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On the interface between surface and underground transport networks

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Abstract
In urban areas underground logistical systems - designed as delivery service to provide shops, industrial sites and office locations - may help to relieve the pressure of the road network in particular in the old inner cities which have to deal with increasing traffic congestion. When shops are provided by such an underground logistic system unloading trucks will not disturb shoppers in shopping streets or traffic flows in streets where cars are allowed.
Recently a number of pilot studies on the feasibility of such systems have been held in The Netherlands. The emphasis of those studies is on technical, conceptual, strategic, legal and economic feasibility. So far, no studies have been carried out on the impact of such systems on the spatial structure of cities. In this paper we will address two topics. Firstly, we will discuss the potential impacts of such a system on the spatial location of economic activities - in particular shopping centres - in urban areas. Secondly, we will discuss by a number of case studies promising locations for Urban Logistic Parks. These are sites – located near the urban built environment - where goods will be transferred from traditional surface transport modes, such as truck, train and barge, to the logistic underground system to be transported into the city.

Contents

1 Introduction

Space is a scarce resource in many countries. More and more claims are laid upon it. People need more space for living, working, recreation and movements (infrastructure) and at the same time nature has to be preserved. These spatial claims cause certain tensions concerning the quality of the environment (pressure on space, environment and social factors). This causes an increasing pressure upon goals with relation to accessibility and quality of life.

This problem of land scarcity is of particular importance for the Netherlands, because the present intensity of land use is already very high. From several initiatives of the public and private sectors in The Netherlands to come to a more efficient use of the scarce space, it becomes clear that the above mentioned developments lead to great concern. An example of such an initiative is the formation of an expert network on Multiple Land Use. Govemments, private parties and scientists jointly participate in this initiative in order to develop concepts and knowledge with the aim to use space in multiple ways. One can think of the use of the third (building upwards or downwards) and the fourth (time) dimension.

One of the possibilities for using the third dimension of space is the development of underground infrastructure networks. This kind of infrastructure use prevents the landscape from further fragmentation and forms a solution for noise problems. In this article, we study underground transport networks in urban areas and in particular the use of such networks for freight. For the success of such underground transport networks it is essential that they are well linked with surface networks. Therefore, we will focus in this paper on Urban Logistic Parks, being locations where goods are transhipped from surface transport modalities to the underground logistic system and vice versa.

An interdepartmental study group - IPOT - in which the Ministries of Transport, Economic Affairs and Spatial Planning participate, started a research program on the feasibility of underground logistic systems in The Netherlands at the beginning of 1997. The main targets to be achieved by such a system are (IPOT, 1998):

- To secure and improve accessibility of cities and major economic areas for goods transport;
- To improve the quality of life in cities and major economic areas by reducing emissions, noise levels and traffic accidents caused by trucks and vans;
- To strengthen the economic structure of regions by a competitive transport system.

The underground logistic system concepts that are under investigation in The Netherlands have the following characteristics: they

- aim at the segment of rolling containers and pallets;
- have a range up to 50 kilometres;
- aim at fully automated transport including automated transfer;
- will be a non-rail but self-navigation system, such as Free Ranging On Grid (FROG);
- will be an independent transport-environment.

Underground logistic systems can be implemented as private business systems or as public systems to transport good flows within an urban area. An example of a private system is the planned underground logistic system between the flower auction in Aalsmeer, Schiphol airport and the rail terminal at Hoofddorp. In this paper, however, we focus on the public systems. In the initial phase the underground logistic system is planned to be developed in the larger urban agglomerations, mainly located in the western part of the Netherlands. In a second phase the agglomeration networks are planned to be linked to a network at the leve1 of the Randstad, with some extensions to other large urban areas in the eastem and southem part of the country. In a final phase the underground logistic system might cover all Dutch cities

and might even have connections with foreign networks, for instance networks in Belgium or Germany.
The function of an urban underground logistic system for freight transport in relation to shopping centres and the inner city is threefold (Gordijn, 1999):

- To connect warehouses with exchange points, where customers from outside the orbital motorway area that have come by car to the city can pick up goods immediately after they have bought them; these interchange points will also be used by express delivery services that deliver goods at home for those who came by public transport or do not want to transport the goods themselves;
- To connect warehouses with intermodal terminals if the warehouses are not already intermodal exchange points themselves; this connection is especially relevant for the procurement of goods to warehouses from factories that are located on longer distances;
- To connect warehouses, exchange points and intermodal terminals with delivery points within the conurbation for consumers who live in the neighbourhood of that delivery point.

