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A FRAMEWORK FOR ASSESSING THE IMPACT OF TRANSPORTATION FACILITY INVESTMENT ON LOCAL DEVELOPMENT

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ABSTRACT

This study proposes an approach for assessing the impacts resulting from a new inter modal terminal in a regional transportation system. This problem is of importance when choosing a location for a transportation terminal and then planning the corresponding investments. 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 transportation revenues and costs as well as on local economy. 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 case study considered to illustrate the proposed approach is relative to a new medium size airport in a rapid developing rural area of Brazil.

Keywords: M*ultimodal Transportation Networks, Demand Prediction, Airport planning*

Subject area: (Please put a "X" as appropriate, you may choose more than one)

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X	Transportation and Geography
X	Transportation, Land Use and Built Environment
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1. INTRODUCTION

Transportation and economic development have always been entwined sectors. It is admitted that, 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. For example, in the case of air transportation, its relationship with economic activity is quite complex (Kanafani *et al*., 1987, Ishutkina, 2009). The main objective of this study is to provide a framework to assess the impact of the implantation of a new transportation terminal in a region where some other transportation terminals and multimodal networks already provide transportation services to passengers and freight (see in general Lubis *et al*., 2003, Jain *et al*., 2007, Drummond, 2008). It is supposed that each transportation terminal, pre-existing or new, is attached to a particular urban center. 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 facility. 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 (Leurent, 1997) with distinct urban centers and economic activities. 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 the cost/capacity structure characterizing accessibility, given the origin-destination matrices.

The proposed approach is illustrated with the case study of the insertion of a new airport of medium size in a rapid developing rural area. With respect to regional economy, air transportation provides a rather low investment cost solution to create access to other people, markets, ideas and capital. In that case, air transportation can be an efficient enabler for regional economic development.

2. PREDICTION OF POTENTIAL PASSENGERS TRANSPORTATION DEMAND

Demand for transportation at a given location is the result of different factors such as the space distribution and composition of socio-economic activities, the competition with other transportation modes and the competition with other urban centers. Here we adopt a multiple stage approach to transportation demand prediction composed of generation/attraction and distribution models for passengers and freight. The adopted generation model is such as:

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

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, σ_{ar}^i is the percentage of population of local center i involved in activity a with revenue level r (index $a = 0$ for transportation activity), σ_{ar}^i represents residual generation of trips from people of revenue level r, $i \in I$, I being the set of regional urban centers considered) and λ_{ar}^O is the corresponding trip generation factor. The associated attraction model is such as:

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

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, $r \in R$, λ_{ar}^D is the corresponding trip attraction factor, V_a^i is level of activity a at location i producing attraction with a μ_{ar}^i rate to outside people of revenue level r. The existing 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 π_{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 retained two levels space structure.

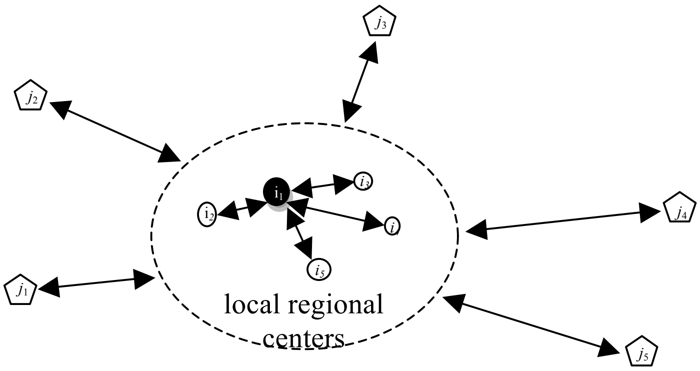

Figure1. Hierarchical view of intra and inter regional transportation

The generalized transportation modalities include multimodal transportation corresponding for instance to the use of concurrent transportation facilities from other nearby local centers. The modalities available for local center i to regional center j are given by the set M_{ij} , with $M_{ij} = M_{ij}^{A} \cup M_{ij}^{\overline{A}}$, where M_{ij}^{A} is the set of transportation paths using a local terminal, starting from a terminal at local center i when it exists, $M_{ij}^{\overline{A}}$ 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 activity-revenue level (a,r) and each transportation modality m, as well as is available an a priori generalized transportation cost from interregional center j to local center i for 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):

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

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

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

$$T_{ij}^{arm} \ge 0 \tag{7}$$

where $T_{kj}^{arm_{ij}}$ is the number of trips 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. Observe that the above problem 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 paradigm will be also adopted for the other predictive models. Then the total passenger demand for center i is estimated by:

$$\sum_{a\in A_i}\sum_{r\in R}\sum_{j\in J}\sum_{k\in I} T_{kj}^{arm_{ij}} \tag{8}$$

and if it is higher than the corresponding capacity, an additional capacity should be installed to cover this deficit.

