# Planning airports within regional multimodal transportation systems

Marcella Autran Burlier Drummond, Luiz Gustavo Zelaya Cruz, Amaranto Lopes Pereira, Felix Mora-Camino

# CONINFRA 2011 – 5º CONGRESSO DE INFRAESTRUTURA DE TRANSPORTES (*CONINFRA 2011 - 5º TRANSPORTATION INFRASTRUCTURE CONFERENCE)*

**August 10th to 12th 2011**
São Paulo – Brasil

## PLANEJAMENTO DE AEROPORTOS EM UM SISTEMA DE TRANSPORTES MULTIMODAL REGIONAL (*PLANNING AIRPORTS WITHIN REGIONAL MULTIMODAL TRANSPORTATION SYSTEMS)*

Marcella A. B. Drummond, M.Sc., ENAC - Air Transportation Department. Endereço: 7, Av. Edouard Belin, BP 54005 – 310055, Toulouse, France. Tel.: (+33) 05 62 17 46 95, Tel./Fax: (+33) 05 62 17 44 03. Bolsista da Capes – Proc. no. 0503/10-0. E-mail: marcella.drummond@enac.fr

Luis Gustavo Zelaya Cruz, D.Sc., UFF - Pólo Universitário de Rio das Ostras. Endereço: Rua Recife, s/n, Jardim Bela Vista, Rio das Ostras – RJ, CEP: 28890-000. Tel.: (22) 2760-0848, Tel./Fax: (22) 2764-9164. E-mail: lgustavozelaya@gmail.com

Amaranto L. Pereira, Dr.-Ing., COPPE/UFRJ - Programa de Engenharia de Transportes. Endereço: Av. Horacio de Macedo, 2030 - Centro de Tecnologia, bloco H sala 106, Ilha do Fundão - Rio de Janeiro, RJ, CEP: 21941-914. Tel.: (21) 2562-8168, Tel./Fax: (21) 25628131. E-mail: amaranto@pet.coppe.ufrj.br

Félix Mora-Camino, Dr. D'Etat, ENAC - Air Transportation Department. Endereço: 7, Av. Edouard Belin, BP 54005 – 310055, Toulouse, France . Tel.: (+33) 05 62 17 43 58, Tel./Fax: (+33) 05 62 17 44 03. E-mail: felix.mora@enac.fr

**RESUMO**

O objetivo deste trabalho é propor uma ferramenta de avaliação de impactos advindos pela instalação de um novo aeroporto em uma região onde já exista uma rede de transportes multimodal. Este problema é crucial na escolha da localização de aeroportos e no planejamento de terminais, de conexões de vôo e de frotas utilizadas pelo aeroporto. Uma das principais dificuldades desta tarefa é obter uma boa previsão da demanda futura, considerando a inserção do novo aeroporto na rede de transporte multimodal existente. Tais impactos influenciam diretamente na avaliação das condições de operação, custos e receitas do novo aeroporto. A abordagem proposta utiliza-se de dois modelos de otimização diferentes: Um modelo é dedicado à previsão da demanda de passageiros e carga, considerando a alteração da acessibilidade da rede de transporte multimodal e o outro define a oferta global de transporte de acordo com o comportamento de maximização do lucro no sistema de transporte implicado. O processo de previsão da demanda é baseado em uma abordagem de maximização de entropia com restrições de níveis gerados ou atraídos pelas atividades econômicas dos distintos centros urbanos. Isso permite determinar a intensidade e a distribuição das matrizes de origem-destino por tipo de produto e modalidade de transporte. O esquema de solução proposto é composto de um processo interativo entre a solução da previsão da demanda e o problema de otimização da oferta: o problema de distribuição da maximização da entropia gera a matriz de origem-destino, dada uma estrutura de custo/capacidade, enquanto o problema de otimização da oferta gera essa estrutura de custo/capacidade caracterizando a acessibilidade, dadas as matrizes de origem-destino. A abordagem proposta é ilustrada com um estudo de caso de inserção de um novo aeroporto de médio porte em uma área rural de rápido desenvolvimento.

