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Dpto. de Historia Económica e Instituciones
Universidad Carlos III de Madrid
Calle Madrid, 126
28903 Getafe (Spain)
Fax (341) 624-98-75

LOCATION OF SPANISH INTEGRATED STEEL, 1880-1936

Stefan Houpt*

Abstract

This analysis questions whether or not Biscay was an optimal location for Spanish integrated steel mills at the end of the century and tries to determine Spain's optimal site as coal found substitutes all throughout the twentieth century. The contrast of the correct location of Spain's main production center is relevant, because a wrong location could have been introducing the inefficiencies and redundant costs which may have made Spain lose its competitivity on international markets and could have been biasing the competitivity of its products to low coal consumption. The suspicion of a mistaken location has been commented upon by a number of Spanish historians and economists.

The first part of this paper will introduce the relevant aspects for formalizing a model for the location of integrated steel mills; together with some specific considerations for the case of Spain. Part two will show the methodology applied, i.e. the underlying assumptions, the model of transport cost minimization and the calibration of parameters. The contrast of the model will be completed by combining each of the two alternative sources of coal with the different iron ore sites respectively. Each combination will give us the numerical results presented in the next section. We will be able to observe how the reduction of coal consumption affects the optimal location for each of these alternative combinations of inputs. At the same time it will be easy to identify 'the supreme site' given the overall tendency to reducing the weight of coal as an input.

Our preliminary conclusions were then scrutinized by introducing the different aspects excluded from the model. Uniform transport costs were questioned and the alternative of sea transport was contemplated. Scope economies, such as port capacities, ore transportation costs, and labor and capital availability were considered in order to question the results we have obtained. Our final conclusions are that Bilbao was second-best, but that Gijón as a feasible alternative never really existed. Locating Spain's principle steel mill in Bilbao guaranteed its technical drive to reduce coal consumption and sealed the loss of natural hegemony once its ore reserves depleted.

Keywords: Spain, Iron and Steel Industry, Location, Transport Cost Minimization, Weber.

* Houpt, Departamento de Historia Económica e Instituciones, Universidad Carlos III de Madrid and Saint Louis University, Madrid Campus. E-mail: houpts@spmail.slu.edu.

The question to be posed in this analysis is whether or not Biscay was an optimal location for integrated steel mills at the end of the century and and at the same time to determine how the optimal site we determine varies as coal found substitutes all throughout the twentieth century. A contrast of the correct location of Spain's main production center is essential, because a wrong location could have introduced the inefficiencies and redundant costs which made Spain lose its competitivity on international markets and could have biased the competitivity of its products to low coal consumption; both results obtained in our previous research. The suspicion of a mistaken location has been commented on by a number of Spanish historians and economists.

Nadal (1989) called it "a twist of logic" which situated the center of gravity of Spanish iron and steel industry near Biscay's ore mines rather than on Asturias' coal fields[1]. Tortella (1994), given the lack of coking coals and the competitivity of its ores, situates "competitive Spanish iron and steel industry outside of the country: in Cardiff, Newcastle, Essen, o Pittsburgh and not in Bilbao, Avilés, Málaga or Sagunto[2]." Tamames (1992) refers to picking Biscay as a prime location as "a site that did not result rational in the long run, [but that] followed a certain logic in its origins[3]." The existence of a mislocation has never been contrasted, nor have the criteria effecting it been formally exposed.

The first part of this paper will introduce the relevant aspects for formalizing a model to this extent together with some specific consideration for the case of Spain. Section two will show the methodology applied, i.e. the underlying assumptions, the model of transport cost minimization and the calibration of parameters. The numerical results presented in the next section are the result of combining the two alternative sources of coal with the different feasible iron ore sites. At the same time these tables will show how the reduction of coal consumption, the predominating technical change in this period, affects each of these alternative combinations of inputs. They will also allow us to identify 'the overall optimum site' given the overall trend to reducing the weight of coal as an input.

[1] Nadal (1989), p. 134.

[2] Tortella (1994), p. 74.

[3] Tamames (1992), p. 322.

These conclusions will be scrutinized by introducing different aspects originally excluded from the model. Uniform transport will be questioned and the alternative of sea transport will be contemplated, scope economies, such as port capacities, ore transportation facilities, labor and capital availability will be considered to question the results we have obtained. Our results show that Bilbao was second-best, but that Gijón as a practical alternative may never have really existed. We also find, that locating Spain's principal steel mill in Bilbao guaranteed its technical drive to reduce coal consumption and sealed the loss of natural hegemony once its high-grade ore reserves depleted.

The only thing that had made the Bilbao mills competitive internationally had been it preferential ore prices. English and Welsh coal were imported easily as an externality to iron ore exports, but the cyclical behavior of foreign coal prices and the decline of iron ore exports demanded different strategies. Scale and speed economies or product innovations which provided solutions to ailing mislocations elsewhere, could not be considered. Attaining scale and speed economies implied larger markets or selling abroad because the home market was limited. English and Welsh coal had no full substitutes to permit Spanish steels to compete on world markets. Basque mill's preferential ore contracts were limited which further inhibited scale economies and the product innovations which were dominating steel production —Siemens scrap steel, new alloys and structural steels— were being developed near to their emerging markets.

Location theory.

Von Thünen's 'Isolated State', published in 1842, is one of the first known treatise on location in economic theory. Von Thünen established the location process of agricultural activity. The use of different soils for particular crops and their distance from the potential market determined the plant strain or alternative use of land and its intensity. The industrial revolution was to change the focus of location theory and to bring manufacturing sites to the center of attention. Location problems in industrial transformation was defined from a very different perspective. The optimal production process itself was now predetermined and the problem was reduced to finding the optimal site given potential markets and input sources.

In this context location theorists of the German School[4] conceived a more general theory which incorporated von Thünen's work as a specific case in which land is considered an unconditionally source-bound commodity or what we now call an immobile stock. This explains why, in agricultural location, production factor combinations are established by and on the land. Whereas in transformation processes the knowledge of the 'state of the art' techniques determine the best practice and the location exercise is reduced to placing this process economically on the site which minimizing weight-distance transport costs of raw materials and final products. Alfred Weber's theory of industrial location — based on transport cost, fixed technical coefficients, and cost minimization— provides the ideal framework for optimizing the location of high volume, input-reducing industries with a low degree of permissible factor substitution, as is the case of the steel industry.

The procurement of natural resources in high volume transformation industries is a good point of reference for site selection[5]. The exact pinpointing of a site needs to consider the disposition of material factors as decision variables in the firm's objective of cost minimization. Nevertheless we do not find many bulk-transformation industry structures responding strictly to this criterion. This may be attributed to the fact that circumstances which determined location at the time of establishment, may have become obsolete, disappeared or have been forgotten in the meantime[6].

Also, producers will not only attend rationale related to resource-acquiring only but must counterbalance these attraccion forces with the proximity to their markets. The convexity of procurement and distribution costs with respect to distance will usually determine an extreme point location, i.e. near markets or inputs.

Location near inputs is very common in volume-reducing production processes such as the smelting of ores, crushing of sugar cane or those which imply large combustion of bulky fuel. Being

[4] Weber (1909), Predöhl (1925) and (1927), Engländer (1926), Weigmann (1931) and (1933), Palander (1935) and Lösch (1938) and (1940).

[5] see Lüth and König (1967), p. 141-2, Haven (1954), p. 347, Isard (1948), Day and Nelson (1973), Hekman (1978).

[6] see Arthur (1989), Rauch (1993) and Krugman (1991)

closer to production inputs would be strictly advantageous for volume-reducing processes, *ceteris paribus*[7], and if freight rates per ton were similar on materials and product. This is generally not the case: the transport of final products is more expensive than moving the equivalent amount of raw materials the same distance.

