LOGISTICS TERMINALS PLANNING FOR AN OPTIMAL FREIGHT MOBILITY SYSTEM: AN APPLICATION ON A REGIONAL SCALE

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Abstract. This paper suggests an approach to plan logistics terminals. In particular, it describes an application to the freight transport by road involving the sicilian area. The modelling framework, which is inspired by the "Stackelberg game" paradigm, uses an objective function representing some relevant public interests and simulates the choice behaviour of freight transport operators. Basic assumptions concern the involvement of the public sector in terms of a share in investments and incentives to foster the use of terminals; for some scenarios on the public budget constraints, a set of optimal location patterns is determined.

1. Problem definition

Inside Sicily, the short distances separating freight generations from attractions have promoted the development of road haulage: in 2001, the 94% of the inland freight traffic uses the road mode. As for the Sicily-External Area non-oil traffic, in 2001, the road travel demand shows the significant incidence of 30 %.

The main features of the road freight transport in Sicily have been highlighted combining the data base resulting from a recent survey concerning Italy (source: Italian Trucker Register, 2000) and the outcome of meetings with managers of the main sicilian associations of freight movers: great presence of small-sized firms, which implies a weak propensity to invest in advanced technologies and low load factors; lack of areas for parking vehicles under good conditions of safety; there is no sanitary control and an inadequate packaging for local products coming of the primary sector, which play a key-role for sicilian exports towards north italian and european markets.

In order to make the road-based transport more efficient and the regional productive system more competitive, sicilian policy makers have examined the possibility of creating

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logistics facilities. Thus, also by implementing Intelligent Transport Systems, the transportation process could be optimized, as regards load factors (consolidation of loads bound for the same destination), path costs, environmental impacts, and several services for goods could be offered like storage, processing, assembling, packaging, quality checks, …

So, the research presented here faces the following challenging questions: how many terminals should be built in Sicily? Where? How much of the considered freight traffic could this logistics network capture? Is it advisable for public administrators (national, regional level) to provide incentives for transhipment?

2. Survey of literature and model framework

The present work is based on different research trends. Firstly, readers have to learn that, generally speaking, facility location problems have been tackled by applying the methodologies of operations research. Crainic and Laporte (see [2]) classify the main location models as follows: *covering models*, that place facilities at the vertices of a network so as to minimize facility costs and to make all the remaining vertices be within a maximal distance from a facility; *center models*, that locate facilities at the vertices of a network, minimizing the maximal vertex-facility distance; *median models*, that locate facilities at the vertices of a network and allocate demand, minimizing the total weighted distance between facilities and demand points.

Secondly, the present work is inspired by von Stackelberg's studies about the leader-follower approach (see [5]). The economist von Stackelberg introduced a model in which one of the competing enterprises in a duopolistic market (leader) carries out its own choice first, taking into account the reaction of the other economic agent (follower) so as to provide this one with the input for its decisions.

Thirdly, it is opportune to mention the research activity about discrete choice behaviour modelling through the random utility theory. This postulates 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 modeller (see [1], [3], [4]).

The approach illustrated in this paper can be defined as a two player extensive game with perfect information. In detail, it consists of two levels of problem:

- the *strategic or leader level*, relative to the planner choice dimension. The object is maximizing the welfare function including the following elements: facility users' surplus, facility costs (terminal construction) chargeable to the public sector, public expenditure to favour transhipment. Decision variables: location pattern of terminals and public incentives.
- The *tactical or follower level***,** relating to the facility users (transport operators) choice behaviour. The aim is maximizing the shipment utility function, depending on the following elements: trasportation monetary cost, travel time, waste of time at terminal (function of demand to simulate congestion), price for using the considered set of logistics services. Decision variables: choice between the "No transhipment" option and the "transhipment" one, terminal choice, route choice.

In particular, the model riproduces the different decision processes according to a "top-down" hierarchy: the planner sets the optimal pattern in terms of terminal locations and incentive policy, taking account of the transport operators reactions and the resulting goods movements on the transport network.

3. Mathematical formulation

3.1. The leader problem

$$\max_{x,\alpha} W.F. = \beta_c^{-1} \cdot \sum_{od} \left(S_P^{od}\left(x,\alpha,q^*(x,\alpha)\right) - S_{NP}^{od} \right) - c_{Terminal} \cdot \sum_k x_k + \\ - \alpha \cdot \sum_k x_k \cdot c_{Transhipment} \cdot q_k$$

subject to:

$$\sum_k x_k \leq N$$
$$0 \leq \alpha \leq 1$$

where,

$W.\ F.$ stands for Welfare Function;
x : vector representing the location pattern of transhipment terminals;
α : percentage of the price for using the services of a terminal chargeable to public funds;
β_c : coefficient associated with monetary cost attributes;
S_P^{od} : surplus for transport operators referring to the o-d link and the scenario set by the planner, P (util);
$\mathbf{q}^*$: vector of the equilibrium freight flows (tons/annum) caught by the several choice options for transport firms ("No transhipment", "Terminal i", "Terminal j", …);
S_{NP}^{od} : surplus for transport operators in the case of the o-d link and the reference solution (util);
$c_{Terminal}$: cost for creating a single terminal at public expense, fundamentally due to land purchase and basic equipments (euros per annum);
$x_k = 1$ if a consolidation terminal is located at the node k; $x_k = 0$ otherwise;
$c_{Transhipment}$: price for using the services of a terminal (euros per ton);
q_k : demand for the terminal k (tons per annum);
N: number of candidate sites for logistics facilities.

