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Intermodal transport in urban passengers mobility

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Abstract

The aim of the paper is to point out the role for intermodality in urban passengers transport. The main benefit of intermodal transport is due to the opportunity of reducing externalities through a segmentation of transport demand. Since this strategy implies the segmentation of the transportation system in a number of different modes, a key role is played by the nodes of the urban transport network in which interchanges take place. So that the achievement of a better "quality" of nodes becomes a major purpose of urban mobility policies. In the paper a technique is developed in order to quantify the performance of urban intermodal nodes, to allow performance comparison between nodes and over time, and to support decision-making concerning the nodes efficiency. In the meanwhile an analysis of the role played by nodes within an intermodal network, with regard to their relationships, is proposed, in order to classify them by their "value".

1 Introduction

In the last decades the idea of intermodality has become one of the most important subjects of interest in the economic studies concerning freight transport [3,4,6]. So far, however, little or no attention is paid to intermodal passengers transport, even if intermodality is already a feature of growing importance in passengers mobility (after the "ages" of mass transit, and private mobility) with regard to urban and metropolitan transport.

Since urban intermodality can be roughly defined as the utilisation of different transportation modes as to allow people to reach a specified destination from a point of departure, it can be seen as a suitable way for urban development and growth passing round the obstacle of the today's increasing external costs of mobility, and, generally speaking, of the diseconomies of scale of urban concentration.

The achievement of urban concentration economies (depending both on location and urbanization factors) points out the aspect of their sharing, which involves directly the problem of the *internal-accessibility* of urban areas. As a consequence, there is a growth in the demand for accessibility which causes an increase of the demand for mobility. In this way greater economies of urban concentration can be obtained only by improving the urban transportation system. Such improvement may determine a better quality in transportation service (and a reduction of the generalized cost of transport) just in the short run, while in a long term, due to the possibility of fruition of agglomeration benefits, this may imply a growing size of the cities with a subsequent worsening of urban congestion. In this process shifting from mass transit to private one has allowed the achievement of a relevant progress in accessibility, and urbanization economies, but, on the other side, has caused growing external costs for congestion and pollution in urban areas [10].

It is therefore at this stage of the urban development process that, from the derived demand for mobility, rises a demand for intermodal transport. This implies a segmentation of urban paths into different modes and a consequent better sizing of each mode (segment) with respect to the importance of the mobility demand of the correspondent modality. Note that the demand for mobility derives from the demand for accessibility, which, in turns originates from the demand for urban concentration economies. We can assert that intermodal transport, aiming at reducing urban diseconomies, should lead to a further increase of cities sizing and of its related concentration economies.

A major problem is the comparison between costs and benefits for different players (i.e. final users and social community). In fact, an increase in intermodality may cause higher costs (such as longer times and disadvantages related to the modal shifts) for those users who pass from a monomodal to an intermodal transportation system; monetary benefits for local public transport companies; and not monetary benefits lower level of congestion and pollution for other people (especially for those passengers who do not have to change for intermodal transport).

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Due to the goal of reducing externalities it is quite correct to consider intermodality as a relevant matter of the local government planning and decision making. So far, however, the debate on intermodality come down to an identification of a *trade off* between the greater efficiency and the lower efficacy of the intermodal transport compared with the monomodal one.

In this work we overlook an approach for determining an "optimal level" of intermodality in urban transport (where marginal costs equal marginal benefits), being aware that the different subjects involved make quite impossible a market equilibrium. Moreover a comparison between costs and benefits related to intermodality mixes monetary and not monetary quantities, what can be hardly evaluated according to satisfactory objective criteria.

The main object of this paper is therefore to develop a general framework of analysis of some aspects related to intermodal transport in a metropolitan area. Our proposal is to point out the strategic tasks of an intermodal node from a twofold point of view: the intermodal node as a single element where to change the mode of transport, and as a link of an intermodal transportation network. Section 2 aims at analysing the idea of "quality" of intermodal nodes, and provides some consideration in order to quantify the nodes performance. In Section 3 the focus is on intermodal network as a system, in which each single link plays an important role in achieving a better fruition of urban mobility. Starting from the proposed approach we develop a scheme for an hypothesis of taxonomy of intermodal nodes due to their importance and significance (Section 4). A case study of the city of Genoa is briefly described. Finally, some conclusions are given together with outlines for future developments of research.