High terminal costs, both in shipping and rail transport, determine widespread discrimination in rates, usually in favor of materials and against products. The pattern of transport price discrimination reflects the lower unit value of material inputs and the greater demand elasticity for this kind of transport. Price discrimination is introduced to compensate the terminal costs of lines with low traffic.

Transshipment costs are another very relevant characteristic for final location. The railroad and shipping services mentioned before have high terminal but low line costs and are both ideal for bulk transports. They tend to promote concentration and integration of high volume production in large plants to reduce transhipments to a minimum. Junction points can reduce transshipment costs significantly and allow for one-haul provision of various materials each originating from different points[8]. These strategic advantages are especially pertinent in the case of ports and railheads[9].

Besides the high volume inputs mentioned above, processing costs will include direct labor costs, overhead costs, interest payments, rents, royalties, maintenance and depreciation, taxes and other

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[7] This is to say that the same process, with the same factor shares, will be applied if production is located near any of its materials or the market.

[8] Chandler (1975), pp. 264-5, show a map of the Edgar Thomson Works bordered by the Pittsburgh & Lake Eire Railroad (ore from Great Lakes), Pennsylvania Railroad (coal), Baltimore and Ohio Railroad and the Monongahela River. An excellent example of junction point location.

[9] For example: "Much of the world's productive capacity is found at places intermediate between material sources and the center of gravity of the material market —at ports. In moving between land and sea unavoidable transhipment costs are incurred. These costs of loading and unloading, and of the capital facilities used, must be borne no matter where the processing plant is located. If raw material is off-loaded straight over the dock into a processing plant and then the product is loaded straight onto the land carrier, clearly a set of loading and off-loading costs has been avoided compared with any other location than the material and market end-points." O'Sullivan (1981), p. 39.

conventional expenditures. When transfer costs vary little between alternative locations, these other processing costs will constitute the key element to location. This is the case of low volume material-input production.

As a summary we could establish the following patterns for transformation processes using more than one bulk material and turning out more than one bulk-reduced product, assuming all along that substitution of material factors is not applicable:

1. if the marginal procurement cost per added km per unit of product of one material is greater than the sum of all other material marginal procurement costs, the firm should locate near this dominant factor[10].
2. if no single force exceeds the sum of the others, the point of minimum transfer cost can be at any of the material sources or at some intermediate junction point depending on the exact composition of prices and costs. The optimal point is such that no other point produces at a cheaper total cost at the given prices structures and production possibilities[11].

As a first definition, we can define an optimal site as that, which provides a vector of prices and other circumstantial variables[12] which minimize costs for a firm. Specifically for the case of an integrated iron and steel plant, we can add some additional considerations.

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[10] "Dominance can be rigorously defined in the locational sense. A raw material of limited geographic occurrence is dominant in a transport-oriented production process when its weight exceeds the sum of weights of all other materials that have to be transported plus the weight of the finished product, with due modification for varying transport rates on raw materials and products." Isard (1948), p. 205.

[11] O'Sullivan (1981), p. 40 proposes minimizing the following total transport bill with respect to the coordinates x_0 and y_0 of plant location on a map:

$(x_0, y_0) = \sum a_i c_i d_i$ where

- * $\bar{a}_i$ is the weight of material i per unit of product, unity in the case of the product itself, or a fraction representing the proportion sold in each market if there are several markets.
- * c_i is the transport rate applicable to the good or material.
- * d_{i0} is the distance of source of material or market i to the location of the plant.

[12] circumstantial variables can be distance, supply delay times and factor quality variability.

The iron and steel industry uses two principal material factor, iron ore and coal, and two minor material inputs, limestone and scrap. Scrap was generally scarce in backward countries and frecuently replaced with pig iron. This narrows the important factors down to three, because pig iron was made with coal, limestone and iron ore. Or actually it reduces the input variable to two, because limestone is a very commonly found input. Considering both of these inputs, a number of relevant material sites can be considered for Spain: coal fields which qualify both in terms of coking coal quality and sufficient reserves were situated in Asturias and León, whereas the most important ore fields were in Biscay, Teruel, Almería, León and, given their relative proximity and early 20th century Spanish protectorate status, the Riff mines in Morocco.

During the 19th century input coefficients have varied in the production of iron and steel. For Spain, Biscayan foundries in 1827 averaged 3.02 mt of iron ore and 5.13 mt of charcoal to produce a ton of iron[13]. A one ton iron ingot in Navarran foundries in 1867 used 4.32 mt of charcoal and 2.88 mt of iron ore. A ton of puddle iron, the direct predecessor of steel, was being produced with 2.41 mt of ore and 2.32 of coal en *La Fábrica de El Carmen*, Biscay for the same year. These high volumes of coal and ore were reduced to some extent with modern blast furnaces and steel processes, but also dominated the modern era of steel production. A ton of Siemens-Martin steel consumed 1.75 mt of coal and 2.39 mt of ore in *Altos Hornos de Bilbao*, Biscay in 1890[14]. This gives a certain importance to the disposition of both coal and ore fields used for input supply. Even though the weight of coal and ore consumed worldwide per ton of final steel product summed up to more than 3 tons up to the middle of the twentieth century, we can observe that iron and steel plants have not always been located strictly following the criterion of proximity to either or both of them.

Geographical examples of oriented location:

Coal:

* Pittsburgh, Pennsylvania-US
* Youngstown, Pennsylvania-US
* Ruhr, Germany

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[13] Uriarte (1985), p. 140.

[14] Bilbao (1988), p. 245.

	* Durham, GB
Iron ore:	* Lorraine, France
	* Duleth, Great Lakes-US
	* Bilbao, Spain
	* Cleveland, GB
	* Middlesbrough, GB
	* Teeside, GB
Limestone:	* Volta Works, Brazil
Coal and ore:	* Birmingham, Alabama-US
Transhipment points:	* Cleveland, Ohio-US
	* Buffalo, Indiana-US
	* Gary, Indiana-US
Coastal or waterside:	* Sparrows Point, Baltimore-US
	* Stettin, Germany
	* Sagunto, Spain
Market:	* Ford Steel Plant Detroit, US

A general trend we can observe in the leading iron and steel companies could be the key to understanding sites which were not situated on coal fields. The amount of coal being employed to produce a ton of pig iron[15], was gradually and persistently reduced. Iron ore input oscillated between 1.6 and 3 tons depending on the degree of metallic content. Coal input was steadily reduced from 8 to 10 tons in the 1750's to an average 1.67 or 1.27 in 1938 for Great Britain and United States respectively. This reduction was due to the introduction of hot-blast techniques, the improved homogeneity standards of the coal used, and other improvements in the furnaces practices[16].

The table below, taken from Isard (1948), can illustrate this trend with aggregate data from the Iron and Steel Federation and Institute for Great Britain and US, respectively. As mills integrated backwards into coke production large energy savings became available. Both coke oven and blast

[15] Yields for pig iron are usually expressed in coke/pig iron but the conversion to coal is fairly easy. For Great Britain and US the average coke yield per ton of coal ranged between 60 and 70 percent. Isard (1948), p. 206 quoting US Bureau of Mines, *Mineral Yearbook*, annual issues and Burnham and Hoskins (1943), appendix III, pp. 303-313.

[16] see chapter 2 for a more detailed account of how these changes brought down per unit coal consumption.

