Regional - Sectoral Analysis Mexico

Investment would promote efficiency of the railway network

The current infrastructure does not respond to the needs of its main demanders.

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New way of measuring railway efficiency in the face of a changing reality

The faltering railway operations in Mexico have been the object of discussion on economic matters and regional development.[1] The history of railroads in Mexico dates back to the end of the 19th century, when its main purpose was to mobilize the labor force and mining production of the time.[2] During the twentieth century, the development of the national railway network followed this same direction, despite the fact that, gradually, the demand for railway transportation shrank with the development of the national road system and with the penetration of automobiles in the national logistics network. In addition, on the supply side, rail transportation as a state provision did not facilitate the development and maintenance of the network to adjust to the changing needs of the population and national industry and, particularly from 1986 to 1991, an operational crisis was evident in the subsector, which made it necessary to open the railways to private investment.[3]

The Mexican Institute of Transportation (*Instituto Mexicano del Transporte*, IMT) divides the process of privatization of railway activities in Mexico into three stages:

1. A first approximation characterized by a greater participation of private towing equipment necessary for the growing demand of freight transportation originated by foreign trade activities (1988-1991).
2. The restructuring of the Mexican railway system and the privatization of some of its ancillary services, accompanied by policies aimed at opening up trade and reorganizing its finances (1992-1994).
3. The concession of the transportation service, legislative reforms to adapt regulations to the participation of private capital in the rail transportation service (1995-1999).[4]

Even with the participation of private initiative, the current reality of the railway network in Mexico is far from the development and efficiency levels of the railway networks in the developed world. As a point of reference, we can consider the transportation of freight by rail in the United States of America (USA), our main commercial partner. For example, in 2014, the U.S. rail network carried 2.5 billion ton-kilometers, in contrast to the 78,770 million ton-kilometers transported in our country. Even when standardizing with respect to manufacturing activity, knowing that the value added of manufacturing in Mexico and the U.S. was 209 and 2,085 billion dollars,[5] respectively, 376.89 ton-kilometers per billion dollars are obtained for Mexico and 1,199.04 for the United States.

In addition, rail transportation has a cost advantage over road haulage, its main substitute for ground freight. In fact, the potential benefits of a rail network responding to the needs of the economy are due in large part to this advantage, in part to this cost advantage, as already mentioned in the article *Inversión y eficiencia ferroviarias: vías*

1: **Regulatory Aspects of the Railway Sector in Mexico**, by Eduardo Romero, General Coordinator of Regulatory Impact Statements Federal Commission for Regulatory Improvement, at the *Forum on the reform of the Railway Service Regulatory Act Communications and Transport Commission* of the Senate of the Republic, 5 and 6 March 2014.
2: Ramírez P., David**. The counterparts of technological diffusion: The regional economic impact of the railway during the Porfiriato period 1876-1911 in Mexico**, in *Paakat: Revista de Tecnología y Sociedad*, no. 5 (3). Mexico 2014.
3: Mexican Institute of Transportation, "Evolución creciente de algunos indicadores operativos y de eficiencia del ferrocarril mexicano" (Increasing evolution of some operational and efficiency indicators of the Mexican railroad), IMT, Mexico, 2009.
4: *Idem*
5: With World Bank data for 2014, the value added in manufacturing in Mexico and the U.S. was 209 and 2,085 billion dollars, respectively. This implies 376.89 ton-kilometers per billion dollars for Mexico and 1,199.04 for the United States.

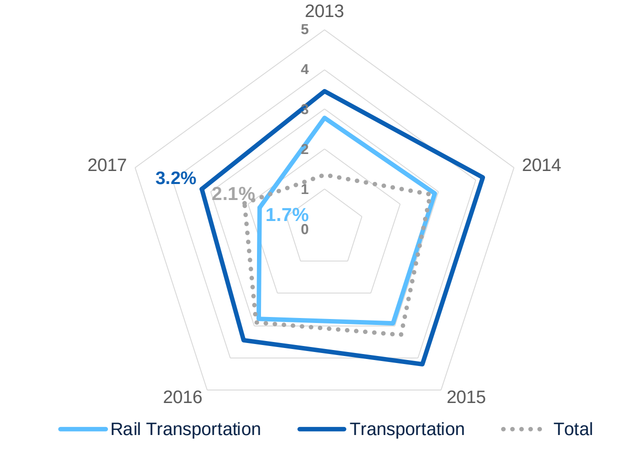
hacia un mayor crecimiento (Railway Efficiency and Investment: Tracks towards Higher Growth) in the last issue of the magazine ***Regional - Sectoral Outlook Mexico***.[6]