2 The "key" role of the quality of the node

From a simple connection among transportation modalities, intermodal nodes have become one of the most significant factors of the urban transportation system, playing a strategic role in urban planning decision making. Therefore, by the measurement of their quality, two kinds of goals may be pursued:

- An analysis of the quality of the transportation service at each node (what allows comparisons with other nodes and with the same node at different times);

- a decision support for a better *ex ante* and/or *ex post* evaluation of the efficacy of feasible actions concerning the node.

The logic of such a quality measure can be based on the computation of an "evaluation function" with respect to an ideal intermodal node (the so-called *non-node*) having no-time, no-cost, no-disadvantage shifts among transportation modalities. Our idea is to split this function into two components:

- a negative one, the so-called *impedance* of the node;
- a (possible) positive one, which represents the *utility* added by services supplied at the node.
-

2.1 An approach to the measurement of the node impedance.

An index of a global evaluation of a node related to its impedance may allow not only to estimate the quality in terms of low impedance, but also to provide some elements for the definition and identification of intermodal nodes, getting over the usual spatial and time depending parameters. Therefore, the user's perception of distances, travel comforts, speed, and transit costs becomes more and more relevant, with regards to the motivational and social features of urban mobility.

Some remarkable preliminary statements are to be taken into a proper account. First, the transit cost of a node has to be considered as a generalized transportation cost which includes not homogeneous elements, so that every attempt for quantifying it is affected by subjectivity. Second, it has to be outlined that in at n-modalities transit node at most $n(n-1)$ possible modal shifts involve different flows according to all the possible interchanges between modalities. Moreover, we would like to point out that the identification of the radius of the centroid representing an intermodal node seems to be rather "fuzzy". Therefore those approaches, who *a priori* define the criteria for determining the "maximal radius" of the node seem to be quite unsatisfactory. For this reason it would depend on the flow related to different classes of users.

In this paper a four-step technique for deriving an impedance measurement function is consequently defined as follow:

(a) Identification of an global unit measurement of cost, time and discomfort for intermodal transit nodes.

A proposal for comparing and adding not homogeneous factors could be to express them in terms of *perceived time*. Results from stated and revealed preference interviews to a meaningful users sample can show

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how different values of time perception depend on both node features and passengers characteristics. Empirical studies carried out in the city of Genoa [7] emphasise as impedance factors elements like age of the user, hand baggage to bring, slopes tracks to walk, presence of obstacles (scales, street crossings, etc.), temperature and weather, mobility reasons, origin and destination of the path. Moreover, how much the transit of the node affects the whole distance and travel time is also a relevant factor. From the basic statistical multivariate regressions results we can define the set of *weighting factors* of the above *m*-conditions as vector $A = [\alpha_1, \alpha_2, \ldots \alpha_m]$.

Elements in A can be hence considered as generalized time indexes including time, cost and discomfort related to intermodal nodes, with reference to the users distinctive characteristics.

(b) Evaluation of the above time function to all the node connections.

The factors derived from the previous phase should be applied to the $n(n-1)$ possible modal interchanges, by weighing each average real time

distance with those impedance factors relevant for the involved path. We also may obtain an unit index d_j of impedance of node j given by:

where t_{il} is the average real time distance computed for each change

$$d_j = \sum_{i \neq l, i, l = 1}^{n} A(t_{il}) \qquad (2.1.1)$$

of modality (from mode i to l).

(c) Consideration of the traffic volumes.

The average generalized perceived time derived at step (*a*) is subsequently weighted with the percentage of user flows f_{il} through the feasible i,l-modality connection (empirically collected), so that the total user flow F_j of node j is thus given by:

$$F_j = \sum_{i \neq l, i, l = 1}^{n} f_{il} = 1 \qquad (2.1.2)$$

(d) Estimation of the global index of intermodal node.

Considering all the modalities and the generalized transit times of each node, from (2.1.1) and (2.1.2) it is possible to derive a global index D_j related to the impedance of the intermodal node. It is given by:

$$D_j = \sum_{i \neq l, i, l = 1}^{n} (A(t_{il})) f_{il} \qquad (2.1.3)$$

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Note that from (2.1.3) it is also possible to compute a general index for a set of k nodes, in order to get an idea of the impedance of the urban intermodal nodes under consideration. It is given by:

$$D = \frac{\sum_{j=1}^{k} D_j}{k} \qquad (2.1.4)$$

2.2 The Utility of the node

After deriving a measure of the *disutility* that users pay for passing through an intermodal node, we can now consider the *utility* of such a node as those additional elements and services available while the interchange takes place. Such factors can improve the global disutility (2.1.3) depending on their presence and significance. For instance, the above mentioned empirical survey, concerning some of the intermodal nodes of the city of Genoa shows as utility elements (in decreasing order): the presence of toilets, information maps, tickets sales (the problem can be reduced by the introduction of the so-called “pass-tickets” which allow people to move from bus to metro or to train -and viceversa-, with the same ticket for a time period) and call boxes (wider circulation of mobile phones should decrease their importance); the presence of bars, newspaper kiosks, drugstores, bank-card points (bancomat), post boxes.

