget period k is made} \\ 0, & \text{otherwise} \end{cases}$$

and

$$X_{stkB} = \begin{cases} 1, & \text{if part t in product s during budget period k is bought} \\ 0, & \text{otherwise} \end{cases}$$

In Equation (30) part j and part t are identical. The equation allows for the part used in two products to be either made or bought but not both. Thus the possibility of making the same part for one product and buying for a second product is eliminated.

When this analysis is extended to a part used in three different products it is required that the identical part is either made or bought. In addition to Equation (28) the following two equations are required:

$$X_{ijkM} + X_{s_1t_1kB} = 1 \tag{31}$$

and

$$X_{s_1t_1M} + X_{s_2t_2kB} = 1 \tag{32}$$

where

$$X_{ijkM} = \begin{cases} 1, & \text{if part j in product i is made during budget period k} \\ 0, & \text{otherwise} \end{cases}$$

$$X_{s_1t_1kB} = \begin{cases} 1, & \text{if part } t_1 \text{ in product } s_1 \text{ is bought during budget period k} \\ 0, & \text{otherwise} \end{cases}$$

$$X_{s_1 t_1 kM} = \begin{cases} 1, \text{ if part } t_1 \text{ in product } s_1 \text{ is made during budget} \\ \quad \text{period } k \\ 0, \text{ otherwise} \end{cases}$$

$$X_{s_2 t_2 kB} = \begin{cases} 1, \text{ if part } t_2 \text{ in product } s_2 \text{ is bought during budget} \\ \quad \text{period } k \\ 0, \text{ otherwise} \end{cases}$$

Parts j, t_1, and t_2 are identical but used in different products i, s_1, and s_2. The result of Equations (28), (31), and (32) is a forced decision for either making or buying, but not both. This allows for labor, capital equipment, facilities, and materials resources to be distributed to each product.

The analysis of one part being used in more than three products is expressed in general terms as follows. One product is used in q products (where $q \leq n$). The constraints required are expressed below.

$$X_{ijkM} + X_{s_1 t_1 kB} = 1 \tag{33}$$

$$X_{ijkM} + X_{s_2 t_2 kB} = 1$$

$$\vdots$$

$$X_{ijkM} + X_{s_q t_q kB} = 1 \tag{34}$$

where parts j, t_1, t_2 ... t_q are identical but used in different products i, s_1, s_2 ... s_q. The result of Equations (33) and (34) is a forced decision for either making or buying a part. Thus the part used in q different products during budget period k can be either all made or all bought. The possibility of making the part for a fraction of the q products and that of buying the remaining parts is eliminated. This same analysis is used when different budget periods are considered.

2.4 Sample Problem

To illustrate the mathematical formulation of the make-buy problem developed in Section 2.3, the following sample problem is presented. The data was obtained from an industrial firm. Because of the low profit, if any, for the operations of the manufacturing plant, the objective function for maximizing priority index values is utilized. It should be noted that the data provided below (and in subsequent problems presented in Chapter 3) is adjusted to prevent any disclosure of information or trade secrets. The author of this report accepts complete responsibility for results which are not necessarily indicative of final decisions of the industrial firm.

This problem, referred to herein as Problem 1, is a single product, multiple parts, and a single budget period problem. The single product consist of five parts. For each of the five parts a priority value is assigned for making and for buying. In this problem (and those discussed in Chapter 3) the priority values are integers with a possible range of 1 to 10. Since an initial assumption was that as many parts as possible should be made through internal manufacturing, higher priority values are assigned (as coefficients) to the variables representing the make decision. Correspondingly lower priority values (or the value 1, as assigned in Problem 1) are assigned to the buy variable. Data for Problem 1 designating the priority values for making the five parts is a value of 8 for part 1, a value of 7 for part 2, for part 3 a value of 3, a value of

4 for part 4 and for part 5 a value of 8. The priority values, assigned for the buying decision of each part, are 1 for all five parts. A low priority value assigned to buy coefficients is necessary because of the "make as many as possible" assumption. In addition, data is given for administrative hours of work (Stage 1), research and Development (Stage 2) and Capital Equipment (Stage 3). Data for Stages 4 and 5 of part flow is not included in this problem.

TABLE 1 - DATA PROBLEM 1

	Part 1		Part 2		Part 3		Part 4		Part 5		Limit
	M	B	M	B	M	B	M	B	M	B	
Administrative Hours	1.0	0.05	0.5	0.1	0.3	0.05	1.8	0.01	0.3	0.1	2.8
Research and Development	1900.	-	1500.	-	700.	-	1200.	-	600.	-	4800.
Capital Equipment	1000.	-	25000.	-	15000.	-	5000.	-	2000.	-	40000.

For this problem, Equation (9) is utilized to establish the objective function with coefficients C_{ijkM} (or C_{ijkB}) as priority values assigned to each part. It is required that the priority values of parts in the products be maximized as in the following equation.

Maximize

$$Z = \sum_{j=1}^{5} C_{1j1M}X_{1j1kM} + \sum_{j=1}^{5} C_{1j1B}X_{1j1B} \tag{35}$$

In addition, Equations (10), (11), and (12) are utilized for the administrative hours, capital equipment, and research and development respectively. The administrative hours represent time required by administrative personnel for each part for either the make or buy decision. A limit of 2.8 hours is established as the total administrative hours available during budget period 1. For the constraint concerning capital equipment, the internal production of each part requires a specified dollar amount to satisfy production requirements. Again a limited total dollar amount is available for allocation to capital equipment procurement during the one budget period. Research and development funds are allocated similar to capital equipment dollars. A total amount of research and development funds available is the limiting factor for full allocation to each part.

In addition to formation of constraints from data for administrative hours, research and development, and capital equipment the following type of constraint is required to establish the make-buy decision.

$$X_{1jM} + X_{1jB} = 1 \qquad (36)$$

This constraint is necessary for each of the five parts.

