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Conference Paper

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50th Congress of the European Regional Science Association: "Sustainable Regional Growth and Development in the Creative Knowledge Economy", 19-23 August 2010, Jönköping, Sweden

Provided in Cooperation with:

European Regional Science Association (ERSA)

Suggested Citation: Migliore, Marco; Amoroso, Salvatore; Cardaci, Valeria; Catalano, Mario (2010) : The role of passenger modal shift nodes in the interaction between land use and transport system, 50th Congress of the European Regional Science Association: "Sustainable Regional Growth and Development in the Creative Knowledge Economy", 19-23 August 2010, Jönköping, Sweden, European Regional Science Association (ERSA), Louvain-la-Neuve

This Version is available at:

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The role of passenger modal shift nodes in the interaction between land use and transport system

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Abstract

In the last years, we have observed a sub-urbanization process or “sprawl” process (low density of inhabitants), caused by new economic and production conditions, a new pattern of social relationships and the widespread use of private car for travelling.

Commuters need to reach quickly their own destinations and the traffic-related problems in central areas require multimodal platforms as nodes of an integrated transport system to foster car-public transport interchange.

The optimal location and design of modal shift nodes, for potential users involved in multimodal transfers within an urban or metropolitan context, is one of the most important issues in transport system planning.

Several methods have been developed to deal with this topic. The basic idea is to locate such nodes in areas of adequate size, well connected to the road network and public transit in order to minimise the time required for the transfer, taking into account the variation of transport demand under the various steps of decision-making process (generation, distribution, mode and route choice).

The aim of the proposed research is to tackle the aforesaid planning issue through a methodological approach focusing on a land use-related aspect: the attractiveness of such

modal shift nodes in relation to their potential territorial role as providers of several services other than mobility-related utilities.

In particular, the metropolitan area of Palermo and its outskirts, which is taking the connotation of an expanded city, will be an interesting case study to test for the goodness of the proposed methodology.

The results showed in this paper define the criteria for the optimal location of intermodal nodes within a context characterized by a dispersed urban area composed of many municipalities, based on also the role that can be played by each node as multi-service centre affecting passenger travel behaviour. Furthermore, the paper describes the modelling framework we are going to apply.

Introduction

The proposed study aims at developing a methodology to plan the location pattern of facilities for car-public transport intermodalism within urban areas. In particular, this research is based on the analysis of city development over the last decades, its causes and effects. Moreover, the paper evaluates as the transport system have influenced city sprawl, which, from one hand, have raised the life quality of individuals, who have moved their residences towards less congested areas, from the other hand, have not solved the problem of city centre traffic congestion.

So, our objective consists in proposing an approach to plan a system of transport nodes where park-and-ride facilities could be placed for mitigating traffic congestion inside city centre, along with other services meeting the different needs of travellers (such as, for instance, the services offered by department stores).

The paper illustrates the criteria for the optimal location of intermodal nodes and the modelling framework we intend to apply.

City sprawl and transport system

In recent years, the phenomenon of decentralization or widespread urbanization (city sprawl) has occurred. Previous development models, especially the expansion based on concentric outer rings, have been given up. Congestion has saturated city centres and suburbs, production facilities and residences have been more and more placed within smaller centres, physically separated from cities. This process has led to metropolitan areas, no longer characterized by continuity in building, thanks to the fact that moving is far easier, given the high level of public and private transport development.

The metropolitan-based evolution pattern has produced systems of towns, either consisting of satellite centres developing around a big city or consisting of a network of small-medium sized towns, without a relationship of dominance.

The dispersion of urban functions within vast areas requires a great diffusion of private vehicles capable of guaranteeing mobility inside contexts which are so dispersed that they can't be served by conventional public transport systems with economical convenience. Thus, the gradual transformation of private car from a luxurious elitist good to widespread property is an important factor of the territorial changes occurred over the last decades.