It is therefore necessary to develop a weighting-sum process as described in 2.1 to get a synthetic value U for the nodes utility.

The development and application of this technique imply that the main goal of the local government and transportation companies aimed at improving the quality of the nodes, as to achieve a better quality for the urban intermodal transportation system, would be in the direction of minimizing D in (2.1.4) while maximizing U.

Note that he problem related to the spatial “border” of an intermodal node is implicitly solved since connections between far points of interchange would be not relevant because of low traffic flows which are likely to be estimated.

However, some difficult analytical and methodological matters persist, mainly concerning the definition and estimation of the generalized cost or time [1]. Up to now there are not any satisfactory solutions in literature, mainly because of the role played by the discomfort variable usually overlooked.

Finally, it has to be stressed that results obtained in this direction can support guidelines for future actions only after a subsequent *multicriterial* framework for a better political evaluation.

3 A multimodal urban transportation network model

An analysis aimed at pointing out the role for intermodality in urban passengers transport is certainly partial without considering the urban transportation system as a whole and the impact that intermodal transport would produce on mobility.

Our proposal is first to characterized each single intermodal node and then to include it into a urban multimodal transportation network model [8]. We derive the model with the aim of capturing all the possible transportation modalities and the intersection among them. In particular, the model must enable the possibility of moving between a pair of locations by using (and changing) any of the transportation modalities allowed in the urban area under consideration.

As a realistic and generic representation of urban multimodal transportation networks we consider the following transportation modalities:

- private modality (mode 1), i.e. users' property cars and motorbikes;
- scheduled mass transport services (mode 2), i.e. bus, metro, subway, funiculars, etc.
- on demand public transport services (mode 3), i.e. cabs;
- railway transport (mode 4), i.e. urban and metropolitan trains;
- sea public transport (mode 5), i.e. ferries;
- pedestrian modality (mode 6), i.e. by walking.

Note that the demand for public transport services is considered as an independent travelling mode since from the user point of view it has cost, capacity, speed and quality different from the mass transit. Moreover, note that the pedestrian network is here considered as a transportation modality; in fact, some road connections are only allowed to walkers, sometimes making cheaper and faster a path than by using a public mean.

We model a urban transportation network by a digraph $G = (V,E)$, where V is the set of intermodal nodes in the urban area and E is the set of direct arcs (j,k) connecting node j to node k, $\forall\, j,k \in V$; E hence gives the possible path connections between the selected nodes. In the present case, G can be actually considered as the union of six subgraphs, representing, respectively, the transportation modalities listed above. More formally, $G = (V,E)$ is such that $G = \cup_{i=1,\dots,6}\, G_i = (V_i,E_i)$, where each G_i models the transportation network of the corresponding modality. V_i and E_i, $i = 1, \dots, 6$, are, respectively, the set of nodes reachable by the corresponding transportation mean and the set of arcs representing roads, sequences of roads, or paths which can be travelled by cars, buses, cabs, trains, ferries and on foot, respectively. Note that, by definition, $\cap_{\, i=1,\dots,6}\, V_i \neq \emptyset$, that is the commutation among the networks takes place at the intermodal nodes.

Weights $t_i(j,k)$ and $c_i(j,k)$ are associated with each arc $(j,k) \in E_i$, given by the time and cost required to travel along it using the relative transportation modality. In particular, the temporal weight associated with each arc belonging to E_1, E_2 and E_3 is derived adapting a classical downflow function to the urban area under consideration [9], including the travelling time at zero flow and in the rush hour and the typology of the road modelled by the arc (e.g. its length, capacity, tortuosity, possible bus lines and the number of intersections per km.). The time weights associated with the pedestrian arcs are computed by estimating the walking time between a pair of nodes considering the lenght of each arc, that in many cases consists of stairs, hills and the average urban walking speed (about 4 km /hour). Different considerations hold for the temporal weights of urban paths belonging to the railway and sea public transport. In both cases, in fact, either we consider the average time required to travel between two adjacent stops, that necessarily are intermodal nodes, or we estimate the frequency of arrivals / departures from outside the network The cost of arcs in E_1 and E_3 is computed according to the gasoline consumption on the basis of the average speed and its length plus the required (average) fee in the case of cabs. Finally, we set $c_6(j,k) = 0\ \forall\ (j,k) \in E_6$, while the cost of each arc in E_2, E_4 and E_5 is equal to the related ticket.

