# A bi-level scheme for assessing the impact of air transportation on local development

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## *A BI-LEVEL SCHEME FOR ASSESSING THE IMPACT OF AIR TRANSPORTATION ON LOCAL DEVELOPMENT*


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### *ABSTRACT*

*An approach to assess the impact of the creation or either the expansion of an air transport infrastructure over regional development is proposed in this paper. Effective long term planning of this investment requires performing an overall analysis of socio-economic consequences through long term forecasting, scenario generation and risk analysis. One of main aspects of this task is related with the estimation of future demand over the modified transportation network which attends the considered region.*

*The proposed approach makes use of two complementary models: One model is devoted to demand forecasting taking into account the modified accessibility of the multimodal transportation network, the other one defines the economic performance of local activity sectors and transportation modalities. The demand forecasting process is based on an entropy maximization approach with flexible origin-destination levels to determine the intensity and the distribution of new origin-destination vectors.*

*A two level analysis considering passengers and freight flows at the first level and activity flows at the second level is made possible and becomes available to process the assessment of different regional development scenarios.*

*The proposed approach is illustrated in the case of a fast developing rural agro-industrial area in central Brazil, where the consequences of the installation of a medium size airport are assessed.*



***KEY WORDS:*** *Transportation networks, airports, air transportation,regional development.*



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SPECIAL SESSION
*Air Transportation and Local Development (ZL SS)*

## 1. INTRODUCTION

Transportation and economic development have always been entwined sectors. 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 air transportation and economic activity is quite complex. With respect to regional economy, air transportation 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.

The main objective of this study is to provide a framework to assess the impact of the implantation of a new airport in a rural area where some other airports as well as ground transportation networks already provide transportation services to passengers and freight. It is supposed that each airport, pre-existing or new is attached to a particular urban center.

## 2. 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.

The generation model:

$$O_{iar}^{pax} = Pop_i \ \sigma_{ar}^{i} \ \lambda_{ar}^{O} \qquad i \in I, a \in A_i \cup \{0\}, r \in R \tag{1}$$

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 local center $i$, $\sigma_{ar}^{i}$ is the percentage of population of local center $i$ involved in activity $a$ with revenue level $r$ (Index $a = 0$ for $\sigma_{ar}^{i}$ represent residual generation of trips from people of revenue level $r$, $i \in I$, $I$ being the set of regional urban centers considered) and $\lambda_{ar}^{O}$ is the corresponding trip generation factor.

and the attraction model:

$$D_{iar}^{pax} = Pop_i \ \sigma_{ar}^i \ \lambda_{ar}^D + V_a^i \ \mu_{ar}^i \qquad i \in I, a \in A_i \cup \{0\}, r \in R \qquad (2)$$

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 a location *i* producing attraction at a $\mu_{ar}^i$ rate, to outside people of revenue level *r*.

Here we consider that transportation modalities from a given local urban center to and from a major urban center outside the considered region 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 local center *i* to interregional center *j* through generalized transportation modality *m*. Figure 1 gives a sketch of the two retained level space analysis.

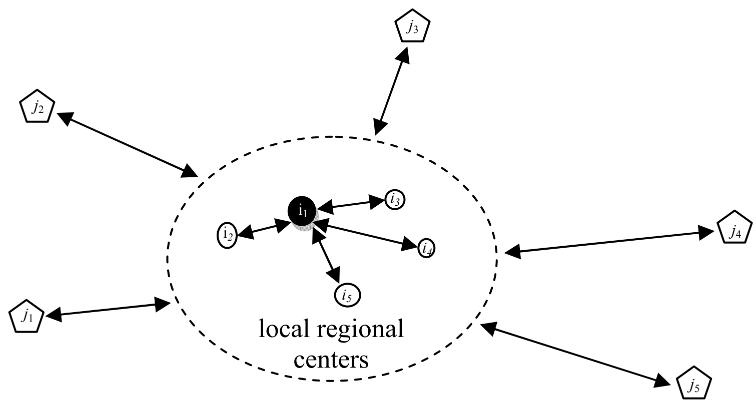



**Fig.1** Hierarchical view of intra and inter regional transport

These generalized modalities include multimodal transportation corresponding for instance to the use of concurrent transportation facilities (airports) from other local centers. The modalities available for local center i to regional center j are given by the set $M_{ij}$, with:

$$M_{ij} = M_{ij}^A \cup M_{ij}^{\overline{A}} \qquad (3)$$

where $M_{ij}^{A}$ is the set of transportation paths using a local airport, starting from the airport of local center *i* when it exists, $M_{ij}^{\bar{A}}$ is the set of other transportation paths between local center *i* and interregional center *j*.

