Efes Beverage Group Makes Location and Distribution Decisions for Its Malt Plants

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We conducted a study for Efes Beverage Group to evaluate various sites as potential locations for new malt plants. We performed an economic analysis that showed the inferiority of some alternatives. To evaluate the remaining alternatives, we developed a mixed-integer-programming model that considers both the location of new malt plants and the distribution of barley and malt. It considers the long-run effects of the decisions and minimizes the present value of total costs. Sakarya, Izmir, and Ankara turned out to be the best locations for new malt plants. Efes is currently using the model for distribution decisions. Based on our results and new developments that occurred since then, top managers are currently debating where and when to locate the new malt plants.

We conducted a study for a beer company in Turkey, Efes Beverage Group (Efes), to determine the locations of new malt plants. Efes has both domestic and international operations. Its international operations are based mainly on soft drinks and cover a region from the Balkans to Central Asia. Domestic operations consist of three beer breweries, two malt plants, and a hops-processing plant. Efes has about 1,500 employees for its domestic operations and has an annual beer brewing capacity of 7.85 million hectoliters. In 1994, Efes' beer production was about 4.5 million hectoliters, which constituted around one percent of total beer produc-

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tion in Europe. Efes has a market share of about 75 percent of the beer consumption in Turkey and brews four types of beer: nonalcoholic, light, regular, and strong.

Turkey has been living under high inflation for over a decade, as high as 100 percent per year at times. In the early years of this period, companies had difficulty changing the habits they had acquired under low inflation [Kirca and Köksalan 1996; Dogrusöz 1989]. However, many companies adjusted to the conditions after several years, and managers have developed the ability to make sound decisions under high inflation. Efes, for example, is one of those Turkish companies that copes with high inflation successfully by estimating the inflation rate quite accurately, accounting for the inflation explicitly, making frequent price adjustments on its products, and working with low inventory levels as much as possible. In this study, we converted cost estimates to US dollars, assuming that this would take care of the issues related to inflation. This assumption is justified based on the past data on increases in the costs used in this study (transportation and fixed costs).

We previously conducted a project [Köksalan, Süral, and Kirca 1995] to determine the locations of new breweries, and Efes has already implemented some results of that project. In this follow-up project we used some findings and the model from the earlier project. Our clients in this project were Serdar Bölükbasi, a middle-level manager of Efes, and Ayhan Atilir, the manager of a malt plant of Efes. In this project, our clients originally wanted a study to help determine the location of a new malt plant to open in 1998. Some early analysis showed that ignoring the long-term effects of the decisions would yield misleading results by overemphasizing the fixed costs and underemphasizing the transportation costs. Through discussions with our clients, we converged on a model that considers both location and distribution decisions and minimizes the present value of total costs over an infinite horizon.

Facility location problems have been well studied [Aikens 1985; Francis, McGinnis, and White 1983; Hax and Candea 1984; Jacobsen 1990]. Though the problem is usually treated as a single-period problem because of computational difficulties, there are several multiperiod formulations. Klein and Klimpel [1967] suggest maximizing the net present value while Wesolowsky and Truscott [1975] consider minimizing the present value of costs for a multiperiod problem. Schulman [1991] develops heuristics to solve large-scale multiperiod models and reports favorable results in terms of both the quality of solutions and the computational efficiency. Pooley [1994] discusses an application for a food-processing company and evaluates different strategies regarding production and distribution decisions.

In our application, the problem size is fairly small, which allows us to study various aspects of the problem in detail without running into computational difficulties.

Problem Definition

As early as 6000 BC, people were brewing beer made from malted grain in Mesopotamia, the land between the Tigris and Euphrates, rivers that originate in Turkey in southeast Anatolia. Barley, the main in-

gredient of malt, was cultivated around Konya (an agricultural region for grains and the location of one of Efes' two malt plants) in 7000 BC. However, it is not known whether people were brewing beer in the region then. The first ancient civilization known to have brewed beer in Anatolia was the Hittite around 2000 BC. People have brewed and consumed beer in Anatolia ever since. Even during the Ottoman Empire, the restrictions on alcoholic beverages were only sporadic, depending on the attitude of the reigning sultan. Sultan Süleyman the Magnificent (1520–1566) was a strict prohibitionist, for instance. On the other hand, Sultan Ahmed III (1718–1730) permitted alcohol consumption. During the War of Liberation (1920–1923), the new Turkish government imposed a ban on alcohol, but since then there have been no restrictions in modern Turkey, a secular state [Gülerman 1993]. Current surveys indicate that around 48 percent of the adult population consumes alcoholic beverages, and about 42 percent of those who do not drink state that their religious beliefs are the main reason for abstaining.

