Chapter 11
Network Redesign in Turkey: The Supply, Production, and Distribution of Malt and Beer

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Abstract In this chapter, we consider a network redesign problem that contains decision problems of opening new malt plants and breweries in order to increase the malt and beer production capacities of a Turkish corporation, Efes Beverage Group. We briefly discuss several beer logistics applications in Turkey and other countries, and some location applications in Turkey. Some attention is also given to the overall status of logistics in Turkey. We construct a mixed integer programming model for the multi-period, multi-item, multi-level capacitated facility location/relocation problem of Efes. The model determines the locations of new malt plants and breweries as well as the distribution decisions for barley, malt, and different types of beer while minimizing fixed costs and annual transportation costs. We suggest a procedure to set effective capacities of breweries due to seasonality of demand. We solve the model under different parameter settings in order to obtain a variety of solutions that the decision makers may find useful. We discuss our results and experiences from this application process.

11.1 Introduction

Beer is one of the world's oldest alcoholic beverages. As early as 6000 BC, people were brewing beer in Mesopotamia, the land between the Tigris and Euphrates, rivers that originate in southeast Anatolia. Hittites, one of the most sophisticated

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civilizations 4000 years ago in Anatolia, were drinking beer. Today, the brewing industry is a huge business worldwide.

Beer is produced by the fermentation of carbohydrates in cereals, such as wheat, corn, rice, and most commonly barley. The main ingredients of Efes' beers, which are the most consumed beers in Turkey by far, are water, malted barley, hops and yeast. Malted barley is the processed grain that has begun germination by being soaked in water, and provides beer its body and color. Hops are used in small amounts as a preservative agent. It also gives beer a bitter flavor and a pleasant aroma. Yeast is composed of micro-organisms that convert sugar in malt juice to alcohol and carbon dioxide. From the start of the production process, it takes approximately 21 days until the beer is ready for consumption. Beer tastes best if consumed when fresh; soon after bottling.

11.1.1 Brewing Industries and Beer Logistics

The European brewing industry, covering 31 countries, includes 4,000 brewers and employs 2.5 million people, directly or indirectly. Its contribution to the European economy is about 0.43 % of total GDP (see The Brewers of Europe 2010). The U.S. brewing industry, the second largest producer of beer after China, includes more than 2,000 brewers, over 2,800 wholesalers, over 521,000 retailers, and roughly 1.9 million employees, including indirect employment (see Beer Serves America 2009). Its contribution to the economy is about 1.5 % of GDP (see The Beer Institute 2009). The Canadian brewing industry, including over 100 breweries and having one of the most highly taxed beer industries in the world, second only to Norway, contributes $4.3 billion annually (2.6 %) to tax revenue, employs 0.2 million people, amounting to 1.2 % of the workforce of Canada, and is among the top ten largest exporters by volume. Its contribution to the economy is about 1.1 % of GDP (see Brewers Association of Canada 2009).

An earlier overview of the European beer market can be found in Vrontis (1998). For an assessment of the role of branding in product management within the market, Vrontis uses three companies, the British Bass, the Danish Carlsberg, and the Dutch Heineken, in order to exemplify marketing issues. Houthoofd and Heene (1997) describe features of the Belgian brewing industry and present an analysis for strategic groups and firm performance relations in the industry. Beugelsdijk et al. (2002) discuss how Heineken has experienced different organizational changes due to different challenges such as a shift in origin of demand from pubs to supermarkets, which has radically altered distribution channels of beer. A comprehensive analysis of the German and the Croatian brewing industries with an emphasis on managerial implications is presented in Niederhut-Bollmann and Theuvsen (2008). A broad account of evolution of the U.S. brewing industry is provided in Warner (2010). Carroll and Swaminathan (2000) explain how microbrewery movement (i.e., a dramatic increase in the number of small brewers in the industry) emerged in the U.S. beer brewing industry in the late 1980s, following the domination of the industry by a few large brewing companies, and also show that these two opposite trends are essentially interrelated. Sass (2005) analyzes the effects of exclusive-dealing contracts between brewers and distributors in the U.S. beer industry, that prohibit distributors from selling the products of other brewers.

