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Intermodality and the Changing Role of Nodes in Transport Networks

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INTERMODALITY AND THE CHANGING ROLE OF NODES IN TRANSPORT NETWORKS

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1.Introduction

Intermodality is characterised by the combination of different technologies into a unified transport process. Although transport activities have always involved, to some extent, the use of a number of complementary modes, modern intermodal technologies go beyond this by performing transport operations as single integrated processes, where transhipment time and costs are substantially reduced through an extensive standardisation.

Due to the enlargement of scale economies in the transport industry, to the growing interactions among world regions, and to the political goal of promoting efficient and sustainable transportation activities, intermodal transport represents nowadays a rapidly expanding segment in the freight transport sector, and its market share is likely to further increase over the next years.

This paper aims to relate the emerging intermodal logic (that is, the combined transport by rail, truck, sea vessel or barge under a particular contractual scheme) to the changing functions performed by the transport nodes. As a point of fact, technological innovations and organisational arrangements which are at the basis of the emerging intermodal era (Hayuth, (1987, 1992)) are also producing dramatic changes in the way transport nodes work and operate within the transport system.

To this end, we consider first under what conditions intermodal technologies may prove to be superior to traditional transport modes. A simple economic model will be used to highlight that, if transhipment costs are kept sufficiently low in relative terms, some consumers will prefer intermodal transport to other modes.

The main way to achieve this market potential is by standardising loading and unloading operations; for example, through the adoption of containers. This also implies that heterogeneous goods can be more easily combined together into single shipments, and that economies of scale in the transport system can be exploited in different ways. In some nodes, like ports, warehouses have been used to stock products and raw materials, but the economic advantage of having large quantities transported and subsequently stored is reduced when intermodality is available.

Considering that the determination of the level of inventory stock is an intertemporal optimisation problem for a firm facing a demand variable over time, in the third section a model shows how intermodality may induce a firm to adopt just-in-time strategies (that is, zero level stocks).

As storage functions are progressively reduced, the role played by the nodes within transportation networks is substantially changed. This is especially evident in the recent evolution of seaports and in the organisation of maritime transport. The changing role of seaports and the major consequences arising form the emerging intermodal and network logic will be analysed in section four, as an example of a more general phenomenon affecting also other means of transport.

2.The Market Potential for Intermodal Transport Services

An essential feature of the consumption of transport services is given by the heterogeneity of actors and transported items. This makes possible the co-existence in the market of services which are different in terms of price and qualitative characteristics. Transported goods differ, for example, in terms of weight, size, value, fragility, etc. Consumer of transport services (households and firms) also differ in terms of value of time, internal organisation and logistics, risk aversion, perceptions, and so on. Given a certain set of alternative transport modes, consumers may rationally make different choices, but changes in prices or in other characteristics may bring about a revision of these choices.

To highlight this aspect, it is customary, following Quandt and Baumol (1966), to express the demand for transport services in terms of the relevant characteristics of the service. The expected utility, or profit, coming from the use of a transport service may then be expressed - at the individual level - as a function of characteristics such as, for example, speed (v) and safety level (s):

$$U = U(\alpha v, (1-\alpha)s) \tag{2.1}$$

where a ($0<a<1$) is a parameter accounting for individual "preferences", expressing the relative importance of the factor speed. We assume here that there exist a set of potential consumers having all the same utility structure, but different values of the parameter α. Suppose that they must make a choice between two alternative transport modes A and B, where each mode has a specific combination of attributes v and s.

The choice would be based on the comparison of potential utility levels obtainable through the utilisation of alternative modes, so that the preferred mode would be associated with the highest utility level. The two cases (choice of *A* and choice of *B*) are graphically represented in figures 2.1 and 2.2, where indifference curves of individuals with different preference parameters are displayed.