In 1994, Efes' beer production constituted about one percent of total beer production in Europe.

Though the annual per-capita beer consumption in Turkey, about 10 liters, is not high compared with that of many other European countries (it ranges from 50 to 160 liters for the 20 countries with the highest rates of consumption), it has been steadily increasing in recent years. According to studies conducted by Efes, the age range of people who consume most of the beer in Turkey is 18 to 45. The demographics of the country show that the population in this age range will grow substantially over the next two decades even if the overall population growth slows down. Based on these observations, Efes plans to open new breweries and malt plants to meet the increasing demand.

The main ingredients of beer are malt, water, and hops. Hops is used in small amounts to give beer its characteristic flavor. Malt production is a rather simple process. Barley is first soaked in water in large tanks to take in oxygen and give off carbon dioxide. Next it is stored in "germination streets" to transform barley into malt with the help of a cool and moist airflow. Finally, hot air is forced through malt at another storage place to complete the process. The whole process takes close to 10 days.

In selecting a site for a malt plant, the transportation costs of barley and malt are the main factors to be considered. Efes has two malt plants, both located close to main barley regions in Konya and Afyon (Figure 1). About 750 to 800 kilograms of malt are produced from each metric ton of barley. The malt produced is either transported to Efes' beer breweries or exported.

At the start of this project, one of the managers we were working with was strongly inclined to locate the new malt plant at a port town and to either construct the company's own harbor or to make the necessary investment in an existing harbor for private loading and unloading equipment. In studying these invest-

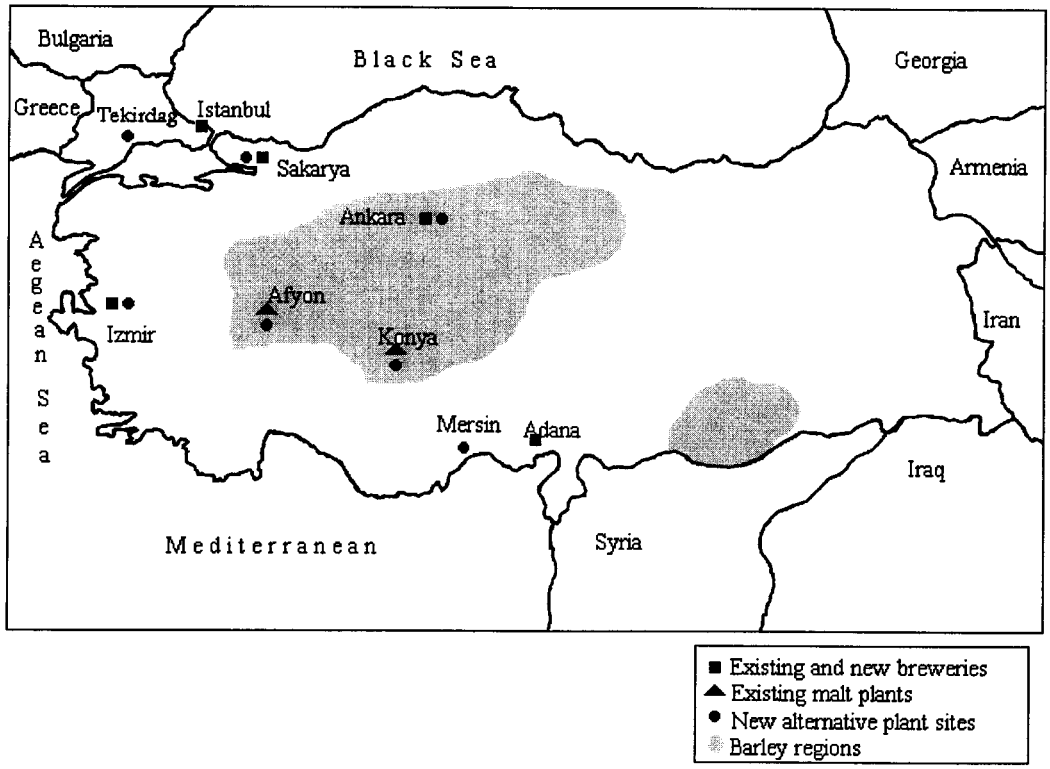

Figure 1: Locations of the facilities and barley regions.

ment alternatives, it turned out to be cumbersome to find the necessary information but straightforward to perform the economic analysis.