**PALAVRAS-CHAVE:** Rede, otimização, transporte multimodal, aeroportos.

***ABSTRACT***

*In this communication is proposed an appraisal tool for measuring the impacts of the installation of a new airport within a region already connected by a multimodal transportation network. This problem is crucial when choosing location for airports and then when planning the investments in terminals, connection links and fleets. One of the main difficulties of this task is related with the estimation of future demand over the modified transportation network which has direct influence on the evaluation of operational conditions, revenues and costs of the new airport. The proposed approach makes use of two different optimization models: One model is devoted to passenger and freight demand forecasting taking into account the modified accessibility of the multimodal transportation network, the other one defines the global transport supply according with a profit maximization behavior for the involved transport system. The demand forecasting process is based on an entropy maximization approach with distinct urban centers' economic activities generated or attracted constraints levels to determine the intensity and the distribution of origin-destination matrices by the kind of product and transport modality. The proposed solution scheme is composed of an iterative process between the current solution for demand forecasting and the supply optimization problem: the entropy maximizing distribution problem provides the origin-destination matrix given a cost/capacity structure, while the supply optimization problem provides this cost/capacity structure characterizing accessibility, given the origin-destination matrices. The proposed approach is illustrated with the case of the study of the insertion of a new airport of medium size in a rapid developing rural area.*

***KEY WORDS:*** *Network, optimization, multimodal transportation, airports.*

## INTRODUCTION

Transportation and economic development have always been entwined sectors (Jain, 2007), (Petrakos, Dimitris, & Ageliki, 2007). It is admitted that, in general, for transport as a whole, the increase in the provision of transport services in a country increases the overall productivity, which improves the national GDP. However, the relationship between transportation and economic activity is quite complex (Ishutkina, 2009).

The main objective of this study is to provide a framework to assess the impact of the implantation or the development of a new terminal facility in a multimodal transportation network in a fast developing regional economy. This is done in two steps: first a model of transportation demand is developed for passengers and freight, then supply of transportation service is optimized leading to the definition of necessary terminal capacities.

In this study, the proposed approach is illustrated with the case of the creation of a new airport in a rural area where ground transportation networks already provide transportation services to passengers and freight. Considering air transportation, it provides a rather low investment cost solution to create access to people, markets, ideas and capital. Thus air transportation can be an efficient enabler for regional economic development.

## PREDICTION OF GENERATED PASSENGERS TRANSPORTATION DEMAND

Here it is supposed that demand for air transportation at a given airport is the result of different factors: the distribution and composition of socio-economic activities, the competition with other transportation modes and the competition with other airports. This leads us to adopt respectively the following generation and attraction models for passengers demand.

A possible model for passenger generation is:

$$O_{iar}^{pax} = Pop_i \ \sigma_{ar}^i \ \lambda_{ar}^O \qquad i \in I, a \in A_i, r \in R \tag{1}$$

where $O_{iar}^{pax}$ is the potential passenger annual demand from urban center *i* with respect to people related with activity *a*, $a \in A_i$ and revenue level $r, r \in R$. $Pop_i$ is the population of center *i*, $\sigma_{ar}^i$ is the percentage of population of center *i* involved in activity *a* with revenue level *r*, *I* being the set of urban centers considered ($|I| = N$) and $\lambda_{ar}^O$ is the corresponding trip generation factor. Then a possible passenger attraction model is given by:

$$D_{iar}^{pax} = Pop_i \ \sigma_{ar}^i \ \lambda_{ar}^D + V_a^i \ \mu_{ar}^i \qquad i \in I, a \in A_i, r \in R \tag{2}$$

where $D_{iar}^{pax}$ is the annual passenger attraction to urban center *i* with respect to people related with activity *a*, $a \in A_i$ and revenue level *r*, $r \in R$. $\lambda_{ar}^D$ is the corresponding trip attraction factor. $V_a^i$ is level of activity *a* at location *i* producing attraction at rate $\mu_{ar}^i$ to outside people of revenue level *r*.

Here we consider that transportation modalities from a given urban center to and from another urban center can be distinguished, from the user point of view, by their generalized transportation costs. Here generalized transportation costs include fares, transportation delays, waiting times and comfort. Let $\pi_{ij}^m$ be the generalized transportation cost from center *i* to center *j* through transportation modality *m*.