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 interregional center *j* to local center *i* with each modality *m* [$\hat{\pi}_{ji}^{m}$], we can consider the solution of the following max entropy problem for each local center and each pair (*a,r*):

$$\max_{T_{ij}^{arm}} \quad -\sum_{i\in I}\sum_{a\in A_i}\sum_{r\in R}\sum_{j\in J}\sum_{m\in M_{ij}} \pi_{ij}^{m} T_{ij}^{arm} Log(\pi_{ij}^{m} T_{ij}^{arm} / \hat{\pi}_{ij}^{m} \hat{T}_{ij}^{arm}) \qquad (4)$$

$$\sum_{j\in J}\sum_{m\in M_{ij}} T_{ij}^{arm} = O_{iar}^{pax} + D_{iar}^{pax} \qquad i\in I, a\in A_i, r\in R \qquad (5)$$

$$\sum_{a\in A_i}\sum_{r\in R}\sum_{j\in J}\sum_{k\in I} T_{kj}^{arm_{ij}} \le C_i^{m\,pax} \qquad i\in I \qquad (6)$$

$$T_{ij}^{arm} \ge 0 \qquad (7)$$

where $T_{kj}^{arm_{ij}}$ is the distribution trip from the local regional center *k* to the interregional center *j*, for each pair (*a,r*) and using the same modality *m* from the intermediate city *i* to arrive at *j*. $C_i^{m\,pax}$ is the infrastructure capacity of the local center *i,* considering the passenger modality *m* used.

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.

Then the total passenger demand for airport *i* is estimated by:

$$\Delta_i = \sum_{a\in A_i}\sum_{r\in R}\sum_{j\in J}\sum_{k\in I} T_{kj}^{arm_{ij}} \qquad (8)$$

In the case where:

$$\Delta_i = \sum_{a\in A}\sum_{r\in R}\sum_{j\in J}\sum_{k\in I} T_{kj}^{arm_{ij}} > C_i^{pax} \qquad (9)$$

the no-capacity saturation assumption will lead to install an added capacity given by:

$$\delta C_i = \Delta_i - C_i^{pax} \tag{10}$$

## 3. PREDICTION OF FREIGHT DEMAND DISTRIBUTION

Here we distinguish 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 $C_{\text{Im}}^{im}$ 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 local center *i* is given by:

$$\max_{\phi_{ji}^{am}} \quad -\sum_{a \in A_i} \sum_{j \in J_a^{\text{Im}}} \sum_{m \in M_i} P_{ji}^m \, \phi_{ji}^{am} Log(P_{ji}^m \, \phi_{ji}^{am} / \hat{P}_{ji}^m \, \hat{\phi}_{ji}^{am}) \tag{11}$$

$$\sum_{j \in J_a^{\text{Im}}} \sum_{m \in M_i} \phi_{ji}^{am} = \alpha_{aa}^{\text{Im}} V_a^i + \sum_{r \in R} \sum_{a \in R_i} Pop_i \; \sigma_{ar}^i \; \beta_r^i \qquad a \in A_i \tag{12}$$

$$\sum_{a \in A_i} \sum_{j \in J_a^{\text{Im}}} \phi_{ji}^{am_{ij}} \leq C_{\text{Im}}^{im} \qquad m \in M_i \tag{13}$$

$$\phi_{ji}^{am} \geq 0 \qquad j \in J_a^{\text{Im}}, \; a \in A_i, \quad m \in M_i \tag{14}$$

Where $\phi_{ji}^{am}$ is the imported goods flow of sector *a* with the modality *m* from *j* to the regional 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*. Appling the same argument, $\phi_{ij}^{am}$, $P_{ij}^m$, $\hat{P}_{ij}^m$ *and* $\hat{\phi}_{ij}^{am}$ are used for the exported goods.