Kioulafas (1985) presents a multiple regression study to explain the relationship between the sales and advertisement of beer in Greece. Gelders et al. (1987) consider the beer distribution for a Belgian brewer and determine the number and locations of depots to be opened. Duran (1987) considers the integrated production and distribution problem of a Colombian brewer. These are examples of earlier studies using quantitative techniques to solve beer logistics problems. Ramirez-Beltran (1995) develops a production planning model to minimize the labor costs for a Puerto Rican beer producer. A time series study is presented by Lenten and Moosa (1999) to model trend and seasonality in the consumption of beer in the U.K. Bommer et al. (2001) propose a performance system for distributors in the U.S. beer and soft drink industry so that they develop a service strategy based on several service categories such as price, customer service, delivery, etc. for their retailers. In a reverse logistics study of U.K. industries including the beer industry, Breen (2006) finds that customer non-compliance, in returning distribution equipment back to their sources, damages the performance of the logistics system. Kant et al. (2008) report a Coca-Cola implementation to handle daily construction of routes for beverages and its extension to beer distributors like Carlsberg, Heineken, and Inbev. Implementation at Inbev in France and Belgium included finding optimal depot-retail outlet pairs and optimal frequency to deliver an outlet, and realized a 100 % return on investment within one year.

11.1.2 Brewing Industry and Beer Logistics in Turkey

Turkey, the 11th largest beer producer among 31 European countries, has more than ten breweries run by seven brewing companies. Turkey brews about 0.9 billion liters of beer annually, which is equivalent to 2.4 % of the total annual beer production in Europe (see The Brewers of Europe 2010). Having a domestic market share of about 78 %, Anadolu (Anatolian) Efes (or Efes in short) is the leader of the Turkish brewing industry. In the domestic beer market, Efes supplies a large number of popular flavors under license agreements. Efes, with a brewing capacity of 3.3 billion liters, and a malt production capacity of 0.2 million tons annually, also offers a wide variety of local brands with different tastes and appeals in the international markets, especially in the former Soviet Union, Southeast Europe, and the Middle East (see Efes Beverage Group, Anadolu Efes 2009).

There are several location and forecasting applications conducted for Efes that are reported in the literature. Köksalan et al. (1995) and Köksalan and Süral (1999) present their results on the locations of new breweries and malt plants, respectively. The former is one of the earliest studies in the literature that incorporate inventory issues into the location-distribution problem. Both studies aggregate beer types and costs, and consider liters of beer to study production and distribution decisions. Using their findings from an earlier application conducted for Efes, Köksalan et al. (2010) develop a case study that requires building a multiple linear regression model for explaining the monthly beer demand in Turkey to help Efes Group in its beer demand predictions.

Köksalan et al. (1999), in an earlier study on beer logistics in Turkey, present medium and short-term regression models to explain and forecast the beer demand in Turkey. Pamuk et al. (2004) develop a product delivery system of Efes in Ankara, and report a savings potential of up to 25 % in distribution costs.

11.1.3 Where does Turkey Stand in Worldwide Logistics?

The quality of logistics services differs from one country to another because of differences in customs regulations, infrastructure, policies, etc. We refer the reader to Schoenherr (2009) for an extensive review of logistics and its applications in the global context.

The logistics performance index (LPI), created by the World Bank, is a comprehensive index,[1] rated on a scale from one (worst) to five (best), that summarizes the performance of 155 countries in six areas.[2] This index captures the most important aspects of the current logistics environment (Arvis et al. 2010). Eight of the top 10 countries in this index are from Europe and the entire group of 31 European countries is within the top 50 percent of LPI performers. Croatia has the lowest rank of 74 among the European countries. The first-ranking country in this list is Germany. Turkey, ranked 39th in the list of 155 countries, with an index value equal to 71.4 % of that of Germany, has the 21st highest score within the European countries and is in the top 40 % of logistics performers worldwide. Furthermore, in an assessment that considers both country income and logistics performance, Turkey is the sixth logistics performer among upper middle-income countries (Arvis et al. 2010). Based on interviews with 428 logistics companies operating in Turkey, Agaran et al. (2010) find that increasing and improving information technology use, a worldwide current trend today, is seen as the most essential requirement to achieve strategic goals by all logistics parties in Turkey.

Of course, the above remarks do not directly indicate the performance of beer industry's logistics in Turkey because "an organization's- or industry's -logistics success is only partly due to the overall business environment," as explained in

[1] LPI is based on standard statistical techniques to aggregate the data into a single indicator (Arvis et al. 2010).