After insertion of priority values in the objective function and the eight constraints, the mathematical formulation is expressed as follows

Maximize

$$Z = 8X_{111M} + X_{111B} + 7X_{121M} + X_{121B} + 3X_{131M} + X_{131B}$$

$$+ 4X_{141M} + X_{141B} + 8X_{151M} + X_{151B} \qquad (37)$$

Subject to

$$100X_{111M}+5X_{111B}+50X_{121M}+10X_{121B}+30X_{131M}+5X_{131B}$$

$$+ 180X_{141M}+X_{141B}+30X_{151M}+10X_{151B} \leq 280 \quad (38)$$

$$X_{111M}+ 25X_{121M}+ 15X_{131M}+ 5X_{141M}+ 2X_{151M} \leq 40 \quad (39)$$

$$19X_{111M}+ 15X_{121M}+ 7X_{131M}+ 12X_{141M}+ 6X_{151M} \leq 48 \quad (40)$$

$$X_{111M}+X_{111B} =1 \quad (41)$$

$$X_{121M}+X_{121B} =1 \quad (42)$$

$$X_{131M}+X_{131B} =1 \quad (43)$$

$$X_{141M}+X_{141B} =1 \quad (44)$$

$$X_{151M}+X_{151B} =1 \quad (45)$$

Thus in this problem, 5 parts having 10 variables, 1 budget period, and 1 product are considered. Three main constraints for administrative hours, research and development, and capital equipment are included. In addition five constraints required for making the make-buy decision are included.

For the solution of this problem a zero-one algorithm developed by Hammer and Rudeanu [34] and coded by Char [14] is used. A maximum value of 25 was obtained for the objective function. Thus the maximum priority value that could be obtained for the 5 parts was 25. For the variable X_{ijkM} (or X_{ijkB}), the following solution was obtained. Parts 1, 2, and 5 in the one product considered are to be made internally during budget period 1. Correspondingly parts 3 and 4 are to be bought externally during the same budget period. That is, the solution to the 10 variables is as follows

$$X_{111M} = X_{121M} = X_{131B} = X_{141B} = X_{151M} = 1$$

and

$$X_{111B} = X_{121B} = X_{131M} = X_{141M} = X_{151B} = 0.$$

When sensitivity analysis is applied manually (due to the lack of an algorithm or computer program for sensitivity analysis of a zero-one formulation) the following can be stated about the formulation of and solution to Problem 1. For Equation (38), the constraint on administrative hours, the results are obtained such that only 186 hours out of 280 hours available are allocated to the five parts. This shows that 94 hours are still available for use. The constraint on research and development, as expressed in Equation (40), illustrates that 40 out of 48 total available are allocated to the three parts that are selected to be made internally. Allocation of dollars to capital equipment requirements is 28, below the maximum limit of 40. As a result a reserve of 94 administrative hours, 8 on research and development, and on capital equipment is available. Thus if the right hand side for the administrative hours, process development, and capital equipment constraints were respectively decreased to 186 hours, 4, and 28. The solution as stated above would not be affected. If the right hand side of equations (38), (39) and (40) were increased to 390, 48 and 59, respectively, all parts would be made.

The question then arises, "Why weren't these resources fully allocated?" The reason is that the optimal decision, based on the priority value assigned to each part, is obtained where parts 3 and 4 should be bought externally. Why? In Equation (38), the coefficient, D_{11141M} of 180 hours on variable X_{141M}, prevents a make decision, otherwise the limit of 280 hours would be exceeded. In Equation (40) the coefficient 12 on variable X_{141M} prevents a make decision for part 4, also, because the limit of 48 would be exceeded which is not allowed if a feasible solution to the problem is desired. Thus, if *in addition to* the three previous make decisions, part 4 is also to be made it is necessary to:

1. Reduce the coefficient, $D_{11141M} = 180$ hours, in Equation (38) to less than 94 hours or to increase the total administrative hours available to greater than 366 hours,

and

2. Reduce the coefficient, $E_{21141M} = 12$, in Equation (40) to less than or equal to 8 or to increase B_{211} to be greater than 52.

If instead, Part 3 is to be made in addition to the original make decisions for Parts 1, 2, and 5, Equation (39) needs to be readjusted. That is, the coefficient, F_{31131M} which is 15, needs to be decreased to less than or equal to 12. Otherwise the limit of 40 on capital equipment is exceeded. If the coefficient is to remain at 15 then the other coefficients F_{311j1M} in Equation (39) need to be reduced be 3 or the right hand side needs to be increased to 52.

Time required for computation of the problem discussed above was 1.28 seconds as calculated in the program coded by Char [14].

TABLE 2 - TABULATED FORMULATION OF PROBLEM 1

Variables		1										Right
X_{ijkM}	K - budget period	1										Hand Side
(X_{ijkB})	i product number	1										P_0
	j part number	1		2		3		4		5		
	M - make B - buy	M	B	M	B	M	B	M	B	M	B	
Objective Function Coefficients		8	1	7	1	3	1	4	1	8	1	
Stage Number	Constraint Number	Constraint Coefficients										
1	1	100	5	50	10	30	5	180	1	30	10	$\leq$ 280
2	1	19	0	15	0	7	0	12	0	6	0	$\leq$ 48
3	1	1	0	25	0	15	0	5	0	2	0	$\leq$ 40
Make-Buy Decision Constraint												
Part 1 - Decision		1	1									= 1
Part 2 - Decision				1	1							= 1
Part 3 - Decision						1	1					= 1
Part 4 - Decision								1	1			= 1
Part 5 - Decision										1	1	= 1

CHAPTER III

VARIOUS RAMIFICATIONS

The mathematical development of the make-or-buy problem presented in Chapter II illustrates the possibility of its ramifications. In this chapter four variations are presented in which each is formulated mathematically and illustrated with sample problems. In addition, the solution for make-or-buy decision making is given. An important aspect of the solution discussed below is the sensitivity analysis. This type of analysis presents additional information to the decision maker. The sample problem presented in Section 2.4 is considered as Problem 1.