Then, considering that an a priori distribution of trips [ $\hat{T}_{ij}^{arm}$ ] is available for each pair (*a,r*) and each modality *m*, as well as an a priori generalized transportation cost from center *j* to center *i* with each modality *m*, $\hat{\pi}_{ji}^{m}$ (Drummond, Mancel, Mora- Camino, & Pereira, 2008), (Drummond, Mora-Camino, & Pereira, 2008), we can consider the solution of the following max entropy problem (Handou A. , 2006) between each center and for all pair (*a,r*):

$$\max_{[T_{ij}^{arm}]} \; -\sum_{i\in I}\sum_{a\in A_i}\sum_{r\in R}\sum_{j\in J}\sum_{m\in M_{ij}} \pi_{ij}^{m} T_{ij}^{arm} Log(\pi_{ij}^{m} T_{ij}^{arm} / \hat{\pi}_{ij}^{m} \hat{T}_{ij}^{arm}) \tag{3}$$

$$\sum_{j\in J}\sum_{m\in M_{ij}} T_{ij}^{arm} = O_{iar}^{pax} + D_{iar}^{pax} \qquad i\in I, a\in A_i, r\in R \tag{4}$$

$$T_{ij}^{arm} \geq 0 \quad a\in A_i\;, i\in I, j\in I-\{i\}, m\in M \tag{5}$$

where $T_{kj}^{arm}$ is the distribution trip from urban center *k* to center *j*, for each pair (*a,r*) and using the same modality *m*.

Observe that this is a new version of the entropy maximization model where instead of traffic flows, transportation costs have been introduced since it is considered here that they are the main drivers of travel behavior without being exclusive. This procedure will be also adopted for the other predictive models.

## PREDICTION OF FREIGHT DEMAND DISTRIBUTION

Here we distinguish for a given location between freight imports and exports. It is considered that for activity sector *a* a $V_a^i$ level of production needs an amount of $\alpha_{aa}^i V_a^i$ to be imported, while the final re-exported production is given by $V_a^i - \sum_{b\in A_i, b\neq a} \alpha_{ba}^i V_b^i$, where the positive coefficients $\alpha_{ba}^i$ are Leontief multipliers. Let $\sum_{r\in R}\sum_{a\in A_i} Pop_i\; \sigma_{ar}^i\; \beta_r^i$ be the imported final costumer consumption at location *i* and let $C_{\mathrm{Im}}^{im}$ and $C_{Ex}^{im}$ be respectively the importation and exportation handling and storing capacities at location *i* for transport mode *m*. An estimate of the modal and spatial distribution of imported goods by center *i* is given by:

$$\begin{aligned} \max_{\phi_{ji}^{am}} \; -\sum_{i\in I} \Big[ & \sum_{a\in A_i}\sum_{j\in J_a^{\mathrm{Im}}}\sum_{m\in M_i} P_{ji}^{m}\,\phi_{ji}^{am} Log(P_{ji}^{m}\,\phi_{ji}^{am} / \hat{P}_{ji}^{m}\,\hat{\phi}_{ji}^{am}) \\ & + \sum_{a\in A_i}\sum_{j\in J_a^{Ex}}\sum_{m\in M_i} P_{ij}^{m}\,\phi_{ij}^{am} Log(P_{ij}^{m}\,\phi_{ij}^{am} / \hat{P}_{ij}^{m}\,\hat{\phi}_{ij}^{am}) \Big] \end{aligned} \tag{6}$$

$$\sum_{j\in J_a^{\mathrm{Im}}}\sum_{m\in M_i} \phi_{ji}^{am} = \alpha_{aa}^{\mathrm{Im}} V_a^i + \sum_{r\in R}\sum_{a\in R_i} Pop_i\; \sigma_{ar}^i\; \beta_r^i \qquad a\in A_i, i\in I \tag{7}$$

$$\sum_{j\in J_a^{Ex}}\sum_{m\in M_i} \phi_{ij}^{am} = V_a^i - \sum_{b\in A_i, b\neq a} \alpha_{ba}^i V_b^i \qquad a\in A_i, i\in I \tag{8}$$

$$\sum_{i\in I}\ \sum_{j\in J_a^{\mathrm{Im}}}\ \sum_{m\in M}\phi_{ij}^{am}=\sum_{i\in I}\ \sum_{j\in J_a^{Ex}}\ \sum_{m\in M}\phi_{ji}^{am}\qquad a\in\bigcup_{i\in I}A_i \tag{9}$$

$$\phi_{ji}^{am}\geq 0\qquad j\in J_a^{\mathrm{Im}},\ a\in A_i,\ m\in M, i\in I \tag{10}$$

$$\phi_{ij}^{am}\geq 0\qquad j\in J_a^{Ex},\ a\in A_i,\ m\in M, i\in I \tag{11}$$

where $\phi_{ji}^{am}$ is the imported goods flow of sector *a* with the modality *m* from *j* to the urban center *i*, $P_{ji}^{m}$ is its generalized transportation price and $\hat{P}_{ji}^{m}$ *and* $\hat{\phi}_{ji}^{am}$ is an a priori distribution and cost that are available for the modality *m*. Similar notations are adopted for exported goods: $\phi_{ij}^{am}$, $P_{ij}^{m}$, $\hat{P}_{ij}^{m}$ *and* $\hat{\phi}_{ij}^{am}$.