The aim of this paper is to give insight into the factors that will play a role in the establishment of firms on Urban Logistic Parks. The spatial implications of the construction of underground logistic systems in the existing urban structures will be discussed in section 2. In Section 3 various types of potential users will be considered. The implications for the size of these Urban Logistic Parks are assessed in section 4. Special attention will be paid to the location of Urban Logistic Parks in section 5. The paper concludes with a short summary and some recommendations for further research.

2 Spatial consequences

Underground logistic systems are most attractive where space is most scarce and where enough potential freight flows are available to make the system operate competitively with surface transport modes (or on places where no other possibilities are available than underground transport). This means that these systems will first be introduced in, and later on between, the larger urban areas. It is obvious that in developing intra-urban underground logistic systems, it is important to consider future connections and extensions into inter-urban logistic systems.

Two aspects will be discussed in this section. Section 2.1 deals with locations that could be connected to urban underground logistic systems (see Bruinsma et al., 2000) and Section 2.2 deals with locations in, or close to, the urban areas that could be suitable for the establishment of an Urban Logistic Park.

2.1 What kind of locations will be connected?

In developing urban underground logistic systems, it is important that the right locations will be connected. Analysing the spatial structure of urban areas, it becomes clear that shopping centres, industrial sites and office locations are spread out over the urban area. In general, three types of areas can be distinguished. The first one is the inner city with emphasis on high-leve1 ‘urban services. The second type of areas are the shopping centres in the densely populated areas around the heart of the city and in the suburbs. The third type of areas are the industrial sites and office locations at the fringes of the urban agglomeration where, next to producers, also certain categories of retailers (fumiture-stores and shops for building-materials) are located. It is important to check whether or not an underground logistic system will be able to serve the variety of locations within the urban area adequately.

It goes without saying that an underground logistic system will connect the inner city (type one) since the sales of shops in this area are high and it becomes increasingly difficult to supply centra1 areas by surface transport, especially when they have historic value.

With regard to the shopping centres in densely populated areas (type two), the level of shopping centres is of utmost importance. If all smal1 shopping centres would be connected a very extensive underground logistic system would result, in which the efficiency of supply will rapidly decrease due to the large number of smal1 distribution points where goods have to be transferred from underground to surface transport to the client. On the other hand, if only the city centre and some large shopping centres are connected this will imply that the smaller shopping centres will remain to be supplied by surface transport. If surface transport would be charged heavily to stimulate the underground logistic system, this would result in the decline of smal1 shopping centres. If such smal1 shopping centres survive, the urban area will stil1 carry the burden of surface freight transport, which will reduce the impact of the underground logistic system on the decrease of good flows in urban areas.

With respect to industrial sites and office locations (type three) it is difficult to come to an assessment of locations that have to be connected to the urban underground logistic system. The difficulty is that most companies will benefit more by an inter-city underground logistic system than by an intra-city system for the delivery and removal of goods. Given the expected subsequent order in which the different systems will be constructed (intra-city systems first, followed by inter-city systems) the connection of the systems requires vision and insight into future use of the underground logistic system on a certain location in the urban area. Notice that the foregoing sentence deals with the future use of underground logistic systems "on a certain location" and not "by certain companies". Reason for this is that it is well possible that the companies that are currently located on the site will have moved when the underground logistic system has been developed into an inter-city system. Thus, predictions are required on the type of company and on the type of activities that one expects on the industrial site in future. Moreover, one requires insights into the opportunities that an underground logistic system offers to companies.