Table 1. *Consumption of coal per ton of pig iron produced, 1873 - 1938*

year	Great Britain (tons)	United States (tons)
1873	2.55	-
1879	2.19	2.10
1884	2.06	-
1889	2.01	1.85
1894	2.00	-
1899	2.02	1.72
1904	2.02	1.70
1909	2.04	1.62
1914	2.06	1.57
1919	2.14	1.53
1924	2.01	1.45
1929	1.91	1.31
1934	1.75	1.28
1938	1.67	1.27

Sources: Home Office reports on mines and quarries (1894-1920), *Statistics of the Iron and Steel Industries*, of the British Iron and Steel Federation, data in the volume of manufactures of the *Tenth*, *Eleventh*, *Twelfth*, *Thirteenth*, and *Fourteenth Census of the United States*, and data in the *Annual Statistical Report* of the American Iron and Steel Institute. Table taken from Isard (1948), p. 205.

The table above, taken from Isard (1948), can illustrate this trend with aggregate data from the Iron and Steel Federation and Institute for Great Britain and US, respectively. As mills integrated backwards into coke production large energy savings became available. Both coke oven and blast furnace waste gases were used to generate energy needed for providing motion and heating to the rolling mills, for blasting machinery and for transportation of materials and products. A similar set of energy-saving economies became available as liquid iron was directly converted into steel or when fresh steel, which had soaked out heat evenly in a pit, was immediately rolled to its intermediate and final shape without being reheated. In the latter cases substantial reheating costs were avoided. Even further savings on coal consumption were introduced with the gas-driven electrification of motors in the twenties.

Coal reduction was a very gradual, input specific process. As late as 1953 ENSIDESA[17] in Asturias, off the northwest coast of Spain, projected a minimum of 1.43 tons of coal for processing

[17] see *INI Ensidesa - Proyecto de la Fábrica de Avilés*, June 1953.

Spanish iron ore from León to a ton of pig iron, and an additional 3-3.5 tons would have been necessary to process the necessary amount of pig iron to structural steel using coal as caloric input. The real amount to consider is significantly lower than that. Theoretically waste gas production would fully cover the heat requirements without using any additional coal except that applied to the processing of pig iron. Even though waste gases were being used as a source of heat and motive power in Spanish plants previous to the Civil War, we can not consider coal being fully replaced in the processing of iron to steel and of steel to its final rolled form. A reasonable 'guesstimate' for the total amount of coal employed in rolled steel products would be somewhere between 1.5 and 4 tons per ton of finished product. The amounts for iron ore, as we mentioned before, would then be between 1.6 and 2.2, depending on the iron content of the ores.

Before going on to applying these ranges of input consumption in the location model to be formulated, some industry specific caveats should be mentioned for interpreting the results obtained with both. So much money was invested in steel plants[18], that much more care was given to location than in other more disintegrated production processes with less voluminous inputs and outputs. The high fixed cost goes into explaining why this industry has been and is reluctant to changing both sites and equipment[19]. Even when technological advances have made older plants obsolete, Isard detected "slow response of business organization to these changes, owing to the conservatism [...] to the continually expanding scope of operations which was generally found expedient, if not necessary, and to the inflexibility and long life of iron and steel plant, which often tempted entrepreneurs to deter adopting new techniques until the old facilities were fully depreciated[20]." The model which we are

[18] Sánchez Ramos (1945), p. 285 estimates that the average mill investment at the end of the 19th century was around $ 10 million, $ 25 million around 1913, and close to $ 45 million in 1938. White (1957) estimates that it costs between 300 and 500 million dollars to build a plant in the late fifties.

[19] Adams and Dirlam (1966) consider the case of American steel producers delay in adopting the oxygen steelmaking process.

[20] Isard (1948), p. 211. The installations of an iron and steel plant in Völklingen, recently declared a monument of humanity were built in 1873 and renovated in 1923 but remained in use with slight improvements in its original parts until it closed down in 1986.

about to formulate will neither reflect these decisions nor explain why industry maintained mislocation if it existed.

The model.

The Weberian model we propose for the cost minimizing exercise is based on some of the assumptions included in the original model[21] and others have been added to apply it to this specific case.

Assumption 1: We are looking at one firm which produces a known amount of product.

Assumption 2: We have determined the weighted *loci* of consumption and the points of origin of raw material are known points in space.

Assumption 3: Transportation costs are uniform along each transportation vector.

Assumption 4: The production function is Leontief with fixed technical coefficients.

Assumption 5: The consumption distribution is known and remains invariable to changes in the location of the production center.

The generalization of Weber's original location triangle can be defined as the following points $\mathbf{O}_i$ (x_i, y_i) the iron ore mines, $\mathbf{C}_l$ (x_l, y_l) the coal fields and $\mathbf{B}_k$ (x_k, y_k) which we have generalized for (k = 1, 2, ... J) multiple consumption points. Originally the model was taken from Launhardt (1882). This methodology has been used by Kuhn and Kuenne (1962), Cooper (1967), Nijkamp and Paelinck (1973) and Paelinck and Nijkamp (1978).

The combined 'distance - transport cost - fixed material weight' pull of each of these points will codetermine the optimal production site in terms of transport cost minimization. Mathematically this can be expressed as below:

[21] see Paelinck and Nijkamp (1978), p. 34 for a summary.

Variables	$\mathbf{q_k}$	the amount of product distributed at consumption point $\mathbf{B_k}$.
	$\mathbf{q}$	the total volume of product.
	$\mathbf{r_i}$	the raw materials at **O** and **C**, (i = 1, 2)
	$\mathbf{d_i}$	the distance from the unknown production location to the raw material sites.
	$\mathbf{d_k}$	the distance from the unknown production location to the consumption center $\mathbf{B_k}$.
	$\mathbf{a_i}$	denotes the weight volume of raw material required to produce one weight unit of final product.
	$\mathbf{t_i}$	is the unit transportation cost per ton kilometer for raw material.
	$\mathbf{t_j}$	is the transportation cost per ton kilometer for finished products.
	$\mathbf{a_i \cdot q}$	is the total requirement of input $\mathbf{r_i}$ used to produce on unit of final product.
	$\mathbf{T_i = t_i \cdot d_i \cdot a_i \cdot q}$	is the total transportation cost of raw material $\mathbf{r_i}$.
	$\mathbf{T_k = t_k \cdot d_k \cdot q_k}$	is the total transportation cost of final products $\mathbf{q_k}$.

With these we can develop following equations to determine total transportation cost **T**.

$$(1)\quad T = \sum_{i=1}^{I} t_i d_i a_i q + \sum_{k=1}^{K} t_k d_k q_k$$

$$= \sum_{j=1}^{J=I+K} t_j d_j a_j q$$

$$for \quad j = (1, 2, \ldots, I, I+1, \ldots, I+K)$$

$$\wedge \quad \exists a_j \; such\,that \; a_j q = q_k \;\; \forall j > I \wedge \forall k$$

$$(2)\quad d_j = \sqrt{(x_j - x)^2 + (y_j - y)^2} \quad \forall j$$

$$(3)\quad q = \sum_{k=1}^{K} q_k$$

The optimal location will be found by minimizing respect to the unknown location, an unkown set of coordinates:

First Order Conditions

$$(3a)\quad \frac{\partial T(x,y)}{\partial x} = -\sum_{j=1}^{J} t_j a_j q \cdot \frac{x_j - x}{d_j} = 0$$

$$= -\sum_{j=1}^{J} \frac{t_j a_j q}{d_j} \cdot x_j + \sum_{j=1}^{J} \frac{t_j a_j q}{d_j} \cdot x = 0$$

$$\therefore \quad x = \frac{\sum_{j=1}^{J} \frac{t_j a_j q}{d_j} \cdot x_j}{\sum_{j=1}^{J} \frac{t_j a_j q}{d_j}}$$

$$(3b)\quad \frac{\partial T(x,y)}{\partial y} = -\sum_{j=1}^{J} t_j a_j q \cdot \frac{y_j - y}{d_j} = 0$$

$$= -\sum_{j=1}^{J} \frac{t_j a_j q}{d_j} \cdot y_j + \sum_{j=1}^{J} \frac{t_j a_j q}{d_j} \cdot y = 0$$

$$\therefore \quad y = \frac{\sum_{j=1}^{J} \frac{t_j a_j q}{d_j} \cdot y_j}{\sum_{j=1}^{J} \frac{t_j a_j q}{d_j}}$$