Each shipload of imported barley or exported malt requires around 100 truckloads to transport the material between the harbor and the malt plants. Because this operation cannot be performed while the ship is docked at the harbor, barley and malt must be stored at the harbor. In addition to the storage related costs, Efes incurs penalty costs for delays in loading and unloading the ships and transportation costs to and from the harbor. The storage, penalty, and transportation costs could be avoided if the company were to invest in a private harbor. If the company were to invest in private loading and unloading equipment in an existing harbor, it could avoid just the penalty costs. Penalty costs are well-established costs and are known accurately. Efes personnel gave us a rough estimate of the storage cost, and we estimated the transportation costs by fitting a regression model to the available data.

Since Efes does not anticipate much change in the amounts of exported malt and imported barley in the foreseeable future and since the savings are directly proportional to the volume of imports and exports, we assumed a constant annual savings corresponding to each investment alternative. Assuming a yearly interest rate of 0.10 and an economic life of 20

years for the investment, we found the net present value of total savings for the two alternatives. This revealed that the savings to be obtained are far below the necessary investments in either a new harbor or an existing harbor. Since there was an order-of-magnitude difference, we concluded that we did not need to estimate the annual savings or the required investment amounts accurately. After this analysis, Efes agreed to eliminate these alternatives from further consideration.

One could think that Efes managers might have strategic reasons for locating a plant at the harbor. Such reasons never came up during our lengthy discussions. That they quickly ruled out these investment alternatives after seeing the economic analysis leads us to believe that they had not realized the magnitude of the necessary investments. In the final analysis, Efes' yearly import and export volumes were too small to justify investing in harbor facilities, and these facilities would have stayed idle much of the time. There is, of course, the possibility of renting out the facilities during idle periods but such alternatives were beyond the scope of our study.

Sultan Süleyman the Magnificent (1520–1566) was a strict prohibitionist.

We considered the location decisions of malt plants during a time horizon for which the demand forecast should be reasonably accurate. Efes had already decided upon the capacities of new malt plants, based on available technologies and their costs. It had also decided to open no new malt plant so long as the existing malt plants could meet the demand. This policy decision also turned out to be economically justified. The problem turned out to be determining the locations of the two malt plants that would start their operations in 1998 and 2002 and planning the distribution of barley and malt. We consider 15 barley regions (one of them representing imports), two existing malt plants (Konya and Afyon), seven alternative sites for the new malt plants (Izmir, Ankara, Sakarya, Mersin, Tekirdag, Konya, Afyon), three existing breweries (Istanbul, Izmir, Adana), and four new breweries that are planned to start operating within the planning horizon (Ankara and its expansion, Sakarya and its expansion) (Figure 1). The alternative sites still include several port towns but without investments in harbor facilities. Efes uses three ports, Istanbul, Izmir, and Mersin, for imports and exports. Each malt plant uses its closest port.

The Model

We formulated the problem as a mixed-integer program. The model uses a year as the time period. We used an infinite planning horizon, but studied the first T years in more detail. T is the more predictable portion of the planning horizon, during which the currently considered new malt plants will start operating and reach full capacity. To represent the long-term transportation costs, we used the present worth of a representative year's cost as if it would repeat each year beyond T.

The model's solution determines where to locate the new malt plants as well as the amounts of barley and malt transported among different locations each

year. Constraints of the model make sure that malt demands of all breweries are satisfied, necessary amounts of barley are shipped to each malt plant, and the capacities of malt plants as well as barley availability in each region are observed. The objective function of the model is to minimize the long-term discounted total cost which includes the fixed cost of opening new plants and transportation costs of barley and malt. We give the detailed formulation of the model in the appendix.