The second variation, illustrated by Problem 2, considers multiple products, multiple parts in each product, and a single budget period. In addition, each part is independent. Since it is a single budget period problem, only three stages are considered for the products included. The third variation illustrated by Problem 3 is similar to Problem 2 except for the fact that a part is used in two products. Thus a special constraint is required to take the case of dependency among parts into account. In the case of Problem 4, multiple products, multiple parts in each product and multiple budget periods are considered. The important addition to this problem is consideration of more than one budget period. Also a constraint is established for each of the five stages of product flow. All parts are independent of each other in problem 4. Problem 5 basically represents problem four except that some parts are used in one or more products. That is, the case of dependency is presented.

In all problems sensitivity analysis is utilized to extract information on the limitation of the constraints. Important to this analysis is finding the constraints which are critical and restricting the maximization of priority values. An additional element of interest to management is the effect on the problem if one or more products is eliminated from the formulation.

3.1 Sample Problem 2:

This section is a presentation of one of five variations of the make-buy problem treated in this report. The first variation was discussed in Section 2.4 is Problem 1. The second variation discussed below is for a multiple product, multiple parts in each product, and single budget period problem.

As in problem 1, it is desired that the priority values, assigned to the parts being considered, be maximized. That is, most products which have a high priority for being made internally probably are selected for being made internally. Correspondingly, those products which have a lower priority value have a higher probability of being bought externally. Of course, whether a product is made or bought depends a great deal on the constraints established.

As mentioned previously, the problem discussed in this section is a multiple product, multiple parts, and a single budget period problem. That is, there are 3 products, 2 parts in Product 1 and 3 in Product 2 and 5 in Product 3. All parts are indivisible in nature, that is, they are either made or bought. In addition, no part for Problem 2 is used in two products. Only three stages of the mathematical development are considered because of the single budget period problem. Administrative stage, research and development stage, and capital equipment stage are considered in the constraints. The data for Problem 2 is given in Table 3.

For Problem 2 Equation (9) is utilized to establish the objective function with coefficients C_{ijkM} (or C_{ijkB}) as priority values assigned to each part. It is required that the priority value of parts in the products be maximized as in the following equation.

Maximize

$$Z = \sum_{j=1}^{2} C_{1j1M} X_{1j1M} + \sum_{j=1}^{2} C_{1j1B} X_{1j1B}$$

$$\sum_{j=1}^{3} C_{2j1M} X_{ij1M} + \sum_{j=1}^{3} C_{2j1B} X_{ij1B}$$

$$\sum_{j=1}^{5} C_{3j1M} X_{ij1M} + \sum_{j=1}^{5} C_{3j1B} X_{ij1B} \tag{46}$$

In addition, Equations (10), (11), and (12) are utilized for the data for administration (stage 1), research and development (stage 2), and capital equipment (stage 3). Administration represents time (in hours) required by administrative personnel for each part for either the make or the buy decision. A limit of 1200 hours is established as the total administrative hours available during budget period 1. For the constraint concerning research and development, the internal operations is limited to \$70,000 (note that the formulation below is expressed in thousands of dollars). Also a limited total dollar amount is available for allocation to capital equipment procurement during the budget period. The amount is \$80,000.

After insertion of data in the mathematical formulation, the objective function and thirteen constraints are expressed as follows:

Maximize

$$Z = 6X_{111M} + X_{111B} + 5X_{121M} + X_{121B} + 7X_{211M} + X_{211B}$$
$$+9X_{221M} + X_{221B} + 8X_{231M} + X_{231B} + 8X_{311M} + X_{311B}$$
$$+7X_{321M} + X_{321B} + 4X_{331M} + X_{331B} + 5X_{341M}$$
$$+ X_{341B} + 4X_{351M} + X_{351B} \qquad (47)$$

Subject

$$60X_{111M} + 5X_{111B} + 70X_{121M} + 5X_{121B} + 90X_{211M}$$
$$+ 30X_{211B} + 600X_{221M} + 40X_{221B} + 200X_{231M} + 30X_{231B}$$
$$+300X_{311M} + 30X_{311B} + 100X_{321M} + 10X_{321B} + 20X_{331M}$$
$$+ 5X_{331B} + 30X_{341M} + 5X_{341B} + 10X_{351M}$$
$$+ 5X_{351B} \leq 1200 \qquad (48)$$

$$5X_{111M} + 20X_{121M} + 3X_{211M} + 10X_{221M}$$
$$+ 6X_{231M} + 12X_{311M} + 2X_{321M}$$
$$+ 5X_{331M} + 7X_{341M} + 5X_{351M} \leq 70 \qquad (49)$$

$$+ 2X_{111M} + 4X_{121M} + 10X_{211M} + 30X_{221M}$$
$$+ 25X_{231M} + 10X_{311M} + X_{321M} + 5X_{331M}$$
$$+ 5X_{341M} + X_{351M} \leq 80 \qquad (50)$$

$$X_{111M} + X_{111B} = 1 \tag{51}$$

$$X_{121M} + X_{121B} = 1 \tag{52}$$

$$X_{211M} + X_{211B} = 1 \tag{53}$$

$$X_{221M} + X_{221B} = 1 \tag{54}$$

$$X_{231M} + X_{231B} = 1 \tag{55}$$

$$X_{311M} + X_{311B} = 1 \tag{56}$$

$$X_{321M} + X_{321B} = 1 \tag{57}$$

$$X_{331M} + X_{331B} = 1 \tag{58}$$

$$X_{341M} + X_{341B} = 1 \tag{59}$$

$$X_{351M} + X_{351B} = 1 \tag{60}$$

Thus in this problem, 3 products, a total of 10 parts having 20 variables, and one budget period are considered. Three main constraints for administration, research and development, and capital equipment are included. In addition ten constraints required for making the make-buy decision are included.

The solution to this mathematical formulation was obtained as follows. A maximum value of 55 was obtained for the objective function. Thus the maximum total priority value that could be obtained for the 10 parts of the 3 products was 55. Three iterations were required before the optimal solution was obtained.