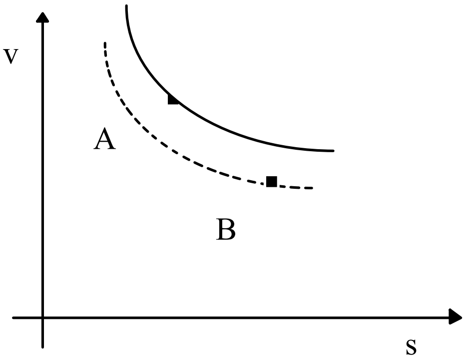

Fig. 2.1 - Mode A is chosen

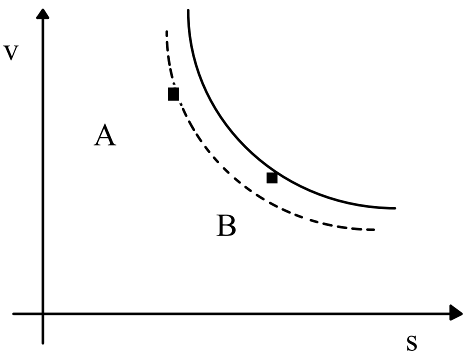

Fig. 2.2 - Mode B is chosen

Unless one of the two modes is superior in both attributes[1], there will be a specific value of the parameter α making a certain consumer[2] indifferent in the choice. For this consumer, a switch from one mode to the other would produce utility gains in one characteristic which are exactly compensated by utility losses in the other characteristic:

$$U(\bar{\alpha}v_A,(1-\bar{\alpha})s_A) = U(\bar{\alpha}v_B,(1-\bar{\alpha})s_B) \qquad (2.2)$$

If every individual in a given population demands only one service, the total demand for each mode would be given by:

$$D_B = \int_0^{\bar{\alpha}} f(\alpha)d\alpha$$

$$D_A = \int_{\bar{\alpha}}^{1} f(\alpha)d\alpha \qquad (2.3)$$

$$(Hp: v_A > v_B)$$

where $f(\alpha)$ is the density function of the parameter in the population, and it has been assumed, without loss of generality, that the mode *A* is superior in the attribute *v*.

Now, suppose that a third alternative is considered, namely an intermodal transport in which a fraction β of the trip is carried out with mode *A*, and the remaining part with mode *B*. For the sake of simplicity,

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[1] And preferences are non-satiated.

[2] This consumer may not even exist in the population considered.

we disregard for the moment the existence of possible transhipment costs. In this case the attributes of the intermodal service could be expressed as linear combinations of the attributes of existing modes[3]:

$$\begin{aligned} v_M &= \beta v_A + (1-\beta) v_B \\ s_M &= \beta s_A + (1-\beta) s_B \end{aligned} \qquad (2.4)$$

Graphically, the point associated with the characteristics of the intermodal service would be found along a segment connecting the two points representing the existing modes, as can be seen in figure 2.3.

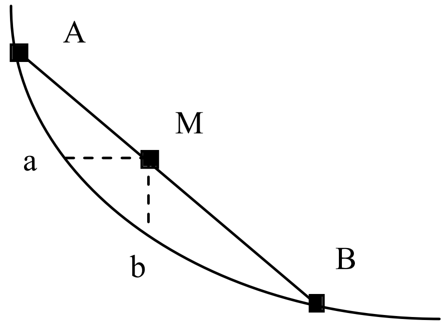

Fig. 2.3 - Attributes of the intermodal service

The marginal consumer, for which (2.2) holds, must have points *A* and *B* along the same indifference curve. If her or his preference set is convex, point *M* must be found inside the indifference curve, meaning that *M* is strictly preferred to both *A* and *B*, as in figure 2.3. The preference set is convex when the marginal utility that can be derived by further gains in speed or safety is decreasing.

Consumers whose preferences are quite similar to those of the marginal consumer may also choose *M*, but consumers for which one of the two attributes is very important will continue to choose either *A* or *B*. The market would therefore be split in three parts: market sizes are in this case determined on the basis of indifference conditions like (2.2) between *B* and *M*, and between *M* and *A*.

This situation identifies the *maximum* market potential for intermodal services combined in a proportion *b*. Actually, the existence of transhipment operations normally make the characteristics of the service worse than those implied by a simple average, like (2.4). For example, speed is usually lower than the average speed of the existing modes, whereas the risk of accidents during transhipment operations may lower the global safety level.