2.2 Potential locations for Urban Logistic Parks

In this section, a couple of requirements that a location will have to meet to be suitable for the establishment of an Urban Logistic Park will be considered. First of all, it is important to realise that Urban Logistic Parks have to fit in the current urban structures. An Urban Logistic Park can be established on a 'Greenfield' location (an urban enlargement area in the rural area) or on a 'Brownfield' location (an existing industrial site within the urban area, e.g. a restructuring area). Second, Urban Logistic Parks have to be established on locations favourable with regard to both the supply by surface transport modes and the location of the customers of the underground logistic system (shops, industries and offices). A favourable location with regard to the supply by surface modes will very often imply a location outside the present built-up area where it can be connected directly to the interregional infrastructure networks. Consequently, the underground network required to deliver the goods to the customers in the urban area will be relatively long, which brings about high construction costs. On the other hand, an Urban Logistic Park within the urban area means short distances to the customers of the system, but the supply of the Urban Logistic Park itself by surface modes will come into play due to growing congestion in and around urban areas.

Next to the above-mentioned choices, a couple of supplementary strategic choices will have to be made to select the most suitable location for an Urban Logistic Park. The first two supplementary choices concern the underground logistic system itself. Will it be a system with a dense or a wide grid, and what will be the diameter of the system. Most probably this choice will be a joint choice: either a system with a dense grid and a smal1 diameter, or a system with a wide grid and a large diameter.

The first system – dense, with a smal1 diameter- will lead to a decrease in distances between exit points and final consumers, but additionally to a decrease of the size and volume of the goods that are suitable – in size - to be transported through an individual pipeline.

The second system – a wide system with a large diameter - faces the problem that relatively much attention has to be given to final surface distribution (again in distance and costs) to the customers. This development can be questioned in connection with the desired decrease of the inner-city traffic congestion.

To find a strategy for the former mentioned choices, it is important to make an inventory of the distribution points (shopping centres, office locations and industrial sites) on the one hand, and the needs of the customers (size of the flows and volume of products) on the other hand.

A final strategic choice concerns the number of Urban Logistic Parks that can serve one individual city. Would one Urban Logistic Park be sufficient or would it be better to have several distribution points that can be supplied by transport flows from different directions and/or that take care of the distribution in specified segments of the urban area? This choice is closely connected to the choice that has to be made with regard to the grid density of the system, the diameter of the underground logistic system and the location of the customers in the urban area.

3 Potential users

The centra1 question in this section is what kind of firms might be interested to settle on Urban Logistic Parks. Based on the attractiveness of Urban Logistic Parks for several kinds of activities a typology of firms will be developed. Obviously, this section has a tentative character.

The most important classification that can be made of firms interested in settling on an Urban Logistic Park is the aim these firms have in using an underground logistic system (specific firms) and firms that want to be connected to an underground logistic system for public use.

Besides firms that have a direct interest in an underground logistic system (the tied firms), also firms that do not have a direct interest in an underground logistic system itself want to be settled on Urban Logistic Parks; the so-called untied firms. These firms can perform many kinds of activities. The next sections will give an overview of a – tentative - typology of firms.

3.1 Tied firms

There are several kinds of tied activities: customers (shops, industries and offices) and suppliers (firms that distribute goods in the urban area and firms that collect goods that are produced in the urban area). Our focus is on the role of Urban Logistic Parks as a link between the regional/national transport system (in principal surface) and the underground urban system. Firms that are interested in locating on an Urban Logistic Park when the underground logistic system is only available at the urban leve1 will also be interested in a settlement on Urban Logistic Parks when the underground logistic system is extended to a network with a Randstad or national coverage. Vice versa this will not be the case.

The tied firms on Urban Logistic Parks are firms that will actually supply or distribute goods by the underground logistic system. These firms can mainly be found in the transport, wholesaling and parts of the manufacturing sectors.

Wholesaling

As long as there is just an urban underground logistic system, wholesaling can be regarded as a tied activity. Especially wholesale trade of food and luxury goods, consumer articles and wholesale trade with a general assortment can profit from settling on Urban Logistic Parks since they belong to the retail-trade related wholesale firms.