In order for the priority values to be maximized management should make decisions on each of the products as follows. Both, parts 1 and 2 in product 1 should be made. In product 2 only part 2 should be bought and parts 1 and 3 should be made internally.

All parts in product 3 should be made. The solution can also be expressed as follows.

Product 1: $X_{111M} = X_{121M} = 1$

and

$X_{111B} = X_{121B} = 0$

Product 2:

$$X_{211M} = X_{221B} = X_{231M} = 1$$

and

$$X_{211B} = X_{221M} = X_{231B} = 0$$

Product 3:

$$X_{311M} = X_{321M} = X_{331M} = X_{341M} = X_{351M} = 1$$

and

$$X_{311B} = X_{321B} = X_{331B} = X_{341B} = X_{351B} = 0.$$

Since part 2 in product is the only part bought sensitivity analysis could be important to decision making. If Equations (48), (49) and (50) are examined, it is noted that when the limit on administrative hours, process development and capital equipment constraints are changed to 1520, 75, and 93 respectively then all parts would be made. If reductions in the right hand side is enforced then the possibility of more parts being bought is established. Also if the coefficients D_{11221M}(= 600), E_{21221M}(= 10), and F_{31221M}(= 30) in Equation (48) are reduced respectively

TABLE 3 TABULATED FORMULATION OF PROBLEM 2

Variables	k-budget period	1																				Right
X_{ijkM}	i product number	1				2						3										Hand
(X_{ijkB})	j part number	1		2		1		2		3		1		2		3		4		5		Side P_o
	M-make B-buy	M	B	M	B	M	B	M	B	M	B	M	B	M	B	M	B	M	B	M	B	
Objective Function Coefficients		6	1	5	1	7	1	9	1	8	1	8	1	7	1	4	1	5	1	4	1	
Stage Number	Constraint Number	Constraint Coefficients																				
1	1	60	5	70	5	90	30	600	40	200	30	300	30	100	10	20	5	30	5	10	5	$\leq$ 1200
2	1	5	0	20	0	3	0	10	0	6	0	12	0	2	0	5	0	7	0	5	0	$\leq$ 70
3	1	2	0	4	0	10	0	30	0	25	0	10	0	1	0	5	0	5	0	1	0	$\leq$ 80
Make-Buy Constraints																						
Product 1																						
Part 1		1	1																			= 1
Part 2				1	1																	= 1
Product 2																						
Part 1						1	1															= 1
Part 2								1	1													= 1
Part 3										1	1											= 1
Product 3																						
Part 1												1	1									= 1
Part 2														1	1							= 1
Part 3																1	1					= 1
Part 4																		1	1			= 1
Part 5																				1	1	= 1

to 280, 5, and 17, then all products would be made because of forced decision making. Additional information is that with the solution obtained, all parts in product 1, 2 and 3 are made internally.

If the limit, B_{211}, for Equation (49) is reduced from 70 to 58, then parts 1 and 2 in product 1, parts 1, 2, and 3 in product 2 and part 2, 4, and 5 in product 3 are made internally and parts 1 and 3 in product 3 should be bought at an external source.

However, the priority value is only maximized to a value of 53. For this case, the right hand limit of B_{111} and B_{311} in Equations (48) and (50) can be reduced only to 1160 and 78 before additional changes in the solution would occur.

Computation time for Problem 2 was 6.93 seconds. There were 20 variables and 13 constraints.

3.2 Sample Problem 3:

In problem 2, all parts are considered independent. Problem 3 presented below is the same as Problem 2 except that part 2 in product 2 is identical to part 3 in product 3. Also part 1 in product 2 is the same as part 5 in product 3. Thus, the assumption of independent parts is dropped. As a result of this, the mathematical formulation for problem three uses Equation (47) as the objective function and Equations (48) through (60) for the constraints. Also, two additional constraints are required for the formulation because of the parts which are used in different products. The constraints are stated as follows:

$$X_{211M} + X_{351B} = 1 \tag{61}$$

and

$$X_{221M} + X_{331B} = 1 \tag{62}$$

Equations (61) and (62) forces a make-buy solution for a part made in two products.

The constraints included consist of one on administration stage, research and development stage, and capital equipment stage. In addition, ten constraints consisting of the basic make-buy decisions for each part are included, besides Equations (61) and (62).

The solution obtained for problem 3 as a multiple product, multiple parts, single budget period is as follows.

Parts 1 and 2 in product 1 are to be made internal. In product 2 parts 1, 2, and 3 are to be made. Parts 2, 3, and 5 in product 3 are to be made internally. Parts 1 and 4 in product 3 should be bought.

Expressed in terms of variable the solution is as follows.

Product 1

$$X_{111M} = X_{121M} = 1$$

$$X_{111B} = X_{121B} = 0$$

Product

$$X_{211M} = X_{221B} = X_{231M} = 1$$

$$X_{211B} = X_{221B} = X_{231B} = 0$$

and

TABLE 4 TABULATED FORMULATION OF PROBLEM 3

Variables	k-budget period	1																				Right Hand Side P_o
X_{ijkM}	i product number	1				2						3										
(X_{ijkB})	j part number	1		2		1		2		3		1		2		3		4		5		
	M-make B-buy	M	B	M	B	M	B	M	B	M	B	M	B	M	B	M	B	M	B	M	B	
Objective Function Coefficients		6	1	5	1	7	1	9	1	8	1	8	1	7	1	4	1	5	1	4	1	
Stage Number	Constraint Number	Constraint Coefficients																				
1	1	60	5	70	5	90	30	600	40	200	30	300	30	100	10	20	5	30	5	10	5	≤ 1200
2	1	5	0	20	0	3	0	10	0	6	0	12	0	2	0	5	0	7	0	5	0	≤ 70
3	1	2	0	4	0	10	0	30	0	25	0	10	0	1	0	5	0	5	0	1	0	≤ 80
Make-Buy Constraints																						
Product 1																						
Part 1		1	1																			= 1
Part 2				1	1																	= 1
Product 2																						
Part 1						1	1															= 1
Part 2								1	1													= 1
Part 3										1	1											= 1
Product 3																						
Part 1												1	1									= 1
Part 2														1	1							= 1
Part 3																1	1					= 1
Part 4																		1	1			= 1
Part 5																				1	1	= 1
Dependency Constraints																						
Product 2 - Part 1 and Product 3 - Part 5						1															1	= 1
Product 2 - Part 2 and Product 3 - Part 3								1									1					= 1

