ANALYSIS OF THE CONTRIBUTION OF RAILWAYS TO THE TRANSPORTATION MATRIX FOR AGRICULTURAL PRODUCTS IN THE STATE OF PARANÁ[1]

Ricardo Silveira Martins[2]
José Vicente Caixeta Filho[3]

ABSTRACT- The primary goal of this study is to evaluate the transportation of corn, soybean, wheat and soybean meal in Paraná , a southern Brazilian state, with the purpose of expanding the railway system's relative share of this transport in the state. Agriculture and agribusiness related sectors play an important income generation role in the state of Paraná, making Paraná's economy very sensitive to recent changes in these sectors. In this research, transportation cost minimization models were generated through application of a linear programming tool and then applied to rationalize the use of Paraná transportation system. A study of these models revealed significant potential contributions which could be made by the railroad system to reduce transportation costs in Paraná. Modal distribution models showed that the railroad system's share in the transportation matrix of selected products could be expanded, especially the system's share in the transport of agricultural products to Paraná's largest port, Paranaguá. Some priorities for investment in Paraná's rail system were highlighted: an increase in the capacity of the Curitiba-Paranaguá rail stretch, and the correction of the bottleneck in the Guarapuava-Ponta Grossa rail stretch to bring FERROESTE (Eastern Railroads Co.) into a better competitive position. The model did not favor freight flow allocation to intermodal alternatives.

Key words: Modal split, linear programming; intermodal transportation.

---

[1] Based on the Doctor's Thesis on Applied Economics of the first author at ESALQ/ USP, under the supervision of the second author.

[2] Economist and Lecturer at the Department of Economics, UNIOESTE/*Campus* of Toledo (PR). Cx. Postal 520 85903-000 Toledo PR. E-mail: rsmartins@toledonet.com.br

[3] Associate Professor at the Department of Agricultural Economics, ESALQ/USP. E-mail: jvcaixet@carpa.ciagri.usp.br

INTRODUCTION

Agriculture and agroindustry have been affected by deficiencies in Brazil's transportation systems. Ferreira et al. (1993) point to transportation costs as among the main difficulties restricting the economic competitiveness Brazilian agricultural commodities. Wilkinson (1995) highlights the importance of a radical improvement in transportation infrastructure as one of the most important steps toward the creation and maintenance of Brazilian agroindustry competitiveness. These improvements are needed for two interrelated reasons: a large percentage of goods are being transported over the county's highway system; and since 1980 a lack of sufficient investment has been provided for the maintenance and expansion needed to accommodate the increasing demands being placed on Brazil's transportation system.

The condition of the state of Paraná's transportation infrastructure impacts both the local and the national economies. Paraná's agricultural products, especially grains, and the local agricultural processing industries contribute significantly to both the Brazilian export and internal economies. The location of available economic transportation alternatives is an important business consideration seriously affecting the choice of agroindustrial processing sites and distorting farm product costs.

The state's transportation infrastructure has many inadequacies, notably the existing highway system. The fact that a lesser cost modal is not being used and the lack of an efficient connection between modals (intermodality) represents additional costs for industry and growers. These transportation sector inefficiencies hinder Paraná's competitive position in both the home and external agricultural products markets.

The overall goal of this study is to evaluate the systems used for the transportation of corn, soybean, wheat, and soybean meal in the state of Paraná, with special emphasis on the relative participation of the railway modal. Thus, this study's has two specific goals: a) To identify and analyze the participation of railroads in the optimum modal allocation, an allocation which rationalizes the use of the available transportation infrastructure to convey grains and soybean meal between the hubs with the simulation of new railway connections; b) to evaluate

an alternative, intermodal transportation hypothesis, focusing on the shipment of grains and soybean meal in Paraná.

MATERIAL AND METHODS

Transportation problems are usually represented by a network comprised of nodes and arcs connecting areas of recognized interdependent economic activities among regions. The modeling of network transportation problems has had broad application by numerous researchers: Prastacos & Romanos (1987) studied the allocation of transportation investments in Greece; Oliveira (1996) evaluated the competitiveness of waterway transportation of grains and meals in areas influenced by Brazil's Tietê-Paraná Waterway; Arbage (1996) studied soybean grain barge transportation in the state of Rio Grande do Sul, Brazil; Guarim (1992) analyzed the interregional impact of transportation systems on traditional Brazilian soybean production, competitiveness, and crop expansion into newly cultivated areas; Wright (1980) evaluated grain transportation system infrastructure and grain storage capabilities at the port of Paranaguá in Paraná; Koo et al. (1985) evaluated transportation infrastructure in the United States to derive basic transportation data and to determine the impacts of transportation capacities and prices on grain commerce. Martins (1998) delineated freight product types and estimated quantities shipped using various transportation modes. The Office of Brazilian Transport Planning (GEIPOT) recurrently uses modeling to determine least costly transportation routes and to evaluate transportation infrastructure along Brazil's export corridors (GEIPOT, 1994 and 1995). For this current study, the basic data utilized are related to product types and estimated quantities shipped using various transportation modes; detailed documentation can be found in Martins (1998).

Geographic area under study

The state of Paraná historically contributes approximately 25% of total Brazilian grain production. National grain production from the 1994/95 growing season was 81 million tons, harvested from 38.5

million hectares of cultivated land; corn, soybean, and wheat accounted for 80% of this total (Companhia Nacional de Abastecimento, CONAB, 1996). That season, Paraná led the nation in production of these grains, accounting for 24.5% of the nations corn crop, 21.4% of its soybean crop, and 68.7% of its wheat crop (Table 1).

Table 1 - Planted area and production of corn, soybean, and wheat in Brazil and in the state of Paraná, 1994/95 season.