Transport

Transport related firms could also have direct interest in settling on an Urban Logistic Park since these firms take care of the supply and distribution of goods from and to the underground logistic system. Also companies that transport their own products are to be found in this category.

Manufacturing

For the classification of manufacturing firms, it is important whether or not a company produces products that can be directly supplied to the underground logistic system. One can think of a brewery that directly supplies beer via the underground system to its distribution centre or a shop. It is plausible that this will only be interesting for industrial companies if the underground logistic system provides an integrated network for several cities or even for the whole country.

3.2 From tied firms towards untied firms

In the ideal case only those companies that actually want to use an underground logistic system will settle on an Urban Logistic Park. However, next to location factors that are important for tied activities, in practice there are additional location factors that play a role in the location decisions of firms. In this way, a sliding scale from tied towards untied activities arises. One can think of companies that are engaged in one or more connections within the logistic chain, such as distribution, production, Value Added Logistics (VAL) and assemblage. These kinds of activities are transport oriented, but not dependent on the underground logistic system. Nevertheless, the Urban Logistic Park guarantees a flexible supply and distribution of goods via the surface transport modes in which the companies concemed are interested.

There are four more reasons to be mentioned why firms not specifically intending to use the underground logistic system may want to settle on Urban Logistic Parks:

1. Localisation economics: the spatial concentration of a branch of industry. Companies that are tied to an Urban Logistic Park can attract less tied parts of their branch of industry, e.g. due to the importance of neamess in the conceming branch of industry (face-to-face contacts, exchange of information, R&D efforts etc.);
2. Image effects. An Urban Logistic Park containing dynamic firms and modem transport systems has a positive image to companies under the cloak of "we have to be settled there where the action is";
3. The proximity of an urban area can make an Urban Logistic Park attractive for activities without any transport orientation;
4. Supply of industrial sites. If Urban Logistic Parks take a large share in the overall supply of industrial sites in urban areas, these parks could attract firms that would rather have settled somewhere else in the urban area, but due to the scarcity of locations, no altemative was found;

It is important to note that untied activities will hardly lead to extra use of the underground logistic system (which means no higher direct returns) but it does lead to higher returns via land exploitation.

The above mentioned criteria are so diverse that a broad range of companies could be considered for the establishment on Urban Logistic Parks. An enumeration would result in long lists of possibilities, so a reversed approach will be followed here: only those companies that will definitely not settle on an Urban Logistic Park will be discussed.

In principle, two types of firms can be excluded right away: (1) firms that are under-qualified to locate on such parks and (2) firms that are over-qualified to locate on such parks. The first category contains for instance the branches 'Agriculture and Fishery', 'Exploring of minerals' and the raw materials industries. These activities are not only under-qualified to fit in the locational profile of an Urban Logistic Park, moreover, they also deal with raw materials which means that they are often tied to certain geographical regions. Also substantial parts of the manufacturing sector can be excluded from settling on Urban Logistic Parks. At the opposite end, some firms may require a higher locational profile than a Logistic Park offers. One could think of the top segment of manufacturing activities like high-tech industries, and offices of for instance business services and parts of the non-profit services.

4 Size of Urban Logistic Parks

To be able to estimate the space required by the Urban Logistic Parks, information about two aspects is needed:

1. The volume of goods suitable to be transported by the underground logistic system;
2. The space-volume parameter of distribution centres.

By combining the volume of goods of each city with the space-volume parameter we are able to make an estimation of the space required to facilitate an Urban Logistic Park for each city.

4.1 The potential good flows

The volume of goods to be transported by the underground logistic systems of seventeen Dutch cities has been studied in the Dutch case study 'Gaat Leiden Ondergronds?' (Does Leiden go underground?, BCI et al., 1999). In this pilot study the potential delivery of goods to be transported by a future underground logistic system in the Dutch city of Leiden has been calculated. The city of Leiden is a medium sized city with about 200.000 inhabitants. It has an attractive old historica1 centre where it is difficult to enter for trucks. The calculation is based on weekly good flows delivered to various economic activities and the suitability of those good flows to be transported by an underground logistic system. The last precondition means the suitability of the goods to be transported on pallets or in roller containers. The results of this pilot study are shown in Table 1.