[2] These areas are 'efficiency of the customs clearance process', 'quality of trade and transport-related infrastructure', 'ease of arranging competitively priced shipments', 'competence and quality of logistics services', 'ability to track and trace consignments', and 'frequency with which shipments reach the consignee within the scheduled or expected time'(Arvis et al. 2010).

Bookbinder and Tan (2003). Perhaps its performance can be assessed by using findings of Ulengin and Nuray (1999) analyzing the status of logistics in Turkey. They argue that the beverage industry is one of the industries having a proactive logistics management compared to other industries in Turkey, which is consistent with Turkey's macro logistics indicators in the global context.

11.1.4 Supply, Production, and Distribution Network Redesign for Efes

In this study, we consider the (re)location decisions for malt plants and breweries of Efes, in addition to the decisions on transportation of barley, malt, and beer. We develop a multi-period, multi-item, multi-level capacitated location/relocation model. In addition to capacity restrictions on barley supply and malt production, we consider differences in transportation costs of, and capacity limits on, differently-packaged beer as distinct products. We develop a procedure to specify the effective yearly capacities of breweries in order to capture the seasonality in the monthly beer demand. Determining the effective capacities with this procedure prevents holding excessive inventories for long periods during the year.

Another aspect we consider is to maintain a homogeneous taste in the beer regardless of where it is brewed or where its barley is grown. This is achieved by either mixing different types of barleys, whose malt yields vary from 75 to 80 %, depending on the region, in the same proportions in each malt plant, or mixing various malts of different plants in the same proportions in each brewery. Considering the mixing of grains, however, causes nonlinearity in the mixed integer linear model. We formulate two types of linearization to solve the model.

Facility location problems have been mostly studied for single-level systems, as discussed by Şahin and Süral (2007) in the context of systems of different levels of interacting facilities. In a review of facility location and supply chain management, Melo et al. (2009) state that around two thirds of the surveyed papers model locations in a single level. The dynamic multi-item, multi-level location problem studied in Melo et al. (2006) is similar to our current work and involves several aspects that affect the network design. We refer the reader to Melo et al. (2006) for a list of studies in the literature on the dynamic location problems, and to Klose and Drexl (2005) for a review of the multi-item location problems.

11.1.5 Other Location Applications in Turkey

Şahin et al. (2007) develop a hierarchical design approach for the Turkish Red Crescent Society's blood service network, where regional facilities are located in the highest level and mobile units that are allocated to service regions are in the lowest level. Tan and Kara (2007) consider a hub location problem encountered by cargo delivery systems; they report that speed and reliability are more important than cost in cargo delivery. According to their interviews with different cargo delivery companies operating in Turkey, delivering the cargo in a timely manner is the key factor in the Turkish market. Alamur and Kara (2009) develop a mathematical model to design hub networks, focusing on needs of a cargo company operating in Turkey. Bozkaya et al. (2010) suggest a GIS-based optimization framework for a competitive multi-facility location-routing problem, and report their computational results for a supermarket store chain in Istanbul. Çetiner et al. (2010) consider the combined hubbing and routing problem in postal delivery systems and present the results of a case study for the Turkish postal services. Demirel et al. (2010) report an application of warehouse location selection for a Turkish logistic company, using an uncommon multi objective approach. Erden and Coskun (2010) study the selection of fire station locations in Istanbul. Their approach combines the analytic hierarchy process and geographic information systems to support the decision maker.

11.1.6 Outline

Let us now concentrate on the specifics of our problem. We define the problem in detail in Sect. 11.2, and discuss various problem parameters and assumptions in Sect. 11.3. Section 11.4 contains the development of our models. We discuss various solutions obtained with the model in Sect. 11.5, and present our concluding remarks in Sect. 11.6.

11.2 Problem Definition

Efes currently has two malt plants and five breweries in Turkey (as of December 2010). We consider seven and eight sites as the possible locations for the new breweries and malt plants, respectively. Locations of the existing sites, new potential sites, and the barley regions are shown in Fig. 11.1.

Due to confidentiality, we conceal the identity of the specific breweries, malt plants, and the barley regions in the rest of our discussions. Codes will refer to each facility and region. We assign a number to each city and add the letters, A for barley, ME for existing malt plants, MP for potential malt plants, BE for existing breweries, and BP for potential breweries before the numbers.

