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# PRODUCTION PLANNING FOR A WINERY WITH MIXED INTEGER PROGRAMMING MODEL

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## ABSTRACT

This paper presents a Mixed Integer Programming (MIP) model to wine production planning. In a MIP problem, some of the decision variables are constrained to have only integer values at the optimal solution. The use of integer variables greatly expands the scope of useful optimization problems. The purpose of this paper is to propose a concise formulation of the production planning problem oriented at the food industry and in particular to wine production. The main idea is the selection of new products to be produced and the determination of the quantity of them in order to maximize profit of a winery. This is a fixed-charge problem and in this paper branch and bound method is used to solve the problem. The results obtained from a MIP model indicate that the selection of new products can favorably produce optimal schedules.

Key Words: Wine production planning, Mixed Integer Programming (MIP), Fixed-Charge problem, Branch and Bound method

## 1. INTRODUCTION

The development of optimization models for planning and scheduling is one of the most useful tools for improving productivity of a large number of firms (Bellabdaoui and Teghem, 2006: 260). Production planning in manufacturing industry is concerned with the determination of the production quantity of some items over a time horizon, in order to satisfy the demand with minimum cost, subject to some production constraints. In general, production planning problems become harder when different types of constraints are present, such as capacity constraints, minimum lot sizes, changeover times (Constantino, 2000: 75).

The increasing variety of products offered by the food industry has helped the industry to respond to market trends, but at the same time has resulted in a more complex production process, calling for greater flexibility and more efficient coordination of existing resources. A critical function for the efficient management of production in a food manufacturing company is production planning (Doganis and Sarimveis, 2007: 445). This paper addresses a production planning problem faced by a winery which has to decide new products to produce. The problem involves the selection of new products to produce or not and if it is produced how many products has to be produced in order to maximize profit. This is a fixed-charge problem and it is formulated as a MIP model. The objective function seeks to maximize the total profit. Constraints on the system include the time of these new products' production processes and available capacities for them. When the model is solved, it produces: (1) the decision whether to produce or not these new products. (2) the quantity of each product that is decided to be produced (3) the total profit of a firm. The data is analyzed by using WinQSB package programme. Branch and bound method is used to solve the problem. Numerical results are presented to demonstrate the feasibility of the real world production planning model (Bilgen and Ozkarahan, 2007: 555).

The rest of the paper is organized as follows: Section 2 introduces the integer and MIP problem. In section 3, production planning model of a winery in Denizli/Turkey is developed. Finally, section 4 concludes the paper with a summary.

## 2. MIXED INTEGER PROGRAMMING MODEL FORMULATION

Decision making process is getting harder in today's complex enviroment (Ertuğrul and Güneş, 2007: 647). Reducing complex real-world systems into precise mathematical models is the main trend in science and engineering. Operations Research (OR) is a method that is applied to real-world decision making problems. Decision making problem is the process of finding the best option from all of the alternatives (Ertuğrul and Karakaşoğlu, 2007: 151). Emprical surveys reveal that Linear Programming (LP) is one of the most frequently applied OR techniques in real-world problems (Ertuğrul and Tuş, 2007: 31). However, one key limitation that prevents many more applications is the assumption of divisibility which requires that noninteger values be permissible for decision variables. In many practical problems, the decision variables actually make sense only if they have integer values. For example, it is often necessary to assign people, machines and vehicles to activities in integer quantities. If requiring integer values is the only way in which a problem deviates from a LP formulation, then it is an Integer Programming (IP) problem (Hillier and Lieberman, 1990).
Mathematical programming techniques have been widely used in the scientific literature to address the problem of production planning (Arcuri et al., 2007: 1430). In the literature, there have been a few published studies on IP (see the papers of Ashford and Daniel, 1999; Eiselt and Sandblom, 2000; Garfinkel and

Nemhauser, 1972; Hillier and Lieberman, 1990; Nemhauser and Wolsey, 1999; Smith and Pickard, 1993; Taha, 1997; Winston, 1994). The potential power of an ability to solve mixed integer linear problems have been known since the mid 1950's (Forrest and Tomlin, 2007; 81). IP is rapidly gaining acceptance as a powerful computational tool that can provide optimal or near optimal solutions to real-life strategic and operational planning problems (Atamtürk and Savelsbergh, 2005: 69). A complete survey in MIP and techniques for several application problems are presented by Wolsey (1998) and Williams (1999) (Magata˜o et al., 2004: 171).