An estimate of the modal and spatial distribution of exportations from local center *i* is given by:

$$\max_{\phi_{ij}^{am}} \quad -\sum_{a\in A_i}\sum_{j\in J_a^{Ex}}\sum_{m\in M_i} P_{ij}^{m}\,\phi_{ij}^{am} Log(P_{ij}^{m}\,\phi_{ij}^{am} / \hat{P}_{ij}^{m}\,\hat{\phi}_{ij}^{am}) \tag{15}$$

$$\sum_{j\in J_a^{Ex}}\sum_{m\in M_i} \phi_{ij}^{am} = V_a^i - \sum_{b\in A_i, b\neq a} \alpha_{ba}^i V_b^i \qquad a\in A_i \tag{16}$$

$$\sum_{a\in A_i}\sum_{j\in J_a^{Ex}} \phi_{ij}^{am} \le C_{Ex}^{im} \quad m\in M_i \tag{17}$$

$$\phi_{ij}^{am} \ge 0 \qquad j\in J_a^{Ex}, a\in A_i, m\in M_i \tag{18}$$

4. LOCAL DEVELOPMENT PERFORMANCE INDICATORS

Following the above model of regional economics and transportation, we get different and, in general, competing performance indicators:
The net revenue of activity sector *a* at local center *i* is given by:

$$R_a^i = (p_a - \theta_a^i)\, V_a^i - \sum_{m\in M_i} \Big(\sum_{j\in J_a^{Ex}} P_{ij}^m \phi_{ij}^{am} + \sum_{j\in J_a^{\text{Im}}} P_{ji}^m \phi_{ji}^{am}\Big) - \theta_{ia}^0 \qquad a\in A_i \tag{19}$$

where $p_a$ is the generalized price of the goods, $\theta_a^i$ is the average variable cost and $\theta_{ia}^0$ is the fixed cost of production of goods in activity sector *a* of the local center *i*.
The net revenue of transportation mode *m* is given by $R_{im}^{pax} + R_{im}^{fre}$ where :

$$R_{im}^{pax} = \sum_{a\in A}\sum_{r\in R}\sum_{j\in J}\sum_{k\in I} (\pi_{ij}^m - c_{ijm}^{pax})\, T_{kj}^{arm_{ij}} - c_{0im}^{pax} \qquad m\in \bigcup_{j\in J} M_{ij} \qquad i\in I \tag{20}$$

$$R_{im}^{fre} = \sum_{a\in A}\sum_{j\in J} (P_{ij}^m - c_{ijm}^{fre})(\phi_{ji}^{am} + \phi_{ij}^{am}) - c_{0im}^{fre} \qquad m\in \bigcup_{j\in J} M_{ij} \qquad i\in I \tag{21}$$

with $c_{0im}^{pax}$ and $c_{0im}^{fre}$ being respectively the fixed cost of transportation of passengers and goods which are used in the local center *i* with the modality *m*.
Since $m_0$ is the index assigned to air transportation activity, here part of the cost of modality $m_0$ at local center *i* is the main component of airport revenue which is given by:

$$R_i^{aerop} = \left( c_{0im_0}^{pax}(1-\tau_f^{pax}) + c_{0im_0}^{fre}(1-\tau_f^{fre}) \right) + \left( (1-\tau_v^{pax})(\sum_{j\in J} c_{ijm_0}^{pax} \sum_{k\in I} \sum_{r\in R} T_{kj}^{arm_{ij}}) + c_{ijm}^{fre}(\phi_{ij}^{am_0} + \phi_{ji}^{am_0})(1-\tau_v^{fre}) \right) \quad (22)$$

where $\tau_f^{pax}$ and $\tau_f^{fre}$ are the proportions of airlines fixed costs corresponding to airport taxes while $\tau_v^{pax}$ and $\tau_v^{fre}$ are the proportions of airlines average variable costs corresponding to airport taxes, either for passengers or goods air transportation.