Efes' two malt plants are located close to main barley regions in central Anatolia at locations ME6 and ME7. The malt produced is either transported to Efes' beer breweries or exported. Existing breweries are located at BE1-BE5. The potential locations for the new malt plant are MP1, MP2, and MP7-MP12. Two

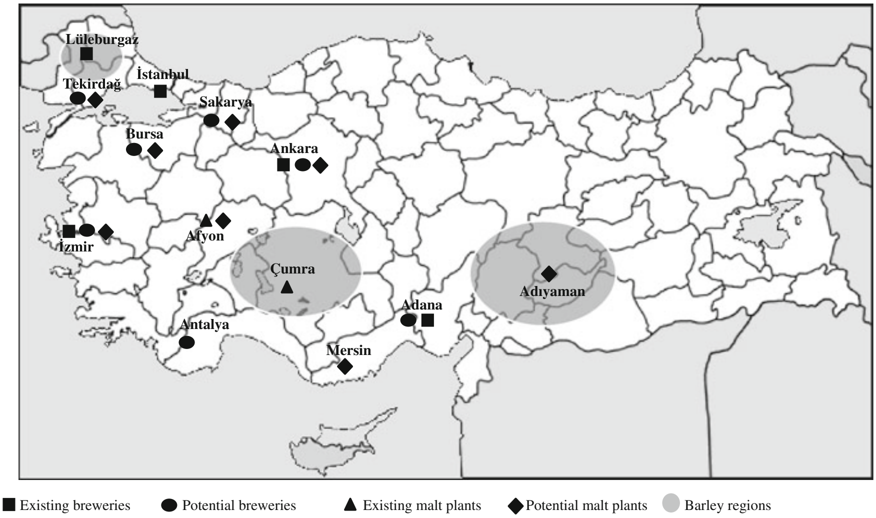

Fig. 11.1 The locations of existing and potential facilities

alternatives correspond to building next to the existing breweries and another alternative is to expand an existing plant. The potential locations for the new brewery are BP1-BP3, BP8-BP10, and BP13.

The problem is to determine where to locate the new brewery and malt plant as well as the amounts of barley, malt and beer to transport among different locations each year. In doing so, beer demands of all customers and malt demands of all breweries should be satisfied, necessary amounts of barley should be shipped to each malt plant, and the capacities of breweries and malt plants as well as barley availability in each region should be taken into account. The objective is to minimize the long term discounted total cost which includes the fixed cost of relocating a brewery and opening a new malt plant, and the transportation costs of barley, malt, and beer.

There are several complicating issues in this problem. The location of new breweries and malt plants is a strategic decision and has important long-term effects. Therefore, the decision should be made after a detailed analysis. In the analysis, the capacities of the new breweries are not fixed in advance and we want to choose the optimal capacity configuration by trying different scenarios. Another difficulty arises due to high seasonality of beer demand and necessity of producing the beer in a homogeneous taste in multiple locations. The former difficulty requires incorporation of inventory issues into decisions on capacity settings of the plants, whereas the latter requires considering balanced distributions of different barley types or various malts or both from their multiple origins to their multiple destinations. We further discuss and address these difficulties in the next section.

11.3 Model Parameters and Assumptions

There are about 40 barley supply regions and they are aggregated to four centers: A8, A6, and A12 represent north-west, central, and south-east Anatolia regions, respectively, and the imported barley is assumed to be transported from the closest harbor to each malt plant. Upper limits for barley supply amounts for each region are provided by Efes, and excess demand for barley is always satisfied by A12. Amounts of malt obtained from 100 kg of barley are approximately 78 kg for the barley of north-west and south-east Anatolia regions, 75 kg for the barley of the central Anatolia region, and 80 kg for the imported barley. Production of 1,000 liters of beer requires 0.136 tons of malt.

Efes has about 740 demand points and supplies beer in three different types of containers, namely, bottle, can, and barrel. Demand points are aggregated into 82 centers in addition to exports; demand is assumed to increase 4.5 % annually, based on other forecasting studies conducted by Efes. In order to determine the transportation costs for barley, malt, and beer types, the regression equation obtained in a previous study (Köksalan et al. 1995) is revised and used here. The production cost differs in the two malt plants due to using different technologies, but is approximately the same in all breweries.

