PLANNING OF THE MEXICAN STEEL PRODUCTION

1 Introduction

The background to this project comes from a study of the steel production in Mexico, performed jointly by Mexico and the IMF. All numerical data comes from a report by David Kendrick, Alex Meeraus and Jamie Alatorre. The material has been adapted to a smaller project by aggregating the original data into fewer, larger regions.

The original report treated 6 coal mines, 8 ore mines, 9 steel mills consisting of more than 30 different production facilities, approximately 20 different groups of steel products and more than 30 different groups of raw materials and intermediate products. The finished products where distributed to nine different market areas and it was possible to import and export raw materials as well as intermediate and finished products. In this assignment we have eliminated the smaller mills and mines and aggregated market areas and product groups. We are left with one coal mine, 5 ore mines, 5 mills with 7 different production processes, two different kinds of raw materials, 2 different intermediate products, 2 consumer products and 3 different market areas.

The following sections gives a short description of steel production, in particular the processes used in the year 1985, which is when the study was originally done. After this follows a short description of the raw materials, the different steel mills, the processes in those mills, which intermediate and finished products are produced, and finally a short description of the different demand regions as well as the transportation system used in Mexico. The description includes prices, capacities, demand data and data regarding the efficiency of the different production processes.

2 STEEL PRODUCTION

During the last two centuries, steel has been produced in a two-step process, first the reduction of ore to raw iron, after this the removal of carbon in order to produce steel.

In the reduction phase of the production the iron ore, consisting mainly if iron-oxides, and coke is poured into a blast-furnace, where some of the coke is burnt to heat the mixture. The production includes a surplus of coke and at high temperatures, some of the coke reacts with the oxygen in the iron oxide reducing it to pure iron. In temperatures in excess of 800 degrees Celsius, coal tends to blend with the iron, hence the output form the blast furnace will be raw-iron containing approximately 4 % coal. A medium-sized blast-furnace may produce approximately 2000 tones of raw iron per day. The iron is tapped out every 3-9 hours, removing 300 - 900 tones of raw iron. Impurities in the ore and the coke forms a layer of slag floating on the raw iron. Different substances is added to the slag (mainly limestone) to decrease its viscosity in order to make it possibly to tap it off as well.

Some of the raw iron is used directly as pig-iron. As pig-iron is fairly brittle, one need to reduce the carbon contents below 1% in order to produce steel, which is more tough. At the time of this study three different processes were used to reduce the level of carbon.

In the Bessemer process, named after its British inventor, the hot raw iron is poured into a large container through which air is blown. The carbon reacts with the oxygen in the air producing carbon oxide, reducing the level of carbon in the steel. Unfortunately the nitrogen in the air may react with the iron reducing the strength of the resulting steel. To prevent this some mills are switching to using pure oxygen in the Bessemer process, a method which shows great potential.

In the Martin oven, named after the Frenchman Pierre Martin, the raw-iron is heated using large burners blowing hot air over large tubs of hot raw iron. An excess of oxygen in the hot air reacts with the carbon in the iron. An advantage of the martin oven compared to the Bessemer process is

Place	Capacity, Mton/Yr	Price, pesos/ton
Coahuila	13.2	500

Table 1: Data for the coal mines of Mexico

the possibility to add extra iron ore directly to the raw iron. The oxygen in the raw iron reacts with the carbon, reducing the carbon contents of the raw iron, and a cooling of the raw iron is obtained by adding the extra mass. The Martin oven is also named Siemens-Martin oven after some improvements of the processes heat-economy made by the German Siemens. The steel from these ovens is called SM-steel.

The third tempering-process is done in electro-ovens, The raw iron is kept in a large tub, similar to the Martin oven. The heat is provided by large electrodes, forming electric arcs to the tub of hot iron. Around the arcs, the carbon reacts with the oxygen in the air and the resulting carbon dioxide is vented out. The process is comparatively expensive, but produces steel of a higher quality compared to the two processes described above.

The processes described above having raw iron as an intermediate product has been used for a long time, although the combination blast-furnace/electro-ven is no longer used. A newer process used in the more modern mills in Mexico consists of reducing the iron ore to sponge iron using natural gas. The sponge iron is turned to steel using electro-ovens described above.