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[3] An implicit assumption here is that the level of attributes is proportional to the distance covered. In general, this may not be so, and the characteristics of the intermodal service may be non-linear combinations of existing characteristics. For example, intermodal speed may be lower than the average speed of the two modes, because of the need of slowing down

The “real” attributes of the intermodal service could therefore be expressed as $(v_M - v_T, s_M - s_T)$, and the point indentifying the intermodal service in figure 2.3 would then be found to the left and below point *M*. If the new point falls within the area *aMb*, the marginal consumer (and other consumers as well) will continue to prefer the intermodal service, although less consumers will now choose it. On the other hand, if reductions in speed and safety are significant, nobody will choose the intermodal service.

A key determinant of the market potential for intermodal services is therefore the technical efficiency of transhipment operations[4]. For the existence of a market, reductions in speed and safety may be kept below threshold values computed for the marginal consumer[5]:

$$U(\overline{\alpha}(v_M - \tilde{v}_T),(1-\overline{\alpha})(s_M - \tilde{s}_T)) = U(\overline{\alpha}v_A,(1-\overline{\alpha})s_A) = U(\overline{\alpha}v_B,(1-\overline{\alpha})s_B) \qquad (2.5)$$

where the variables written with a tilde are the threshold levels.

Alternatively, an intermodal service may become viable if the attributes of one of the existing modes are worsened. For example, speed may be reduced for one mode because of traffic congestion. In figure 2.3, points like *A* or *B* may shift down or to the left, making it possible to bring the point associated to the intermodal service inside the area *aMb*.

The worsening of the quality of existing modes may also be imposed by environmental protection and taxes. A special limit case would be the prohibition of the use of a mode, say *A*. In this case, using *M* would become the only way to achieve speed levels higher than those given by *B*, so that consumers with a sufficiently high preference for speed will opt for the intermodal service. A threshold value for reduction in speed would therefore be:

$$\tilde{v}_T = v_M - v_B \qquad (2.6)$$

To sum up, intermodal transport can have a market potential if transhipment operations are efficient. Conversely, whenever intermodal traffic is growing faster than traditional traffic, this may be interpreted as the results of two phenomena:

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while approaching the transhipment point. The reduction in the quality of the service, however, can be considered as equivalent to transhipment costs, considered later in this analysis.

[4] Of course the competitiveness of intermodal services may well be determined by other factors: detour effects, waiting times, etc. However the latter factors are not specific to the intermodal transport but affect the efficiency and the attractiveness of any transport service.

[5] It is sufficient to look at the marginal consumer because this consumer has the largest area *aMb*, and consequently the highest threshold values. If this would not hold, two indifference curves should intersect more than once. But this is impossible here, because in each point two intersecting curves have slopes whose difference is given by a factor *a/(1-a),* depending on the parameter but not on the specific point chosen.

- increasing technical efficiency in transhipment, via the introduction of new intermodal technologies (containers, special carrying units, etc.) and automation of transhipment operations. For example, containerization has radically improved transhipment operations in seaports. Decreasing time spent by ships in seaports, rising labour productivity, increasing reliability in handling activities have all contributed to make the transhipment operations more and more efficient; this can be a stimulus to promote the adoption of new intermodal services in which attributes of different transport modes are combined;
- worsening of the quality or increased cost for some traditional modes. This, in turn, may be due to lack of infrastructure, to restrictive legislation, or new taxes. Several examples could be easily found here, mainly related to the environmental impact of road traffic in international transportation. In these cases, the adoption of intermodal services is encouraged by elements which are not directly related to individual or collective “preferences” on attributes of different transport modes or to increased efficiency in transhipment operations; rather the above elements can act as the leading force in the search for introducing new transhipment techniques capable of combining attributes of different modes. This aspect is well evident in the adoption of new bi-modal and combined technologies (which represent a particular segment of intermodal transportation) aimed at reducing the environmental impact of road transportation.

3. Intermodality and warehousing

As it will be discussed in more detail in section four, substantial reductions in transhipment costs have been achieved through the standardisation of carrying units. This is because standardised units, like containers, make it possible to carry out transhipment operations without having to adjust the loading/unloading machinery to the nature of the transported goods. In turn this may help and sustain new technological improvements in transhipment operations as well as the search for economies of scale both in sea and land transport modes.