Product thousand t.)	Area (in thousand ha.)		Production (in	
Paraná	Brazil	Paraná	Brazil	Paraná
Corn	14.282,2	3.150,0	37.441,9	9.180,0
Soybean	11.678,7	2.120,6	25.934,1	5.534,0
Wheat	1.033,8	635,0	1.524,0	1.047,0

Source: CONAB (1996)

For the transportation study presented in this paper, the state was divided into zones largely determined by the location of centers of economic activity. It was assumed that near these centers more consistent and significant transportation flows would be generated and commercial agricultural and agroindustrial activities would concentrate. Thus, we have followed the regionalization methodology adopted by the Instituto Brasileiro de Geografia e Estatística (IBGE), as documented by the Fundação Instituto Brasileiro de Geografia e Estatística (FIBGE, 1987).

Transportation infrastructure

Highway transportation prevails in the state of Paraná. According to Paraná (1996), there are 40,200 km of Federal, State, and municipal highways, while the railway system is comprised of about 2,500 km of track. Most highways in the state are in the generally unpaved municipal network. Seventeen federal highways (BRs) amount to 3,300 km and 149 state highways (PRs) total 12,400 km. Of Paraná's highway system, 2,039 km have been entered into a State program which ceded rights to manage and improve these highways; this system of roads makes up

the Integration Ring. The program was created to implement timely road maintenance, add traffic lanes (lane duplication), construct weigh stations and emergency medical facilities, and build city ring roads (Paraná, 1996).

Paraná's railroad system is concentrated in the state's east, yet the system can channel agricultural production from the state's north to distant processing centers. FERROESTE's construction of a rail line uniting Cascavel with Guarapuava is the first step in the expansion of the state's railway system towards Paraná's western region. FERROESTE's entire network has been put under private administration, which hopefully can more intensively use the current infrastructure and more flexibly initiate new rail projects.

The Port of Paranaguá completes the state's transportation infrastructure. This strategically located port is used by producers in Paraná and segments of the states of Santa Catarina, Rio Grande do Sul, Mato Grosso do Sul, and São Paulo.

Application of the model

The evaluation of the minimum transportation cost modality for grains and soybean meal in Paraná is based on a linear programming model. This model was used to discover an optimum modal split of product flows between agricultural centers to minimize the total cost of transportation (Z) in Paraná, considering constraints (2) and (3). The General Algebraic Modeling System (GAMS) (Brooke et. al., 1996) was one of the software packages applied to the following mathematical structure:

$$Min \quad Z = \sum_{m=1}^{3} \sum_{i=1}^{13} \sum_{j=1}^{13} FM_{ij}^{m} TM_{ij}^{m} \tag{1}$$

subjected to

$$\sum_{m=1}^{3} TM_{ij}^{m} = T_{ij} \text{ for every } i,j \tag{2}$$

$$\sum_{m=1}^{3} TM_{ij}^{m} \leq C_{ij} \text{ for every } i,j \tag{3}$$

where:

Z = function of total transportation cost for the flow of grain and soybean meal;

m = highway (1), railway (2), and intermodal (3) transportation modes;

FM_{ij}^{m} = freight (in US$/t) between centers i and j, associated to highway, railway, and intermodal systems;

TM_{ij}^{m} = amount transported (t) between centers i and j, associated to highway, railway, and intermodal systems;

T_{ij} = flows of grains and soybean meal with origin in i and destination in j (matrixes O/D estimated);

C_{ij} = traffic capacity of products in the rail system.

The restriction incorporated into this study's model concerned only railway line traffic capacity and used information supplied by the railway transportation companies operating in the state, the Sul Atlântico Railway (FSA) and the Paraná Railway (FERROPAR). Restrictions associated with highway traffic capacity were not considered. Transportation capacities are shown in Table 2.

Table 2 - Grains and meals railroad traffic capacity (*t*/year) in the state of Paraná determined by stretch of track

Stretch	Amount		Transportation Capacity[1]
	Trains	Train cars	(in *t* /year)
Londrina-Apucarana	9	54	8,048,160
Maringá-Ponta Grossa	8	74	8,823,168[2]
Cascavel-Guarapuava	4	40	2,649,600
Guarapuva-Ponta Grossa	1	60	993,600
Ponta Grossa-Curitiba	13	74	15,930,720
Curitiba-Paranaguá	16	42	11,128,320

Source: Information supplied by companies FSA and FERROPAR

1- Total transportation capacity is 46t per car per 360 days/year.

2- Transportation capacity for grains and meals along this stretch has historically been 90% of the per car capacity shown in Footnote 1.

the Integration Ring. The program was created to implement timely road maintenance, add traffic lanes (lane duplication), construct weigh stations and emergency medical facilities, and build city ring roads (Paraná, 1996).

Paraná's railroad system is concentrated in the state's east, yet the system can channel agricultural production from the state's north to distant processing centers. FERROESTE's construction of a rail line uniting Cascavel with Guarapuava is the first step in the expansion of the state's railway system towards Paraná's western region. FERROESTE's entire network has been put under private administration, which hopefully can more intensively use the current infrastructure and more flexibly initiate new rail projects.

The Port of Paranaguá completes the state's transportation infrastructure. This strategically located port is used by producers in Paraná and segments of the states of Santa Catarina, Rio Grande do Sul, Mato Grosso do Sul, and São Paulo.

Application of the model

The evaluation of the minimum transportation cost modality for grains and soybean meal in Paraná is based on a linear programming model. This model was used to discover an optimum modal split of product flows between agricultural centers to minimize the total cost of transportation (Z) in Paraná, considering constraints (2) and (3). The General Algebraic Modeling System (GAMS) (Brooke et. al., 1996) was one of the software packages applied to the following mathematical structure:

$$Min \quad Z = \sum_{m=1}^{3} \sum_{i=1}^{13} \sum_{j=1}^{13} FM_{ij}^{m} TM_{ij}^{m} \tag{1}$$

subjected to

$$\sum_{m=1}^{3} TM_{ij}^{m} = T_{ij} \text{ for every } i,j \tag{2}$$

$$\sum_{m=1}^{3} TM_{ij}^{m} \leq C_{ij} \text{ for every } i,j \tag{3}$$

where:

Z = function of total transportation cost for the flow of grain and soybean meal;

m = highway (1), railway (2), and intermodal (3) transportation modes;

FM_{ij}^{m} = freight (in US$/t) between centers i and j, associated to highway, railway, and intermodal systems;

TM_{ij}^{m} = amount transported (t) between centers i and j, associated to highway, railway, and intermodal systems;

T_{ij} = flows of grains and soybean meal with origin in i and destination in j (matrixes O/D estimated);

C_{ij} = traffic capacity of products in the rail system.