Product 3

$$X_{311B} = X_{321M} = X_{331M} = X_{341B} = X_{351M} = 1$$

$$X_{311M} = X_{321B} = X_{331B} = X_{341M} = X_{351B} = 0$$

The objective function reaches a maximum priority value of 52, which is 3 smaller than the solution of 55 obtained in problem 1. From the solution it is observed that parts 1 and 2 in product 1, parts 1, 2, and 3 in product 2, and parts 2, 3, and 5 in product 3 are made internally and parts 1 and 4 in product 3 are bought from an external source. For Equations (48), (49) and (50), which are the constraints on administrative hours (stage 1), research and development (stage 2), and capital equipment (stage 3), the respective right hand side coefficients can be reduced to 1185, 56, and 78 before a change in the solution occurs. It might be noted however, that the inclusion of a part which is used in two or more products may or may not effect the final make-buy decision.

Problem 3 consists of 20 variables and 15 constraints. Two of the constraints are specifically required for those parts which are utilized in more than one product. The time required for computation of this problem was 5.54 seconds.

3.3 Sample Problem 4

In the three variations of the mathematical development for make-buy decision making discussed thus far only a single budget period was considered. In this section, however, the case of multiple budget periods is taken into account. The format for the mathematical formulation follows those used previously. That is, the priority values assigned to each part for the make-buy decision is maximized. In addition, data for at least one constraint in each of the five stages established in Section 2.3 is utilized in Problem 4. The data is listed in Table 5.

The problem presented in this section is a multiple product (2), multiple parts (3 in product 2, and 2 in product 1), multiple budget period (2) and independency among parts. All parts are indivisible in nature, that is, they are either made or bought. Problem 4 has no parts which are used in two or more products. As mentioned above, five stages of the mathematical development are considered because of the two budget periods taken into account. The stages and their constraints included in the first budget period are as follows:

Stage 1: Administrative Hours
Stage 2: Research and Development
Stage 3: Capital Equipment

Those included in the second budget period are:

Stage 3: Capital Equipment
Stage 4: Direct Standard Labor Hours
Stage 5: Shipping and Inventory Cost

For problem 4 Equation (9) is used to establish the objective function with coefficients c_{ijkM} (or c_{ijkB}) as priority values assigned to each part. It is required that the priority value of parts in the products be maximized as in the following equation.

Maximize

$$Z = \sum_{j=1}^{2} C_{1j1M} X_{ij1M} + \sum_{j=1}^{2} C_{1j1B} X_{1j1B} + \sum_{j=1}^{3} C_{2j1M} X_{2j1M}$$

$$+ \sum_{j=1}^{3} C_{2j1B} X_{2j1B} \quad \sum_{j=1}^{2} C_{1j2M} X_{1j2M} + \sum_{j=1}^{2} C_{1j2B} X_{1j2B}$$

$$+ \sum_{j=1}^{3} C_{2j2M} X_{2j2M} + \sum_{j=1}^{3} C_{2j2B} X_{2j2B} \qquad (63)$$

In addition, Equations (10), (11), and (12) are utilized for the data for budget period 1 for administrative hours (stage 1), research and development (stage 2), and capital equipment (stage 3). The administrative hours represents time required by administrative personnel for each part for either the make-or-buy decision. A limit of 300 hours is established as the total administrative hours available during budget period 1. For the constraint concerning research and development, the internal operations is limited to $55,000 (note that the formulation below is expressed in thousands of dollars). Also a limited total dollar amount is available for allocation to capital equipment procurement during budget period 1. The amount available is $70,000.

For budget period 2, Equations (12), (17), and (26) are used for the data for capital equipment (stage 3), direct standard labor hours (stage 4), and shipping and inventory cost (stage 5). Capital equipment expenditures during budget period 2 represents a continuation of dollars spent during budget period 1. The amount available is $21,000. Direct standard labor hours available for the parts during budget period 2 is 60,000 hours (expressed in thousands of hours in the mathematical formulation). The cost of inventory and shipping during budget period two is $10,000. This cost is expressed in hundreds of dollars in the formulation. After insertion of data in the mathematical formulation, the objective function and twenty one constraints are as follows.

Maximize

$$\begin{aligned} Z = {} & 8X_{111M} + X_{111B} + 5X_{121M} + X_{121B} + 5X_{211M} + X_{211B} \\ & + 5X_{221M} + X_{221M} + 2X_{231M} + X_{231B} + 8X_{112M} + X_{112B} \\ & + 4X_{122M} + X_{122B} + 4X_{212M} + X_{222B} + 6X_{222M} + X_{222B} \\ & + 5X_{232M} + X_{232B} \end{aligned} \tag{64}$$