Second Order Conditions

In order to define a transport cost minimum, the transport cost function **T** should be convex. As **T** is the sum of distance functions $\mathbf{d_j}$, it will be sufficient to show that $\mathbf{d_j}$ is convex for all j, i.e. that its Hessian matrix is semi-definite positive.

$$H = \begin{bmatrix} \frac{\partial^2 d_j}{\partial x^2} & \frac{\partial^2 d_j}{\partial x \, \partial y} \\ \frac{\partial d_j}{\partial x \, \partial y} & \frac{\partial^2 d_j}{\partial y^2} \end{bmatrix} = \begin{bmatrix} d_j^{-1} - (x_j - x)^2 d_j^{-3} & -(x_j - x)(y_j - y) d_j^{-3} \\ -(x_j - x)(y_j - y) d_j^{-3} & d_j^{-1} - (y_j - y) d_j^{-3} \end{bmatrix}$$

This verifies when the eigenvalues of the determinant are non-negative. Using the properties of quadradatic expressions:

$| H-\lambda I | = (h_{11} - \lambda)\cdot(h_{22} - \lambda) - h_{12}\cdot h_{21} = \lambda^2 - (h_{11} + h_{22})\cdot\lambda + h_{11}\cdot h_{22} - h_{12}\cdot h_{21}$

the λ's will be non-negative if:

1. the trace of the Hessian is positive, i.e. $h_{11} + h_{22} > 0$, and
2. the determinant of the Hessian is non-negative, i.e. $h_{11}\cdot h_{22} - h_{12}\cdot h_{21} \geq 0$.

1.
$$d_j^{-1} - (x_j - x)^2 d_j^{-3} + d_j^{-1} - (y_j - y)^2 d_j^{-3} =$$
$$d_j^{-1}[1 - (x_j - x)^2 d_j^{-2} + 1 - (y_j - y)^2 d_j^{-2}]$$
$$d_j^{-1} \textit{ is positive} \quad \wedge$$
$$[(x_j - x)^2 + (y_j - y)^2] d_j^{-2} < 2$$
$$d_j^2 \cdot d_j^{-2} < 2 \qquad q.e.d.$$

2.
$$[d_j^{-1} - (x_j - x)^2 d_j^{-3}]\ [d_j^{-1} - (y_j - y)^2 d_j^{-3}] - [-(x_j - x)(y_j - y) d_j^{-3}]^2 \geq 0$$
$$d_j^{-2}\ [1 - (x_j - z) d_j^{-2}]\ [1 - (y_j - y) d_j^{-2}] - (x_j - x)^2 (y_j - y)^2 d_j^{-6} \geq 0$$
$$d_j^{-2} - [(x_j - x)^2 + (y_j - y)^2] d_j^{-4} + (x_j - x)^2 (y_j - y)^2 d_j^{-6} - (x_j - x)^2 (y_j - y)^2 d_j^{-6} \geq 0$$
$$d_j^{-2} - d_j^2 d_j^{-4} \geq 0 \qquad q.e.d.$$

This can be shown to be true and because of this, we know that any local optimum of T is a unique global minimum of this transportation problem. The first order conditions provide a system of non-linear equations which require a solution algorithm, which will generate a numerical solution for the optimum in a finite number of stages. The parameters are defined below and the algorithm is included in appendix F.

The iron ore mines and coal fields for the exercise have been determined by their degree of importance, reserves and quality. Fernández-Miranda (1925) has been very useful for identifying both the coal fields[22] and iron ore mining districts[23]. We have chosen the coal fields near Mieres in Asturias and La Robla, León - given their sufficient coking, steam and heat qualities[24]. The choice of the mining districts includes the mines around Bilbao and Castro Urdiales, the Sierra Menera mines in Teruel and Guadalajara, the mines in Almería and Granada, the mines near Ponferrada in León and, as a remote option, we have added the Riff mines in Morocco given their relative proximity and their Spanish protectorate status until 1956. We had identified the amount of coal consumed for a ton of final steel product as somewhere between 1.5 and 4 tons per ton of final output[25]. The model will consider locations for discrete amounts, between 1.5 and 4 tons, being employed per ton of final steel product made. The weight of the iron ores in the finished products has been determined with much higher

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[22] Fernández-Miranda Gutiérrez (1925), p. 21, shows the major coal producing areas in 1922, the maximum amount produced in one year, their probable reserves and the coal classes available.

[23] Fernández-Miranda Gutiérrez (1925) shows regional iron ore production between 1913 and 1922 by provinces. Apraiz Barreiro (1978), pp. 122-124, complements that with a description of the most important iron ores used to the date, their chemical composition, annual production, and reserves.

[24] Merello Llasera (1943), pp. 80 and 88, defines the mines around Mieres and La Robla as the only coal mining districts capable of supplying coal for coking and steel processing purposes. Merello was a mining engineer, who worked as Director of *Altos Hornos de Vizcaya's* coal mines in Asturias for 6 years and was Chief Executive Officer of AHV for 27 years.

[25] Between 1.4 and 1.5 tons of coal are necessary to reduce them to one ton of coke. Approximately 0.9 tons of coke were used to process ore to pig iron. Further processing of pig iron to steel and steel to its final form used energy equivalent to 3.5 tons of good quality coal. We assume the at least one ton of coal energy had been already replaced by waste gas energy which gives us the upper bound, a 4 ton total consumption for one ton of steel product. The lower bound is assuming that gradually all coal consumption with the exception of coking coal could be substituted for waste gas energy, leaving us with a minimum requirement of 1.5 tons.

precision. As processing losses are compensated by a small percentage of scrap added in steel processing, the various ores have only been adapted to reflect their different iron contents[26].

The major consumption points are projected from the steel demand schedule provided by Paris Eguilaz (1954) for 1953. The coordinates used in the algorithm, concentrate the regional consumption figures in the region's capitals. This is the earliest regional breakdown of steel consumption we have

Table 2. *The weight of Spanish iron ore in steel products.*

Iron Ores from	Iron Content	Ore needed for 1 ton of steel product
Bilbao - Castro Urdiales	49 %	2.05 tons
Sierra Menera	53 %	1.90 tons
Almería - Granada	55 %	1.80 tons
Ponferrada, León	50 %	2.00 tons
Riff, Morocco	64 %	1.60 tons

Source: Apraiz (1978), p. 262-4.

been able to find. The demand schedule is probably biased by over a decade of economic autarky and far below the 1 million ton production of steel obtained in 1929, but it is indicative of the consumption patterns for steel inputs in industry, transport and construction. We can assume that population distribution and previously existing economic structure has remained relatively unchanged and is determining demand to a great extent. Also the algorithm will be normed to one unit of production and later generalized to production of half a million tons of steel products[27]. The solutions are insensitive to production levels. But it will be interesting to interpret both the total cost of transport and the total ton-kilometers transported.

The last set of parameters that need to be defined are transport costs. As we have assumed uniformity of transport costs, we will assign a unique transport cost to each coal, ore and final products. Origin and destination will not be taken into account. As a benchmark we have used the rail

[26] Data on the iron content were taken from Apraiz (1978), pp. 122-4.