The restriction incorporated into this study's model concerned only railway line traffic capacity and used information supplied by the railway transportation companies operating in the state, the Sul Atlântico Railway (FSA) and the Paraná Railway (FERROPAR). Restrictions associated with highway traffic capacity were not considered. Transportation capacities are shown in Table 2.

Table 2 - Grains and meals railroad traffic capacity (*t*/year) in the state of Paraná determined by stretch of track

Stretch	Amount		Transportation Capacity[1]
	Trains	Train cars	(in *t* /year)
Londrina-Apucarana	9	54	8,048,160
Maringá-Ponta Grossa	8	74	8,823,168[2]
Cascavel-Guarapuava	4	40	2,649,600
Guarapuva-Ponta Grossa	1	60	993,600
Ponta Grossa-Curitiba	13	74	15,930,720
Curitiba-Paranaguá	16	42	11,128,320

Source: Information supplied by companies FSA and FERROPAR

1- Total transportation capacity is 46t per car per 360 days/year.

2- Transportation capacity for grains and meals along this stretch has historically been 90% of the per car capacity shown in Footnote 1.

2,549,600 t/year. This increased capacity did not change the distribution of freight flows that originated in Guarapuava, but 954 thousand t/year originating in Cascavel was redirected to the railways.

Optimum distribution for projected flows

Three other simulations (Figures 6, 7, 8) examined the impact of future increased rail freight traffic both with and without railway expansion in Paraná. By the year 2003, we believe that the problems related to rail system infrastructure and modality inefficiencies could be corrected. These problems include freight loading and unloading systems, transshipment terminals, and railway rolling stock. Thus, simulations set in the year 2003 have been idealized in the expectation of increased railway system flexibility, improved infrastructure, and to discount current management failures arising from recent railway privatization in Paraná.

One scenario (Figure 6) applied the assumption that there will be no railway expansion in Paraná other than FERROESTE, and that the correction of FERROESTE's bottleneck beginning in Guarapuava had no effect in terms of optimum modal allocation relative to origin and destination of freight flow. The model also allocated no new freight flow to FERROESTE.

It was found that the only binding capacity restriction was on the Curitiba-Paranaguá stretch of track. If this restriction were removed, each 1 t increase in this rail segment's capacity would provoke a US$0.60 reduction in transportation expenses within Paraná. Utilizing the maximum capacity of the Curitiba-Paranaguá stretch of track prioritizes shipments starting in Ponta Grossa that have already been incremented by the traffic from the state's north. This implies the use of the Ponta Grossa-Guarapuava-Cascavel stretch of track only for shipments originating in Guarapuava. Using the Cascavel-Guarapuava stretch for freight destined for Paranaguá implies an opportunity cost of US$0.27/t.

Another simulation explored possible expansion of branch railways (Figure 7) while leaving the Guarapuava bottleneck uncorrected. Initially, alternative route hypothesis were investigated which would integrate the Umuarama pole into the railway network. This analysis was spurred by historic precedent: decades past, two rail projects were

conceived which focused on the Umuarama pole.

In the 1940s, the Estrada de Ferro São Paulo-Paraná railroad company considered connecting Guaíra (a city within the Umuarama pole) to Londrina-Ourinhos (in the state of São Paulo). The link from Ourinhos to Cianorte, 163 km from Guaíra, was finally completed. Actually, this rail line, which was an attempt to link the Umuarama pole with the port at Paranaguá, should begin in Maringá. In the 1970s, the Companhia Vale do Rio Doce designed a railway uniting Guarapava-Guaíra, in an attempt to reach the state of Mato Grosso. The rail link uniting Paraná and Mato Grosso has become a FERROESTE project and is not a priority for the Paraná government.

Guaíra occupies a strategic position in both the state's transportation infrastructure and the Umuarama pole. The new bridge over the Paraná River at Guaíra can be used to bring about important changes in the flow of grains and meals from other states to the Port of Paranaguá. The bridge, opened in January 1998, should increase shipping nimbleness and reduce the transport costs for products coming from a few cities in the states of Mato Grosso and Mato Grosso do Sul. The new bridge may cause the diversion of freight traffic that previously would have entered Paraná at Maringá via highway. In addition, an inter-modal cargo terminal is being designed for construction where the Tietê-Paraná Waterway borders the town of Guaíra.

Models were estimated in regard to freight shipped between Guaíra-Paranaguá to determine the best route. Shipping the estimated amount of freight, following previously adopted procedures, cost US$29.40/t by highway, and US$29.20/t by railway via Cascavel, and US$28.61/t by railway via Maringá. Due to these values, railway flow was only allocated for the route via Maringá, even considering the correction of the bottleneck between Guarapuava and Ponta Grossa.

We then analyzed the railway system starting in Umuarama itself. In this analysis, freight capacity had reached the level of restriction: the rail system was fully employed. We first considered the construction of a branch line to Cianorte, thence integrating with the RFFSA in Maringá. The hypothetical construction of this branch does not imply a change of the traffic restrictions between Maringá and Paranaguá' when it eventually becomes necessary to detour out-of-state freight arriving in Paraná. We then found that the quantity of cargo shipped from

Umuarama to Paranaguá implied the use of the Maringá-Ponta Grossa railway stretch's total capacity. This provoked a partial modal reallocation to the highway system's origin-destination pairs Apucarana-Paranaguá, previously unused, and Curitiba-Paranaguá.

Regarding the investigation of new railway branches, the model allocated total rail transport capacity to all new branches other than the Campo Mourão-Guarapuava branch, for which the model allocated no rail traffic. This underscored the importance of the flow of products shipped from Port of Paranaguá that originated in Campo Mourão and Umuarama. The new branch railroads made an alternative shipping option available that minimized the total cost of transporting Paraná's grains and soybean meal. The new branches also made it possible to more efficiently ship the voluminous flows that originate in Foz do Iguaçu and Cascavel directed to the state's north.