## TRANSPORTATION SUPPLY MODEL

The proposed supply model takes into account *m* types of flows: *m* vehicle flows according to the different transport modalities and freight flows using the resulting transport capacity. The fleets of vehicles and their operation generate fixed and variable costs, while freight flows are the main source of revenue for the freight transportation sector. To each transportation modality *m* is associated a network linking the *N* transportation centers such as:

$$R_m=[G_m,[f_{ij}^{m}]] \tag{12}$$

where $G_m$ is the graph (Berge, 2001) associated to the $m^{th}$ modality, $[f_{ij}^{m}]$ is the flow of vehicles of the $m^{th}$ modality over $G_m$. The flow of vehicles associated to each transportation mode satisfies to conservation and positivity constraints:

$$\sum_{(j,i)\in G_m} f_{ji}^{m}=\sum_{(i,k)\in G_m}^{N_m} f_{ik}^{m}\qquad m\in M \tag{13}$$

$$f_{ij}^{m}\geq 0\qquad (i,j)\in G_m,\quad m\in M \tag{14}$$

where $N_m$ is the number of vertices of graph $G_m$. Here flows integrity constraints are not taken into account since no scheduling or routing problem will be formulated according to these flows which should only provide a global view of the future development of the multimodal transportation system. However for sake of realism, a fleet capacity constraint (Park & Regan, 2006) can be introduced:

$$\sum_{(i,j)\in G_m}^{N_m} f_{ij}^{m}\, d_{ij}^{m}\leq D_m\, F_m\qquad m\in M \tag{15}$$

where $d_{ij}^{m}$ is the block time for travel, including departure and arrival activities, between vertices $i$ and $j$ , $D_m$ is the average time availability of a vehicle and $F_m$ is the fleet size with respect to modality $m$.

## SUPPLY OPTIMIZATION MODEL

Given a distribution of potential passenger demand [$T_{ij}^{arm}$] and freight demand [$\phi_{ij}^{am}$], as well as prices for passenger and freight transportation, respectively $\pi_{ij}^{m}$ and $P_{ij}^{m}$, the optimization problem of the supply of capacity to transport passengers and freight can be considered. To provide a tractable formulation of this problem, a global performance index for the whole transportation sector over a future period of time is adopted. In the case in which passengers and freight transportation (Semet & Crainic, 2005), (Crainic & Laporte, 1997), (Lubis, Elim, Prasetyo, & Yohan, 2003) are segregated, this will result in two independent problems. But when the fleet of some modality (air transportation, interurban bus transport, etc) can be used simultaneously to take care of the two types of transportation activities, these two problems are linked at least by common capacity constraints. Then the optimization criterion of the global problem can be given by:

$$\max_{f_{ij}^{m}, H_{ij}^{m}, \theta_{ij}^{m}} \sum_{(i,j)\in G} \sum_{m\in M} \left(\sum_{a\in A} P_{ij}^{am}\, \theta_{ij}^{am} + \pi_{ij}^{m} H_{ij}^{m}\right) \tag{16}$$

$$-\sum_{m\in M}\left((c_{0F}^{m} + c_{vF}^{m} F_m) + \sum_{(i,j)\in G_m}(c_{ij}^{Fm} f_{ij}^{m} + \sum_{a\in A} c_{ij}^{\theta am}\theta_{ij}^{am} + c_{ij}^{Hm} H_{ij}^{m}) + \sum_{i\in A_m}(c_T^{0m} + c_T^{m} \sum_{j\in A_m-\{i\}} (f_{ij}^{m} + f_{ji}^{m}))\right)$$

Here the decision variables are, for each transportation modality and each origin-destination, the vehicle flow levels $f_{ij}^{m}$, the freight transport capacity $\theta_{ij}^{am}$ and the passengers transport capacity $H_{ij}^{m}$. The first part of this maximization is about revenues: the $P_{ij}^{am}$ are unit freight transport fares and the $\pi_{ij}^{m}$ are unit passenger transportation fares. Then, the second part is about costs: fleet possession cost, transportation cost and terminal cost.