[27] Barreiro Zabala (1943) shows steel products around that level between 1925 and 1931 and later in 1940/1. This figure has been chosen arbitrarily but within the capacity the production centers.

fare for a ton of coal from Mieres, Asturias to Bilbao, 15 pesetas[28] which represents a per ton/km fare of around 0.049 pesetas. We have indexed railway freight price differentials for coal, iron ore and steel products for the United States in 1932 in the middle of economic depression. Rail freight rates themselves may not be considered strictly comparable as distances, rolling stock, demand, etc. differ considerably from Spain. Nonetheless we can consider these depression year figures as indicative of the added value and elasticities which determined the discriminated fares of each of these bulk transports.

Table 3. *Breakdown of Spanish steel product demand in 1953 by provinces.*

Provinces	Percent	Tons	Provinces	Percent	Tons
Biscay	24,508	140.186	Orense	0,259	1.481
Barcelona	14,103	80.669	Palma	0,258	1.476
Madrid	10,609	60.683	Logroño	0,248	1.419
Guipuzcoa	9,787	55.982	Almería	0,197	1.127
Foreign Sales	8,189	46.841	Jaén	0,146	835
Oviedo	5,954	34.057	Castellón	0,143	818
Valencia	3,265	18.676	Teruel	0,135	772
Seville	2,894	16.554	Badajoz	0,127	726
La Coruña	2,046	11.703	Huesca	0,121	692
Saragossa	1,739	9.947	Palencia	0,112	641
Valladolid	1,635	9.352	Lugo	0,108	618
Santander	1,473	8.426	Tenerife	0,089	509
Cádiz	1,376	7.871	Toledo	0,087	498
Málaga	1,205	6.893	Guadalajara	0,073	418
Murcia	1,186	6.784	Gran Canaria	0,070	400
Pontevedra	1,140	6.521	Cáceres	0,058	332
León	0,975	5.577	Granada	0,049	280
Navarra	0,882	5.045	Gerona	0,047	269
Burgos	0,778	4.450	Segovia	0,036	206
Ciudad Real	0,750	4.290	Albacete	0,012	69
Alava	0,682	3.901	Cuenca	0,008	46
Alicante	0,432	2.471	Soria	0,008	46
Tarragona	0,363	2.076	Avila	0,004	23
Córdoba	0,345	1.973	Morocco	0,017	97
Lérida	0,307	1.756	Guinea	0,017	97
Huelva	0,301	1.722			
Salamanca	0,286	1.636	TOTAL	99,904	571.451
Zamora	0,265	1.516			

Source: Paris Eguilaz, H. (1954), Problemas de la Expansión Siderúrgica en España, Madrid. p. 42.

[28] Ojeda (1985), p. 221.

These indexed ratios[29], 127.7 for ore to coal and 226.2 for steel products to coal, are used toextrapolate the ton/km fares of coal, iron ore and finished steel products which maintain these relative price ratios and are close to our benchmark. Coal fares are fixed at 0.0442[30] pesetas per ton and kilometer, iron ore at 0.0564 pesetas and steel products at 0.1 pesetas.

Numerical Results.

Using the two alternative coals as the basis for two separate exercises, they have been combined alternatingly with each of the five iron ores and the proposed demand schedule. The amount of coal used in processing a ton of steel products has been reduced stepwise from 4 tons, which was the upper bound we had established for the beginning of the century, to 1.5 ton which was the lower bound established by the state of the arts in the 1950's.

The results show two clear patterns, at maximum coal consumption levels (4 tons), the cost minimizing site is in Asturias or La Robla respectively, and as we reduce the amount of coal needed, the optimal site is either the ore site or an intermediate point between coal and iron ore location. The overall optimum in terms of the discrete amounts of coal shown here, is in Vizcaya for both coals at a 1.5 ton coal consumption. This combination has a lowest total transport cost of around 28.5 million pesetas. Seen in the context of the model, this is indicating coal sites for high coal consuming production techniques. This was best practice at the end of the 19th century. Therefore Bilbao would have been a mislocation in its beginnings. The model also indicates that this initial mislocation would have been overcome by the steady decrease of coal required to process one ton of steel product. In terms of the analysis we have presented in earlier chapters, we know that those initial inefficiencies and cost redundancies that may have existed in the origins of

[29] Berger (1951), Appendix C, table C-1, pp. 196-7.

[30] This has been biased downward to allow for some adjustment to higher quantities being transported, but the criteria has been to normalize final product transportation to 25 % above the average transportation cost for all goods on the *Caminos de Hierro del Norte de España* and the *Ferrocarril Madrid Zaragoza Alicante* lines, rail tariffs for this calculation were taken from Tedde de Lorca (1978), table IV-17, p. 99. The 25 % differential between average product fare and steel product fare are taken from Berger (1951), p. 199.

the Bilbao mills, disappeared as these mills integrated, tethered alternative energy source, electrified their factories and introduced coal saving innovations. Mislocation may have made their secondary products uncompetitive early on, but these losses due to misallocations should have disappeared throughout the first half of the century.

Table 3. *Optimum locations using Asturian coal.*

	Coal Asturias tons	Coordinates X	Coordinates Y	Transport Cost million Ptas	Total Distance thous. kms	Location
Ore Bicay	4	4.0	11.0	42.2	35.58	Mieres
	3.5	6.0	10.8	40.9	33.13	
	3	6.7	11.0	37.9	33.83	
	2.5	6.8	11.0	34.7	33.83	
	2	6.8	11.0	31.5	33.83	
	1.5	6.8	11.0	28.3	33.83	Bilbao
Ore Teruel	4	3.9	11.0	57.5	36.04	Mieres
	3.5	5.1	10.2	56.7	31.21	
	3	5.9	9.6	54.5	28.94	
	2.5	6.5	9.0	51.4	27.58	
	2	7.3	8.2	47.1	26.72	
	1.5	8.2	7.3	41.5	27.32	Setiles
Ore Almería	4	3.9	11.0	77.0	36.08	Mieres
	3.5	4.3	10.4	76.8	33.05	
	3	5.0	9.4	75.3	29.06	
	2.5	5.5	8.3	72.5	26.55	
	2	6.1	6.6	68.0	24.97	
	1.5	6.1	6.3	62.5	25.06	Getafe-Madrid
Ore Ponferrada	4	3.9	11.0	34.2	36.08	Mieres
	3.5	3.9	11.0	34.2	36.08	
	3	3.9	11.0	34.2	36.08	
	2.5	3.8	10.7	34.1	35.12	
	2	3.6	10.3	33.5	34.20	
	1.5	3.1	9.9	32.4	34.50	Ponferrada
Ore Riff	4	3.9	11.0	72.1	36.08	Mieres
	3.5	3.9	11.0	72.1	36.07	
	3	4.5	10.1	71.7	31.89	
	2.5	5.1	9.2	69.8	28.38	
	2	6.0	8.0	66.7	25.99	
	1.5	6.1	6.6	61.8	24.97	Madrid