On the demand side, the manufacturing industry is the main demanding sector for rail transportation; during the 20th century, the industry consolidated as one of the engines of growth in Mexico and gradually began to demand more rail transportation services. Additionally, the economic reality of Mexico and the region has been transformed since 1994, with the entry into force of the North American Free Trade Agreement (NAFTA), consolidating regional value chains that depend heavily on the mobilization of products between their links, whether they belong to the same country or involve a border crossing. Under this new paradigm, it is useful to analyze the way in which Mexico's railway system responds to the current needs of the national economy, especially with the signing of the new trade agreement between the United States, Mexico and Canada (USMCA), guaranteeing the permanence of such productive chains and representing opportunities for complementarity as an input in manufacturing production for the railway sector.

A study conducted by De la Peña (2012) analyses the road and air transport networks in Mexico. The main results are measures of hierarchization of metropolitan areas in terms of centrality and coherence of the networks studied. In a network context, centrality is a characteristic of each node of the network, which denotes its degree of connectivity and position in it. Coherence, on the other hand, is defined as a measure inversely proportional to the existing dispersion between a suitable network (which responds perfectly to the connection needs of the nodes that make it up) and the network observed.

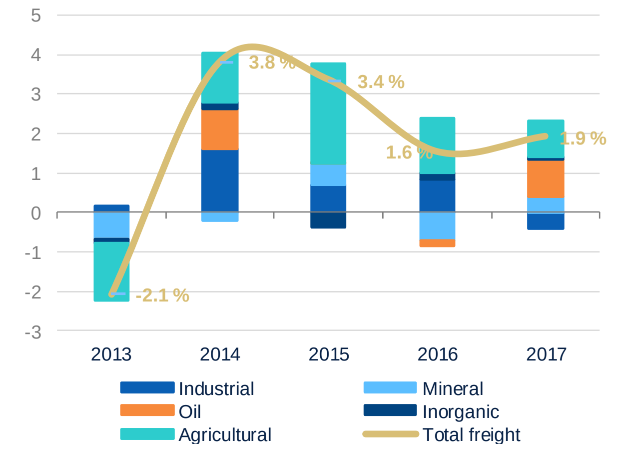
The analysis carried out makes it possible to channel the direction of resources in terms of investment, pointing out the localities where greater investment in railway infrastructure would cover an already existing demand. On the other hand, a locality with high connectivity would require its existing capacity to satisfy the demand for greater local manufacturing production, pointing to localized investment opportunities in manufacturing.

Chart 1 Total GDP, Transport GDP and Railway GDP
(YoY % change, original series)



Source: BBVA Research
Note: Growth rates were calculated on the basis of the original GDP series.

Chart 2 Total rail freight and by product type
(contributions and YoY% change)



Source: BBVA Research
Note: Contributions correspond to the variation in ton-kilometers transported by train during the year.

In this ***Regional – Sectoral Watch***, an equivalent analysis is presented for 55 metropolitan areas in Mexico. After identifying the total gross production of manufacturing industries and the population of the corresponding settlements, an adjacency matrix for the railway system was constructed, which reflects the direct connections of

6: According to data from the Secretariat of Communications and Transport and Universal Transport, in 2016, the cost of transporting a car of 1.2 tons was $5,114.3 pesos per truck load and $2,760 pesos by rail.

each node[7] –or metropolitan area– on the railway network, as well as the distances between them. The analysis refers to manufacturing production and does not capture the effect of the centers of entry and exit of goods from the national territory. This does not affect the result of the analysis, as will become apparent later when analyzing the conclusions of the presented model.

Network model for the calculation of the coherence of the railway network

Following the methodology of the study of De la Peña (2012) and using the Theorem of Perron-Frobenius[8], the own vector of the adjacency matrix corresponding to the spectral radius of the matrix (the highest of the eigenvalues) was calculated to measure the complexity of the railway network in each of the areas connected by the railway.