A secondary but important effect of the standardisation is the ease with which heterogeneous materials can be handled and combined into single transport operations. For example, a ship may carry a bundle of containers with different contents. Alternatively, the combination may refer to shipments with different origin and destination, which are merged and re-divided at intermediate nodes of the transport network.

By combining heterogeneous flows, traffic volumes are increased and economies of scale are achieved. This is especially relevant for some transport modes, characterised by relatively high fixed costs and relatively low marginal costs, like sea transport. Traditionally, economies of scale in these sectors were exploited by organising shipments at regular time intervals, with seaports acting like buffers, collecting incoming and outcoming goods. In this way, the transport process was "broken into segments", and influenced by the firms' strategies of inventory investment.

With the emergence of the new intermodal technologies, high traffic volumes can be obtained by grouping transported items *in space* rather than *in time*. Warehousing where modal change occurs is no more needed, whereas the transport process is made continuous from origin to destination.

A simple model can be used to illustrate this phenomenon, emerging when different customers are served by the same carrier. Suppose that a firm sells a transported good at two periods of time[6], so that the firm profit, net of production costs, is:

$$\pi = p_1 S(e_1) - c(e_1) - w(e_1 - S(e_1)) + \alpha[p_2 S(e_2 + e_1 - S(e_1)) - c(e_2)] \qquad (3.1)$$

where p are expected prices in the two periods, e are transported amounts of the good, determining transport costs $c(e)$ and expected inventory costs w, α is a discount factor and $S(.)$ are expected sales per period, computed on the basis of the available stock and on the subjective probability distribution of demand[7]. In this function, the transported flows in the two periods can be adjusted to maximise profits.

The amount of transported goods in the first period can exceed the level of expected sales in the first period for two reasons:

- to avoid the stock out and the implicit losses associated with the impossibility of satisfying high demand levels;
- to save on transport costs of the second period.

The latter effect is associated with the existence of economies of scale and decreasing marginal transport costs. On one hand, the firm can get savings on total transport costs if shipments are concentrated in one period. On the other hand, by anticipating the transport of goods needed in the second period the firm incurs in capital and storage costs. Depending on the parameter values, the profit maximising choice of e_1 and e_2 will imply a larger or smaller concentration of flows. In particular, more

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[6] We consider here sales that occur at specific points in time. It is possible to generalise the analysis by considering continuous sale periods. This, however, would complicate the mathematics of the model without providing any additional insight.

[7] If the demand exceeding the available stock cannot be satisfied, the function can be written as:

transport in the first period and higher stock levels would be associated with: large economies of scale in transport operations, low inventory costs, low interest rate, and a rising expected price.

Essentially, the firm can choose between two “technologies” for producing goods at period two. If there is no uncertainty about demand levels, either the lowest cost technology will prevail, or the marginal costs of the two technologies will be equalised. Positive stock levels will be found whenever the following condition is satisfied:

$$c'(e_1) + w'(0) < \alpha c'(0) \qquad (3.2)$$

Notice that $c'(e_1) < c'(0)$ if there are economies of scale, but *w'(0)*? *0* and *a*≤ *1*.

Consider now the introduction of an intermodal technology that allows the integrated transport of goods produced by two firms, which have equal demand levels in the two periods. Assume that inequality (3.2) is satisfied for both of them, so that each firm would individually choose to have a stock of goods transported in period one but sold in period two.

Because of cost interdependence, however, the choice of one firm would depend on the other firm choice. Imagine that one of the two firms would choose to have equal transported flows in the two periods, in line with expected demand levels *d*, and no goods stored. For the other firm to make the same choice, the following must holds:

$$c'(e_1 + d) + w'(0) > \alpha c'(0 + d) \qquad (3.3)$$

If *d* is infinitesimally small, inequalities (2) and (3) are satisfied simultaneously if:

$$-c''(e_1) < -\alpha c''(0) \qquad (3.4)$$

which means that economies of scale must be significantly lower at e_1 than at *0*.