The correlation between these changes and the trend of mobility demand in Italy can be clarified by considering for example the traffic volumes recorded with respect to the motorway network in Northern Italy. In detail, the maximum values are reached on the Milan-Brescia A4 (about 90,000 equivalent vehicles / day), on its continuation to Verona, Padua and Venice and on the Milan-Bologna A1 (about 70,000 equivalent vehicles / day). Thus, the highway traffic is concentrated on just that part which forms the support network for urban sprawl; in fact, the area stretching from Verona to Venice, or even up to Treviso, is considered an important example of urban sprawl in Italy. This reflects a key issue: with the progress of widespread urbanization, important highways, designed to connect several urban centres on medium-long distances, have increasingly played the role of links serving urban and suburban travel demand, which is systematically higher than interregional traffic.

This is the general scenario our study rests on, aiming to perform an application to the capital of Sicily, in the south of Italy, that is the city of Palermo. In detail, we will build a model to identify areas where facilities for car-public transport intermodalism could be located along with centres offering other services different from the mobility-related ones. Such a model could support local policy makers in facing the problem of Palermo centre's traffic congestion, due to the remarkable use of private car (partially deriving from the low level of service of public transport).

In recent years, to control traffic, the local administrators of Palermo have imposed limitations of mobility. This has been done without offering an alternative to private transport in terms an effective public transport system along with areas where car-public transport intermodalism could be carried out.

Of course, the problem can not be solved by developing a system of local public transport serving the whole dispersed urban context, because this is not convenient from a cost-benefit perspective. Hence, the idea is to create nodes of interchange between public and private

mobility, nodes-places, where in the long term, in addition to park-and-ride facilities, users could benefit from the presence of other attractive infrastructures providing different services. The nodes for intermodalism are particularly interesting in policy planning, not only because they might improve the accessibility of city centre, but also because, if they are located in underdeveloped areas, they might represent a true opportunity of urban regeneration. To optimize the location pattern of such intermodal nodes or multimodal platforms, we intend to adopt a multicriteria approach; so, first we will select a set of feasible candidate sites and then apply a multicriteria planning method based on a transport system simulation model.

Criteria for the optimal location of intermodal nodes

To solve the problem of optimising the location pattern of nodes for car-public transport intermodalism, the following criteria have been identified:

- Interconnection with the main road network;
- Accessibility by public transport;
- Legal constraints on the possibility of creating new facilities;
- Possibility of urban regeneration and consistence with present land use;

Interconnection with the main road network:

the closer to the existing network infrastructure, the greater accessibility of the considered node;

Accessibility by public transport:

the better the node will be served by the public transport system, the more easily users will be able to reach their destinations.

Legal constraints on the possibility of creating new facilities:

the wider the area free from legal restrictions on the possibility of building new facilities the higher the benefit in terms of new services for the community.

Possibility of urban regeneration and consistence with present land use:

the plans for new intermodal nodes should promote the development of depressed areas and should not conflict with the current land use.

Methodological approach

The decision support system is based on the bi-level non cooperative games concerning transportation (Castelli et al., 2004; Hollander et al., 2006; Taniguchi et al., 1999, 2001; von Stackelberg, 1943), with particular reference to those ones in which one player, the leader,

carries out its own choice first, predicting the reaction of a second player, the follower, who makes its own decision on the basis of the leader's strategy.

Furthermore, the study under consideration is based on the literature about discrete choice behaviour modelling through the random utility theory. This states that an alternative i will be preferred to an option j if i maximizes the decision maker utility function, whose formulation is probabilistic, since it cannot be determined with accuracy by the analyst (Ben Akiva and Lerman, 1985; Cascetta, 2001; Ortùzar and Willumsen, 1994).