We considered years 2008 and 2009 in detail, and used the transportation patterns of year 2009 to represent the long term after 2009. The plan of Efes was to open the new malt plant at the beginning of 2008 and the new brewery in June 2008. We used an annual opportunity cost of 10 % in calculating the discount factor.

11.3.1 Seasonality and Capacity

There is high seasonality in beer demand. Generally, consumption of beer increases during summer. The percentage of total beer demand that occurs each month in a typical year in Turkey is shown in Table 11.1. According to this table, operating a brewery at full capacity all year long would lead to stocking up in winter months to satisfy the peak demand of summer months. This is undesirable, not only because of the cost of carrying inventory, but also due to the fact that beer tastes best when consumed within several months after bottling. Efes tries to enforce this strategy. Since our model considers a medium term, its time periods are years. Due to seasonality effects and the Efes' strategy of selling fresh beer only, it is not straightforward to set the yearly capacity of a brewery. We need to determine an effective yearly capacity that leads to a desirable monthly brewing and stocking plan. The following applies to any brewery. We therefore omit the brewery subscripts to simplify the notation. Let

B: the effective yearly capacity (of a brewery).

p_t: the proportion of the effective yearly capacity (of the brewery) utilized in month t, where $0 \leq p_t$ and $\Sigma_t p_t = 1$.

Table 11.1 Percentage of yearly demand occurring in each month

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.
% Demand	5.90	6.42	7.65	8.85	10.78	11.74
Month	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
% Demand	13.15	12.14	9.09	3.29	4.81	6.18

C the maximum amount that can be brewed (in the given brewery) in any month, where $p_t\, B \le c$.

s_t the proportion of the yearly demand that occurs in month *t*.

Suppose that we decide to use full capacity several months before the summer, operate at that pace throughout the summer, and brew in proportion to the demand during the remaining months. More specifically, let us set the effective monthly capacity to c (i.e., $p_t\, B = c$) for months $M = \{m + 1,\ldots, m + k\}$ and set $p_t = s_t$ for the remaining months $\{1, \ldots, m, m + k + 1, \ldots\}$. Note that we would at least like to set the effective capacity for the month where the peak demand occurs (July) to full capacity.

Using the above, we can write $B = \sum_{t \notin M} s_t B + \sum_{t \in M} c = \sum_{t \notin M} s_t B + kc$ for $k \ge 1$. Simplifying, we obtain $B = kc/(1 - \sum_{t \notin M} s_t)$.

Using the s_t values given in Table 11.1 and setting $p_7\, B = c$ (i.e., using full capacity only in July) we obtain $B = c$ / (1-.0590-.0642-…-.1174-.1214-…-.0618) = 7.61c. In this case, even if the effective capacity is fully utilized, there will be no need to carry any inventory.

Alternatively, if we decide to use full capacity March thru August, the effective capacity will be $B = 6c$ / (1-.0590-.0642-.0909-.0329-.0481-.0618) = 9.33c. In this case, inventory will start to accumulate starting from March if the effective capacity is fully utilized. No inventory will be carried September thru February.

The above analysis can simply be generalized to represent different annual effective capacities by considering any demand seasonality throughout a year and willingness or policy of decision maker for how long to carry inventories in the planning year. In our experiments, we set the effective capacities to 9.33c, in accordance with the strategy of Efes, to avoid holding inventories for long periods.

11.4 The Mathematical Model

We formulated the problem as a mixed integer linear program. The model uses a year as the time period. We used an infinite planning horizon, but studied the first two years in more detail. The new brewery and malt plant are considered to start operating in 2008 and to reach full capacity in 2009. 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 2009.