This condition is normally satisfied in the presence of relevant fixed costs. For example, if variable costs are constant but there are fixed costs, all marginal costs are equal, except for the marginal cost computed at *0*, which include the fixed cost. In this case, (3.2) would be almost identical to (3.3), except for an extra positive term on the right hand side. If this term is sufficiently large, both (3.2) and (3.3) can hold. Under these conditions, the introduction of a standardised transport technology brings about the elimination of stocks and the adoption of a “just in time” delivery strategy. The possibility for firms to adopt “zero level stock” options, made possible by the introduction of standardized cargo units, produces radical changes in the way transport nodes operate. In particular, the increasing need for an

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$S(e) = \int_0^e xf(x)dx + e\int_e^{\infty} f(x)dx$, where *f(x)* is the *a priory* density function of the demand. Observe that *S'(e)* ≤ *1*.

efficient logistical control within an increasingly synchronized transport flow represents a fundamental consequence of the above tendency.

4. Containerisation, intermodality and the changing role of transport nodes: the case of seaports

The use of standardisation in transhipment operations makes it possible to efficiently handle heterogeneous traffic flows and to reduce inventory stocks. The model presented in the previous section has made clear that this phenomenon is related to the existence of economies of scale in transport activities, when these are diminishing with increasing traffic volumes. The latter condition is normally satisfied in several transport modes, characterised by the existence of fixed costs, but it especially evident in the sea transport industry. In this section we therefore focus on this sector in order to illustrate how the introduction of new transport technologies has revolutionised the economic functions of seaports.

The unitisation of general cargo has been the main tendency which has allowed the transport system to be developed into an integrated and intermodal transport system. Mainly through the adoption of standard containers, the above tendency was the technical solution which allowed the major liner companies to invest in mechanised equipment best able to cope with the increasing need for automation in transport process and raising productivity. In the pre-container era, the high cost of maritime services, the low productivity of port operations, the complexity and poor delivery performance of cargo liner systems acted as fundamental bottle-necks in the search for meeting the increasing demand for faster, more reliable and secure intercontinental transport which were resulting from the rapidly growing economy of the 1950s and 1960s. As a point of fact, before the introduction of standardised cargo, ships spent up to 50 per cent of their time in port; this limited the scope for economies of scale, since doubling a cargo liner's capacity implied doubling its port time. While a general cargo berth typically handled 100.000-150.000 tons per year, a new container terminal is able to handle 1-2.000.000 tons of cargo per berth. This results in a reduction of the time spent by a ship in the port (from about 40/50% of its time to 17/20%) (Stopford, 1997). At the same time, the raising productivity of port operations and the new methods of handling cargo have provided the conditions for achieving greater economies of scale in maritime transportation: new greater and greater cellular vessels were introduced[8] (Hayuth e Hilling, 1992).

Since its introduction in the second half of the 1960s, the market share of standardised cargo in maritime transportation has steadily increased; today, only very particular semi-finished or finished products have not been subjected to containerisation, due to their weight or their particular dimensions. Just to give some examples of the relevance of this tendency, in the period 1970-1995 the world container fleet has increased from 500.000 to 9.600.000 TEU (Stopford, 1997); with reference to seaports, the container traffic has increased much faster than any other traffic, and different estimates foresee an yearly container traffic growth in seaports of about 6%. In 1997 the world traffic of container in seaports reached 170 million TEU; the figure is expected to rise to 270 million by 2005 (C.I.S.Co, June 1998).

By increasing productivity and reliability and by reducing cost and time of transhipment operations, the unitisation of cargo has improved integration of liner's services into the rest of the transport system, thus opening the way to the development of intermodal chains[9], in which goods are transferred in a continuous flow on a door-to-door basis, in the most cost- and time-effective way. Although unitisation is a pre-condition for intermodality, the latter concept places more emphasis on elements such as co-operation and co-ordination between the different agents involved in the transport chain (shipping lines, land transportation operators, port operators), and on the provision of organisational and logistical services best able to synchronise the different phases related with production, transport and distribution. Intermodal transportation represents today one of the most dynamic segments in the transport market (Slack, 1998). In this context, important are also the privatisation and deregulation tendencies; in particular, railways deregulation appears to make it possible the realisation of economies of scale in continental transportation. The increasing need - particularly of large firms - to internalise transport operations into their stock management system and the increasing importance of environmental issues related to road transport, which could result in new restrictive legislation (for example, measures to reduce road traffic in Austria or Switzerland), are likely to promote further the adoption of intermodal technologies (Charlier and Ridolfi, 1994).