The associated constraints are composed of flows positivity (14), flows conservation at transportation nodes (13) and fleet capacity (15), under flow transportation capacity constraints:

$$0 \le \sum_{a\in A} \sigma_m^{aF}\, \theta_{ij}^{am} + \sigma_m^{P} H_{ij}^{m} \le f_{ij}^{m} \qquad (i,j)\in G_m,\ m\in M \tag{19}$$

and under demand level constraints:

$$0 \le \theta_{ij}^{am} \le \phi_{ij}^{am} \qquad a\in A, (i,j)\in G, m\in M \tag{21}$$

$$0 \le H_{ij}^{m} \le \sum_{a\in A_i}\sum_{r\in R} T_{ij}^{arm} \qquad (i,j)\in G,\ m\in M \tag{22}$$

with positivity conditions:

$$\theta_{ij}^{am} \geq 0 \qquad H_{ij}^{m} \geq 0 \qquad a \in A, (i,j) \in G, m \in M \tag{23}$$

where $\sigma_m^{aF}$ is a freight occupancy rate and $\sigma_m^{P}$ a passenger occupancy rate with respect to modality $m$.

When the solution of the above problem is such that for modality $m$:

$$\exists i \in I,\ j \in I - \{i\}, a \in A \quad \text{such as} \quad \theta_{ij}^{am} < \phi_{ij}^{am} \ \text{ or } \theta_{ji}^{am} < \phi_{.ij}^{am} \tag{24}$$

this means that all demand for freight transport is not satisfied. Since at this stage, no terminal capacity has been imposed, this can only be the consequence of insufficient fleet size for modality $m$:

$$\exists m \in M, \exists (i,j) \in G_m \quad \text{such that} \quad \sum_{a \in A} \sigma_m^{aF}\ \theta_{ij}^{am} + \sigma_m^{P} H_{ij}^{m} = f_{ij}^{m} \tag{25}$$

and fleet size of modality $m$ should be increased by $\Delta F_m$ according to:

$$\sum_{(i,j) \in G_m}^{N_m} ((\sum_{a \in A} \sigma_m^{aF}\ \phi_{ij}^{am} + \sigma_{m\,ij}^{P\,m} \sum_{r \in R} \sum_{a \in A} T_{ij}^{arm}) - (\sum_{a \in A} \sigma_m^{aF}\ \theta_{ij}^{am} + \sigma_m^{P} H_{ij}^{m}))\ d_{ij}^{m} = D_m\ \Delta F_m \tag{26}$$

Then the supply optimization problem can be restarted with this new fleet constraint level and new fixed costs $c_{0F}^{m}$. Then once a solution satisfying constraints:

$$\theta_{ij}^{am} = \phi_{ij}^{am} \qquad a \in A, (i,j) \in G, m \in M \tag{27}$$

$$H_{ij}^{m} = \sum_{a \in A_i} \sum_{r \in R} T_{ij}^{arm} \qquad (i,j) \in G,\ m \in M \tag{28}$$

is obtained, a lower bound for the necessary capacity of the different terminals can be estimated:

$$C_i^m = \sum_{j|(i,j) \in G_m} f_{ij}^{m} + \sum_{j|(j,i)} f_{ji}^{m} = C_i^m \quad i \in I, m \in M \tag{29}$$

If these levels are under existing capacity at some terminal, increased capacity should be pursued for this terminal and the supply optimization problem should be restarted with an increasing terminal fixed costs $c_T^{0m}$.

In the case in which the global performance of the transportation sector is under acceptable levels, transportation prices should be reviewed as well as the impacted generation and attraction levels for freight and passengers through price sensitivities such as:

$$\partial \lambda_{ar}^{O} / \partial \pi_{ij}^{m}, \quad \partial \lambda_{ar}^{O} / \partial \pi_{ij}^{m}, \quad \partial \mu_{ar}^{i} / \partial \pi_{ij}^{m}, \quad \partial \mu_{ar}^{i} / \partial P_{ij}^{m}, \quad \partial V_a^{i} / \partial P_{ij}^{m}, \quad \partial \beta_r^{i} / \partial P_{ij}^{m} \tag{30}$$

## IMPACT EVALUATION FRAMEWORK OF A NEW REGIONAL AIRPORT


ISSN 1983-3903

The implantation of a new airport in a center which had to use other transportation modalities including remote airports at other centers will have many impacts (Caris, Macharis, & Janssens, 2008) on local development:

- Transportation costs and volumes will be redeployed among the different modalities;
- Sectorial activity levels will be redefined;
- Import/export flows will be redistributed,
- The revenue distribution among the population will be modified on the medium/long run.