Finally, an important contribution has come from a fascinating research direction in the domain of Public Economics consisting in the development of quantitative methods for applied social choice. In particular, we have concentrated on the aggregation of different social interests affected by a transport-related project. In detail, as regards optimization problems with multiple mutually conflicting objectives, we have paid attention to the debate between theories fostering the use of compensatory methodologies and a trend of research, based on pioneering Pareto's ideas about the social evaluation process of alternative policies, that investigate non-compensatory techniques (Giuliano, 1985; Macharis, 2005; Roy and Hugonnard, 1982; Roy and Vincke, 1981).

The approach presented here can be defined as a two player extensive game with perfect information. It consists of two levels of problem:

- the *leader* or *strategic* level, relative to the planner choice dimension. The objective is to maximize the welfare function including the following elements: the increase in the net utility (surplus) perceived by facility users (transport users), facility costs (facility construction) chargeable to the public sector, the decrease in external costs. The decision variables are the following ones: the location pattern of intermodal nodes and the optimal public sector share of investments.
- The *follower* or *tactical* level, referring to the choice behaviour of transport users. The aim is to maximize the user utility function. The decision variables are the following ones: the choice between "No modal shift" and "Modal shift", the intermodal node choice, the route choice.

In particular, the model reproduces the different decision processes according to a "top-down" hierarchy: the planner sets the optimal pattern in terms of intermodal node locations and public investments, considering the reactions of transport users and the resulting flows on the transport network.

The leader problem under the compensatory view

Under the compensatory view, the model assumes that the planner optimizes a welfare function, which is defined as a linear combination of the various social interests involved in the design problem (see eq. (1))

$$\text{Max}_{\mathbf{x}, \alpha} W.F. = \beta_c^{-1} \cdot \sum_{od} [S_P^{od}(\mathbf{x}, \alpha) - S_{NP}^{od}] - \alpha \cdot \sum_k x_k \cdot c_k(q_k) - \sum_{od} [E_P^{od}(\mathbf{x}, \alpha) - E_{NP}^{od}]$$

(1)

Subject to:

$$\sum_k x_k \leq N$$

$$0 \leq \alpha \leq 1$$

Where,

$W.F.$ Welfare Function;

\mathbf{x} vector representing the location pattern, whose generic element is x_k ;

α percentage of investments that is chargeable to public funds;

β_c coefficient associated with monetary cost attributes;

S_P^{od} user net utility concerning pair $o-d$ and project P (util);

S_{NP}^{od} user net utility for pair $o-d$ and the status quo scenario (util);

c_k cost for creating intermodal node k (euros per annum) that is function of the traffic attracted;

x_k 1 if an intermodal node is located at site k ; 0 otherwise;

q_k demand for intermodal node k ;

N number of candidate sites;

E_P^{od} external costs relative to pair $o-d$ and plan P (euros per annum);

E_{NP}^{od} external costs for pair $o-d$ and the status quo scenario (euros per annum)

The leader problem under the non-compensatory view

Under the optimal value of α resulting from the compensatory approach, the numerous feasible facility locations could be ranked also without establishing compensatory trade offs between the several considered social criteria.

Then, for each location pattern, the impact measures regarding the different criteria could be normalized through the technique presented below:

$$x_{ij} = p_{ij} / \text{Max}_j p_{ij}, \text{ for criteria representing benefits;} \quad (2)$$

$$x_{ij} = 1 - \left(p_{ij} / \text{Max}_j p_{ij} \right), \text{ for criteria representing costs.} \quad (3)$$

Where,

x_{ij} normalized value, in the case of criterion i and location pattern j ;

p_{ij} performance of location pattern j , according to criterion i .

So, the project effect matrix, which contains, for each alternative, a vector of performance scores assigned to the various project objectives, can be transformed in a set of dimensionless and comparable values lying between zero and one, so that higher values are better.