The liquid steel produced by any of these methods are poured into large chill-moulds. When the steel is cold enough (but still hot), it is transported to the rolling-mill, where it is formed to its final form of reinforcing bars, plates, beams e.t.c. During the rolling of the steel, it needs periodic re heating, in order to keep it soft enough to process

During the processing of the iron, there is a certain waste of material. As an example the rolling produces scrap-metal when the products are cut to standard lengths. These parts are returned to the production. In order to account for this, the coefficients given are compensated for this spillage. The usage of raw material and intermediate products given is hence the net consumption, and the capacities of the different processes are adjusted in a similar fashion to show net capacity.

3 THE COAL AND ORE MINES OF MEXICO

As mentioned before, this project is limited to studying the largest of the coal and ore mines. Although there are several small coal mines in Mexico this project settles for studying only the mines in the Coahuila-province which supplies the majority of Mexicos coal. Relevant data for this province are given in table 1.

Iron ore is produced mainly in 5 different areas. Data for the different areas are given in table 2. The quality factor in the table gives how large a fraction is effectively used in the production of iron. A quality of 0.9 means that the production requires 1/0.9 times the amount of ore used if the ore had quality 1.0.

The capacities of the different mines, both coal and ore, are adjusted to include the capacity of the smaller mines left out of the study. The capacity of the mines left out are added to the closest mine still in the study.

Place	Capacity, Muon/Yr	Quality	Price, pesos/ton
Penacol	6,60	0,91	140
Lastruchas	2,85	0,96	150
Laperla	3,47	0,96	150
Cerro-Mer	2,24	1,00	160
El-Encino	8,45	0,91	140

Table 2: Data for the ore mines of Mexico

Process / Product	Blast-furnace	Tempering in Martin oven	Tempering in oxygen oven
Iron ore, quality 1.00, ton	−2,30	–	–
Coal, ton	−1,52	–	–
raw-iron, ton	1,00	−1,06	−1,05
Steel, ton	–	1,00	1,00
Energy expenses, pesos	−63,5	−119,5	–
Other expenses– pesos	−720,0	−158,4	−179,6

Table 3: Input (−) and output (+) coefficients of the central products and processes of the mills in Ahmsa, Fundidora and Sicartsa.

4 EXISTING STEEL MILLS

Currently there are 5 large steel mills in Mexico. The three mills Ahmsa, Fundidora and Sicartsa uses a traditional blast-furnace combined with tempering in Martin or oxygen ovens. The other mills, Hylsa and Hylsap, uses reduction to sponge iron using natural gas, followed by tempering in electro-ovens. Relevant data for the different processes are given in table 3 and 4. The coefficients show input (−) and output (+) at unit production, and the relation between input/output and level of production is assumed to be linear. As an example we notes that producing one tonne of raw-iron in a blast-furnace requires 2.3 tonnes of ore and 1.52 tonnes of coal.

The numbers given in table 1 and 2 are normed and do hence not reflect some historical differences in efficiency between the different mills.

Only ore, coal, raw iron, sponge iron and steel are included in the tables. Other materials are aggregated in the entries energy expenses and other expenses. These entries cover the cost of natural gas, electricity, electrodes, salaries and so forth. A division into energy cost and other cost is done, as the price of energy is expected to rise more rapidly than other materials and salaries in the near

Process / Product	Reduction to sponge iron	Tempering in Electro oven
Ore, quality 1.00, ton	−2,11	–
Sponge iron, ton	1,00	−1,08
Steel, ton	–	1,00
Energy, pesos	−187,0	−315,0
Other expenses, pesos	−5,5	−148,2

Table 4: Input/output coefficients for the mills in Hylsa and Hylsap.

Steel mill / Process	Ahmsa	Fundidora	Sicartsa	Hylsa	Hylsap
Blast-furnace	4,30	2,40	1,20	–	–
Martin oven	1,95	0,95	–	–	–
Oxygen oven	2,17	1,60	1,40	–	–
Red. to sponge iron	–	–	–	1,08	1,10
Electro oven	–	–	–	1,23	0,66
plate production	3,50	2,20	1,40	1,30	1,00
Pipe production	1,50	1,20	0,55	0,20	–

Table 5: Capacity of the different processes, given in Mton output.

Energy expenses, pesos	44,2
Other expenses, pesos	5,3

Table 6: Costs for rolling 1 tone of steel.

future.