The above demand and supply models can be used to appraise the marginal effect created by this new situation. Then, let us consider first an initial situation in which modality $m_0$ is not present at location *i* and the volumes of activity and transportation, satisfying all the above capacity and interrelations, are given by:

$$V_a^{io}, T_{kj}^{armo}, O_{iar}^{paxo}, D_{iar}^{paxo}, \phi_{ij}^{amo}, \phi_{ji}^{amo} \quad a \in A_i, k \in I, m \in M_{ij} - \{m_{i0}\}, j \in J \tag{31}$$

with a distribution of revenues given by:

$$Pop_i \ \sigma_{ar}^i \qquad a \in A_i, r \in R \tag{32}$$

Then, introducing the new airport facility at center *i*, for the same level of activity in the different economic sectors, importation and exportation flows can be considered to be solutions of the following problems:

$$\max_{\phi_{ji}^{am}} \ -\sum_{i \in I} \Big( \sum_{a \in A_i} \sum_{j \in J_a^{\mathrm{Im}}} \sum_{m \in M_i} P_{ji}^m \phi_{ji}^{am} Log(P_{ji}^m \phi_{ji}^{am} / \hat{P}_{ji}^m \hat{\phi}_{ji}^{am}) + \sum_{a \in A_i} \sum_{j \in J_a^{Ex}} \sum_{m \in M_i} P_{ij}^m \phi_{ij}^{am} Log(P_{ij}^m \phi_{ij}^{am} / \hat{P}_{ij}^m \hat{\phi}_{ij}^{am}) \Big) \tag{33}$$

$$\sum_{j \in J_a^{\mathrm{Im}}} \sum_{m \in M_i} \phi_{ji}^{am} = \alpha_{aa}^{\mathrm{Im}} V_a^{i0} + \sum_{r \in R} \sum_{a \in R_i} Pop_i \ \sigma_{ar}^i \ \beta_r^i \qquad a \in A_i, i \in I \tag{34}$$

$$\sum_{j \in J_a^{Ex}} \sum_{m \in M_i} \phi_{ij}^{am} = V_a^{i0} - \sum_{b \in A_i, b \neq a} \alpha_{ba}^i V_b^i \qquad a \in A_i, i \in I \tag{35}$$

$$\sum_{i \in I} \sum_{j \in J_a^{\mathrm{Im}}} \sum_{m \in M} \phi_{ij}^{am} = \sum_{i \in I} \sum_{j \in J_a^{Ex}} \sum_{m \in M} \phi_{ji}^{am} \qquad a \in \bigcup_{i \in I} A_i \tag{36}$$

$$\phi_{ji}^{am} \geq 0 \qquad j \in J_a^{\mathrm{Im}}, a \in A_i, m \in M, i \in I \tag{37}$$

$$\phi_{ij}^{am} \geq 0 \qquad j \in J_a^{Ex}, a \in A_i, m \in M, i \in I \tag{38}$$

while travel demand will be now such as:

$$\max_{T_{ij}^{arm}} \ -\sum_{i \in I} \sum_{a \in A_i} \sum_{r \in R} \sum_{j \in J} \sum_{m \in M_{ij}} \pi_{ij}^m T_{ij}^{arm} Log(\pi_{ij}^m T_{ij}^{arm} / \hat{\pi}_{ij}^m \hat{T}_{ij}^{arm}) \tag{39}$$

$$\sum_{j \in J} \sum_{m \in M_{ij}} T_{ij}^{arm} = O_{iar}^{paxo} + D_{iar}^{paxo} \qquad i \in I, a \in A_i, r \in R \tag{40}$$

$$T_{ij}^{arm} \geq 0 \tag{41}$$

Other economic scenarios, considering special development projects, can be considered in this same framework by adjusting the right hand side of equations 34, 35 and 40. Anyway, the net revenue of activity *a* will be affected by the redistribution of import and export freight flows and will be changed by:

$$\begin{aligned}\Delta R_a^i = &\sum_{j \in J_a^{Ex}} \sum_{m \in M_{ij} - \{m_{i0}\}} P_{ij}^m (\phi_{ij}^{amo} - \phi_{ij}^{am}) + \sum_{j \in J_a^{\mathrm{Im}}} \sum_{m \in M_{ij} - \{m_{i0}\}} P_{ji}^m (\phi_{ji}^{amo} - \phi_{ji}^{am}) \\ &- \Big( \sum_{j \in J_a^{Ex}} P_{ij}^{m_{i0}} \phi_{ij}^{am_{i0}} + \sum_{j \in J_a^{\mathrm{Im}}} P_{ji}^m \phi_{ji}^{am_{i0}} \Big) \qquad a \in A_i\end{aligned} \tag{42}$$