Subject to

Budget Period 1

$$120X_{111M} + 10X_{111B} + 20X_{121M} + 5X_{121B} + 50X_{211M}$$

$$+ \quad 5X_{211B} + 100X_{221M} + 5X_{221B}$$

$$+ \quad 40X_{231M} + 5X_{231B} \leq 300 \tag{65}$$

$$25X_{111M} + 20X_{212M} + 9X_{211M} + 20X_{221M}$$

$$+ \quad 8X_{231M} \leq 55 \tag{66}$$

$$5X_{11M} + 40X_{121M} + 10X_{211M} + 8X_{221M}$$

$$+ \quad 25X_{231M} \leq 70 \tag{67}$$

Budget Period 2

$$12X_{112M} + X_{122M} + 5X_{212M} + 5X_{222M}$$

$$+ \quad X_{232M} \leq 21 \tag{68}$$

$$18X_{112M} + 5X_{122M} + 10X_{212M} + 4X_{222M}$$

$$+ \quad 30X_{232M} \leq 60 \tag{69}$$

$$15X_{112M} + 15X_{112B} + 10X_{122M} + 10X_{122B} + 5X_{212M} + 5X_{212B}$$

$$+ \quad 7X_{222M} + 7X_{222B} + 10X_{232M} + 10X_{232B} \leq 100 \tag{70}$$

$$X_{111M} + X_{111B} = 1 \tag{71}$$

$$X_{121M} + X_{121B} = 1 \tag{72}$$

$$X_{211M} + X_{211B} = 1 \tag{73}$$

$$X_{221M} + X_{221B} = 1 \tag{74}$$

$$X_{231M} + X_{231B} = 1 \tag{75}$$

$$X_{112M} + X_{112B} = 1 \tag{76}$$

$$X_{122M} + X_{122B} = 1 \tag{77}$$

$$X_{212M} + X_{212B} = 1 \tag{78}$$

$$X_{222M} + X_{222B} = 1 \tag{79}$$

$$X_{232M} + X_{232B} = 1 \tag{80}$$

$$X_{111M} + X_{112B} = 1 \tag{81}$$

$$X_{121M} + X_{122B} = 1 \tag{82}$$

$$X_{211M} + X_{212B} = 1 \tag{83}$$

$$X_{221M} + X_{222B} = 1 \tag{84}$$

$$X_{231M} + X_{231B} = 1 \tag{85}$$

Thus in this problem, 2 products, a total of 5 parts in the two products (20 variables), and two budget periods are considered. Three main constraints for administrative hours, research and development, and capital equipment are included for budget period 1. In addition, constraints for capital equipment, direct standard labor hours, and shipping and inventory cost are included in budget period 2. Ten constraints required for the make-or-buy decision are included, five for each budget period. In order to assure that a part is either made or bought in both budget periods five constraints connecting the two budget periods are included.

To obtain the solution for the mathematical formulation the computer program written by Char was used. A maximum value of 38 was obtained for the objective function. The maximum total priority value that is obtained for the 5 parts of the 2 products over a two budget period is 38.

The following decisions of make or buy were obtained for Problem 4. Part 1 in product 1 should be made internally in budget period 1 and 2.

Part 2 in product 1 should be bought from an external source in budget period 1 and 2. In product 2 parts 2 and 3 should be made internally during budget period 1 and 2. In addition, part 1 in product 2 should be bought in budget period 1 and 2.

Expressed in terms of the variables, X_{ijkM} (or X_{ijkB}), the following solution was obtained.

Budget Period 1:

Product 1:

$$X_{111M} = X_{121B} = 1$$

$$X_{111B} = X_{121M} = 0$$

Product 2:

$$X_{211B} = X_{221M} = X_{231M} = 1$$

$$X_{211M} = X_{221B} = X_{231B} = 0$$

Budget Period 2:

Product 1:

$$X_{112M} = X_{122B} = 1$$

$$X_{112B} = X_{122M} = 0$$

Product 2:

$$X_{212B} = X_{222M} = X_{232M} = 1$$

$$X_{212M} = X_{222B} = X_{232B} = 1$$

For the constraint on administrative hours in budget period 1, 270 hours out of 300 available are allocated to the parts. The research and development constraint utilizes only \$53,000 out of \$55,000 allocated during budget period 1. Only \$38,000 of the \$70,000 allocated for capital equipment was distributed to the five products. During the second budget period \$18,000 out of \$21,000 available is allocated. In addition, 520 hours out of 600 direct standard labor hours available are allocated. As a result of the limitations utilized in the various constraints all of the right hand sides could be reduced to those amounts before a change occurs in the solution of the problem. If the right hand side of the research and development, and capital equipment constraints in budget period 1 are increased respectively to 73 and 78 then the solution obtained is to make part 2 in product 1 instead of buying the part from an external source. Also, if the upper limit for administrative hours in budget period 1, and direct standard labor hours in budget period 2 are increased to 320 and 62 respectively then a solution is obtained which makes part 1 in product 3 instead of buying.

TABLE 5 TABULATED FORMULATION OF PROBLEM 4

Variables	k-budget period	1										2										Right Hand Side
X_{ijkM}	i product number	1				2						1				2						
(X_{ijkB})	j part number	1		2		1		2		3		1		2		1		2		3		P_o
	M-make B-buy	M	B	M	B	M	B	M	B	M	B	M	B	M	B	M	B	M	B	M	B	
Objective Function Coefficients		8	1	5	1	5	1	5	1	2	1	8	1	4	1	4	1	6	1	5	1	
Stage Number	Constraint Number	Constraint Coefficients																				
1	1	120	1	20	5	50	5	100	5	40	5	0	0	0	0	0	0	0	0	0	0	≤ 300
2	1	25	10	20	0	9	0	20	0	8	0	0	0	0	0	0	0	0	0	0	0	≤ 55
3	1	5	0	40	0	10	0	8	0	25	0	0	0	0	0	0	0	0	0	0	0	≤ 70
3	1	0	0	0	0	0	0	0	0	0	0	12	0	1	0	5	0	5	0	1	0	≤ 21
4	3	0	0	0	0	0	0	0	0	0	0	18	0	5	0	10	0	4	0	30	0	≤ 60
5	1	0	0	0	0	0	0	0	0	0	0	15	15	10	10	5	5	7	7	10	10	≤ 100
Make-Buy Constraints																						
Product 1	Budget 1																					
Part 1		1	1																			= 1
Part 2				1	1																	= 1
Product 2																						
Part 1						1	1															= 1
Part 2								1	1													= 1
Part 3										1	1											= 1
Product 1	Budget 2																					
Part 1												1	1									= 1
Part 2														1	1							= 1
Product 2																						
Part 1																1	1					= 1
Part 2																		1	1			= 1
Part 3																				1	1	= 1
Budget 1 & 2 Constraints																						
Product 1																						
Part 1		1											1									= 1
Part 2				1											1							= 1
Product 2																						
Part 1						1											1					= 1
Part 2								1											1			= 1
Part 3										1											1	= 1

Computation time for problem 4, as formulated above, was 9.83 seconds. There were 20 variables in the objective function with 21 constraints.