There have been numerous applications of IP that involve a direct extension of LP where the divisibility assumption must be dropped. However, another area of application may be of even greater importance, namely, problems involving a number of interrelated "yes-or-no decisions". In such decisions, the only two possible choices are yes or no. With just two choices, we can represent such decisions by decision variables that are restricted to just two values, say zero or one. Thus the jth yes-or-no decision would be represented by $x_j$, such that

$$x_j = \begin{cases} 1, & \text{if decision } j \text{ is yes} \\ 0, & \text{if decision } j \text{ is no.} \end{cases}$$

Such variables are called binary variables. Consequently, IP problems that contain only binary variables sometimes are called Binary Integer Programming (BIP) problems (0-1 IP problems) (Hillier and Lieberman, 1990).

## 2.1. The Fixed-Charge Problem

The fixed-charge problem was initialized by Hirsch and Dantzig in 1968 (Hirsch and Dantzig, 1968). In a fixed-charge problem, there is a cost associated with performing an activity at a nonzero level which does not depend on the level of the activity (Winston, 1994: 472). Examples of fixed charges are the cost of building a new plant, buying a new machine, repairing or refitting a machine that is out of service and setup such as cleanup, cost of an operation. The fixed charge may also express a measure other than cost, such as the setup time of getting a machine into service or the fixed elapsed time before a certain operation can commence (Eiselt and Sandblom, 2000: 113). Up to now, it has been widely applied in many decision-making and optimization problems (Yang and Liu, 2007: 879). In this paper, we shall consider the MIP model for wine production planning problem.

It is quite common to incur a fixed charge or setup cost when undertaking an activity. For example, such a charge occurs when a production run to produce a small batch of a particular product is undertaken and the required production facilities must be set up to initiate the run. In such cases the total cost of the activity and the setup cost required to initiate the activity. Frequently, the variable cost will be at least roughly proportional to the level of the activity. If it is, the total cost of the activity j can be represented by a function of the form,

$$f_j(x_j) = \begin{cases} k_j + c_j x_j, & \text{if } x_j > 0 \\ 0, & \text{if } x_j = 0 \end{cases}$$

where $x_j$ denotes the level of activity j ($x_j \geq 0$), $k_j$ denotes the setup cost, $c_j$ denotes the cost for each incremental unit. Were it not for the setup cost $k_j$, this cost structure would suggest the possibility of a LP formulation to determine the optimal levels of the competing activities. Fortunately, even with the $k_j$, MIP can still be used.

To formulate the overall model, suppose that there are n activities, each with the preceding cost structure (with $k_j \geq 0$ in every case and $k_j > 0$ for some j = 1, 2, ..., n), and that problem is to

Minimize $Z = f_1(x_1) + f_2(x_2) + \ldots + f_n(x_n)$,

subject to given LP constraints.

To convert this problem into a MIP format, we begin by posing n questions that must be answered yes or no; namely, for each j = 1, 2, ..., n, should activity j be undertaken ($x_j > 0$)? Each of these yes-or-no decisions is then represented by an auxiliary binary variable $y_j$, so that

$$Z = \sum_{j=1}^{n} (c_j x_j + k_j y_j),$$

where

$$yi = \begin{cases} 1, & \text{if } x_j > 0 \\ 0, & \text{if } x_j = 0 \end{cases}$$

Therefore, the $y_j$ can be viewed as contingent decisions. Let M be an extremely large positive number that exceeds the maximum feasible value of any $x_j$ (j = 1, 2, …, n). Then the constraints,