There is a sizable tax on imported barley unless it is used for producing malt that will be exported. Therefore, Efes wanted to explicitly restrict the amount of imported barley to within some proportion of the exported malt. Exporting malt is not as profitable as using it in the domestic market. None of the managers of the malt plants are eager to do all the exporting because this reduces their profits. The company headquarters does not want to force any malt plant to do most of the exporting even if such a solution is less costly overall. We therefore include constraints in our model that prevent a solution in which one plant does most of the exporting.

Determining the Parameters

Efes supplied us with the forecasted beer demand for each of the large number of zones they had defined and the yearly export volumes. We input the demand data into the beer-distribution model we had developed earlier [Köksalan, Süral, and Kirca 1995] to find the yearly beer production of each of the breweries. We then calculated the annual malt demand of each brewery for each year.

We determined the unit transportation costs by fitting the data compiled by Efes into a simple linear regression model. The model explains the data well and indicates that there is a fixed cost incurred to transport each ton regardless of the distance and there is an additional variable cost that is proportional to the distance carried. The transportation cost of exported malt and imported barley includes a handling cost at the port in addition to the transportation cost to and from the port. This handling cost, which includes storage and loading or unloading costs, is smaller for sites that are close to the harbor since they do not need to store imports and exports at the harbor.

We used an opportunity cost of 10 percent per year in calculating the discount factor based on consultation with our client.

Solutions

We implemented the computer program using several interacting software modules on a personal computer: the data was entered using the Lotus spreadsheet software; a Fortran program read the data and generated the mixed-integer program; the model was solved using Lindo; and a Fortran program transformed the solutions into tables suitable for our purposes.

Our solutions included the runs for the analysis of the sites for the first new plant alone and for the first and second new plants simultaneously. In these runs, we kept the two existing malt plants at their current locations and capacities. We then made separate runs to analyze the locations and capacities of the existing malt plants.

First New Malt Plant

Although Efes planned to open two new

malt plants within eight years, we first considered the case of four years and opening only one new malt plant. We had two reasons for doing this. First, the forecasts are more reliable in the short term, and we thought it would be interesting to see results based on only the more reliable portion of the data. Second, we thought it would be interesting to see if the location of the first malt plant is sensitive to the time period we used.

We compared the costs of locating the plant at the seven sites, Izmir, Ankara, Sakarya, Mersin, Tekirdag, Konya, and Afyon. Table 1 shows the present value of the total cost that Efes would incur to open the plant at each site, and the percentage by which that cost exceeds the lowest-cost alternative. The total costs for four of the sites are very close. The two sites with the largest total costs are the sites of existing malt plants.

Two New Malt Plants

Table 2 shows the present value of total costs for various scenarios. Opening the first malt plant at Sakarya and expanding that plant later (Sakarya-Sakarya) turns out to be the optimal solution, and Izmir-Izmir, and Izmir-Ankara correspond to the second and third best solutions, respectively. There were a total of $7 \times 7 = 49$ possible sites for the two new plants. Of these, we reported on 21 scenarios that would be interesting or that the clients requested. These scenarios are also representative of the cost range. Several solutions had a total cost very close to that of the optimal solution. A comparison of Table 1 and 2 shows that the results we obtained considering only one new plant do not prevent us from implementing one of the better solutions for the two-plant problem. That is, the lowest cost solutions in Table 2 are not in conflict with the best locations shown in Table 1.

Analysis of Existing Sites

The sites of the existing malt plants turned out to be the worst locations for the new plants. We and Efes wanted to clarify how good the existing sites would be if we had no existing malt plants and we were to locate three new malt plants in 1998 with a total capacity equal to the total capacity to be obtained when the first new plant is opened. Dividing this total capacity equally among three plants, we obtained a plant capacity close to the capacity our clients had decided on for the new malt plants. We assumed that the fixed costs would be approximately the

Site	Total Cost (×$1,000)	Percentage Above Minimum Cost Site
Izmir	40,224	0.00
Ankara	40,460	0.59
Sakarya	40,592	0.91
Mersin	40,775	1.37
Tekirdag	41,997	4.41
Konya	42,975	6.84
Afyon	43,039	7.00

Table 1: In our comparison of sites for the first new malt plant, we found that the total costs for the least costly four sites are very close.