A weight d_j, given by (2.1.1), representing the discomfort or impedence of node j is also associated with each node $j \in V$. It is worth mentioning that both arc and node weights strongly affect the passengers' propensity at intermodality.

In order to take into account more properly the possible commutations among G_i, $i = 1, \dots, 6$, we have to extend the definition of G given above. In particular, starting from G let us define a *6-modal*

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urban transportation network as digraph $G' = (V',E')$ where V' and E' are derived as follows. Let each node $j \in V$ be split into six nodes j_i according to the considered travelling modes, such that all arcs incident to j_i belong to the corresponding E_i and $j_i \in V'_i$, $i = 1, ..., 6$. Note that now $\cap_{i=1,...,6} V_i = \varnothing$ and $V' = \cup_{i=1,...,6} V'_i$. The commutation from one transportation modality to another one at node j $\forall$ $j \in V'$ is then represented by the set $T_{il}(j)$ of direct *transition arcs* giving, for each pair i,l, $i \neq l$, of transportation modality all the allowed intermodal changes between them departing at node j. Note that, as it is considered in Section 2, at most n-1 changes are possible at node j and that $T_{il}(j) = \varnothing$ if no change from mode i to mode l is allowed. In our model transition arcs have weights associated with them representing both the time and cost required for the involved commutation; these weights are counted for the node's impedance function given in (2.1.3).

4 A proposal for a taxonomy of intermodal nodes

Once the intermodal network has been formally defined, the next step is the analysis of its structure and flows to get a synthetic description of some relationships among elements of G, and to investigate some mobility characteristics [5]. Results from an investigation on both aspects can be useful for providing a set of data essentially how to understand some of the major problems in urban mobility, and to support decision-making concerning transportation and urban planning (e.g. the introduction of local government incentives for intermodal transport). Then a comparison among network indexes over time gives guidelines for a better evaluation of performance of the nodes after a specified action or under the hypothesis of alternative scenarios.

In this section we propose a methodological scheme for ranking the intermodal nodes in a urban context as to locate strategic and bottleneck ones. The main assumption is that there is a relationship between some features of the node and its "value" N_j, such that:

$$N_j = f(B_j, F_j, L_j) \qquad (4.1)$$

where:

- B_j is the number of transport modalities at node j ($B_j = 1,\dots,n$).
- F_j is the volume of traffic flows through j for each feasible modality, given by the ratio between the volume of passengers flows

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through *j* (collected at different times of the day) and the global mobility flow at each time.

- L_j is the so-called "*in-out* degree" of the node *j*.

Further explanations are required for the last attribute. We have to distinguish between the so-called *connectivity* and the *accessibility* of a node [3].

In a multimodal transportation network G' having | V'| intermodal nodes, the connectivity (Γ_j) of node *j*, is the number of *outgoing* arcs from *j*, that is the power of communication with other nodes (also called density degree of a node). The accessibility of node *j* (Φ_j), instead, gives the number arcs that have to be travelled from node *j* for going to all the other nodes of the network. It is a measure of the cost of connection from that node to the whole system of transport.

It clearly comes out that ranking the nodes of *G'* by these two criteria (both used for O/D analysis) leads to two different classifications. A node should have a low degree of accessibility but a high level of connectivity (i.e. a central node in a very complex network) and viceversa. Our proposal is to consider index (L_j) as an index of the performance of node *j* both in terms of connectivity and accessibility.

We define the connectivity index γ_j for the node *j* as follows:

$$\gamma_j = \frac{\Gamma_j}{\Gamma_{\max}} \tag{4.2}$$

where Γ_{max} is the number of outgoing arcs for the most connected node.

As accessibility index ϕ_j for the node *j* we refer to the idea of node *eccentricity* [2], such that:

$$\phi_j = \frac{z_{\max} - z_j}{z_{\max} - z_{\min}} \tag{4.3}$$

where z_j is the maximum value among the shortest paths (computed in meters) connecting *j* to all nodes in *V'*. Therefore, z_{max} and z_{min} are respectively the maximum and the minimum value of the shortest paths connecting each pairof node of *G'*.