11.4.1 Indices and Parameters

L: Number of barley supply regions
K: Number of malt plants
J: Number of breweries
I: Number of demand points
P: Nature of beer container ($p = 1, 2, 3$ stand for bottle, can, barrel, respectively)
T: Length of planning horizon
d_{ipt}: Annual demand of point i for beer type p in year t (in kilo liters)
B_{jt}: Annual production capacity of brewery j in year t (in kilo liters)
D_{jpt}: Annual packing capacity of brewery j for type p in year t (in kilo liters)
M_{kt}: Annual production capacity of malt plant k in year t (in tons)
A_{lt}: Annual limit on barley supply at region l in year t (in tons)
α_l: Kg of malt produced from barley at region l
β: Kg of malt to produce one liter of beer
FM_k: Fixed cost of opening alternative malt plant k at the beginning of T
FB_j: Fixed cost of relocation and opening alternative brewery j at the beginning of T
ca_{lkt}: Present value of transportation cost of barley from barley region l to malt plant k in year t (in value of TL/ton)
cm_{kjt}: Present value of transportation cost of malt from malt plant k to brewery j in year t (in value of TL/ton)
cb_{jipt}: Present value of transportation cost of beer from malt plant k to demand point i in year t in terms of $t = 1$ prices (in value of TL/kilo liters)

11.4.2 Decision Variables

z_{lkt}: Tons of barley sent from barley region l to malt plant k in year t
y_{kjt}: Tons of malt sent from malt plant k to brewery j in year t
x_{jipt}: Kilo liters of beer type p sent from brewery j to demand point i in year t
u_k: 1 if malt plant k is built in the beginning of T; 0 otherwise
v_j: 1 if brewery j is built the beginning of T; 0 otherwise

11.4.3 The Model

The objective is to minimize the present value of the total transportation costs of barley, malt and beer, and the fixed costs of opening new malt plant and brewery, plus long term transportation costs:

$$\text{Minimize} \sum_{l=1}^{L}\sum_{k=1}^{K}\sum_{t=1}^{T} ca_{lkt} z_{lkt} + \sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{t=1}^{T} cm_{kjt} z_{kjt} + \sum_{j=1}^{J}\sum_{i=1}^{I}\sum_{p=1}^{P}\sum_{t=1}^{T} cb_{jipt} x_{jipt}$$
$$+ \sum_{k=1}^{K} FM_k u_k + \sum_{j=1}^{J} FB_j v_j + [\text{long term transportation costs}] \tag{11.1}$$

The total amount of barley shipped from barley region l cannot exceed the capacity of that region each year.

$$\sum_{k=1}^{K} z_{lkt} \leq A_{lt} \quad \forall l, t \tag{11.2}$$

Each malt plant should obtain enough barley for its malt production.

$$\sum_{l=1}^{L} \alpha_l z_{lkt} = \sum_{j=1}^{J} y_{kjt} \quad \forall k, t \tag{11.3}$$

The total amount of malt produced at malt plant k cannot exceed its production capacity each year. Constraint 11.4 (11.5) below is for existing (candidate) malt plants.

$$\sum_{j=1}^{J} y_{kjt} \leq M_{kt} \quad \forall t, k \tag{11.4}$$

$$\sum_{j=1}^{J} y_{kjt} \leq M_{kt} u_k \quad \forall t, k \tag{11.5}$$

Each brewery should obtain enough malt for its beer production.

$$\beta \sum_{j=1}^{J} y_{kjt} = \sum_{i=1}^{I}\sum_{p=1}^{P} x_{jipt} \quad \forall j, t \tag{11.6}$$

The total amount of beer produced at brewery j cannot exceed its production capacity each year. Constraint 11.7 (11.8) is for existing (candidate) breweries.

$$\sum_{i=1}^{I}\sum_{p=1}^{P} x_{jipt} \leq B_{jt} \quad \forall t, j \tag{11.7}$$

$$\sum_{i=1}^{I}\sum_{p=1}^{P} x_{jipt} \le B_{jt} v_j \quad \forall t, j \tag{11.8}$$

The total amount of beer type p packed at brewery j cannot exceed its packing capacity each year. As above, constraint 11.9 (11.10) is for existing (candidate) breweries.

$$\sum_{i=1}^{I} x_{jipt} \le D_{jpt} \quad \forall p, t, j \tag{11.9}$$

$$\sum_{i=1}^{I} x_{jipt} \le D_{jpt} v_j \quad \forall p, t, j \tag{11.10}$$

The total amount of beer type p shipped from all breweries to each demand point i must satisfy the demand at that point each year.

$$\sum_{j=1}^{j} x_{jipt} = d_{ipt} \quad \forall i, p, t \tag{11.11}$$

Only one malt plant and one brewery will be opened.

$$\sum_{j=1}^{j} v_j = 1 \tag{11.12}$$

$$\sum_{k=1}^{k} u_k = 1 \tag{11.13}$$

Constraints on variables

$$z_{lkt},\ y_{kjt},\ x_{jipt} \ge 0 \quad \text{and } u_k,\ v_j \in \{0, 1\} \tag{11.14}$$

11.5 Solutions

The above model was generated using Visual C++ and solved by CPLEX 8.1 on a Pentium 4, 2.80 GHz computer with 520 MB RAM. We solved the model under various scenarios. In this section, we discuss the results obtained and their comparisons.