The variation of net revenue of transportation mode $m$ ($\neq m_0$) is given by $\Delta R_{im}^{pax} + \Delta R_{im}^{fre}$ where:

$$\Delta R_{im}^{pax} = \sum_{a \in A} \sum_{r \in R} \sum_{j \in J} \sum_{k \in I} (\pi_{ij}^m - c_{ijm}^{pax})(T_{kj}^{arm_{ij}} - T_{kj}^{arm_{ij}o}) \qquad m \in \bigcup_{j \in J} M_{ij} - \{m_{i0}\},\ i \in I \tag{43}$$

$$\Delta R_{im}^{fre} = \sum_{a \in A} \sum_{j \in J} (P_{ij}^m - c_{ijm}^{fre}) \Big( (\phi_{ji}^{am} - \phi_{ji}^{amo}) + (\phi_{ij}^{am} - \phi_{ij}^{amo}) \Big) \qquad m \in \bigcup_{j \in J} M_{ij} - \{m_{i0}\} \quad i \in I \tag{44}$$

Then, depending of the above estimated benefits/losses for each activity sector and transportation modality, a first sight to potential impacts of the implantation of the terminal facility can be obtained. When an activity sector is found to be beneficiated by the implantation, many opportunities open to it: from keeping away the profit to reinvest it in that same location or others (Petrakos, Dimitris, & Ageliki, 2007). With respect to the ground transportation modalities, even if at first sight the implantation of the new airport seems to retrieve some of their demand, the possible increase of activity sectors should be able to overcompensate the loss of this specific demand. The resulting specialization of ground transportation modalities should be also beneficial to them through increased cost rationalization and to users by improving service quality.

To pursue this analysis, scenarios built up from investment policies in activity sectors and transportation networks, terminals and fleets, should be established. In that case the proposed structure could be used in inter temporal analysis where the lower level (demand forecasting) and the upper level (activity levels) interact along the chosen horizon of time (Handou, Alou, Mancel, & Mora-Camino, 2007).

## ILLUSTRATION OF PROPOSED APPROACH

Here we considered the application of this framework to the implantation of a new regional airport in a fast developing rural agro-industrial area in the center of Brazil.

The area under study is crossed by a main national highway while a new freight railway is planned and has been considered in the study.

The planned airport is supposed to operate light and single aisle aircraft directly towards these regional and national centers on a weekly basis (turbojets) and on demand (light aircraft). A runway of 2.2 K m is projected with three taxiways. The airport capacity is estimated on 300 K/year for passenger and 150 K ton/year for freight. The passenger terminal building will be about 10 K $m^2$ and the cargo terminal building about 3 K $m^2$, within the total airport area of 18 M $m^2$. Embraer 195 is the main operated aircraft, but the dimensioning aircraft will be A330. This investment project is estimated to the amount to US$ 250 M.

Three main activities have been considered: agro-industry (1.5 B US$, 2009), mineral extraction (0.6 B US$, 2009) and tourism (100 M US$, 2009). The total population of the sub region is about 800 000 inhabitants with an average household annual revenue of 4000 US$ with 5% having a household annual revenue higher than 60 000 US$. Activity production costs and prices, transportation flows, costs and prices levels are available from regional and national statistics.

The resulting optimization problems and inequality sets are of small dimensions, so that standard numerical techniques (linear programming) can be applied to solve them with a limited computational effort (Scheel & Scholtes, 2000), (Kanafani, 1983), . This allows to analyze a whole set of differentiated scenarios as well as to perform sensitivity analysis with respect to main exogenous parameters (in general unit prices).

**CONCLUSION**

The goal of this paper was to propose an impact appraisal tool with respect to the installation of new airport within a region already connected by a multimodal transportation network. One of the main difficulties of this task is related with the estimation of future demand over the modified transportation network which has direct influence on the evaluation of operational conditions, revenues and costs of the new airport.