The correction of the bottleneck beginning in Guarapuava brought the affected stretches of track up to normal capacity restriction levels. However, the entire capacity increase of the Guarapuava-Curitiba/Ponta Grossa stretch was channeled to the railway system originating in Pato Branco and destined for Ponta Grossa (Figure 8). The absence of a Guarapuava-Pato Branco railway branch was also simulated. The optimum result encouraged the total amount of freight originating in Guarapuava and destined for Curitiba, Ponta Grossa and Paranaguá to the railway system while idle capacity was filled with flows originating in Foz do Iguaçu, destined for Curitiba and Ponta Grossa.

Intermodal transportation of grains and soybean meal in the state of Paraná

Transportation planning by nations concerned with cost reduction and international market competitiveness has focused on intermodal shipping. Paraná has acknowledged the economic rationality of intermodal freight transportation and recently made changes in both its transportation plan and the state's transportation infrastructure: the Paraná River bridge is now in operation; the intermodal terminal in Guaíra has been opened; the Tietê-Paraná Waterway is more completely integrated into the state's transportation network; and the new dry ports in Cascavel and Maringá are in use.

Using Paraná's intermodal capabilities, simulations were set up that involved only one transshipment operation between origin-destination pairs with a given maximum distance as high as 700 km. The state's main transportation routes were selected using Martins (1988) information on origin and destination of products. Since Paraná directs a great deal of its production to foreign markets, routes classified as 'export' were selected for representation. On the other hand, in view of Paraná's historic production surplus, so-called 'internal supply' routes were selected to reflect the great many products shipped to Brazil's southern and northeastern regions. Thus, we have represented rail lines used as Export routes and Internal Supply routes:

1) Export routes:
- Campo Mourão-Paranaguá
- Cascavel-Paranaguá
- Umuarama-Paranaguá
- Foz do Iguaçu-Paranaguá

2) Internal supply routes:
- Pato Branco-Paranaguá
- Pato Branco-São Paulo
- Foz do Iguaçu-São Paulo

At first, the model was evaluated from two different standpoints. An attempt was made to analyze intermodal shipping in comparison with other the transportation alternatives to identify the least costly route between origin-destination pairs and act as a indicator for transportation services users. We also attempted to identify the highest degrees of intermodal freight that could be shipped over the selected routes by an application of the global model of rational use of modalities. In this, we sought to find the modal split which minimizes the cost of transporting grains and soybean meal throughout the entire state of Paraná.

Intermodal transportation was found to be competitive only for freights routed from Paraná towards São Paulo. The routes to São Paulo were longer than those routes between origin-destination pairs within Paraná: 1,064 km from Foz do Iguaçu to São Paulo and 855

km from Pato Branco to São Paulo.

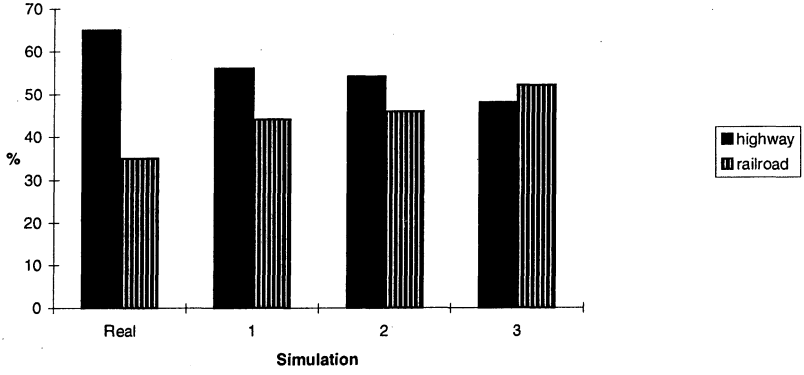
In accordance with the rationality model, the simulation was quite unfavorable for the use of intermodal transportation for intrastate shipping. Intermodal transportation was only recommended when freight rates are very low. Yet, a variation in transshipment cost from US$1.07/ to US$1.50/t did not change intermodal transportation's ranking among the transportation alternatives investigated; although, transshipment cost is often an important element determining the competitiveness of the intermodal shipping option. In addition, the expansion of this study's assumed railway branches inhibited the use of intermodal transportation in several simulations. This evaluation was made in accordance with information gained from the sensitivity analysis, on the *ceteris paribus* hypotheses, which may not actually occur since the motivating factors for this reduction may eventually be spread to other modals.

CONCLUSIONS

The transportation matrix for grains and soybean meal in the state of Paraná is likely to be significantly, incrementally modified through use of the railway system (Figure 1). In 1995, Paraná's railways were responsible for 35.07% of the total transport of grain and soybean meal products; by applying a modal split that rationalizes the use of current transportation infrastructure (Simulation 1) these railways could be responsible for 44% of Paraná's grain and soybean meal transport

If operative, FERROESTE could contribute to a higher rationalization of the transportation in Paraná. However, the railway bottleneck near in Guarapuava jeopardizes FERROESTE's potential contribution (Simulation 2). Once this bottleneck is corrected, conveyance of the majority of grains and soybean meal, in optimum terms, could be handled by the railroads (Simulation 3).

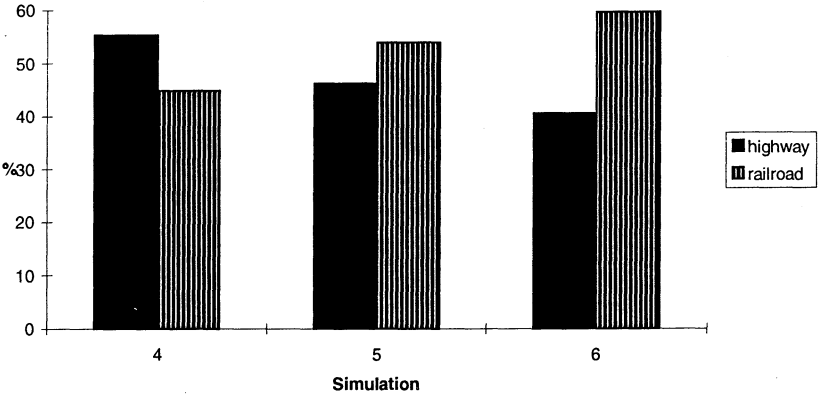
Figure 1 - Transportation matrix of grains and soybean meal in the state of Paraná for 1995, in various simulated situations.