Its net revenue is given by:

$$R_i^{aerop} - (c_{if}^{aerop} + c_{iv}^{pax}(\sum_{j\in J} \sum_{k\in I} \sum_{r\in R} T_{kj}^{arm_{ij}}) + c_{iv}^{fre}(\phi_{ij}^{am_0} + \phi_{ji}^{am_0})) \quad (23)$$

where it is supposed that the fixed cost of airport *i* is such as:

$$c_{if}^{aerop} = \omega_i^{pax} C_i^{m_0} + \omega_i^{fre}(C_{\mathrm{Im}}^{im_0} + C_{Ex}^{im_0}) \quad (24)$$

with $\omega_i^{pax}$ and $\omega_i^{fre}$ referring to a cost coefficient for respectively passengers and freight terminals, $C_i^{m_0}$ the capacity in passengers terminals and $C_{\mathrm{Im}}^{im_0}$ *and* $C_{Ex}^{im_0}$ the infrastructure capacity for goods imports and exports.

Then finally, the distribution of revenue among the population can be related to activity levels by a relation such as:

$$Pop_i \ \sigma_{ar}^i = \delta_{ar}^{i0} + \delta_{ar}^i V_a^i \qquad i \in I, a \in A_i, r \in R \quad (25)$$

## 5. IMPACT EVALUATION FRAMEWORK OF A NEW REGIONAL AIRPORT

The implantation of a new airport in a local center which had to use other transportation modalities including remote airports at other regional centers will have many impacts 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.

The above transportation and sectorial 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:

$$V_a^{io}, T_{kj}^{armo}, O_{iar}^{paxo}, D_{iar}^{paxo}, \phi_{ij}^{amo}, \phi_{ji}^{amo} \quad a \in A_i, k \in I, m \in M_{ij} - \{m_{i0}\}, j \in J \tag{26}$$

with a distribution of revenues given by:

$$Pop_i \ \sigma_{ar}^i \qquad a \in A_i, r \in R \tag{27}$$

Then, introducing the new airport facility at regional center $i$, to get the same level of activity, importation and exportation flows can be considered to be solutions of the following problems:

$$\max_{\phi_{ji}^{am}} \ -\sum_{a \in A_i} \sum_{j \in J_a^{\text{Im}}} \sum_{m \in M_i} P_{ji}^m \phi_{ji}^{am} Log(P_{ji}^m \phi_{ji}^{am} / \hat{P}_{ji}^m \hat{\phi}_{ji}^{am}) \tag{28}$$

$$\sum_{j \in J_a^{\text{Im}}} \sum_{m \in M_i} \phi_{ji}^{am} = \alpha_{aa}^{\text{Im}} V_a^{io} + \sum_{r \in R} \sum_{a \in R_i} Pop_i \ \sigma_{ar}^i \ \beta_r^i \qquad a \in A_i \tag{29}$$

$$\sum_{a \in A_i} \sum_{j \in J_a^{\text{Im}}} \phi_{ji}^{am_{ij}} \le C_{\text{Im}}^{im} \qquad m \in M_i \tag{30}$$

$$\phi_{ji}^{am} \ge 0 \qquad j \in J_a^{\text{Im}}, \ a \in A_i, \ m \in M_i \tag{31}$$

and

$$\max_{\phi_{ij}^{am}} \ -\sum_{a \in A_i} \sum_{j \in J_a^{Ex}} \sum_{m \in M_i} P_{ij}^m \phi_{ij}^{am} Log(P_{ij}^m \phi_{ij}^{am} / \hat{P}_{ij}^m \hat{\phi}_{ij}^{am}) \tag{32}$$

$$\sum_{j \in J_a^{Ex}} \sum_{m \in M_i} \phi_{ij}^{am} = V_a^{io} - \sum_{b \in A_i, b \ne a} \alpha_{ba}^i V_b^{io} \qquad a \in A_i \tag{33}$$

$$\sum_{a \in A_i} \sum_{j \in J_a^{Ex}} \phi_{ij}^{am} \le C_{Ex}^{im} \qquad m \in M_i \tag{34}$$

$$\phi_{ij}^{am} \ge 0 \qquad j \in J_a^{Ex}, a \in A_i, m \in M_i \tag{35}$$

while travel demand will be now such as:

(36)