The suggested approach makes use of two different optimization models: One model is devoted to passenger and freight demand forecasting taking into account the modified accessibility of the multimodal transportation network, the other one defines the global transport supply according with a profit maximization behavior for the involved transport system. The demand forecasting process is based on an entropy maximization approach with distinct urban centers' economic activities generated or attracted constraints levels to determine the intensity and the distribution of origin-destination matrices by the kind of product and transport modality.

The presented solution scheme is composed of an iterative process between the current solution for demand forecasting and the supply optimization problem: the entropy maximizing distribution problem provides the origin-destination matrix given a cost/capacity structure, while the supply optimization problem provides this cost/capacity structure characterizing accessibility, given the origin-destination matrices.

The proposed approach is illustrated with the case of the study of the insertion of a new airport of medium size in a rapid developing rural area. This case study shows that from the points of view of statistics availability and computational complexity, the proposed approach is easy to be performed, allowing the analysis of many different scenarios.

**REFERENCES**


- Alou A., Kaffa, R.and F. Mora-Camino, F. *A multilevel modelling approach for air transportation system*, Laboratoire d'Automatique et de Recherche Opérationnelle-LARA, ENAC, July 2006.
- Assad, A.A. *Multicommodity network flows-a survey*, Networks, 1978, vol. 8.

- Berge, C. *The theory of graphs*, London, Dover, 2001.
- Caris, A. Macharis, C. and Janssens, G.K. *Planning problems in intermodal freight transport: Accomplishments and prospects*. Transport Planning and Technology, June 2008.
- Crainic, T. G. and Laporte, G. *Planning models for freight transportation*. European Journal of Operational Research, September 1997.
- Dempe S. *Foundations of bi-level programming*. Kluwer Academic Publishers, Dordrecht, 2000.
- Drummond, M., Mancel, C., Mora- Camino, F. Pereira, A. *An optimization approach for long planning of multimodal freight transportation systems*. EngOpt, Rio de Janeiro, Brazil, June 2008.
- Drummond, M., Mora-Camino, F. and Pereira, A. *A global model for long term planning of multimodal freight transportation systems*. PANAM, Cartajena, Colombia, September 2008.
- Ford L.R. and Fulkerson, D.R., *Flows in networks*, Princeton, Princeton University Press, 1962.
- Handou, A., Alou Oumarou, A., Mancel, C. and Mora-Camino, F., *A two level optimization approach for the long term planning of a large air transportation network* . Proc. Int. Conf. on Inverse Problems, Design and Optimization, Miami, USA, April 2007.
- Handou, A., *Contribution à l'Optimisation d'un Réseau de Transport Aérien: Proposition d'un Modèle basé sur la Logique Floue et la Maximisation Entropique*, PhD dissertation, LARA/ENAC, Toulouse, December 2006.
- Ishutkina, M. A. *Analysis of the interaction between air transportation and Economic Activity: A worldwide Perspective*. Massachusetts Institute of Technology, 2009.
- Jain, A. *A New Broad Composite Model of Regional Economic Development as Framework for Research*. Proceedings of Small Enterprise Conference 2007, New Zealand 2007.
- Kanafani, A. *Transportation Demand Analysis*. McGraw-Hill Book Company, 1983.
- Lubis, H.R., Elim, S., Prasetyo, L.B.B. and Yohan. *Multimodal freight transport network planning*. In Journal of the Eastern Asia Society for Transportation Studies, October 2003.
- Mora-Camino, F., *Introduction à la Programmation Géométrique* , Editora COPPE, Rio de Janeiro, 1978.
- Park, M. and Regan, A.C. *Capacity Modeling in Transportation : A multimodal Perspective*. California, USA, 2004.
- Petrakos, G., Dimitris, K. and Ageliki, A. *A Generalized Model of Regional Economic Growth in European Union*. Economic and Social Research Institute (ERSI), 2007
- Scheel H. and Scholtes, S. *Mathematical programs with equilibrium constraints: stationarity, optimality et sensitivity*". Mathematics of Operations Research 2000, vol.25, pp.1-22.
- Semet-F. Crainic, T. *Recherche Operationnelle et Transport de Marchandises*, Montreal, Canada, 2005.
- Vasiliauskas, A.V. *Modeling of a national multimodal transport network.* Transport and Telecommunication, Vilnius, Lithuania, 2003.


ISSN 1983-3903