Site (Plant 1–Plant 2)	Total Cost (×$1,000)	Percentage Above Minimum Cost Site
Sakarya-Sakarya	57,091	0.00
Izmir-Izmir	57,225	0.23
Izmir-Ankara	57,270	0.31
Ankara-Sakarya	57,342	0.44
Ankara-Izmir	57,384	0.51
Sakarya-Ankara	57,551	0.81
Mersin-Ankara	57,748	1.15
Izmir-Sakarya	57,875	1.37
Mersin-Sakarya	58,113	1.79
Mersin-Mersin	58,548	2.55
Ankara-Ankara	58,606	2.65
Tekirdag-Ankara	59,049	3.42
Konya-Ankara	59,365	3.98
Mersin-Konya	59,653	4.49
Afyon-Ankara	60,019	5.13
Konya-Mersin	60,586	6.12
Afyon-Mersin	61,166	7.14
Afyon-Afyon	61,430	7.60
Afyon-Konya	61,718	8.10
Konya-Konya	61,928	8.47
Konya-Afyon	61,937	8.49

Table 2: In comparing sites for two new malt plants, we found that the best two actions correspond to opening a new plant in 1998 and expanding it in 2002. We also found that there are many solutions that have total costs exceeding the minimum-cost-solution only slightly.

same at different sites and made the analysis in terms of the transportation costs only. The optimal solution turned out to be Ankara-Izmir-Mersin at a total cost of $19,020,000. On the other hand, when we forced the model to use Afyon, the site of one of the existing plants, then the optimal solution for the remaining two plants was Izmir-Sakarya at a cost of $19,622,000 (Table 3). The difference between the costs of the two solutions is small. When we fixed the locations of two existing plants, that is, Afyon and Konya, then the optimal solution for the third plant was Sakarya with a total cost of $21,167,000 (Table 3). The deviation of the corresponding cost from that of the first solution in this case was significant. The cost of the optimal solution when the existing plants were at their current capacities and the new plant had the planned capacity was $21,335,000. In this case, the increase in the cost compared to the third solution was small. Noting that sites Konya and Afyon are close to each other and near the barley region and that in the last two solutions we have about two thirds of the total capacity, we conclude that it would still be a good choice to have some malt-production capacity (about one third the total capacity) in the barley region. Efes does not plan to replace the existing malt plants in the foreseeable future because these plants are far from the ends of their economic lives. If

replacing existing facilities becomes a feasible option in the future, we can extend our analysis to see which facilities to close and which to open.

Other Variations

We could consider other variations of the model to obtain further useful information. In our analysis we assumed that the installation times of both malt plants were fixed. We considered opening a new plant when Efes expected capacity shortages. A more general approach would be to allow the second malt plant to open earlier if profitable. We studied this case and found out that opening the malt plants as late as possible is indeed the best decision. That is, the savings in the transportation cost are too small compared to the cost of making an investment earlier than needed unless the opportunity cost is very close to zero.

Sensitivity Analysis

There is uncertainty in the malt demand because of the uncertainty in the beer demand. To see how robust the solutions we obtained were, we studied the sensitivity of the solutions to changes in the geographic distribution of demand.

We made different runs by increasing the malt demand in one of the breweries by a certain percentage and decreasing the malt demand in the other breweries, while keeping the total demand fixed. The results of these runs show that the observations we made were still valid. When we increased the malt demand in one of the breweries by as much as 30 percent and decreased it in the other breweries proportionately, our three minimum-cost solutions still yielded the best results. The ranking between the best three changed in some cases, but our main observation that the total cost values for these three solutions are very close still remains valid.

Imports and Exports

We also analyzed the effect on the solutions of changing the amounts of exported malt and imported barley. The sites corresponding to port towns are, as expected, sensitive to the exported and imported amounts. The alternatives that are not sensitive to these quantities may be preferable because there is considerable uncertainty in these amounts. Such robust alternatives are Sakarya-Sakarya and Ankara-Sakarya (Table 2), while Izmir and Mersin are sensitive to exports and imports. We thought that Ankara-Sakarya would be a better choice since it has the potential of extra savings in future expansions as both

Site	Total Cost (×$1,000)	Percentage Above Minimum Cost Site
Ankara-Izmir-Mersin	19,020	0.00
Afyon-Izmir-Sakarya	19,622	3.20
Afyon-Konya-Sakarya	21,167	11.00
Afyon-Konya-Izmir	21,335	12.17