Table 11.2 2009 malt capacity usage

Malt plant	ME7	ME6	MP9
% Usage	–	100	68

11.5.1 The Optimal Solution

The optimal solution of the scenario without mixing grains is to open both the new brewery and malt plant in city 9. According to the optimal solution, malt capacity usages in 2009 are given in Table 11.2. Malt plant ME6 works at full capacity and the remaining demand is satisfied by the new malt plant. It is not economical to satisfy the malt requirements of breweries from ME7. Production cost, included in the transportation costs of the model, in malt plant ME7 is higher than others.

The beer capacity usages for production and packaging in 2009 are given in Table 11.3. When BE4 is closed to relocate, opening the new brewery at the alternative city closest to city 4 gives the best solution. Also, the new brewery uses most of its production and packaging capacities. Can and barrel capacity usages are very low for almost all breweries. This is due to high packaging capacities of the two cases compared to demand.

Table 11.4 reports the distribution of transportation costs among different activities in 2009. Barley and malt transportation constitute around 19 % of total costs, while beer transportation constitutes approximately 81 %. Also a high portion of beer transportation cost belongs to bottled beer. As will be discussed later, the alternatives for the new malt plant result in slight differences in the total cost.

11.5.2 Comparison of Potential Breweries

The solutions obtained for alternative brewery locations are compared and are given in Table 11.5. We forced the model to open the new brewery in one of the alternative locations and solved for finding the best location of the new malt plant and the optimal distribution plan. In the last two rows of Table 11.5, even though city 4 is not a potential location for the new brewery, we searched for the answer to the question, “What happens if the new brewery could be opened at city 4?” In the first implementation we let the model select the new malt plant’s location, and in the second implementation we force to open the new malt plant at city 4. In both implementations, the total costs are lower than the optimal total cost found in Sect. 11.5.1. Table 11.5 shows that the closer the new brewery is to city 4, the less the transportation costs will be.

Table 11.3 2009 beer capacity usage

Brewery	Production %	Bottle %	Can %	Barrel %
BE1	90	70	43	69
BE2	53	43	45	11
BE3	88	99	95	24
BE5	82	100	61	–
BP9	100	98	68	67

Table 11.4 2009 transportation cost proportions

	%	
Barley		13.5
Malt		5.8
Bottle	61.3	
Can	9.1	
Barrel	10.3	
Beer Total		80.7
Total		100.0

Table 11.5 Comparison of potential breweries (2009)

Beer	Malt	Percentage above the optimal
BP10	MP10	5
BP8	MP9	6
BP13	MP11	17
BP2	MP11	29
BP3	MP11	30
BP1	MP1	31
BP4	MP9	−6
BP4	MP4	−6

11.5.3 Comparison of Potential Malt Plants

We also compare the solutions obtained by opening the new malt plant in all potential locations. The results in Table 11.6 show that malt plant location has a small effect on the total cost, and the optimal brewery location BP9 is quite robust.

11.5.4 Capacity Alternatives for the New Brewery

As mentioned earlier, one of the decision problems that we dealt with in this study is the capacity of the new brewery. The previous models were solved assuming that the new brewery would be opened with a high capacity (and grains are not mixed). Another alternative is to open the new brewery with a small capacity

Table 11.6 Comparison of potential malt plants (2009)

Malt	Beer	Percentage above the optimal
MP2	BP9	1
MP11	BP9	1
MP6	BP9	2
MP12	BP9	3

Table 11.7 Results for opening the new brewery with small capacity

Malt	Beer	Percentage above the optimal
MP9	BP8	11
MP9	BP9	12

(almost half of the high capacity) and to expand when needed. Table 11.7 gives the comparison of these new results with the optimal solution, assuming high capacity. As seen in the first row of Table 11.7, the best locations are found to be BP8 for the brewery with small capacity, and MP9 for the new malt plant. The second row of Table 11.7 displays the optimal solution when a brewery with small capacity is opened at BP9. Note that these two solutions, with 11–12 % deviations from the optimal total cost found in Sect. 11.5.1, are very close to each other.