Now we can formally define L_j as follows:

$$L_j = \gamma_j + \phi_j \tag{4.4}$$

Note that due to the normalised structure of the defined γ_j and ϕ_j, L_j will assume real values in [0,2] (as can be seen in **table1** for a set of 27 intermodal node identified in the central area of the city of Genoa).

j	ϕ_j	γ_j	L_j
1	0,000	0,333	0,333
2	0,257	0,667	0,923
3	0,008	0,444	0,453
4	0,444	0,556	1,000
5	0,621	0,556	1,177
6	0,232	0,333	0,566
7	0,784	0,667	1,451
8	0,868	0,667	1,534
9	0,711	0,556	1,266
10	1,000	0,444	1,444
11	0,927	0,667	1,593
12	0,790	0,667	1,457
13	0,835	0,667	1,502
14	0,662	0,444	1,106
15	0,686	1,000	1,686
16	0,415	0,667	1,082
17	0,619	0,333	0,952
18	0,395	0,333	0,728
19	0,542	0,444	0,986
20	0,104	0,333	0,437
21	0,033	0,556	0,588
22	0,075	0,333	0,409
23	0,540	0,444	0,984
24	0,648	0,556	1,203
25	0,835	0,556	1,391
26	0,686	0,444	1,131
27	0,267	0,333	0,600

Table 1 – Values of the proposed parameters in the city of Genoa

A first approach for getting a *B*,*F*,*L*-based ranking of intermodal nodes should be in the direction of fixing threshold levels for the three parameters, then building a matrix of the relative positioning. Note that at this step a weighed sum is required in order to take into account the different scores of the nodes, so that the whole process is affected by extremely subjective choices (both in fixing some thresholds and determining weights). Consequently we suggest a two-steps procedure:

1. Verify through an empirical analysis the relationships between B_j and F_j, and represent nodes scores in a Cartesian graph for identifying their clustering with related importance, as in **figure1**.
2. The above clusters are then to be screened with reference to L_j index, $\forall j$.

After this analysis, it would be possible to individuate a set of intermodal nodes which are really *strategic* (as to location, flows and modal change possibility) for urban passenger mobility, providing a taxonomy of nodes useful for supporting urban transportation planners and city managers decision making.

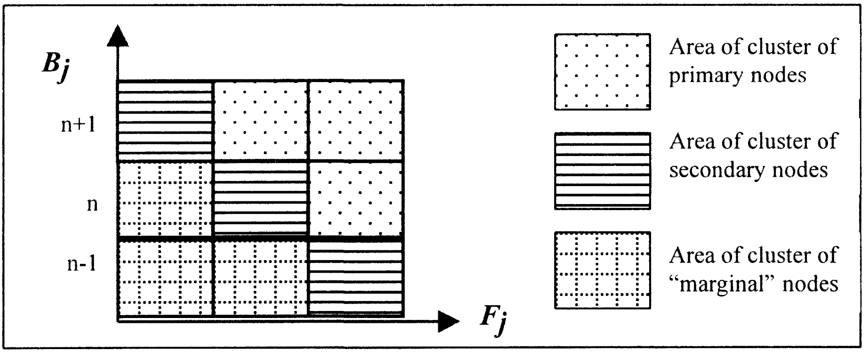

Figure 1 – Graphical representation of the results from step 1

5 Concluding remarks and outlines for future works

Preliminary considerations and results related to the quality and classification of urban intermodal nodes can suggest some conclusions and guidelines for future works.

In particular, referring to the measurement of the quality of intermodal nodes, it is possible to point out that:

- Quality comparisons could be performed among intermodal nodes, or set of nodes (i.e. of different cities), possibly surveyed over different times;
- Ex ante evaluations of alternative scenarios can be performed together with the computation of the marginal efficacy of actions on intermodal nodes (i.e. a cost-benefit analysis between the value of the decrease of the disutility and the cost for getting this improvement);

Moreover, considering the proposed approach for classifying intermodal nodes, results from the application to the city of Genoa of the above procedure, clearly point out that only 20-30% of the examined nodes have good scores for the three defined parameters. This can lead to some considerations (giving outlines for future developments of the research):

- The main target of the actions aiming at improving the quality and the performances of intermodal nodes should be, in the short period, the identification of the so-called "strategic" nodes;
- In the long term, it would be interesting to investigate the impact of improving actions on the other intermodal nodes with respect to the strategic ones.

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