$x_j \leq My_j$ for j = 1, 2, 3, ..., n

will ensure that $y_j = 1$ rather than zero whenever $x_j > 0$. The one difficulty remaining is that these constraints leave $y_j$ free to be either 0 or 1 when $x_j = 0$. Fortunately, this difficulty is automatically resolved because of the nature of the objective function. The case where $k_j = 0$ can be ignored because $y_j$ can then be deleted from the formulation. So we consider the only other case, namely, where $k_j > 0$. When $x_j = 0$, the constraints permit a choice between $y_j = 0$ and $y_j = 1$, $y_j = 0$ must yield a smaller value of Z than $y_j = 1$. Since the objective is to minimize Z, an algorithm yielding an optimal solution would always choose $y_j = 0$ when $x_j = 0$.

## 2.2. Branch and Bound Method

A well-known approach to solve MIP is the application of branch-and-bound type algorithms (Achterberg, 2007: 4). It is a solution procedure which systematically examines all possible combinations of the discrete variables (Mavrotas and Diakoulaki, 2005: 56). It searches for an optimal solution by examining only a small part of the total number of possible solutions. This is especially useful when enumeration becomes economically impractical or impossible because there are a large number of feasible solutions. Branch and bound method works by breaking the area of feasible solutions into sub problems until the optimal solution is reached. It introduces the concept of feasible and infeasible bounds (Render and Stair, 1991).

# 3. AN APPLICATION FOR MODEL FORMULATION OF WINE PRODUCTION PLANNING

The application of optimization techniques as decision-support tools plays an important role in planning problems (Carvalho and Pinto, 2006: 97). In this section, the computational experiment that has been carried out on a real life application is presented. Production manager of the winery in Denizli is making a feasibility study for three new products that are thought to be produced. These products are sparkling wine, bag-in-box and screw corked. When manager decides to produce these products, he should prepare production processes that cause the fixed setup cost. Each product is mainly produced by passing seven processes: filtration, carbonation, rinsing, filling, corking, labeling and packaging. In these processes unit production times that a bottle of product uses and existing production capacity times of the winery can be seen as in Table 1. Also fixed setup costs and unit profit that is foresighted for a bottle of product are showed in Table 1. Manager wants to find which products the winery must produce and the quantity of these products. Hung et al. (2003) called it Production Planning Problems with Setups, which involves the decision for the production quantity of each product in each period. If a particular product is to be manufactured during a certain period, each required machine must be setup once in that period to make production possible. On the other hand, if a certain product is not to be produced, no setups on any machine need to be performed for this product type. A setup means deducting the setup time from the available resource-hours and deducting the setup cost from the objective function in the formulation, which maximizes corporate cash flow (Hung et al., 2003: 616).

Table 1: Related Data of the Winery for the Production Planning Problem

| | Production times (second) | | | |
|---|---|---|---|---|
| Production processes | Product 1 Sparkling Wine | Product 2 Bag-In-Box | Product 3 Screw Corked | Existing capacity times (second) |
| Filtration | 2 | 15 | 2 | 4.680.000 |
| Carbonation | 1 | - | - | 5.760.000 |
| Rinsing | 6 | - | 6 | 6.120.000 |
| Filling | 5 | 38 | 2 | 5.976.000 |
| Corking | 4 | 3 | 5 | 6.120.000 |
| Labeling | 6 | - | 6 | 5.760.000 |
| Packaging | 20 | 10 | 20 | 6.264.000 |
| Unit profit (millionTL) | 1 | 3 | 2 | |
| Setup cost (million TL) | 20.000 | 30.000 | 20.000 | |

Essentially the characteristic of this problem apart from the simple production problem is to be made two decisions. These decisions are the produce-or-not decision of each product and the decision of the production quantity of selected products. Produce-or-not decision must be defined 0-1 integer variables. Production units can also be defined as normal variables or integer variables.