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[8] It has been noted how this trend may ultimately approach the fifth phase, with vessels capable of handling more than 6.000 TEU (Slack, 1998).

[9] As Hayuth pointed out, "The ability of carriers to provide the shipper with a single rate and one bill-of-lading for the entire door-to-door movement, in contrast to a multi-rate structure, is a crucial element of the intermodal transport concept" (Hayuth, 1986, p. 278).

The main characteristic of modern intermodal technologies is the rapid movement of large volumes of cargo through the port without any breaking of bulk. This development strongly modifies the economic role performed by seaports in the transport system, in particular as far as the traditional balance between central place functions and gateway functions is concerned. Historically, seaports have always performed, at various scale and in different contexts, gateway and central place functions. The latter are related both to the existence of stocks of raw materials in the port area and to the traditional role of ports as break-bulk points, thus creating an incentive - especially for heavy and transformation industries - for a localisation in the proximity of the storage points. While central places mainly serve the "land around", thereby producing polarising effects in the spatial distribution of activities, gateways are nodes that link a home region to other regions via national or international transport. With containerisation the traditional balance between central place functions and gateway functions has changed: technological innovation and the arising economies of scale have both contributed to increase the gateway functions performed by seaports at the expense of traditional central place functions[10]. This is, indeed, at the basis of the crisis of the industrial activities related with seaports and commercial functions based on the break-bulk activity. As a point of fact, seaports no longer represent compelled places where production activities are located; rather they tend to act as rapidly passed-through points in an increasingly scattered production system.

As the importance of gateway functions performed by seaports tends to increase, three main consequences has to be considered: firstly, the impacts on seaport competition; secondly, the impacts on the position of seaports in the transport chain; thirdly, the increasing need for an efficient logistic system.

New requirements play the role of crucial factors in seaports competition: availability of suitable backup areas and operational facilities, tailored to the new handling methods, quality of the inland transport and information. Together with the increasing importance of economies of scale in maritime and continental transportation, the above elements have caused the number of seaports involved in the transport chain to decrease (Containerisation International, April 1996). The selection of seaports and the consequential concentration of traffic flows on a limited number of nodes has expanded the

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[10] The clear distinction between central place and gateway functions which is stated above is aimed primarily at focusing on the role played by containerization and intermodality in modifying the traditional relation between port and inland area development. Actually, as it has been pointed out by many scholars (see for instance Bird, 1981, and Vallega, 1996), these different set of functions may be related one another. Moreover, the increasing role of transport nodes as gateway, due to improvements in transhipment operations, may cause the nature of central place functions performed by the node to change.

hinterlands[11]. Moreover, the spatial and economic logic which shapes the hinterlands has also changed (van Klink and van den Berg, 1998): seaports hinterlands are more and more structuring along intermodal axis; this means that the underlying logic is increasingly less the physical distance from the seaport; rather, organisational arrangements, technological partnerships and the structure of transportation networks have become more and more important.

5. Conclusions

Intermodality is not just a new way of organising and synchronising traffic flows in transport networks: it is a technological innovation which is revolutionising the spatial distribution of activities, the economic role of transport nodes and the functioning of the logistic chains.

This paper has first addressed the issue of what makes intermodality an attractive option: although intermodal techniques are not based on new technologies, the intrinsic heterogeneity in the qualitative characteristics of transport services can make intermodality a superior alternative for some operators, under the condition of low transhipment costs.

Secondly, the interaction between inventory and transport choices, at the firm level, has been considered. It was found that the adoption of just-in-time strategies is related to the possible exploitation of economies of scale in transport operations.

In search for empirical evidence, the radical changes that have affected in recent times the sector of maritime transport and seaports have been illustrated in the last section. It was found that most of the undergoing processes are indeed consistent with the insights of the theoretical analysis carried out in the first part of the paper.

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A good example of that is the basic role played by efficient intermodal technologies and organisational schemes in the establishment of a distripark.

[11] For an empirical analysis of the relation between containerization and concentration in port systems’ development at the European scale, see Notteboom, 1997.

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