In an attempt to evaluate the satisfaction of future demand in relation to the state's transportation infrastructure, various railway system scenarios were simulated and the results are represented in Figure 2, Simulations 4,5, and 6. In Simulation 4, FERROESTE was the only new railway option considered in Paraná. New railways were added in Simulations 5 & 6. In Simulation 4, rail transport accounted for 44.80% of the total volume of freight moved in Paraná; and the transportation matrix was indifferent to FERROESTE's rail line bottleneck.

The last two Simulations confirmed that railway transportation is the most important segment in the state's transportation matrix when the optimum choice is based on the lowest shipping price. This was found regardless of the existence or not of another railway in the connections between poles, in accordance with the capacity restrictions. The movement of products by rail could account for 53.8% of the total volume of grain and soybean meal transported in Paraná (Simulation 5); this figure could reach 59.5% should the railroad bottleneck beginning in Guarapuava be corrected (Simulation 6).

Figure 2 - Transportation matrix of grains and soybean meal in the state of Paraná for 2003.



The following is synopsis of the conclusions drawn from this research:

1. Correction of the Guarapuava bottleneck can positively contribute to balance the transportation matrix for grain and soybean meal in Paraná.
2. The eventual construction of the Pato Branco-Guarapuava rail branch can make the use of FERROESTE impractical within the rationalization principles of Paraná's transportation infrastructure. Another route should be developed in order to integrate a Pato Branco branch after Ponta Grossa, possibly linking with RFFSA in União da Vitória.
3. Engineering studies should be undertaken to evaluate the feasibility of linking a few of the railway lines used in this study: linking Guaíra to the RFFSA at Maringá rather than to FERROESTE at Cascavel, and linking the railroad segments between Foz do Iguaçu-Cascavel-Campo Mourão-Maringá.
4. Intermodal transportation was not competitive for flows which both originated and terminated within Paraná.

REFERENCES

ARBAGE, A. P. "Análise econômica do transporte de soja em grão no Estado do Rio Grande do Sul (O caso do Porto de Cachoeira do Sul)." CONGRESSO BRASILEIRO DE ECONOMIA E SOCIOLOGIA RURAL. 34., Aracaju, 1996. **Anais**. Brasília: SOBER (1996): 1557-73.

BROOKE, A.; KENDRICK, D.; MEERANS, A., **GAMS**. Washington: Gams Development Corporation, (1996): 171p.

CONAB (Companhia Nacional de Abastecimento). "**Previsão e acompanhamento de safras**," ano 20, n.5, jul./1996.

FERREIRA, L R.; BURNQUIST, H. L.; AGUIAR, D. R. D. "**Infraestrutura, comercialização e competitividade da agricultura brasileira.**" Rio de Janeiro: IPEA, (1993): 63p. (Textos para discussão, 318)

FIBGE (Fundação Instituto Brasileiro de Geografia e Estatística). "**Regiões de influência das cidades.**" Rio de Janeiro: FIBGE, (1987).

GEIPOT (Empresa Brasileira de Planejamento de Transportes). "**Corredores de transporte: corredor do Paraná/Santa Catarina.**" Brasília: Ministério dos Transportes/GEIPOT, (1994): 58p.

____. "**Corredores de transporte**: proposta de ações para adequação da infra-estrutura e para racionalização de transporte de granéis agrícolas." Brasília: Ministério dos Transportes/GEIPOT, (1995): 277p.

____. "**Corredores de transporte**: proposta de ações para adequação da infra-estrutura e para racionalização de transporte de granéis agrícolas." Brasília: Ministério dos Transportes/GEIPOT, (1997): 314p.

GUARIM, I. "**Análise da competitividade inter-regional da soja em grão no mercado brasileiro.**" Viçosa, (1992): 116p. Tese (Mestrado) - Departamento de Economia Rural/Universidade Federal de Viçosa.

KOO, W. W.; THOMPSON, S. R.; LARSON, D. W. "Alternative Transportation Rate and Cost Structure: a linear programming model." In: KOO, W. W.; LARSON, D. W. **Transportation Models for Agricultural Products**. Boulder: Westview Press, (1985), Chap.7.

MARTINS, R. S. "**Racionalização da infra-estrutura de transporte no Estado do Paraná: o desenvolvimento e a contribuição das ferrovias para a movimentação de grãos e farelo de soja.**" Piracicaba, (1998): Tese (Doutorado) - Escola Superior de Agricultura "Luiz de Queiroz"/Universidade de São Paulo

OLIVEIRA, J. C. V. "**Análise do transporte de soja, milho e farelo de soja na Hidrovia Tietê-Paraná.**" Piracicaba, (1996): 136p. Dissertação (Mestrado) - Escola Superior de Agricultura "Luiz de Queiroz"/Universidade de São Paulo.

PARANÁ (Estado). Secretaria dos Transportes. **Paraná: logística e multimodalidade**. Curitiba: SETR/PR, (1996): 23p.

PRASTACOS, P.; ROMANOS, M. "A Multiregional Optimization Model for Allocating Transportation Investments." **Transportation Research** 21B..2 (1987): 133-48.

WILKINSON, J. "Competitividade da agroindústria brasileira" Agricultura em São Paulo 42.1 (1995): 27-57.

WRIGHT, C. L. "**Análise econômica de transporte e armazenagem de grãos:estudo do corredor de exportação de Paranaguá. Brasília**": Ministério dos Transportes/GEIPOT, (1980): 187p.