$x_j$ = quantity that is produced from jth product; j = 1, 2, 3

$y_j$ = produce or not jth product. Variable of $y_j$ can only be 0 or 1. It shows that if it is 0, don't produce jth product and if it is 1, produce jth product.

$$y_j = \begin{cases} 1, \text{ if } x_j > 0 \\ 0, \text{ if } x_j = 0 \end{cases} \qquad j = 1, 2, 3$$

By subtracting setup cost from total profit, goal function that maximizes total profit is written as:

$$Z_{max} = 1x_1 + 3x_2 + 2x_3 - 20.000y_1 - 30.000y_2 - 20.000y_3$$

Source usage constraints in model are constraints that provide total existing times not to exceed times that products use in production processes:

$2x_1 + 15x_2 + 2x_3 \leq 4.680.000$ (filtration constraint)

$x_1 \leq 5.760.000$ (carbonation constraint)

$6x_1 + 6x_3 \leq 6.120.000$ (rinsing constraint)

$5x_1 + 38x_2 + 2x_3 \leq 5.976.000$ (filling constraint)

$4x_1 + 3x_2 + 5x_3 \leq 6.120.000$ (corking constraint)

$6x_1 + 6x_3 \leq 5.760.000$ (labeling constraint)

$20x_1 + 10x_2 + 20x_3 \leq 6.264.000$ (packaging constraint)

$x_j \geq 0$, $y_j \geq 0$

$x_j$ is integer, $y_j$ 0-1 is integer

Model is built by using all data as above. But there is a deficiency in the model. In this situation when the goal function is examined carefully, mathematically it is not possible that y variables equal to 1 that have negative effect to goal. However some of x variables that have positive effect will have positive values. When this situation is examined from the perspective of the problem, making a production without giving setup cost is impossible. So when one of x variables is in the solution we must make its y value equal to 1 and we must build a model that considers setup costs. For this reason we must prepare constraints which are related each x variables that corresponds to y variables. These kinds of constraints that show normal variables with 0-1 variables together are called as linkage constraints. So we must add linkage constraints for x,y binary as written below:

$x_1 \leq M_1.y_1$ or $x_1 - M_1.y_1 \leq 0$

$x_2 \leq M_2.y_2$ or $x_2 - M_2.y_2 \leq 0$

$x_3 \leq M_3.y_3$ or $x_3 - M_3.y_3 \leq 0$

Lastly, we must find suitable values for $M_j$. Therefore, we will find theoretically maximum value for each $x_j$ variable and we will take this value as $M_j$. Any $x_j$ variable can reach maximum value if the other $x_j$ variables are equal to 0. While finding possible maximum value of $x_1$ we put 0 instead of $x_2$ and $x_3$ variables in source constraints of the model.

$2x_1 + 15x_2 + 2x_3 \leq 4.680.000$

$x_1 \leq 5.760.000$

$6x_1 + 6x_3 \leq 6.120.000$

$5x_1 + 38x_2 + 2x_3 \leq 5.976.000$

$4x_1 + 3x_2 + 5x_3 \leq 6.120.000$

$6x_1 + 6x_3 \leq 5.760.000$

$20x_1 + 10x_2 + 20x_3 \leq 6.264.000$

$2x_1 = 4.680.000$, $x_1 = 2.340.000$

$x_1 = 5.760.000$, $x_1 = 5.760.000$

$6x_1 = 6.120.000$, $x_1 = 1.020.000$

$5x_1 = 5.976.000$, $x_1 = 1.195.200$

$4x_1 = 6.120.000$, $x_1 = 1.530.000$

$5x_1 = 5.760.000$, $x_1 = 1.152.000$

$20x_1 = 6.264.000$, $x_1 = 313.200$

The maximum value of $x_1$ variable to satisfy seven source constraints is 313.200 which is the minimum of seven $x_1$ values above. So it is adequate to take $M_1$ as 313.200. Exactly $M_2$ and $M_3$ are found as below:

$M_2$ = Min (4.680.000/15, 5.976.000/38, 6.120.000/3, 6.264.000/10) = (312.000, 157.263, 2.040.000, 626.400) = 157263

$M_3$ = Min (4.680.000/2, 6.120.000/6, 5.976.000/2, 6.120.000/5, 5.760.000/6, 6.264.000/20) = (2.340.000, 1.020.000, 2.988.000, 1.224.000, 960.000, 313.200) = 313.200