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

$$\sum_{j\in J}\sum_{m\in M_{ij}} T_{ij}^{arm} = O_{iar}^{paxo} + D_{iar}^{paxo} \qquad i\in I, a\in A_i, r\in R \qquad (37)$$

$$\sum_{a\in A_i}\sum_{r\in R}\sum_{j\in J}\sum_{k\in I} T_{kj}^{arm_{ij}} \le C_i^{m\,pax} \qquad i\in I \qquad (38)$$

$$T_{ij}^{arm} \ge 0 \qquad (39)$$

Then, the net revenue of activity *a* will be changed by:

$$\Delta R_a^i = \sum_{j\in J_a^{Ex}}\sum_{m\in M_{ij}-\{m_{i0}\}} P_{ij}^{m}(\phi_{ij}^{amo} - \phi_{ij}^{am}) + \sum_{j\in J_a^{\mathrm{Im}}}\sum_{m\in M_{ij}-\{m_{i0}\}} P_{ji}^{m}(\phi_{ji}^{amo} - \phi_{ji}^{am}) - \Big(\sum_{j\in J_a^{Ex}} P_{ij}^{m_{i0}}\phi_{ij}^{am_{i0}} + \sum_{j\in J_a^{\mathrm{Im}}} P_{ji}^{m}\phi_{ji}^{am_{i0}}\Big) \qquad a\in A_i \qquad (40)$$

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

$$\Delta R_{im}^{pax} = \sum_{a\in A}\sum_{r\in R}\sum_{j\in J}\sum_{k\in I} (\pi_{ij}^{m} - c_{ijm}^{pax})(T_{kj}^{arm_{ij}} - T_{kj}^{arm_{ij}o}) \qquad m\in \bigcup_{j\in J} M_{ij} - \{m_{i0}\} \quad i\in I \qquad (41)$$

$$\Delta R_{im}^{fre} = \sum_{a\in A}\sum_{j\in J} (P_{ij}^{m} - c_{ijm}^{fre})\Big( (\phi_{ji}^{am} - \phi_{ji}^{amo}) + (\phi_{ij}^{am} - \phi_{ij}^{amo}) \Big) \qquad m\in \bigcup_{j\in J} M_{ij} - \{m_{i0}\} \quad i\in I \qquad (42)$$