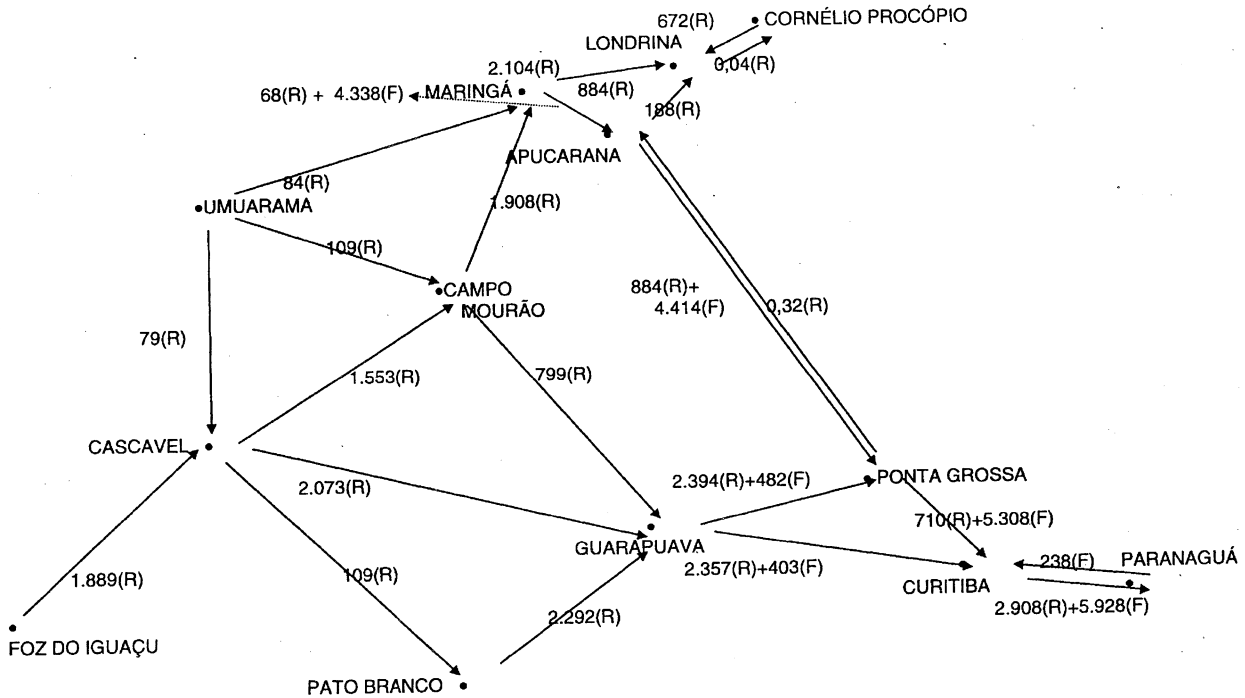


Figure 3 -Illustration of the optimum distribution among highway (R) and railway (F) systems, estimated flows of grains and soybean meals in Paraná (in a thousand t), with the transportation infrastructure available in 1995.

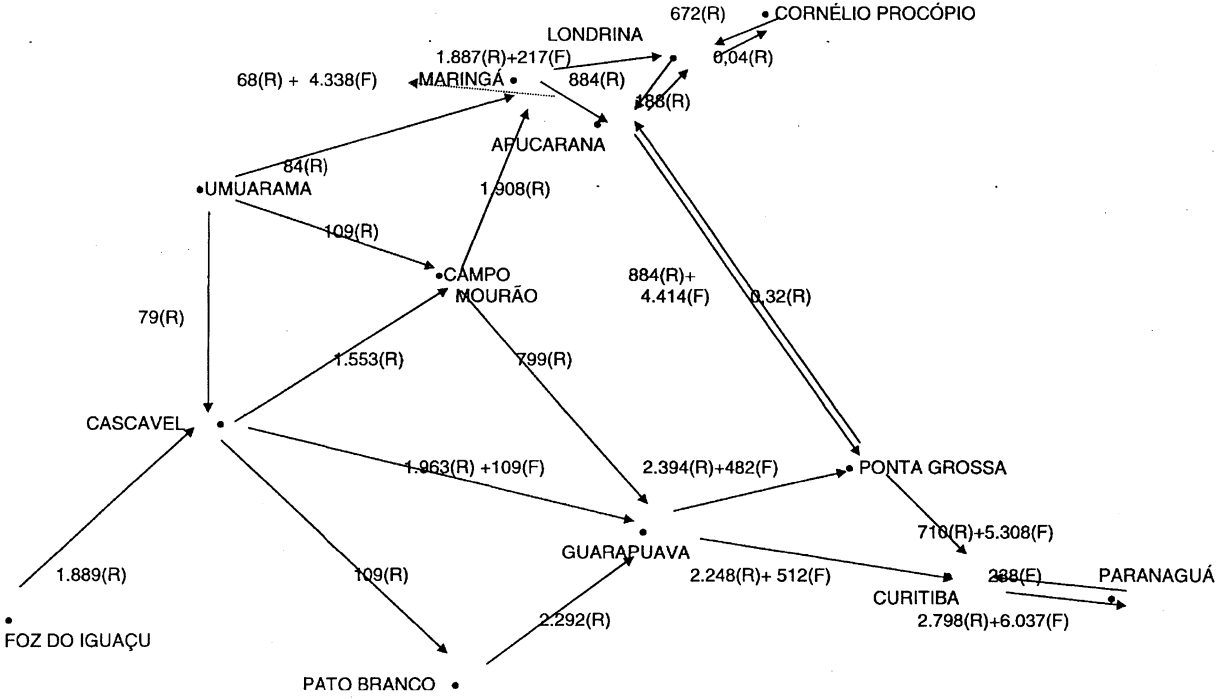


Figure 4 - Illustration of the optimum distribution between the highway (R) and railway (F) systems, estimated flow of grains and soybean meal in Paraná (in a thousand t) if FERROESTE were operative in 1995.