Table 1 Weekly volume of goods suitable for delivery by underground transport in Leiden

	Establishments or surface	Volume of goods per establishment or m^2 per week	Potential volume of the underground logistic system	Percentage of the potential volume
Hotel & catering	357 firms	10.8 m^3	3,856 m^3	16.0%
Retail trade	1,112 firms	6.1 m^3	6,839 m^3	28.5%
Offices	602,600 m^2	0.004 m^3	2,238 m^3	9.4%
Industrial sites	3.303.000 m^2	0.003 m^3	11,065 m^3	46.1%
Total			23,998 m^3	100.0%

Source: BCI et al., 1999

It is important to note that these calculations are based on the assumptions that an underground logistic system exists at the national leve1 and that all goods that are suitable for underground transport are indeed transported in this way. In other words: these are the most optimistic figures about the volume of goods suitable for transport by underground logistic systems.

Remarkable is that, whereas we expect that most volume would be generated by retail shops, this pilot study indicates that firms on industrial sites are the most important freight generators (nearly 50% of the good flows in Leiden are estimated to be delivered to industrial firms). This implies that in the design of underground logistic systems the issue of connecting industrial sites should not be neglected.

For a set of seventeen studies the expected volumes for underground freight transport have been estimated. The results are presented in Table 2. The largest good flow will be generated in Rotterdam. The high volume of this city is in particular generated by industrial firms due to the large surface of industrial sites. One may have some doubts about the suitability of goods for underground transport generated by firms on those industrial sites. In particular in Rotterdam – and to a lesser extent in Amsterdam – there are large port related industrial sites. Most of the goods dealt with on those sites will not enter the city or even the country but will be transported further towards the large European hinterlands of those seaports. Moreover, the majority of industrial sites in harbour areas will mainly handle bulk goods, such as raw materials, that are unsuitable for this new concept of high quality underground logistic systems. A future refinement of the parameters should deal with those aspects.

Table 2 The estimated weekly potential for underground transport of seventeen Dutch cities

	City		Share of the economic activity in the volume of goods			
		Volume (m^3)	Hotel & catering	Retail	Manufacturing	Offices
1	Amsterdam	153,000	28%	29%	37%	6%
2	Rotterdam	201,000	10%	14%	70%	6%
3	The Hague	61,000	30%	39%	11%	20%
4	Utrecht	34,000	24%	37%	22%	17%
5	Eindhoven	32,000	21%	31%	42%	6%
6	Tilburg	34,000	14%	24%	59%	3%
7	Groningen	35,000	18%	26%	49%	7%
8	Breda	30,000	17%	28%	50%	5%
9	Nijmegen	29,000	18%	25%	52%	5%
10	Enschede	25,000	15%	29%	52%	4%
11	Haarlem	19,000	26%	48%	20%	6%
12	Arnhem	22,000	23%	34%	32%	11%
13	Maastricht	22.000	26%	33%	37%	4%
14	Dordrecht	20,000	13%	27%	57%	3%
15	Leiden*	15,000	26%	44%	18%	12%
16	Hengelo	16,000	12%	23%	63%	2%
17	Gorinchem	8,000	14%	28%	55%	3%

* since we used a different database to calculate the potential good flows, the figure of Leiden is lower than the figure calculated in the study 'Does Leiden go underground'. In the latter, suburban areas are included in the calculations as well as industrial sites to be developed in the near future. Both are left out in our study.

4.2 The land use claim

From a number of private parties (retailer, brewery, clothing chain) data on the size of distribution centres, the size of the site and the average stock have been collected. In order to determine the space needed to transport goods underground (this will be done in the next section), average parameters for size of the building versus the size of the weekly flow (building/weekly flow) and the size of the surface of the distribution centre versus the size of the building (surface/building) have to be determined. In this research, a factor of 2.9 m^2 per m^3 in weekly flow will be used for the ratio building/weekly flow (this is the average from the retailer and the brewery). For the ratio surface/building a factor of 1.6 m^2 surface per m^2 building is used. These figures are derived from telephonic interviews with managers of distribution centres in The Netherlands.