Before building and solving model by WinQSB package programme, it will be appropriate to explain one additional condition. When production manager decides to produce any products, minimum production size value can be expressed by a constraint. In this application, manager thinks that if the winery produces sparkling wine, it must be produced at least 70.000 bottles. If it produces bag-in-box and screw corked, it must be produced at least 30.000 bottles of bag-in-box and 210.000 bottles of screw corked. So two linkage constraints for each product must be added to the model. These linkage constraints are written as follows:

$$\left.\begin{array}{l} x_1 \leq 313.200\, y_1 \\ x_1 \geq 70.000\, y_1 \end{array}\right\} \text{linkage constraints for sparkling wine}$$

$$\left.\begin{array}{l} x_2 \leq 157.263\, y_2 \\ x_2 \geq 30.000\, y_2 \end{array}\right\} \text{linkage constraints for bag-in-box}$$

$$\left.\begin{array}{l} x_3 \leq 313.200\, y_3 \\ x_3 \geq 210.000\, y_3 \end{array}\right\} \text{linkage constraints for screw corked}$$

The final MIP formulation of this fixed-charge problem can be given as:

$$Z_{max} = 1x_1 + 3x_2 + 2x_3 - 20.000y_1 - 30.000y_2 - 20.000y_3$$

Subject to

$$2x_1 + 15x_2 + 2x_3 \leq 4.680.000$$

$$x_1 \leq 5.760.000$$

$$6x_1 + 6x_3 \leq 6.120.000$$

$$5x_1 + 38x_2 + 2x_3 \leq 5.976.000$$

$$4x_1 + 3x_2 + 5x_3 \leq 6.120.000$$

$$6x_1 + 6x_3 \leq 5.760.000$$

$$20x_1 + 10x_2 + 20x_3 \leq 6.264.000$$

$x_1 \leq 313.200\ y_1$ and $x_1 \geq 70.000\ y_1$

$x_2 \leq 157.263\ y_2$ and $x_2 \geq 30.000\ y_2$

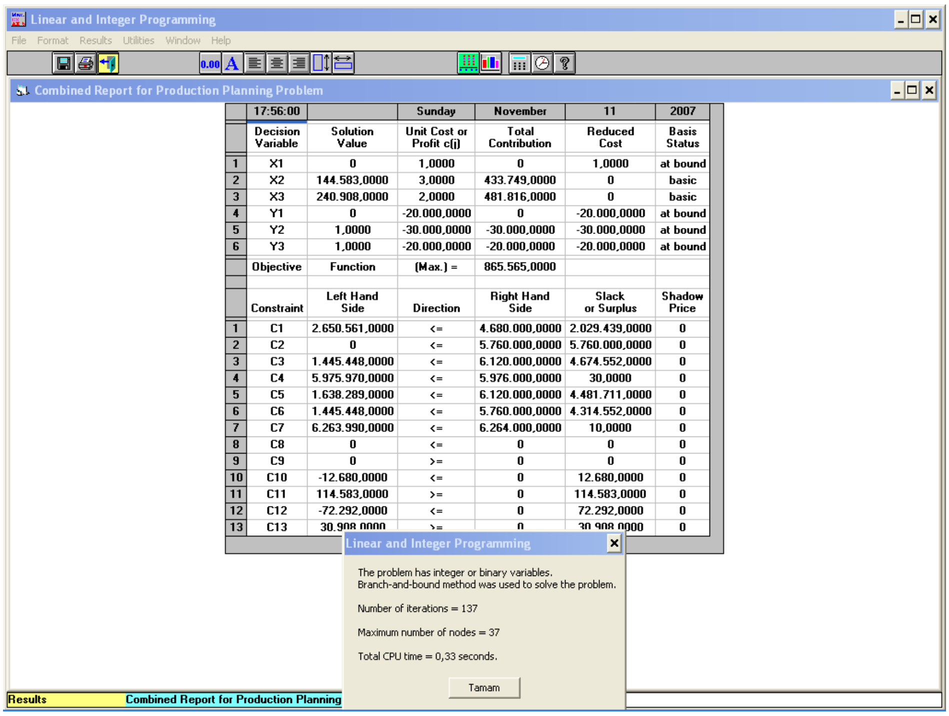
$x_3 \leq 313.200\ y_3$ and $x_3 \geq 210.000\ y_3$