Table 3: We found out that the optimal solution does not include the existing sites Afyon or Konya if we were to decide on the locations of all malt plants now. We also found out that building about a third of the total malt production capacity in one of the existing sites would yield a result close to optimal but using both existing sites increases the costs significantly. Afyon and Konya plants are set at their existing capacities for the fourth solution.

plants can undergo expansions (each plant can undergo only one expansion due to technological reasons). However, when we considered the effect of opening a third malt plant in year 2006, in both alternatives the results did not validate our argument. The best location for the third malt plant turned out to be Ankara and Sakarya for alternatives Sakarya-Sakarya and Ankara-Sakarya, respectively, with respective total costs of $57,090,928 and $57,342,222. This is mainly because the present value of the costs that accrue so late is small and does not affect the difference between the costs of the alternatives much.

To see the effects of the constraints the clients imposed on imported barley and exported malt, we made runs relaxing them. Under these conditions, Ankara-Izmir turned out to be the best solution with a total cost of $53,393,000, and Izmir-Ankara also yielded a small total cost of $53,663,000. These imply that Efes can save about seven percent of the total cost (or about 20 percent of transportation costs) if it relaxes the constraints on imports and exports.

Obtaining the optimal solution alone has very limited benefits.

Alternatively, we could handle the restrictions on barley imports and malt exports more explicitly. The constraints on barley imports can be eliminated by accounting in the objective function for the tax charged on the portion of imported barley that is not used for producing malt to export (appendix). If we also eliminated the constraints that put an upper bound on the amount of malt each plant can export, some plants would end up exporting more than they would like to. Compensating these plants by some sort of transfer payments from the plants that do not export seems a reasonable approach since Efes can realize a sizable overall savings.

Progress of the Project

Several departments of the company were involved in this project. This caused us some delays in the flow of information. However, we were able to obtain the information we needed with less effort than we have experienced in other real-life problems.

One of the main difficulties we had was in studying the feasibility of investments in a harbor. We had to insistently question the sources and magnitudes of savings that would be realized by investing in a harbor. The data we eventually obtained revealed that the savings resulting from such investments were far too small to justify the needed investments.

Another issue that was overlooked at the beginning of the project was related to the imported barley and exported malt. In the early solutions, we did not impose any restrictions on imports and exports. After seeing the solutions, our client wanted to enforce constraints on the total imported barley as well as on the exported malt by each plant. Although we included these constraints in the model, we also provided our client with the solutions relaxing the constraints on the exports each plant could make. These solutions demonstrate the potential value of an alternative way of looking at the problem from a centralized perspective.

We had difficulty obtaining data on the availability of barley of the required quality in different regions in different years. We had to go back and forth several times to get the information. We were first provided with the total barley production in each region. It took us some time to realize that barley conforming to Efes' quality requirements was only a small proportion of total available barley in each region.

The fixed cost of locating a plant at a specific site turned out to be one of the most critical pieces of data. Company personnel provided us with rough estimates. The values for many of the sites were quite close to one another. We suggested that Efes do a more detailed study of the fixed costs of opening a plant before making a final decision on locating the new plants. The fixed cost of opening a plant is an important part of the total cost and the results may be quite different when these costs are estimated accurately.

Company personnel told us that the operating and maintenance costs would be approximately equal at different candidate sites because the production process for malt is quite simple and the sites considered are all in well-developed regions. Therefore, we did not incorporate those costs into our model. It is straightforward to make the necessary changes in the model if and when Efes wants to account for these costs.

Conclusions

One of the main uses of the model we developed was to evaluate the various scenarios our clients requested or we generated. We worked closely with Efes to interpret various solutions, and company personnel appreciated this because it helped them learn more about their problem. Our experience in this and other projects shows that obtaining the optimal solution alone has very limited benefits. The decision makers usually benefit from the opportunity to compare different solutions and appreciate it more. We believe that it is necessary to provide both good solutions and some poor solutions to give a client a sense of the range of available solutions.

In the current situation, it seems best for Efes to locate the new plants close to beer breweries. We suggested that Efes carefully reevaluate and accurately estimate the fixed costs of opening a plant at each site before making the final decision. Currently, top managers are debating where to locate the new plant in light of the results we presented. We submitted the user-friendly software that we developed to our clients together with a user's manual. Efes intends to use the software in future for both location and distribution decisions, changing the values of the parameters when necessary. We are in close contact and will be involved in further analyses if necessary before Efes makes its final decision on plant locations.