Building a brewery with a high capacity may not be advantageous due to making the high investment early. On the other hand, such a brewery may be advantageous due to savings in transportation costs and more production flexibility (having ability to adapt to unexpected situations). When these advantages are taken into account, we suggest opening the new brewery with high capacity.

11.5.5 Opening Second New Brewery

According to the long term demand forecasts, the brewery capacity of Efes will not be enough to meet demand in 2014. The model is solved to find the optimal location of the second new brewery, assuming that the first new brewery will be opened in BP9 and the second new brewery will start to work with full capacity in 2014. First, we let the model find the optimal malt plant location and MP11 turns out to be the best alternative. Then we consider opening the new malt plant in MP9. In both implementations, whose results are given in Table 11.8, BP13 is found as the (unique) optimal location for the new brewery.

Since the malt plant location does not significantly affect the total cost and city 9 is the optimal location of that plant before year 2014, opening the new malt plant in city 9 now seems more reasonable.

Table 11.8 Results for second new brewery

Malt	Beer	Percentage above the optimal
MP11	BP9 + BP13	0
MP9	BP9 + BP13	0.07

11.5.6 Barley or Malt Mix

It is important that Efes maintains the same quality and taste of products produced in different facilities. For this purpose, either the barley from different regions is mixed in malt plants in the same proportions (as given by constraint 11.15), or the malt supplied from different plants is mixed in breweries in the same proportions (as given by constraint 11.16).

$$z_{lkt} = \left(\sum_n z_{nkt}\right)\left(\frac{\sum_p z_{lpt}}{\sum_{n,p} z_{npt}}\right) \quad \forall l, k, t \tag{11.15}$$

$$y_{kjt} = \left(\sum_n y_{njt}\right)\left(\frac{\sum_p y_{kpt}}{\sum_{n,p} y_{npt}}\right) \quad \forall k, j, t \tag{11.16}$$

Both (11.15) and (11.16) are nonlinear. We can, however, linearize (11.15) as Efes works with barley producers on a contract basis. Considering the yearly agreements done in a given region, the amount of barley that would be supplied from that region is roughly estimated, and thus the total amount of barley supply from all regions is computed. For instance, the ratio of the annual total barley supply from region l to the total barley supply from all regions, $\left(\sum_p z_{lpt}\right)/\left(\sum_{n,p} z_{npt}\right)$ from Eq.(11.15), is computed. If we denote this ratio by rb_l for barley region l, that equation can be written as

$$z_{lkt} = \left(\sum_n z_{nkt}\right) rb_1 \quad \forall l, k, t \tag{11.17}$$

Alternatively, if we can assume that the amount of malt supplied from each plant is known, then we can find the ratio $rm_k = \left(\sum_p y_{kpt}\right)/\left(\sum_{n,p} y_{npt}\right)$ for every malt plant k. For instance, if we fix the supply amounts from malt plants at their supply amounts in the optimal solution of the case without mixing grains, we would have a linear approximation of (11.16), which can be written as

$$y_{kjt} = \left(\sum_n y_{njt}\right) rm_k \quad \forall k, j, t \tag{11.18}$$

Table 11.9 Effect of barley or malt mix on the transportation costs: Results when constraint (11.18) or (11.17), respectively, is appended to the model

	Malt plant	Percentage above the optimal
Malt mix	MP9	15
Barley mix	MP9	22

We add constraint (11.17) to solve the model enforcing the barley mix, and constraint (11.18) to solve the model enforcing the malt mix. As seen in Table 11.9, as expected, adding any of these constraints increases the transportation costs.

11.6 Conclusions

In their previous collaborations with Efes on the malt location problem, Köksalan and Süral (1999) conclude that "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." We believe that the current work fulfills their desire of using a general combined approach.

The procedure developed in Sect. 11.3.1 gives an effective yearly production capacity setting that leads to desirable monthly production and inventory control plans for Efes. It may be applied to any similar problem with seasonal variations in demand over a year.

Searching for effective solution techniques for the dynamic combined location, distribution, and inventory management problem with nonlinear constraints may be an interesting future research area.

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