- Identify the N populations (cities or metropolitan areas) connected by the railway network and build an adjacency matrix $D = [d_{11} \cdots d_{1N} \vdots \ddots \vdots d_{N1} \cdots d_{NN}]: d_{ij} = d_{ji}, d_{ii} = 0\ \forall i,j \in G$, in which each element d_{ij} represents the distance between two towns (in kilometers) if there is a direct connection between them. If the connection is through another population included in the adjacency matrix, the distance is equal to zero. Also, the distance from a population to itself is defined as zero (the entries in the diagonal of the symmetrical matrix D).
- Identify total gross output of manufacturing industries, m_i, of municipalities –or sets of municipalities– represented by each node in the matrix D described in the previous point and define a production vector $m = [m_1, m_2, \dots, m_N]$, ordering its elements in the same way as in the adjacency matrix.
- Similarly, define a total population vector $p = [p_1, p_2, \dots, p_N]$, in which each p_i represents the population in node i.
- Calculate the eigenvalues e_i of the adjacency matrix D and define E^i as the eigenvector associated with each e_i; locate the spectral radius S of D (the largest of the eigenvalues, i.e. $S = e_j : e_j \geq e_i \ \ \forall i,j \in N$) and calculate the corresponding eigenvector $U = E^S = [u_1, u_2, \dots, u_N]$. By the Perron-Frobenius Theorem, it can be guaranteed that this vector will have elements greater than or equal to zero for all the nodes involved.
- Perform the calculation of a comparative centrality vector by dividing Perron's vector input, u_i, between the exogenous variable to be compared in that node, either population, p_i or total gross output of manufacturing industries, m_i. In order to standardize and eliminate units of measure, the resulting measure is divided between the quotient of the average complexity in the network and the average of the exogenous variable in question; that is, for each node i, the measure is calculated:

$$v_i(x,u) = \frac{\frac{u_i}{\sum_{j=1}^{N} u_j}}{\frac{x_i}{\sum_{j=1}^{N} x_j}} \qquad x \in \{p, m\}$$

This quotient represents the compared centrality or relative degree of connection of the node i.

In the case of being equal to one, it is said that the node is connected efficiently, responding to the needs of the exogenous variable in question at that point. If it is greater than one, the node is over-connected, and there is excessive railway infrastructure for manufacturing production or local population; and if it is less than one, the node is sub-connected, and the connections within the railway network are not sufficient to meet the needs of the population or manufacturing at that point.

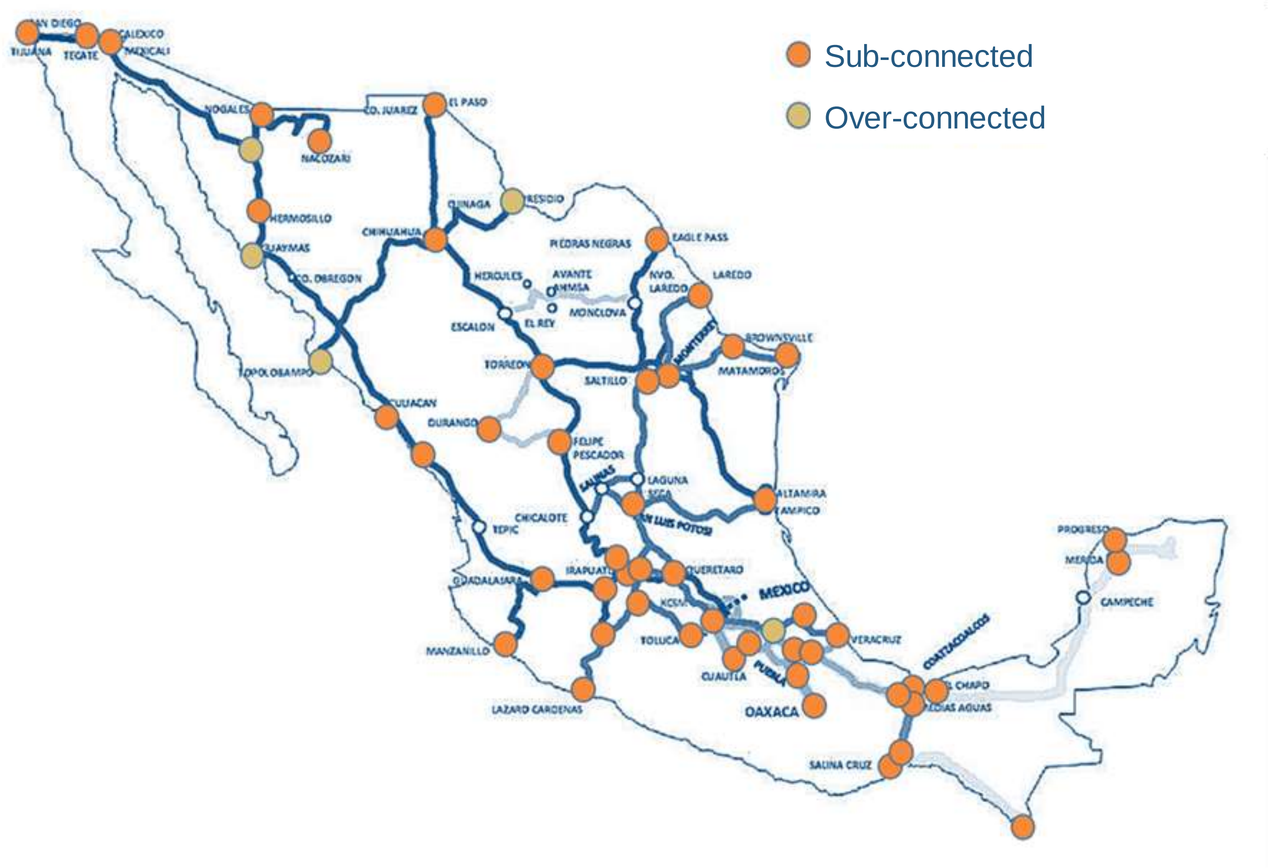
7: A node can be defined as an element of a linked list of a chart; these in turn are interrelated in a non-hierarchical way and form a network. In this way, the network would be a "set of interconnected nodes."
8: The Perron-Frobenius theorem guarantees the existence of a positive eigenvalue (spectral radius of the matrix), which delimits in module the rest of the eigenvalues of the matrix, and has associated a positive eigenvector, guaranteeing certain conditions of existence, uniqueness, positivity and stability of the solutions in static and dynamic multisectoral linear models.