A more general approach to the problems of our client would be to consider the locations of the new malt plants together with the locations of the new beer breweries. This problem could again be represented as a mixed-integer-programming problem. Computationally, the model would be manageable if treated as a single-period model. The multiperiod version is difficult both because of the large number of binary variables and because of the very large number of continuous vari-

ables caused by the abundance of beer-demand zones. However, the model would be separable by year for a given set of open locations and it may be solvable. To reduce the number of smaller-sized linear programming (or transshipment) problems to be solved, one could perform an initial screening to eliminate some of the alternative sites. There may also be many application-dependent features that can be exploited in these types of problems to improve the efficiency of the solution procedure.

The managers we worked closely with throughout the project were not the final decision makers on the locations of new plants. However, they had a strong influence on top management. The fact that these middle level managers could communicate very well both with us, the analysts, and with the final decision makers, had an important positive effect on the success of the project.

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APPENDIX

We present the decision variables, the parameters, and the mathematical model.

Decision Variables

X_{ijt}: tons of barley shipped from region i to malt plant j in year t ($i = 1$ stands for imports).

Y_{jkt}: tons of malt shipped from malt plant j to demand point k in year t ($k = 1$ stands for exports).

$$Z_{jn} = \begin{cases} 1 & \text{if } j\text{th site is used to open } n\text{th new plant } (n = 1,2), \\ 0 & \text{otherwise.} \end{cases}$$

$$Z_j = \begin{cases} 1 & \text{if both new plants are opened at site } j, \\ 0 & \text{otherwise.} \end{cases}$$

Indices and Parameters

I: the set of barley supply regions.

J_A: the set of current malt plants.

J_B: the set of alternative sites for new malt plants.

$J = J_A \cup J_B$.

K: the set of malt demand points.

T: number of years in the more predictable part of the planning horizon.

T': the year in which the second new malt plant will be opened.

D_{kt}: tons of malt demand at point k in year t.

C_j: the yearly capacity of malt plant j (tons).

A_{it}: tons of barley supply at region i in year t.

r_i: tons of malt that can be produced using one ton of barley of region i.

a_{ijt}: present value of the cost of shipping barley from region i to malt plant j in year t ($/ton).

m_{jkt}: present value of the cost of shipping malt from plant j to demand point k in year t ($/ton).

s_{jn}: fixed cost of opening nth new malt plant ($n = 1,2$) at site j at the beginning of the planning horizon ($).

s_j: present value of the savings in fixed cost when both new malt plants are opened at site j($).

α, β, and γ: parameters predetermined by the decision maker.

The Mathematical Model

The total amount of malt shipped from all malt plants to each demand point k must satisfy the demand at that point each year:

$$\sum_{j\in J} Y_{jkt} \geq D_{kt} \quad \forall\, k \in K,\ t = 1, \ldots, T.$$

The balance between the total malt production in malt plant j and the necessary amount of barley for that production must be satisfied each year:

$$\sum_{k\in K} Y_{jkt} \leq \sum_{i\in I} r_i X_{ijt} \quad \forall j \in J,\ t = 1, \ldots, T.$$

The total amount of malt produced at malt plant j cannot exceed its capacity each year:

$$\sum_{k\in K} Y_{jkt} \leq C_j \quad \forall j \in J_A,\ t = 1, \ldots, T,$$

$$\sum_{k\in K} Y_{jkt} \leq C_j Z_{j1} \quad \forall j \in J_B,$$
$$t = 1, \ldots, T' - 1,$$

$$\sum_{k\in K} Y_{jkt} \leq C_j Z_{j1} + C_j Z_{j2} \quad \forall j \in J_B,$$
$$t = T', \ldots, T.$$

The total amount of barley shipped from each barley region i cannot exceed the capacity of that region each year:

$$\sum_{j\in J} X_{ijt} \leq A_{it} \quad \forall i \in I,\ t = 1, \ldots, T.$$

Only one new malt plant will be opened in 1998 (i.e., year 1) and another one will be opened in 2002 (i.e., year T'):

$$\sum_{j\in J_B} Z_{jn} = 1 \quad n = 1,2.$$

Special constraints are needed for using the same site for both new malt plants:

$$Z_j \leq Z_{jn} \quad \forall j \in J_B,\ n = 1,2.$$

The amount of barley imported by malt plant j each year must be within an interval proportional to the amount of malt exported by that plant that year:

$$\alpha Y_{j1t} \leq X_{1jt} \leq \beta Y_{j1t} \quad \forall j \in J,\ t = 1, \ldots, T.$$