Table 4. *Optimum locations using León Coal.*

	Coal León tons	Coordinates X	Y	Transport Cost million Ptas	Total Distance thous. kms	Location
Ore Biscay	4	3.9	10.1	41.4	32.88	La Robla
	3.5	5.3	10.3	40.7	31.67	
	3	6.6	10.9	38.4	33.29	
	2.5	6.7	11.0	35.1	33.83	
	2	6.8	11.0	31.8	33.83	
	1.5	6.8	11.0	28.5	33.83	Bilbao
Ore Teruel	4	3.9	10.1	53.2	32.90	La Robla
	3.5	4.8	9.7	52.9	30.13	
	3	5.7	9.2	51.2	27.99	
	2.5	6.4	8.7	48.4	26.89	
	2	7.2	8.0	44.7	26.46	
	1.5	8.2	7.2	39.7	27.33	Setiles
Ore Almería	4	3.9	10.1	71.2	32.90	La Robla
	3.5	4.0	10.1	71.2	32.54	
	3	4.7	9.1	70.4	28.62	
	2.5	5.4	8.0	68.3	26.23	
	2	6.1	6.6	64.5	24.97	
	1.5	6.1	6.2	59.9	25.14	Aranjuez
Ore Ponferrada	4	3.9	10.1	30.3	32.90	La Robla
	3.5	3.9	10.1	30.3	32.90	
	3	3.9	10.1	30.3	32.90	
	2.5	3.9	10.1	30.3	32.90	
	2	3.9	10.1	30.3	32.90	
	1.5	3.8	10.1	30.3	32.89	La Robla
Ore Riff	4	3.9	10.1	67.0	32.90	La Robla
	3.5	3.9	10.1	67.0	32.90	
	3	4.1	9.8	66.9	31.60	
	2.5	5.0	8.8	65.8	27.86	
	2	5.6	7.7	63.4	25.71	
	1.5	6.1	6.6	59.2	24.97	Madrid

Discussion of results.

The first important variable to be reexamined in order to contrast the relevance of these results is the formalization of transportation cost. We have assumed that transport cost is uniform, i.e. equivalent in any direction and that the transport distance paid will be the shortest distance between two points, a straight line. The transport system used well up to the Civil War was a combination of coastal shipping and rail transportation. The geography of Spain, especially its topography, shows that land transport is highly disfavored by the ascent and fall of the sierras which surround the two central mesetas. Sea transport to a point of easy access was many times preferable to land transport.

We have readapted the previous parameters for a seaboard model. All inland steel demands have been allocated in the following way:

a) the dominant criterion has been to choose the ports which provide the minimum number of railway transshipments on its way to the final destination; ideally one-haul routes were chosen.

b) as a secondary criterion, if equivalent transshipment hauls existed, we chose the port which minimized the distance to the final destination.

We maintained the freight differentials between coal, ores and final products as those used above, given that we assume the same added value differentials and elasticities. We establish the per-ton and kilometer sea freight for coal at 0.015 pesetas, less than a third of rail fare[31]. Sixteen major ports were chosen given their importance as a final consumption point or as a transshipment points to inland demand. They were ordered in one dimension according to the distance between them.

Almost all the non-port consumption points had unique optimal land routes, with the exception of Madrid with alternative routes. The islands and foreign locations posed additional problems. The consumption of the Balear Islands was included with Valencia, that of the Canary Islands was added to Cádiz. Madrid and foreign sales were finally assigned to Barcelona as a strong bias against Cantabrian ports which is where coal was located. As we can assume that the decision rule taken for assigning the

[31] We have used freights for Asturian coal to Barcelona and Bilbao to regress the fixed component of freight, between 4 and 5 pesetas, and the variable component which depends on distance, between 0.015 and 0.022 pesetas. These calculations are for 1890 and 1895. As 1890 was a year of exceptionally high English coal prices in Spain which may have biased Spanish coal freights we chose the second benchmark. Our rail-fare benchmark was for 1894 so this is quite coherent.

inland transport minimizes its cost, this would allow us to abstract the transport cost minimization problem to that of reducing sea transport. Table 5 below shows the results.

Table 5. *Optimum locations for coastal transport.*

	Coal Asturias tons	Coordinate Y	Transport Cost million Ptas	Total Distance thous. kms	Location
Ore Vizcaya	4	4,5	34,69	36,35	Gijón
	3,5	4,5	34,69	36,35	
	3	4,5	34,69	36,35	
	2,5	4,4	34,69	36,35	
	2	1,1	34,20	41,27	
	1,5	1,1	32,95	41,28	Bilbao
Ore Teruel	4	4,5	81,60	36,35	Gijón
	3,5	4,5	81,60	36,35	
	3	4,5	81,60	36,35	
	2,5	4,5	81,60	36,35	
	2	22,8	78,11	26,93	Seville
	1,5	34,9	67,85	34,86	Valencia
Ore Almería	4	4,5	72,30	36,35	Gijón
	3,5	4,5	72,30	36,35	
	3	4,5	72,30	36,35	
	2,5	4,5	72,30	36,35	
	2	23,5	67,91	26,93	Cádiz
	1,5	28,9	58,87	28,47	Almería
Ore Ponferrada	4	4,5	28,17	36,35	Gijón
	3,5	4,5	28,17	36,35	
	3	4,5	28,17	36,35	
	2,5	4,5	28,17	36,35	
	2	4,5	28,17	36,35	
	1,5	4,5	28,17	36,35	Gijón
Ore Riff	4	4,5	65,33	36,35	Gijón
	3,5	4,5	65,33	36,35	
	3	4,5	65,33	36,35	
	2,5	4,5	65,33	36,35	
	2	8,8	65,17	32,91	La Coruña
	1,5	28,9	58,87	28,47	Almería

A first result to be underlined, is that Gijón comes out much stronger than in the previous exercises. The coal coefficient has to drop below 2.5 tons per ton of steel product to break Gijón's grip on minimum transport costs for any of the iron ores used. The absolute minimum of 28.17 million pesetas, for Ponferrada ores and 1.5 tons of coal in Gijón, tends to reaffirm the adequate location of the Spanish public-owned integrated mill, Ensidesa, in the late fifties.

Our seaboard model strengthens the view of Bilbao as a mislocation and question its status as the overall optimum location. The depletion of Biscay's ores reserves and its falling ore grades reinforce this conclusion. The transport savings which could have been attained by locating steel production in Gijón, were around 5 million pesetas a year or 14.5 percent of sea transportation cost, for a production of half a million tons of finished products. At the same time it is important to remember that once Biscayan factories ran out of home ores they would lose considerable pull on the optimum site. Locations move along the coast to the west and then to the south when we consider using southern reserves while and coal inputs below 2 tons.

We must be cautious about jumping to wrong judgments. An important premise for conclusions are the significant scope economies provided by the iron ore mining sector in the Bilbao area. Harbor facilities and the line and tramp shipping gave Bilbao clear advantages over Gijón. According to Frax (1981) the volume of coasting trade docking at Bilbao and Gijón are similar. Between 1878 and 1920 they average 347,200 tons for Bilbao and 385,000 tons for Gijón[32]. In the case of Gijón practically all of its maritime trade was limited to other Spanish ports. For Bilbao this was far from true, the volume being shipped to and from Spanish ports was only 8 % of its total shipping volume[33]. The potential for commercial expansion in Bilbao was backed by a modern harbor. Gijón's limited harbor facilities had been a serious impediment for expanding coal production in Asturias already at the turn of the century[34]. Gijón admitted a gross tonnage of around 300 t, one fifth of average British tonnage towards the end of the 19th century and the water line dropped below navigation limits twice a day when the tide went out. Bilbao had not only modernized its installation to

[32] Frax (1981), pp. 93 and 102. Standard deviations are 275,000 and 260,800 respectively, due mainly to a significant increase in coastal shipping volume during World War I.

[33] Churraca (1951), table 8. These figures have been contrasted with data obtained from the Spanish Foreign Commerce data presented by Puerta (1994), table 13, p. 127. for decades and similar results for those reference points are obtained.

[34] Ojeda (1985), p. 229.

admit higher tonnages but its lighting and signaling services allowed boats to navigate day and night and it had an extensive Ría for docking and loading facilities.