$x_j \geq 0,\ y_j \geq 0$

$x_j$ integer, $y_j$ 0-1 integer

The model has been solved using the software WinQSB through the branch and bound method. A schedule obtained from the optimal solution is given in Figure 1. It is seen that optimal solution value is 865.565 (million TL). To reach this value the winery mustn't produce sparkling wine but it must produce 144.583 bottles of bag-in-box and 240.908 bottles of screw corked.

Figure 1: Solution Values of the Production Planning Problem

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|---|---|---|---|---|---|---|
| | Decision Variable | Solution Value | Unit Cost or Profit c(j) | Total Contribution | Reduced Cost | Basis Status |
| 1 | X1 | 0 | 1,0000 | 0 | 1,0000 | at bound |
| 2 | X2 | 144.583,0000 | 3,0000 | 433.749,0000 | 0 | basic |
| 3 | X3 | 240.908,0000 | 2,0000 | 481.816,0000 | 0 | basic |
| 4 | Y1 | 0 | -20.000,0000 | 0 | -20.000,0000 | at bound |
| 5 | Y2 | 1,0000 | -30.000,0000 | -30.000,0000 | -30.000,0000 | at bound |
| 6 | Y3 | 1,0000 | -20.000,0000 | -20.000,0000 | -20.000,0000 | at bound |
| | Objective | Function | (Max.) = | 865.565,0000 | | |
| | | | | | | |
| | Constraint | Left Hand Side | Direction | Right Hand Side | Slack or Surplus | Shadow Price |
| 1 | C1 | 2.650.561,0000 | <= | 4.680.000,0000 | 2.029.439,0000 | 0 |
| 2 | C2 | 0 | <= | 5.760.000,0000 | 5.760.000,0000 | 0 |
| 3 | C3 | 1.445.448,0000 | <= | 6.120.000,0000 | 4.674.552,0000 | 0 |
| 4 | C4 | 5.975.970,0000 | <= | 5.976.000,0000 | 30,0000 | 0 |
| 5 | C5 | 1.638.289,0000 | <= | 6.120.000,0000 | 4.481.711,0000 | 0 |
| 6 | C6 | 1.445.448,0000 | <= | 5.760.000,0000 | 4.314.552,0000 | 0 |
| 7 | C7 | 6.263.990,0000 | <= | 6.264.000,0000 | 10,0000 | 0 |
| 8 | C8 | 0 | <= | 0 | 0 | 0 |
| 9 | C9 | 0 | >= | 0 | 0 | 0 |
| 10 | C10 | -12.680,0000 | <= | 0 | 12.680,0000 | 0 |
| 11 | C11 | 114.583,0000 | >= | 0 | 114.583,0000 | 0 |
| 12 | C12 | -72.292,0000 | <= | 0 | 72.292,0000 | 0 |
| 13 | C13 | 30.908,0000 | >= | 0 | 30.908,0000 | 0 |

## 4. CONCLUSION

One of the most important elements of today's business understanding is to use resources in the most productive way. Therefore, firms have to use the methods which will provide maximum profit and minimum cost. In this paper, IP model has been explained first and mathematical indications of IP have been introduced. Then, an optimization problem related to the wine industry is introduced, modeled and solved using an enumeration algorithm and MIP. The problem is the production planning of new products. Our approach consists of the fixed-charge problem to find which products must be produced and production quantity of selected products to maximize total profit. So we have formulated and solved mixed integer problem. The problem has integer or binary problem and branch and bound method has been used to solve the problem. The whole procedure has been completed in a reasonable amount of time by WinQSB package programme.

In this paper the production planning model has been tested on a real life project. As a conclusion, it can be said that MIP can be used as an important tool in decision making in the considered industry. This model provides a reasonable point for many industries where production planning problem is considered.

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