The amount of malt exported by plant j cannot exceed a proportion of the total exported malt each year:

$$Y_{j1t} \leq \gamma D_{1t} \quad \forall j, t.$$

Restrictions on variables:

$$Z_{jn} = \{0,1\},\ Z_j = \{0,1\} \quad \forall j \in J_B,\ n = 1,2.$$

$$X_{ijt} \geq 0 \quad \forall i \in I,\ j \in J,\ t = 1, \ldots, T.$$

$$Y_{jkt} \geq 0 \quad \forall j \in J,\ k \in K,\ t = 1, \ldots, T.$$

The objective function to be minimized is the total discounted transportation and fixed costs:

$$\begin{aligned}\text{Min } V = &\sum_{t=1}^{T} \sum_{i\in I} \sum_{j\in J} a_{ijt} X_{ijt} \\ &+ \sum_{t=1}^{T} \sum_{j\in J} \sum_{k\in K} m_{jkt} Y_{jkt} \\ &+ \sum_{j\in J_B} (s_{j1} Z_{j1} + s_{j2} Z_{j2} - s_j Z_j) \\ &+ L(T-1)\delta^2/(1-\delta),\end{aligned}$$

where

$$\begin{aligned}L(T-1) = &\sum_{i\in I} \sum_{j\in J} a_{ij(T-1)} X_{ij(T-1)} \\ &+ \sum_{j\in J} \sum_{k\in K} m_{jk(T-1)}\, Y_{jk(T-1)},\end{aligned}$$

and δ is the discount factor.

The objective function includes all discounted transportation and fixed costs incurred in years 1 through T and an additional term, $L(T-1)$, to represent the long-term transportation costs. We used the total transportation cost incurred in year $T-1$ to represent the transportation cost of each year beyond T. As the increase in the malt demand is expected to continue in the foreseeable future, Efes plans to open a new malt plant every three or four years. Therefore, the capacities of malt plants will not be tight on average and year $T-1$ is more representative of years beyond T in terms of capacity utilization since the capacities of all malt plants are almost fully utilized in year T. Alternatively, one could employ other approaches such as using the average transportation cost of the T years to represent the long-term behavior. We would not, however, expect any important differences in the results by changing this approach.

Accounting for Tax

Let X'_{1jt} be the amount of imported barley that is not used for exported malt in malt plant j in year t and a'_{1jt} be the additional tax charged for each ton of X'_{1jt}. Then we need to add constraints $X'_{1jt} \geq X_{1jt} - \beta Y_{j1t}$ for all j,t and add the terms $\Sigma\Sigma a'_{1jt} X'_{1jt}$ into the objective function to explicitly account for the tax charged on the imported barley that is not used in exported malt.

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Serdar Bölükbasi, Marketing Director, Efes Beverage Group, Turunçlu Sokak No. 25, Merter 34010 Istanbul, Turkey, writes: "We have been utilizing the results of the study . . . in several ways. Prior to this study, locating a new malt plant at a port town and investing in a private harbor or in at least private loading and unloading equipment was seen as a viable alternative because of barley imports and malt exports of the company. The economic analysis conducted in this study clearly demonstrated that this alternative was far too expensive relative to its benefits. Consequently, we ruled this alternative out.

"Throughout the study, many solutions and their corresponding costs were generated. This was an important learning process for us. It was important to know that there were several good alternative sites having total costs in the same neighborhood. It was also useful to know how much better these sites were, compared to other sites.

"So far, we have partially adapted the distribution plans implied by the model and enjoyed important savings in the transportation costs. We intend to use the model and repeat the analysis with updated data before making a final decision on the locations of our new malt plants.

"An additional important benefit of this study (as well as several other studies we conducted) is its positive effect on the

company personnel in developing scientific thinking.

"We found the project team's approach to our problem very refreshing, and their ability to adapt from a theoretical stance to an industrial view point was very much appreciated."