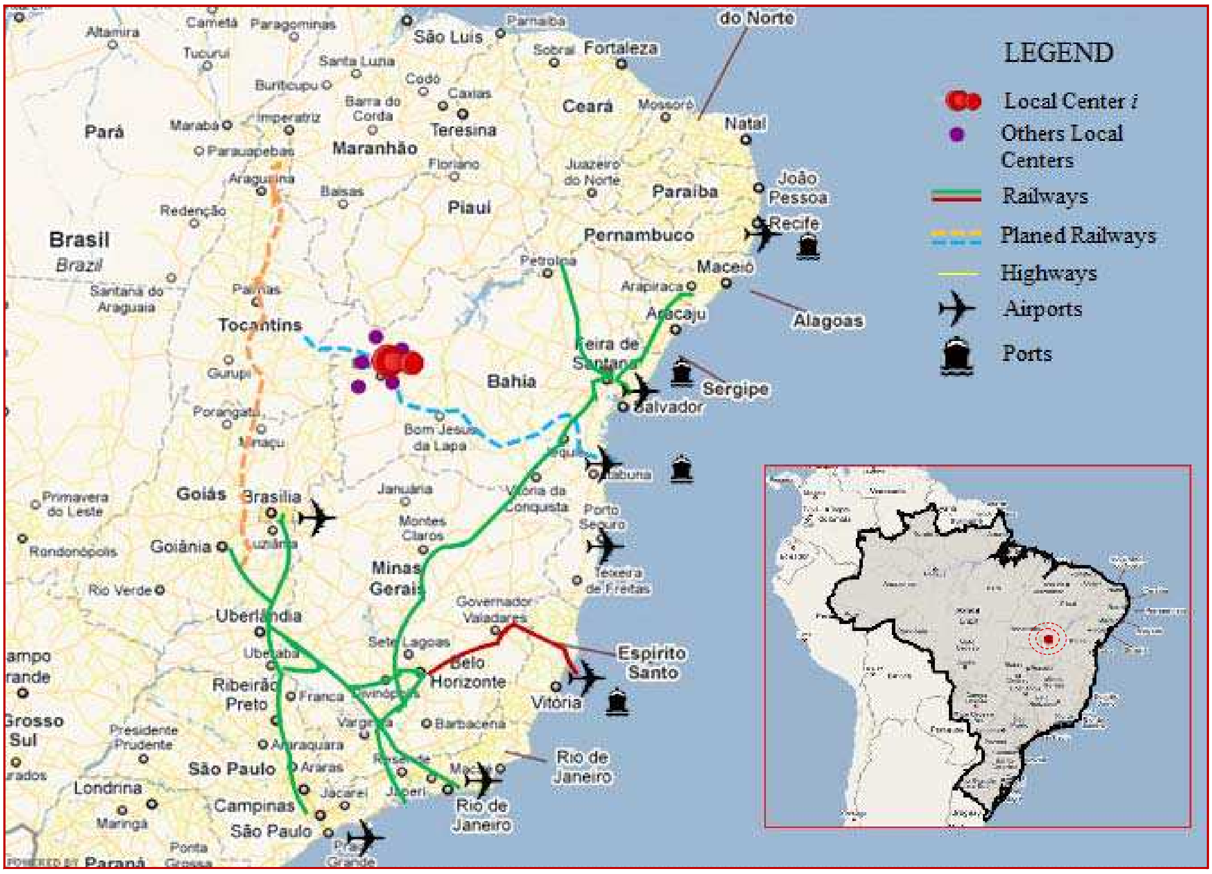
Then, depending of the above estimated benefits/losses for each activity sector and transportation modality, a first sight to potential impacts of the implantation of the new airport can be obtained. When an activity sector is found to be beneficiated by the implantation, many opportunities open to it: from keeping away the profit to reinvest it in that same location or others. When the activity levels saturate some capacity constraints at solution of problems (28-31), (32-35) and (36-39) it will be interesting to restart the analysis with increased capacity levels.

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 an inter temporal analysis where the lower level (demand forecasting) and the upper level (activity levels) interact along the chosen horizon of time.

## 6. ILLUSTRATION OF PROPOSED APPROACH

Here we considered the application of this framework to the implantation of a medium regional airport in a fast developing rural agro-industrial area in the center of Brazil (Western Bahia State). The considered region is shown in map 1:




**Map 1.** National position of study area

The area under study consists of a set of six local centers located near a main highway (BR242) and the planned LESTE-OESTE freight railway has been considered in the study.
Only one short runway airport is already operating in the sub region with turbo-powered light aircraft to connect this area with two larger regional airports in Bahia state where turbo jets link them to major regional and national centers (Salvador, Ilhéus, Brasilia, Belo Horizonte and Recife). The planned airport is supposed to operate light aircraft and turbo jets directly towards these regional and national centers on a weekly basis (turbojets) and on demand (light aircraft).
Three main activities have been considered: agro-industry (1.5 B US$, 2009), mineral extraction (0.6 B US$, 2009) and tourism (100 MM US$, 2009). The total population of the sub region is about 300 000 inhabitant with an average household annual revenue of 6000 US$ 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 dimension, so that many numerical techniques can be applied to solve them with a limited computational effort allowing the study of differentiated scenarios.

## 7. CONCLUSION

This communication has considered the problem of long term forecasting of passengers and freight transportation in a large network and its impact when a new air transport infrastructure is created or improved. The proposed approach has introduced two different optimization models: A model devoted to demand forecasting and another one defining the economic performance of local activity sectors and transportation modalities. The prediction of generated demand of passengers and freight process is based on an entropy maximization approach with flexible origin-destination levels to determine the intensity and the distribution of new origin-destination vectors.

Then, a bi-level approach considering passengers and freight flows at the first level and activity flows at a second level has been developed with the objective of providing a tool for the appraisal of different regional development scenarios related with air transportation investment.

The case study considered of rural a area in the center of Brazil, characterized by agro-industrial activities, shows that from the points of view of statistics availability and computational complexity, the proposed approach is feasible.

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