3.4 Sample Problem 5

In problem 4 all parts are considered independent. Problem 5 presented below is the same as problem 4 except that part 1 in product 1 is the same as part 1 in product 2. Thus the assumption of independency between parts is dropped. As a result of this, the mathematical formulation for problem 5 uses Equation (64) as the objective function and Equations (65) thru (85) for the constraints. Also, an additional constraint is required for the formulation if the part used in two different products is taken into account. The constraint required is stated as follows:

$$X_{111M} + X_{211B} = 1 \tag{86}$$

Equation (86) forces a make-or-buy solution for a part made in two products.

The constraints included consist of one on administrative hours (stage 1), research and development (stage 2), and capital equipment (stage 3) for budget period 1. In addition constraints for capital equipment (stage 3), direct standard labor hours (stage 4), and shipping and inventory cost (stage 5) are included. Ten constraints are formulated for forcing the make-or-buy decision for the five products during the two budget periods. For each product a special constraint is included to tie the two budget periods together. Then the constraint given in Equation (86) above is included because part 1 in product 1 is the same as part 1 in product 2.

The solution obtained for problem 5 as a multiple product, multiple parts, multiple budget period and dependent parts problem is as follows.

The objective function reaches a maximum priority value of 38, which is the same as problem 4. The solution for problem 5 is as follows.

In product one part 1 and 2 should be made at the internal source in budget periods 1 and 2. Because of the special constraint (Equation 86), part 1 in product 2 should also be made internally. Parts 2 and 3 in product 2, according to the solution of problem 5, should be bought at an external source.

Expressed in terms of the variables, X_{ijkM} (or X_{ijkB}), the following solution was obtained.

Budget Period 1:

Product 1:

$$X_{111M} = X_{121M} = 1$$

$$X_{111B} = X_{121B} = 0$$

Product 2:

$$X_{211M} = X_{221B} = X_{231B} = 1$$

$$X_{211B} = X_{221M} = X_{231M} = 0$$

Budget Period 2:

Product 1:

$$X_{112M} = X_{122M} = 1$$

$$X_{112B} = X_{122B} = 1$$

TABLE 6 TABULATED FORMULATION OF PROBLEM 5

Variables	k-budget period	1										2										Right Hand Side
X_{ijkM}	i product number	1				2						1				2						
(X_{ijkB})	j part number	1		2		1		2		3		1		2		1		2		3		P_o
	M-make B-buy	M	B	M	B	M	B	M	B	M	B	M	B	M	B	M	B	M	B	M	B	
Objective Function Coefficients		8	1	5	1	5	1	5	1	2	1	8	1	4	1	4	1	6	1	5	1	
Stage Number	Constraint Number	Constraint Coefficients																				
1	1	120	1	20	5	50	5	100	5	40	5	0	0	0	0	0	0	0	0	0	0	≤ 300
2	1	25	10	20	0	9	0	20	0	8	0	0	0	0	0	0	0	0	0	0	0	≤ 55
3	1	5	0	40	0	10	0	8	0	25	0	0	0	0	0	0	0	0	0	0	0	≤ 70
3	1	0	0	0	0	0	0	0	0	0	0	12	0	1	0	5	0	5	0	1	0	≤ 21
4	3	0	0	0	0	0	0	0	0	0	0	18	0	5	0	10	0	4	0	30	0	≤ 60
5	1	0	0	0	0	0	0	0	0	0	0	15	15	10	10	5	5	7	7	10	10	≤ 100
Make-Buy Constraints																						
Product 1	Budget 1																					
Part 1		1	1																			= 1
Part 2				1	1																	= 1
Product 2																						
Part 1						1	1															= 1
Part 2								1	1													= 1
Part 3										1	1											= 1
Product 1	Budget 2																					
Part 1												1	1									= 1
Part 2														1	1							= 1
Product 2																						
Part 1																1	1					= 1
Part 2																		1	1			= 1
Part 3																				1	1	= 1
Budget 1 & 2 Constraints																						
Product 1																						
Part 1		1											1									= 1
Part 2				1											1							= 1
Product 2																						
Part 1						1											1					= 1
Part 2								1											1			= 1
Part 3										1											1	= 1
Part 1 - Product 1 and Part 1 - Product 2		1											1									= 1

Product 2:

$$X_{211M} = X_{221B} = X_{231B} = 1$$

$$X_{211B} = X_{221M} = X_{231M} = 0$$

If Equations (65) through (70) lower their right hand side respectively to 190, 54, 55, 18, 33, and 47 the final solution would not change. If the right hand side for research and development (stage 2) in budget period 1 and capital equipment in budget period 2 are increased to 74 and 23 respectively the solution for part 1 in product 2 would change from a buy decision to a make decision. When the right hand side for research and development (stage 2) and capital equipment in budget period 1, and direct standard labor hours in budget period 1 are increased to 62, 80, and 63 respectively then part 2 in product 2 changes the original buy decision to a make decision.

Problem five is constructed with 20 variables in the objective function (2 variables for each budget period for the 5 parts), and 22 constraints. One constraint is specifically required for the part used in two products. Computation time required for obtaining the optimal feasible solution was 6.40 seconds.