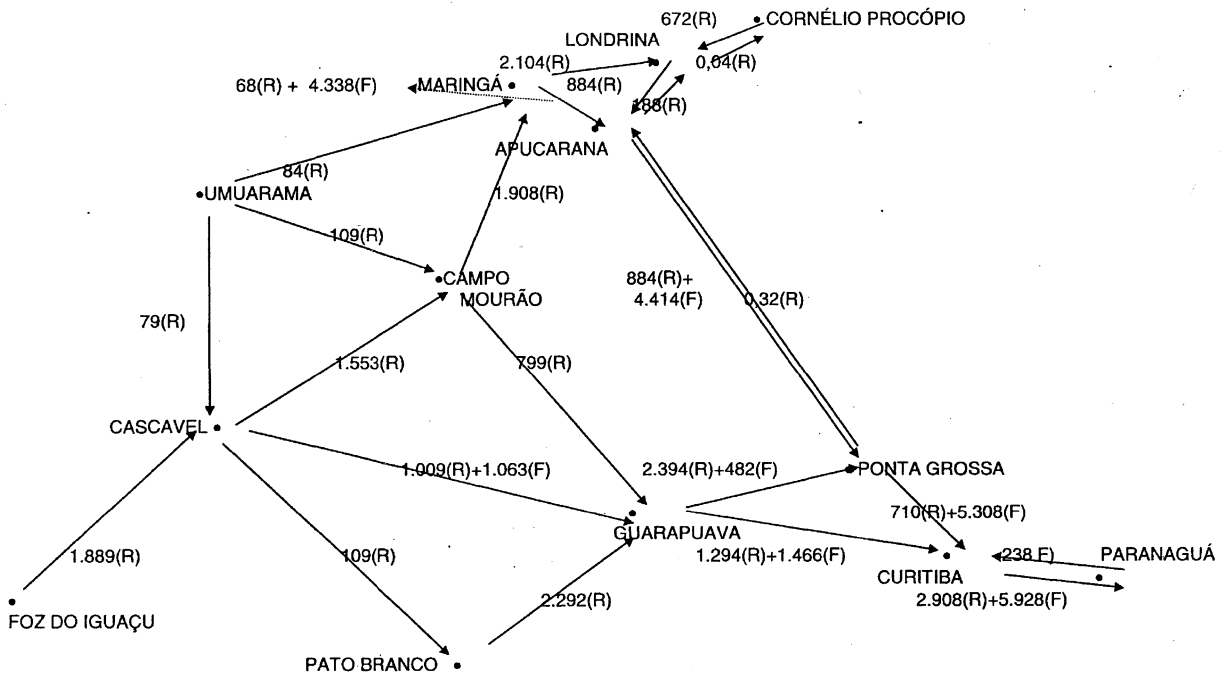


Figure 5 - Illustration of the optimum distribution between the highway (R) and railway (F) systems, estimated flow of grains and soybean meal in Paraná (in a thousand t) if FERROESTE were operative in 1995 and considering that the bottleneck starting in Guarapuava did not exist.

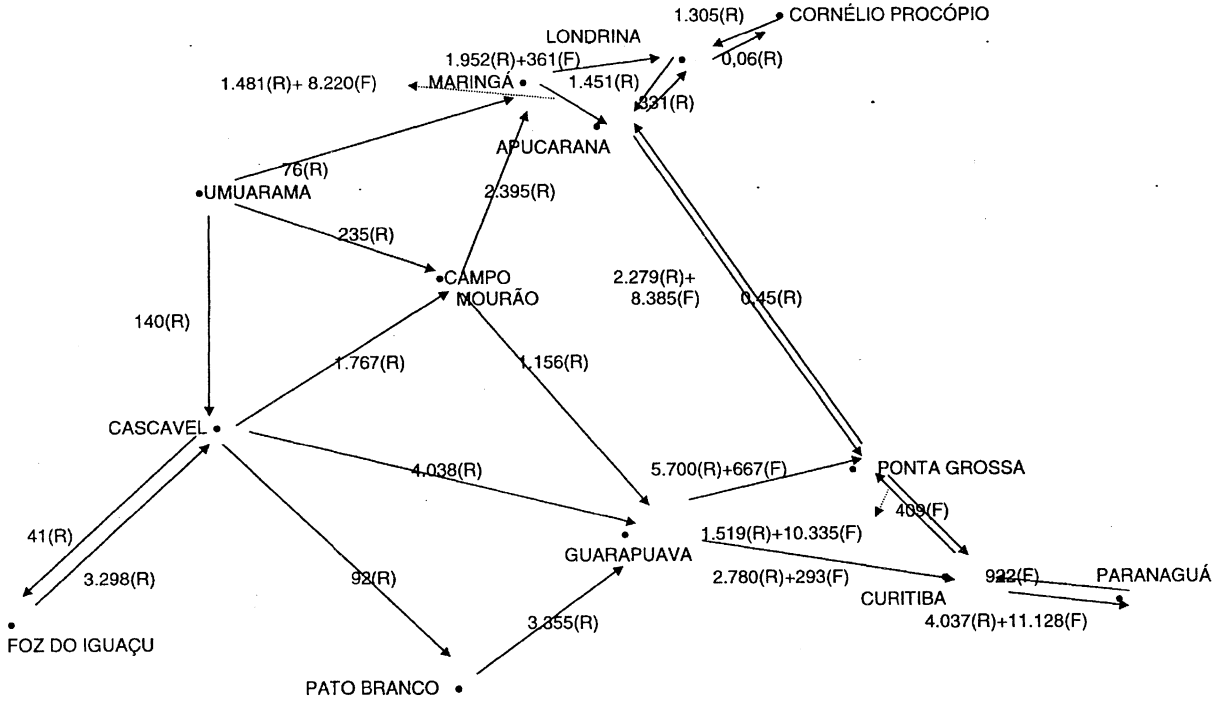


Figure 6 - Illustration of the optimum distribution between the highway (R) and railway (F) systems, estimated flow of grains and soybean meal in Paraná (in a thousand t) for 2003, considering FERROESTE as the only railway expansion, with or without bottleneck correction starting in Guarapuava.