Coal is given as the input to the blast-furnaces, although coke is used. The coal is processed to produce coke at the mill. By-products of this production, such as gas, are sold or used in other processes. In the costs given these differences has been accounted for. In the data given for the Martin oven we have ignored the possibility if mixing in extra iron ore, in order to simplify the problem. In addition we have ignored the possibility of including scrap-metal in the process, and adjusted the coefficients as described earlier.

The capacity of the different steel-producing processes at the different mills are given in table 5. The cost of rolling the steel is given in table 6.

5 Demand

The demand is distributed over a large number of products, and it is neither practical nor possible to include all of them in a large-scale planning model. Hence the products has been aggregated to groups using approximately the same kind and amount of processing resources, making the products in a group interchangeable from a production perspective.

In this project we settle for only two groups, plates and pipes (including beams and bars). The rationale behind this division is that the newer mills almost exclusively produces plates, where as the older mills has a more versatile production capacity.

The demand prognosis is given as a total demand for all of Mexico, given in table 7, which is divided among the regions according to table 8. The demand distribution is assumed to be equal for the two groups of products. As an example we note that Mexico City has a demand of $0.5 * 3.28 = 1.64$ tonnes of pipes per year.

Product group	Demand, Mton
Plates	5,08
Pipes	3,28

Table 7: Demand of the two product groups.

Area	%
Mexico City	50
Monterey	31
Guadalajara	19

Table 8: Regional distribution of demand.

Steel mill / Mine	Ahmsa	Fundidora	Sicartsa	Hylsa	Hylsap
Coahuila	120	400	1500	400	1420
Penacol	1490	1396	337	1376	1116
Lastruchas	1416	1322	10	1312	995
Laperla	403	621	1797	626	1595
Cerro-Mer	677	636	1275	640	1245
El-Encino	1401	1307	965	1300	1033

Table 9: Distance by rail from mines to mills, Km.

6 EXPORTS AND IMPORTS

As given by the following problem formulation, the main focus of the study will be to find an production and transportation pattern which minimises the cost of supplying the domestic demand for steel, although it may be interesting to include import and export of products. As the cost of transportation is rather high, only import and export of plates and pipes will be of interest.

In the following description of the transportation system, "Import" is included as an additional producer, and the distance given is the distance between the demand area and the closest harbour. In the same fashion "Export" is included as a consumer, and the distance given is the distance between each mill and the closes harbour.

7 THE TRANSPORTATION SYSTEM

The coal, the ore and the finished products are all transported by railway, and we assume that the transport capacity present is enough to serve the demand. Hence the transport system does not impose any restriction on the production, but it is included as the cost of transportation will affect the optimal solution.

The transportation cost is divided into two parts. There is a starting cost for loading the goods and running the terminal. In addition to this there is a running cost proportional to the transportation distance. The distance between the mines and the mills is given in table 9. the distance from the mills to the demand areas are given in table 10. The cost of transportation is given in table 11.

Steel mill / Dem. area	Ahmsa	Fundidora	Sicartsa	Hylsa	Hylsap	Import
Mexico City	1204	929	819	920	185	428
Monterey	218	10	1305	17	1085	521
Guadalajara	1125	1030	704	1033	760	300
Export	739	521	10	520	315	–

Table 10: Distance by rail from producers(including imports) to consumers (including exports), Km.

Product group	Fixed costs, pesos/ton	Proportional cost, pesos/(ton*km)
Coal, ore	17,46	0,106
Plates	57,16	0,194
Pipes	57,16	0,204

Table 11: Fixed and proportional transportation costs for raw materials and products.

8 EXERCISES

Using the given information, construct a model minimizing the cost of supplying the domestic demand of steel in Mexico. You do not need to give explicit values of the coefficients in the model, on the contrary, we encourage the use of general notation, such as d_ij for the distance from mine i and mill j. The numerical constants are included for the second part of the project. The model should be clear and easy to understand, variables, constants, indexes and sets should be clearly defined. The purpose of each constraint or group of constraints should be stated. Each member of the group should, on request be able to answer questions regarding the model.

To the groups delivering a valid model, we will later distribute a version of the model, implemented in ampl, which will be used to answer questions.

The purpose of this project is to solve a problem large enough not to have a obvious solution, which is too often the case with exercises of lower dimension.

Good luck