3.2. The follower problem

For each o-d pair, it consists in splitting freight flows among the alternatives of a certain scenario deriving form the strategic level, “No transhipment”, “Terminal i”, “Terminal j”, …, assuming for transport operators a random choice behaviour and including terminal capacity restraint effects. In literature, this problem is referred to as Stochastic User Equilibrium (SUE); an algorithm to perform the SUE assignment is the method of successive averages (MSA); see [1], [3], [4].

4. Application

4.1. Freight transport demand estimation

To determine the potential demand for logistics terminals, the following steps have been carried out: the study area has been divided into nine zones (the sicilian provinces); to capture the Sicily-External Area freight traffic, four macro-zones have been selected; to quantify the goods movements by road and by road-sea system involving the identified zones, an o-d matrix has been obtained (year 2000) by disaggregating data from national and regional sources; the aforesaid matrix has been improved by truck traffic counts and applying the GLS estimation technique; the resulting o-d flows have been reduced so as to consider only some commodities (agricultural products, food-stuffs, machinery, clothes).

4.2. The leader problem solution

Nine feasible candidate sites for terminals have been selected on a graph representing the regional road network, also according to the outcome of meetings with managers of the main sicilian associations of freight movers.

For each of the examined incentive policies, all the possible location alternatives have been tested by solving the follower problem. The result of this procedure permits the policy maker to identify which is the optimal solution of the strategic problem, but also the plan optimizing the welfare function, under a given public budget constraint limiting the number of the terminals to finance.

4.3. The follower problem solution

A Nested Logit model has been used to simulate the decision making process of facility users, according to a sequential approach: for each o-d pair, there is a first stage of choice between the “No transhipment” option and the “Transhipment” one; there is a second decision step concerning the specific terminal to employ, whose availability depends on inputs from the leader level. Utility functions have been specified by aggregate data relating to the different commodity types involved:

$$U^{od}_{No\,transhipment} = \beta_c \cdot \left(c^{od} \cdot ss^{od}\right) + \beta_t \cdot t^{od} + \eta_{No\,transhipment}$$

$U^{od}_{No\,transhipment}$: perceived utility if the "No transhipment" option is chosen for the single consignment relating to the o-d link (util);

c^{od} : average transport monetary cost in the case of the o-d link (euros per ton);

ss^{od} : average shipment size for the o-d connection (tons per shipment);

t^{od} : travel time to move from o to d (hours);

β_c, β_t : parameters; $\eta_{No\,transhipment}$: random part.

$$U^{od}_k = \beta_c \cdot \left[c^{od}_k + (1-\alpha) \cdot c_{Transhipment}\right] \cdot ss^{od} + \beta_t \cdot \left(t^{od}_k + t_k\right) + \\ + \beta_0 \cdot TRANSHIPMENT + \eta_{Transhipment}$$

U^{od}_k : perceived utility if services of the terminal k are demanded for the single consignment relative to the o-d link (util);

c^{od}_k : average transport monetary cost for the o-d link if the terminal k is used (euros per ton); it takes account of the rise in average load factor (caused by transhipment) and the distance between the origin and the node k;

t^{od}_k : travel time to move from o to d through the node k (hours);

t_k : waste of time at the terminal k (hours); it presents the BPR functional form to simulate congestion (see [3]);

TRANSHIPMENT: alternative-specific attribute; β_0 : alternative-specific constant;

$\eta_{Transhipment}$: random part.

For the description of β_c, β_t and ss^{od}, see above; for α and $c_{Transhipment}$, see 3.1.

The various explanatory variables have been measured by employing several sources: Italian Trucker Register; a survey by authors about logistics terminals existing in Italy. The Logit model has been calibrated by adjusting coefficients drawn from scientific literature (Cascetta, Iannò, 2000) to consider the peculiarities of the sicilian area. To gain this result, observations on the sicilian freight traffic split between the road mode and the sea-road one (Ro-Ro transport) have been used (sources: National Institute of Statistics; various italian port authorities) and least squares curve-fitting techniques have been applied.

Finally, the MSA algorithm has been implemented to achieve equilibrium between supply (logistics network) and demand (facility user preferences).

4.4. Computational results

The optimal solution consists in no public incentive and the creation of eight terminals:

n	Freight traffic captured by terminals (tons per annum)								
	TP	PA	AG	CL	EN	ME	CT	RG	SR
9	282007	392661	345800	230658	172602	265111	721842	274223	339054
8	**282102**	**392241**	**355622**	**0**	**303493**	**264696**	**797989**	**274364**	**339366**
7	0	607734	355660	0	303559	264698	798051	274383	339396
6	0	628282	0	594404	0	265588	773975	274446	339537
5	0	628303	0	594584	0	266005	1012562	300323	0
4	0	628315	0	610308	0	266511	1214288	0	0
3	0	628562	0	609560	0	0	1302090	0	0
2	0	0	647801	0	0	0	1629137	0	0
1	0	0	0	0	0	0	1812271	0	0

Table 1. Location patterns maximizing the welfare function for various assumptions on the number of facilities, n, in the case of no public incentive.

5. Conclusions

The output data concerning the freight traffic attracted by terminals under the optimal solution, could be useful for facility sizing and employing Project Financing techniques, as the solution method has considered the reaction of potential terminal users. Future steps consist in appraising the impact of terminals on the regional economic development and in modelling the modal split, so as to take into account the possibility of integration between the aforesaid logistics centres and other nodes like ports and terminals for rail-road intermodality.

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