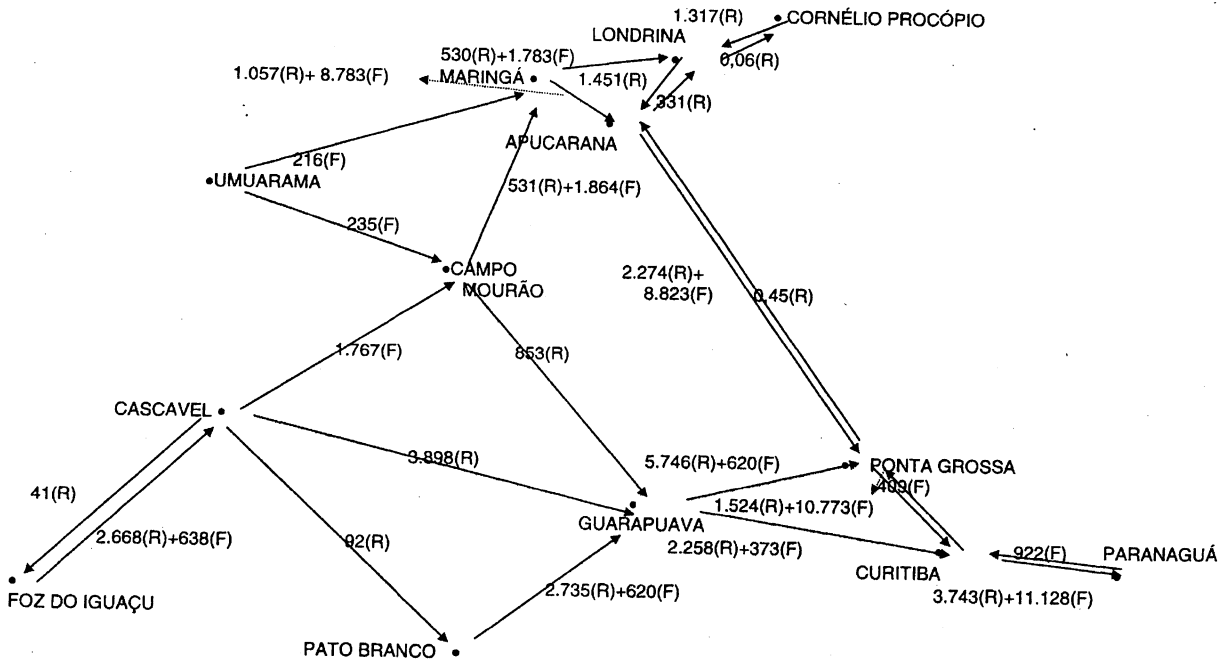


Figure 7 - Illustration of the optimum distribution between the highway (R) and railway (F) systems, estimated flow of grains and soybean meal in Paraná (in a thousand t) for 2003 considering the possibility of new railway branches, without bottleneck correction starting in Guarapuava.

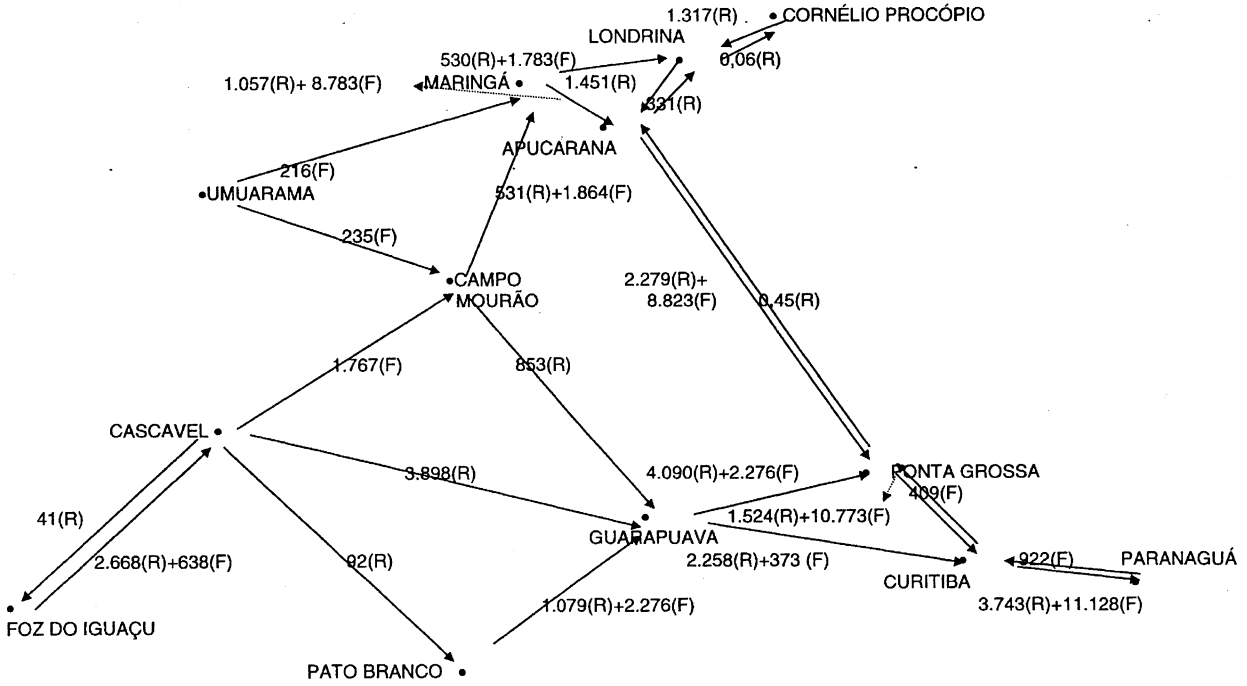


Figure 8 - Illustration of the optimum distribution between the highway (R) and railway (F) systems, estimated flow of grains and soybean meal in Paraná (in a thousand t) for 2003 considering the possibility of new railway branches, with bottleneck correction starting in Guarapuava.