3. PREDICTION OF FREIGHT DEMAND DISTRIBUTION

Here we distinguish between freight imports and exports. It is considered that for the a^{th} activity sector at location i, a production level V_a^i implies freight imports to an amount of $\alpha_{aa}^i V_a^i$, while the final exported production of this activity from location i is given by:

$$V_a^i - \sum_{b \in A_i, b \neq a} \alpha_{ba}^i V_b^i \tag{9}$$

where the positive coefficients α_{ba}^i are Leontief multipliers. Let the imported final costumer consumption at location i be:

$$\sum_{r \in R} \sum_{a \in A_i} Pop_i \ \sigma_{ar}^i \ \beta_r^i \tag{10}$$

and let C_{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 at local center i is given by the solution of the following entropy maximization problem:

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

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

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

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

where ϕ_{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. Applying the same argument, ϕ_{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 then given by:

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

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

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

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

4. TRANSPORTATION SUPPLY MODEL

The proposed model takes into account m+1 types of flows: m vehicle flows according to the different transport modalities and freight flows using the resulting transport capacity (Park *et al.*, 2004). 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 is associated a network linking the N transportation centers such as $\boldsymbol{R_m} = [\boldsymbol{G_m}, [f_{ij}^m]]$ where $\boldsymbol{G_m}$ is the graph associated to the m^{th} modality, $[f_{ij}^m]$ is the flow of vehicles of the m^{th} modality over $\boldsymbol{G_m}$. The flow of vehicles associated to each transportation mode satisfies to conservation and positivity constraints:

$$\sum_{(j,i) \in G_m} f_{ji}^m = \sum_{(i,j) \in G_m}^{N_m} f_{ik}^m \qquad i \in G_m, \quad m \in M \tag{20}$$

$$f_{ij}^{m} \geq 0, \quad (i,j) \in \boldsymbol{G_m} \quad m \in M \tag{21}$$

where N_m is the number of vertices of graph $\boldsymbol{G_m}$. 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 can be introduced:

$$\sum_{(i,j)\in G_m}^{N_m} f_{ij}^{m}\ d_{ij}^{m} \leq D_m\ F_m \qquad m \in M \tag{22}$$

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 for modality m. It can be also of interest to introduce node capacity constraints related with intermodal stations and terminals:

$$\sum_{m,n\in M}\ \sum_{(i,j)\in G_m \cup G_n} S_{mn}(i,j)\ f_{ij}^{m} \leq C^{m} \quad m \in M_{ij} \tag{23}$$

where C_i^m is the traffic capacity of terminal t, $S_{mn}(i, j, t)$ are incidence matrices between vehicle flows of different transportation modes.

5. SUPPLY OPTIMIZATION MODEL

Given a distribution of potential passengers demand $[T_{ij}^{arm}]$ and freight demand $[\phi_{ij}^{am}]$, as well as prices for passengers and freight transportation, respectively π_{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 (Crainic *et al*., 1997), (Vasiliauskas, 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:

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

$$- \sum_{m\in M} \left((c_{0F}^{m} + c_{vF}^{m} F_m) + \sum_{(i,j)\in G_m} \Big(c_{ij}^{Fm} f_{ij}^{m} + \sum_{a\in A} c_{ij}^{\theta am} \theta_{ij}^{am} + c_{ij}^{Hm} H_{ij}^{m}\Big) + \sum_{i\in A_m} \Big(c_T^{0m} + c_T^{m} \sum_{j\in A_m - \{i\}} (f_{ij}^{m} + f_{ji}^{m})\Big) \right) \tag{16}$$

Here the decision variables are, for each transportation modality and each origin-destination, the vehicle flow levels f_{ij}^{m}, the freight transport capacity θ_{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 π_{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:

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

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

here σ_m^{aF} is a freight occupancy rate and σ_m^{P} a passenger occupancy rate with respect to modality *m*. When the solution of the above problem is such that for modality *m*:

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

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 ΔF_m according to:

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

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 the following 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 (Scheel *et al.*, 2000) such as:

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

6. IMPACT EVALUATION FRAMEWORK OF A NEW REGIONAL TERMINAL

The implantation of a new transportation terminal in a center which had to use other transportation modalities including remote terminals at other centers will have many impacts (Caris *et al.*, 2008) on local development: Transportation costs and volumes will be redeployed among the different modalities, sector activity levels will be redefined, import/export flows will be redistributed and 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: $Pop_i\ \sigma_{ar}^{i} \qquad a \in A_i, r \in R$ (32)

Then, introducing the new transportation 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 new terminal facility can be obtained. When an activity sector is 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 other transportation modalities, even if at first sight the implantation of the new modality seems to retrieve some of their demand, the possible increase of activity sectors should be able to over compensate the loss of this specific demand. The resulting specialization of the other 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.

7. 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-East of Brazil . The area under study is crossed by an interstate highway while a new freight railway is planned and has been included 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 Km is planned with three taxiways. The airport capacity is estimated on 300 000 pax/year for passengers and 150 000 ton/year for freight. The passenger terminal building will be about 10 $10^6 m^2$ and the cargo terminal building about 3 $10^6 m^2$, within the total airport area of 18 $10^6 m^2$. Embraer 195 is the main operated aircraft, but A330 is the dimensioning aircraft. 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. 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 costs).

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