A second scope economy can be found in the availability of capitals and potential investors. González Portilla (1974) tries to quantify the benefits obtained from iron ore mining and how these capitals were available for reinvestment in the iron and steel industry. Although Valdaliso (1988) has questioned the amount reinvested by mine owners and mining companies in major iron and steel processing enterprises, his figure is still considerable (25% of iron and steel capital proceeds from mining capitals). The infrastructures and economic activity created with its mining boom attracted investors to Bilbao. This was important as the dimension of steel mill investments introduce important liquidity constraints when important investments were necessary. Strong capital injections from outside their industry were needed to overcome the initial liquidity constraints blocking long-run economies. The availability of capitals was crucial for including such investments in firm strategies. Over two billion pesetas were invested in incorporated companies in Bilbao between 1900 and 1936[35], that is eleven times as much as the leading Basque company, *Altos Hornos de Vizcaya*, invested over the same time period.

But the extractive activity had even further externalities, it had created its own transportation infrastructure for bringing ore into the port[36] as 80% of the mineral was exported. This lowered ore transport costs of ores for river side locations considerably[37]. Iron ore extraction also attracted work force to the mining district; the estimated work force for the area surrounding the Ría grew from

[35] Churraca (1951), pp. 108-110.

[36] The port of Bilbao had been improved to allow for a more fluent export of iron ore for which there was a high demand in Great Britain, but at the same time this provided import facilities and the possibility of applying backhaul rates for returning ships.

[37] The five major ore railways had their loading bays in direct neighborhood of the *Altos Hornos de Vizcaya* factories.

26,700 to 72,200 workers between 1877 and 1900[38]. While ore mining attracted unqualified workers, it was an intermediate step to a disciplined working class and in the medium run, other activities were sure to offer better opportunities. In 1896 around 4,000 workers were being employed in Bilbao's steel mills[39]. By 1909 that number had increased to 5,620 and by 1924 to 6,982 alone for the *Altos Hornos de Vizcaya* factories[40].

Two of these factories, Baracaldo and Sestao were the original sites of two of the firms which merged to create *Altos Hornos de Vizcaya* in 1901. The riverside location of both sites together with the company towns constructed around them seriously limited the area left for expansion. While elsewhere plants were doubling and tripling size and extension[41], the Sestao and Baracaldo plants' expansion were restricted in this sense. But the same can be said for the more important Asturian factories, *La Fábrica de Mieres* and *Duro-Felguera,* both were situated in narrow valleys with little space for expansion[42].

These numerical exercises have been conclusive for determining the optimum site on coal fields in terms of domestic transport of products and inputs. But we have seen that there were a number of important criteria that tipped the balance in favor of Bilbao, which was an optimum site for processing its own ores and when reducing total coal consumption below 2 tons of coal. The nature of mislocation, if it ever existed, was of such nature that it was gradually corrected through the reduction

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[38] Shaw (1977), p. 95. Iron ore production rose from 432,418 mt in 1876 to 4,691,000 mt in 1887 and to 5,361,796 in 1900. Population in the mining areas grew from 40,159 persons in 1857 to 105,728 in 1887 and 167,680 in 1900. Gonzalez Portilla (1974), pp. 53, 81 and 82.

[39] Shaw (1977), p. 98.

[40] *Monografía de la Sociedad Altos Hornos de Vizcaya de Bilbao* (1909), Barcelona: Thomas, p. 55. and *Monografía de las industrias siderúrgicas propiedad de la Sociedad Altos Hornos de Vizcaya* (1924), p. 34.

[41] Chandler (1977) describes how US plants for iron and steel processing were being built bigger and more extensively for the late nineteenth and earlier twentieth century. The same can be seen in the Krupp and Thyssen works in Germany or the Bulckow works in Great Britain.

[42] State technicians discarded either of the sites for locating the second integrated iron and steel complex after the Spanish Civil War for this and other reasons.

of coal consumption, and in that sense as long as Biscay used it own ores, it could remain an efficient site. Once its ores were replaced by others, its seaboard location, the accumulated linkages to surrounding industries and the rent-seeking stategy it had adopted would be what permitted *Altos Hornos de Vizcaya* to persist as a prime site in time.