CHAPTER IV

SUMMARY AND CONCLUSIONS

With the advent of technological changes, the scope of problems encountered in industrial firms has broadened and correspondingly presented management with more decisions of a higher degree of complexity to be made. In this paper a specific type of decision is investigated. The decision is made in a system representing the manufacturing of products specifically for government utilization. As a result, a tight money situation exist, that is, profits tend to be low or non-existed and the allocation of resources become a critical item in the decision making process of management. For the capital budgeting problem it is the usual case that products are made only within the system. Sometimes, however, it is more feasible and profitable if a product is bought from an external source. Thus, the make-buy decision making process is formed for each part in the products being considered. A result of the decision making process is that the optimal part-mix of making internally or buying externally is obtained based on the resource constraints and a priority value assigned to make decision and to the buy decision.

A number of approaches have been attempted for the case of considering only products manufactured internally. Dean's approach [22] of investment selection was based on the rate of return potential for each investment and the budgeting of capital. A capital budgeting approach of maximizing the present value of all investments considered was proposed by Lorie and Savage [47]. Weingartner [71] eliminated some deficiencies in the previous approach by proposing linear programming and zero-one integer programming as a method of obtaining a solution. Culliton [20] and Gross [31] were concerned primarily with the make-buy decision and the establishment of principles concerning resource requirements instead of strictly capital budgeting. A proposal by Burton and Holzer [12] was made utilizing linear programming for making the make-buy decision. However, capital budgeting was not considered in the formulation. For the mathematical formulation proposed in this report an algorithm developed by Hammer and Rudeanu [33] and coded by Char [14] is utilized.

The development of a make-buy model is discussed in Chapter II. The nature of the make-buy problem is presented in relation to a manufacturing firm. Factors which have some influence on the make-buy decision are analyzed utilizing the capital budgeting problem as a base for the mathematical formulation. Next, the mathematical formulation is developed in the form of zero-one integer programming. Three variations of the objective function are presented. The objective function for maximizing priority values is discussed because of special application to the firm manufacturing products for government utilization. The priority value objective function is used in all problems discussed. The resource constraints are established for five stages of product flow. The five stages are: (1) initial concept or idea, (2) research and development (3) initial production (4) full production, and (5) storage or shipping. An important addition to the constraints is the forced constraint for forcing either a make or buy decision. A sample problem is presented as Problem 1 for illustration of the mathematical development. Problem 1 takes into account one product, multiple parts in the product and a single budget period. Through the use of Char's [14] computer program the make internally or buy externally decision is made. Only stages 1, 2, and 3 are considered. In addition, in the mathematical formulation 10 variables (5 for make and 5 for buy) and 8 constraints are included. Five of the constraints are forced make-buy constraints. All parts are assumed to be independent.

In chapter three four additional variations for the make-buy problem are discussed. To each of the problems, sensitivity analysis is applied manually. This type of analysis presents additional information to the decision maker for purposes of reallocating resources, of reversal of the make buy decision, and inspection of what resources are utilized internally or externally. Problem 2 considers multiple products, multiple parts (2 in product 1, 3 in product 2, and 5 in product 3), and a single budget period. All products are independent and only three stages of product flow are considered. There are 20 variables (10 make and 10 buy) and thirteen constraints of which ten constraints are forced make-buy constraints. Problem 3 is formulated the same as problem 2 except that the parts are not independent. That is, some parts are used in two or more different products. An additional constraint is required for a part which is used in two or more products in order to guarantee that the part is made only or bought only. Problem 4 considers multiple budget period, multiple product, and multiple parts (3 in product 2 and 2 in product 1) and independency among products. In this problem, all stages of the product (and part) flow are utilized in the model. The model has 20 variables and 21 constraints (6 resource constraints, 10 forced make buy constraints, and 5 budget period connecting constraints). Problem 5 is basically the same as Problem 4 except that a part is used in two different products. Problem 5 is developed with 20 variables and 22 constraints. As a result, a make-buy constraint is required which insures that the part made for two different products is either made or bought.

The results obtained from the solutions of the five problems are similar to the decision made at the manufacturing firm described previously. However, because of company security protection and the desire to keep the final make-buy decision internal, a direct comparison of the results obtained in this problem and those at the manufacturing firm are not presented. The zero-one formulation employed in the report for obtaining the make-buy decision presents an excellent approach for evaluating qualitative and quantitative factors at the same time. Even though the model is developed for five stages of product flow because of the particular industry used, it can be quite flexible for use in other industries for obtaining the make-buy decision.

The model, as developed, proposes to add the additional feature of investing into the making or buying of a part instead of whether to make or not make an investment. The model can be flexible enough to allow for the decision to be make, buy, or eliminate entirely a part from possible investments. Also instead of utilizing the maximization of a concrete value such as present value or rate of return in the objective function, it is suggested instead, because of the nature of make-buy decision making, to establish an abstract value, such as priority value assignment, for maximization of the objective function. The combination of qualitative and quantitative factors in the same model establishes a flexible means of decision making.

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APPLICATION OF ZERO-ONE PROGRAMMING

TO THE MAKE-OR-BUY DECISION

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ABSTRACT

With the advent of technological changes, the scope of problems encountered in industrial firms has broadened and correspondingly presented management with more decisions. A make-buy decision, which is one of these management decisions is investigated.

A manufacturing industry with five stages of product flow is formulated as a zero-one programming problem. These five stages are: (1) concepts or idea, (2) research and development (3) initial production (4) full production, and (5) storage or shipping, a zero-one programming algorithm is utilized to obtain the results. Five ramifications of the model are presented. The combination of qualitative and quantitative factors in the same model establishes a flexible means of decision making.

The coefficients in the objective function are priority values assigned to influence the make or buy decision. The constraints consist of resource constraints and forced make-buy constraints. Problem 1 takes into account one product, multiple parts in the product a single budget period and independency among products. Problem 2 considers multiple parts, multiple products, or single budget period and independency among products. Problem 3 considers multiple parts, multiple products, single budget period and dependency among products. Problem 4 includes multiple parts, multiple products, multiple budget period and independency among products. Problem 5 considers multiple parts, multiple products, multiple budget period and dependency among products.

After the results were obtained for the five problems sensitivity analysis was applied to observe what resources allocations changed when the priority value or right hand side limitations on constraints.