- Calculate a coherence measure defined as $C(G) = \frac{1}{1+\sigma(i)}$, in which $\sigma(G) = \sqrt{\sum_{i \in G}\left[v_i\left(p_i, u_i\right) - 1\right]^2}$. As can be seen, if the dispersion measure, $\sigma(G)$, is greater, the measure of coherence will be smaller. Also, by construction, $0 \leq C(G) \leq 1\ \forall G$. In addition, if the network perfectly responds to the needs of each node in the network, $v_i(p_i, u_i; G) = 1$ and $\sigma(G) = 0$, which implies that $C(G) = 1$. Coherence therefore measures the degree to which the rail network responds to the needs of the variable under consideration – manufacturing or population– on the rail network as a whole.

Railway network does not meet manufacturing needs

The results of the model and the previous calculations, as well as the exogenous characteristics –population and total gross production of manufactures– used in each case, are included in the following tables:

Chart 3 Quality in terms of coherence in the connectivity of the railway network’s main nodes



Source: BBVA Research, based on data from Inegi and the SCT

In the previous map, it is possible to observe the nodes in the railway network that are sub-connected according to the manufacturing production that uses that node as a means of transport. In addition, in the case of over-connection, the infrastructure is excessive for local needs.

Table 1 Centrality and coherence by population on the rail network

Locality	Population (millions)	Compared Centrality
Valle de México	20.1	0.0019
Guadalajara	4.8	0.0122
Monterrey	4.4	0.4689
Puebla - Tlaxcala	2.6	0.0024
León	1.9	0.0975
La Laguna	1.2	2.6182
Aguascalientes	0.9	1.7402
Tijuana	1.8	0.0009
Nuevo Laredo	0.4	1.2732
Ojinaga	0.0	23.2941
Tapachula	0.3	0.0000
Topolobampo	0.4	4.1690
Lázaro Cárdenas	0.2	0.0017
Salina Cruz	0.1	0.0000
Tampico	0.9	1.5459
Coherence of the rail network		**0.24**

Source: BBVA Research

Table 2 Centrality and coherence by manufacturing output on the rail network

Locality	Manufacturing Production (million pesos)	Compared Centrality
Valle de México	856.1	0.0006
Guadalajara	329.5	0.0022
Monterrey	734.8	0.0347
Puebla - Tlaxcala	297.1	0.0003
León	194.3	0.0120
La Laguna	154.1	0.2529
Aguascalientes	134.6	0.1476
Tijuana	101.2	0.0002
Nuevo Laredo	10.6	0.5637
Ojinaga	1.6	4.7443
Tapachula	3.0	0.0000
Topolobampo	7.8	2.7357
Lázaro Cárdenas	46.0	0.0001
Salina Cruz	213.7	0.0000
Tampico	177.2	0.0918
Coherence of the rail network		**0.16**

Source: BBVA Research

In Tables 1 and 2, it can be seen that the coherence of the railway network is greater in the case of the population than in the case of the manufacturing industry. However, the movement of people has a very low share in the use of rail transport, while manufactures represent the main component of rail demand.[9]

As a result of the model, not only is the current railway network not in line with the needs of its main demander, but it may be determined by an initial condition that responded to historical needs that are not binding on the composition of the sub-sector demand today: the movement of the population, together with mining products, the main reasons for its construction.