Furthermore, a method based on binary comparisons could be applied to rank the several alternatives (Giuliano, 1985; Roy and Vincke, 1981). In particular, we intend to perform a concordance analysis calculating, for every pairwise comparison, two different indices, the concordance index quantifying the degree to which one project is preferred to another, that is defined as

$$c_{jk} = \sum_{i \in C_{jk}} w_i \quad (4)$$

and the discordance index expressing the degree to which a project is dominated by another, that is defined as

$$d_{jk} = \max_{i \in D_{jk}} (x_{ik} - x_{ij}) \quad (5)$$

Where,

j, k alternatives;

i generic criterion;

w_i weight assigned to criterion i ;

C_{jk} set of the criteria according to which option j dominates option k ;

D_{jk} set of the criteria according to which option j is dominated by option k .

In the end, in order to get a complete ranking of the numerous location options, for every pattern, two indices could be determined, from the matrices showing the different values of c_{jk} and d_{jk} :

$$c_j = \sum_k (c_{jk} - c_{kj}), \text{ net concordance dominance value} \quad (6)$$

$$d_j = \sum_k (d_{jk} - d_{kj}), \text{ net discordance dominance value} \quad (7)$$

c_j measures the difference between the extent to which plan j is better than the other alternatives and the extent to which these ones are better than j . So, a positive value of c_j is a good result; in addition, the higher c_j , the stronger the global preference for j and consequently the higher its position in the ranking.

d_j measures the difference between the extent to which plan j is worse than the other options and the extent to which these ones are worse than j . So, a negative value of d_j is a good outcome; besides, the lower d_j , the higher its global merit.

The follower problem

For each origin-destination pair, it consists in splitting flows among the alternatives of a certain scenario deriving from the strategic level, “No modal shift”, “Intermodal node i ”, “Intermodal node j ”, ..., assuming for transport users a random choice behaviour and considering terminal capacity restraint effects. In literature, this problem is referred to as Stochastic User Equilibrium (SUE); to perform the SUE assignment the Method of the Successive Averages (MSA) will be adopted (Cascetta, 2001; Ortùzar and Willumsen, 1994; Sheffi, 1985).

Case study: city of Palermo

The study area is Palermo, a city that plays a leading role in Sicily: with a population of about 700,000 inhabitants, its territory holds all the regional level administrative offices.

The inner city consists of a historical centre which is very large and characterized by an Arabian-style urban layout with very narrow and tortuous streets.

Palermo is characterized by a “weak” public transport system. In particular, the urban rail network is not wide enough and its service capacity is limited by the single-track constraint. Moreover, in spite of covering the whole urban area, the road public transport suffers from the interference with car traffic, with a negative impact on frequency and comfort, which can be ascribed to the insufficient development of bus way network. Other problems consist in the remarkable lack of suitable parking areas for private vehicles, especially within the centre, and the need of new parking facilities to favour intermodalism.

An important transport infrastructure is represented by the ring road for users travelling from the western side of Sicily to the eastern one passing through Palermo. This is a typical example of road system, created especially to allow great trucks to by-pass the main urban streets, which is at present used by many car drivers making trips that involve the urban area of Palermo (divided into two parts by this ring road). In fact, the inbound flow of vehicles from the province of Palermo is 61,698 cars daily, while from other Sicilian provinces about 10,000 vehicles a day reach Palermo (source: Urban Traffic Plan of Palermo, 2010), to these flows one should add the number of travellers moving inside the city.

Several roads link the centre to the suburbs, crossing the ring road; amongst them we can mention Via Oreto, Via Basile, Corso Calatafimi, Via Leonardo da Vinci / Michelangelo, Via Notarbartolo and Viale Lazio.

In the early 80s, the high cost of houses, due to city saturation, made many residents move firstly in the neighbourhood and then in near small centres, well connected with the city by the existing transport infrastructures.

In recent years, to control traffic, the local administrators of Palermo have imposed limitations of car mobility (no traffic-zones and park pricing).

Various projects to enhance the public transport system of Palermo are in progress: the creation of double-track railways serving all the metropolitan area, the activation of tram services for mobility in the outskirts and an automated light rail train (VAL) system.

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