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Appendix F. *Weberian location algorithm.*

```
A =  {0,     /* coal Asturias */
      1.5,   /* coal León */
      0,     /* 2.05 iron ore Vizcaya */
      0,     /* 1.85 iron ore Teruel */
      0,     /* 1.9 iron ore Almería */
      0,     /* 2.1 iron ore Wagner-Vivaldi */
      1.6,   /* 1.6 iron ore Riff */
     .24508, /* Vizcaya */     /* Demanda Siderúrgica - Pedidos cursados */
     .14103, /* Barcelona */   /* por Central Siderúrgica */
     .10609, /* Madrid */
     .09787, /* Guipuzcoa */
     .05954, /* Oviedo */
     .03265, /* Valencia */
     .02894, /* Seville */
     .02046, /* La Coruña */
     .01739, /* Zaragoza */
     .01635, /* Valladolid */
     .01473, /* Santander */
     .01376, /* Cádiz */
     .01205, /* Málaga */
     .01186, /* Murcia */
     .0114,  /* Pontevedra */
     .00975, /* León */
     .00882, /* Navarra */
     .00778, /* Burgos */
     .0075,  /* Ciudad Real */
     .00682, /* Alava */
     .00432, /* Alicante */
     .00363, /* Tarragona */
     .00345, /* Córdoba */
     .00307, /* Lérida */
     .00301, /* Huelva */
     .00286, /* Salamanca */
     .00265, /* Zamora */
     .00259, /* Orense */
     .00258, /* Palma */
     .00248, /* Logroño */
     .00197, /* Almería */
     .00145, /* Jaén */
     .00143, /* Castellón */
     .00135, /* Teruel */
     .00127, /* Badajoz */
     .00121, /* Huesca */
     .00112, /* Palencia */
     .00108, /* Lugo */
     .00087, /* Toledo */
     .00073, /* Guadalajara */
     .00058, /* Cáceres */
     .00049, /* Granada */
     .00047, /* Gerona */
     .00036, /* Segovia */
     .00012, /* Albacete */
     .00008, /* Cuenca */
     .00008, /* Soria */
     .00004, /* Ávila */
     .00089, /* Tenerife */
     .00070, /* Gran Canaria */
     .00017, /* Marruecos */
     .00017, /* Guinea */
     .08189}; /* Extranjero */
```

```
X =  {3.85 11,        /* Asturias coal */
      3.9 10.125,   /* La Robla coal */
      6.75 11,      /* Vizcaya coal */
      8.5 7,        /* Teruel iron ore */
      6.875 1.875,  /* Almería iron ore */
      2.9 9.875,    /* Wagner iron ore */
      6.9 1.125,    /* Riff ores */
      6.875 11,     /* Vizcaya */
      12.75 8.125,  /* Barcelona */
      6.06 6.625,   /* Madrid */
      7.95 11,      /* Guipuzcoa */
      3.875 11.125, /* Oviedo */
      9.875 5.125,  /* Valencia */
      3.56 2.125,   /* Seville */
      0.9 11.1,     /* La Coruña */
      9.0625 8.375, /* Zaragoza */
      5 8.75,       /* Valladolid */
      6 11.2,       /* Santander */
      3.3 0.85,     /* Cádiz */
      5.375 1.05,   /* Málaga */
      9.05 2.875,   /* Murcia */
      0.375 9.375,  /* Pontevedra */
      3.9 9.875,    /* León */
      8.3 10.125,   /* Navarra */
      6.1 9.625,    /* Burgos */
      5.75 4.375,   /* Ciudad Real */
      7.2 10.375,   /* Alava */
      9.8 3.625,    /* Alicante */
      11.65 7.625,  /* Tarragona */
      5.01 2.875,   /* Córdoba */
      10.95 8.375,  /* Lérida */
      2.375 1.85,   /* Huelva */
      3.85 7.375,   /* Salamanca */
      3.95 8.375,   /* Zamora */
      1.3 9.625,    /* Orense */
      9.875 5.125,  /* Palma */
      7.6 9.612,    /* Logroño */
      7.625 1.3,    /* Almería */
      6.08 2.625,   /* Jaén */
      10.2 5.875,   /* Castellón */
      9.03 6.625,   /* Teruel */
      2.5 4.375,    /* Badajoz */
      9.8 9.125,    /* Huesca */
      5 9.125,      /* Palencia */
      1.625 10.625, /* Lugo */
      5.75 5.875,   /* Toledo */
      6.825 6.875,  /* Guadalajara */
      3.1 5.125,    /* Cáceres */
      6.05 1.875,   /* Granada */
      13.55 8.875,  /* Gerona */
      5.75 7.375,   /* Segovia */
      7.95 4.375,   /* Albacete */
      7.95 6.126,   /* Cuenca */
      7.61 8.625,   /* Soria */
      5 6.875,      /* Ávila */
      3.3 0.85,     /* Tenerife */
      3.3 0.85,     /* Gran Canaria */
      3.3 0.85,     /* Marruecos */
      3.3 0.85,     /* Guinea */
      6 6};         /* Extranjero */
```

```
T =  {0.0442,     /* Coal Asturias */
      0.0442,     /* Coal León */
      0.0564,     /* Ore Vicaya */
      0.0564,     /* Ore Teruel */
      0.0564,     /* Ore Almería */
      0.0564,     /* Ore Wagner */
      0.0564,     /* Ore Riff */
      0.1,       /* products */
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
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      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1,
      0.1};
```
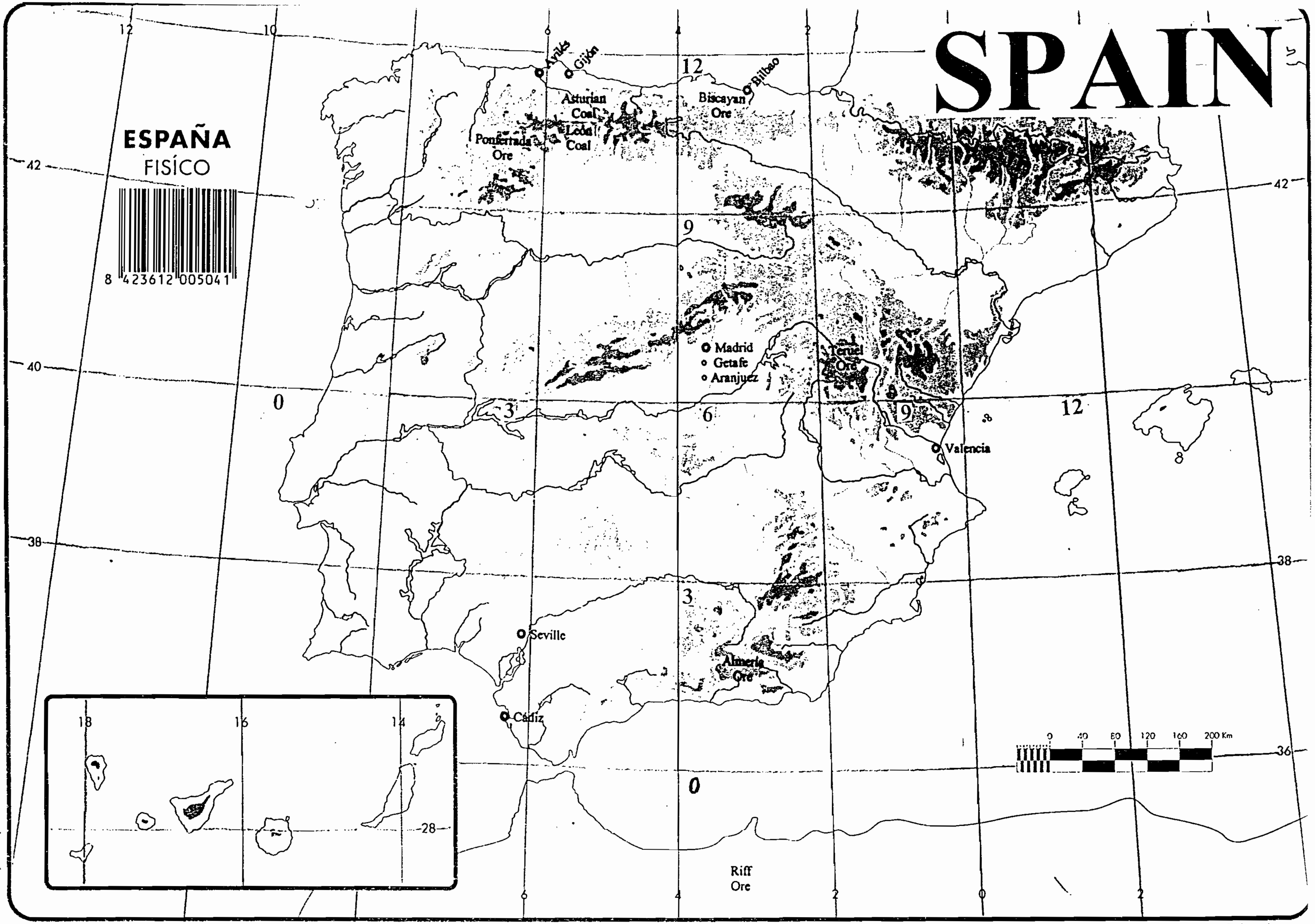

```
I = Ones (60,1);     /* weighted average of the known coordinates xi & yi */
ya = 500000*I;
Ab = A .* ya;
xa = T .* Ab;
xe = X[.,1];
ye = X[.,2];
xc = xe'*xa;
yc = ye'*xa;
s = T'*Ab;
x1 = xc/s;
y1 = yc/s;

            /* Calculate distances from weighted averages */
x2 = x1*I;
y2 = y1*I;
c1 = (xe - x2)^2;
c2 = (ye - y2)^2;
c = c1 + c2;
d = sqrt(c);

b = 1;        /* open loop */
do while b < 2;

x4 = x1;        /* calculate coordinates for new distances */
y4 = y1;
xa = T .* Ab;
x0 = xa ./ d;
xe = X[.,1];
ye = X[.,2];
xc = xe'*x0;
yc = ye'*x0;
s = (T ./ d)'*Ab;
x1 = xc/s;
y1 = yc/s;

I = ONES (60,1);      /* calculate new distances for new coordinates */
x2 = x1*I;
y2 = y1*I;
c1 = (xe - x2)^2;
c2 = (ye - y2)^2;
c = c1 + c2;
d = sqrt(c);

q1 = (x1 - x4)^2;     /* convergence criteria */
w1 = sqrt(q1);
z1 = w1 .<= 0.0001;
q2 = (y1 - y4)^2;
w2 = sqrt(q2);
z2 = w2 .<= 0.0001;
b = z1+ z2;

continue:           /* condition loop */
endo;
```

```
print "the optimal site is";    /* results */
print x1~y1;
print "the total transport cost is";
Ih = I*100;
d1 = d .* Ih;
x5 = xa .* d1;
x6 = I'* x5;
print x6;
x7 = I' * d1;
print "the total distance is";
print x7;
```

Appendix G. *Map with simulation coordinates.*



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