Railway Incompatibilities Point to Investment Opportunities

Following the results of the railway network analysis, it is possible to glimpse the railway network connection points that require more investment, promoting the mobility of its manufacturing production, that is, the localities that are sub-connected according to the analysis presented.

On the other hand, over-connection at a specific node of the railway network can translate into untapped installed capacity; in other words, there is sufficient railway infrastructure to meet the demands of increased manufacturing activity in the locality. This over-connection can be observed in localities that represent railway interconnection points, with low population or manufacturing production, as is the case of Oriental, in Puebla, and Benjamin Hill, in Sonora. An outstanding case is that of Ojinaga, Chihuahua, with the greatest over-connection of the railway network according to the analysis. However, this analysis only takes into account the mobilization of locally produced goods, without taking into account international trade flows. Therefore, it is natural to conclude that Ojinaga is “less over-connected” than the figures suggest, as it also responds to a demand for international goods flows.

Therefore, one of the direct applications of this analysis is to direct the resources to be invested towards the activities that imply a greater profit in the margin, according to the logistic structure within the network studied. These resources can be directed towards greater railway infrastructure or towards increasing the manufacturing

9: Railway Statistical Annex 2017, SCT.

capacity installed in localities that involve taking advantage of existing complementarities due to their high degree of connectivity in the national railway system.

Railway / port integration: Mexico as a global logistics platform

In addition to the analysis of the railway network within the national territory, and according to the manufacturing production, the opportunity that the railway represents should be taken into account because of the cost advantage mentioned above in terms of its integration into the flows of goods and value within and outside the national territory.

In addition to the considerations mentioned above regarding border crossings and the entry of non-manufacturing products (such as grains), the interaction of the railroad with port terminals in Mexico and the opportunities for generating value that they represent must be analyzed. By means of intermodal terminals, an integration of the ports with the national railway network is observed that favors the displacement of goods that are transported by sea towards the interior of the country and of national products towards the exterior.

If the possibility of carrying out an intercostal transfer of goods by land is considered, as in the case of the transisthmian corridor, the advantage in costs of the railway could represent a comparative advantage with transport alternatives that would involve a greater displacement by sea and the payment of transit tariffs, as is the case of the Panama Canal. In fact, in the analysis carried out, it was already observed that the port of Salina Cruz is one of the most sub-connected localities; if one adds to this the possibility of moving goods from the Pacific to the Gulf of Mexico and vice versa, the railway development in the isthmus would involve an alternative way of transporting products between Asia and the east coast of the United States.

In the case of the Panama Canal, a study conducted by the Panama Canal Administration indicates that the transport costs resulting from transporting a 20 cubic feet TEU through the canal is US$65, while the equivalent via the isthmus would be approximately US$350.[10]However, in a cost-benefit analysis that includes costs other than inter-oceanic transportation, it must be considered that the movement of approximately 2,000 kilometers by sea to the Canal crossing implies a fuel cost that has not been considered by the study. Additionally, if one considers the congestion in the Panama Canal (even with its expansion) derived from the greater demand for inter-oceanic transportation and, particularly for liquid natural gas (LNG), the transisthmian corridor seems a much more coherent option in terms of international trade logistics.

Another important factor that could determine the viability of the project and generate a potential demand that would require transisthmian rail transport would be the development plan of the new administration around it, including the modernization of the port of Coatzacoalcos, the opening of a new port terminal in Salina Cruz and the rehabilitation and expansion of the railways between the two ports, as well as the construction of a highway between them.

If the treatment as special economic zones is taken into account, one could see a motivation for the emergence of new industrial zones in the corridor and for the use of the localities in it as a port for sending national production abroad, either through the Gulf of Mexico or through the Pacific. According to the railway infrastructure analysis, the establishment of industrial parks in the isthmus would emphasize its need for railway development, as a greater demand is generated by the new manufacturing clusters established in the region.

Given the implementation of the infrastructure plan and, in particular, of the transisthmian corridor, the potential benefits that would be gained in terms of international trade flows are important; additionally, the generation of employment and a rise in regional production must be considered, which could generate a decrease in the Southeast’s backwardness with respect to the rest of the country. This phenomenon, despite not being contained in the study, would reaffirm the potential benefits of the railway network in the isthmus region and would promote

10: Panama Canal is up to five times cheaper than rail, in *Mundo Marítimo*, 3 March 2006.

gains in both productive and distributive terms that would reaffirm the need for the development of the railway network in these localities resulting from the study.

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