Table 3 Required space to facilitate Urban Logistic Parks

		Building (m^2)		Site (ha)	
	Cities	Minimal	Maximal	Minimal	Maximal
1	Amsterdam	88700	443400	14,6	72,8
2	Rotterdam	116500	582700	19,1	95,6
3	Den Haag	35300	176600	5.8	29.0
4	Utrecht	19500	97600	3,2	16,0
5	Eindhoven	18300	91700	3.0	15.0
6	Tilburg	19800	99000	3,3	16,3
7	Groningen	20200	100800	3,3	16,5
8	Breda	17400	87200	2.9	14.3
9	Nijmegen	16600	82800	2,7	13,6
10	Enschede	14500	72700	2,4	11,9
11	Haarlem	10800	53900	1,8	8,9
12	Arnhem	12500	62400	2,0	10,2
13	Maastricht	12800	64000	2.1	10.5
14	Dordrecht	11800	58900	1,9	9,7
15	Leiden	8600	43200	1.4	7.1
16	Hengelo	9500	47700	1,6	7,8
17	Gorinchem	4400	21900	0,7	3,6

4.3 Land use claim Urban Logistic Parks
Based on the number of m^2 building that is needed for an average weekly flow in m^3, now the minimum amount of space per city that is needed in order to tranship goods suitable for underground transport via an Urban Logistic Park can be calculated. In calculating Table 3, the assumption has been made that on average for every 1 m^3 flow about 2.9 m^2 building is needed. Assuming that the distribution centres for transhipment to underground transport are mainly used as cross-doek centres (maximum storage for 24 hours), then the weekly volume and, with that, the area needed can be reduced to one fifth (the area needed per week divided by 5 working days). Now that the size of the building has been estimated, the amount of surface needed per city to facilitate an Urban Logistic Park, can be calculated with the parameter for the surface/building ratio (1.6).

5 . Location choice

In this section, suitable locations for Urban Logistic Parks in and near cities will be investigated by means of a GIS-model. The GIS-model will be described in section 5.1. Some genera1 results will be presented in section 5.2.

5.1 The model

A GIS-tool "Urban Logistic Parks" has been developed to analyse the suitability of industrial sites as a location for an Urban Logistic Park. Ideally, an Urban Logistic Park would concern a multi-modal accessible location near or in an urban area. Different modalities (water, rail, and road) have to be considered when looking at the accessibility of an Urban Logistic Park.

A second group of criteria regards site characteristics. Conceming the size, the minima1 size (see Table 3) holds as a threshold condition. The assumption is made that goods transhipment from surface to underground transport is efficient without storing the goods (cross-decking concept). Since an Urban Logistic Park is located near or in an urban area, the search can be limited to locations in the direct surroundings of urban agglomerations. Next, a criterion is needed dealing with the location of the customers (industrial sites, office locations and shopping centres in urban areas) of the underground logistic system. Finally, the designated use of the site has to be checked. Sites which are used by heavy industry or port sites have a too low location profile, whereas top segment office locations and high-tech or science parks have a too high location profile to establish an Urban Logistic Park.

The GIS-tool allows experimenting with different weighing factors for - a subset of - the above-mentioned location criteria. The hart of the GIS-tool is formed by the GIS-program Land Use Scanner that provides basic data on the designated land use in a grid format from 500 meter by 500 meter. In addition to the Land Use Scanner data, electronic databases on infrastructure networks are included in the GIS-tool "Urban Logistic Parks". In the GIS-tool the following criteria have been operationalised:

1. Accessibility by road

   One or a combination of the following criteria:
   - Distance to highway;
   - Distance to main road;
   - Distance to regional road;
   - Distance to entrance/exit of highway.

   For every grid cell, the distance from the centre of the cell to the closest road and the nearest entrance/exit is used.
2. Accessibility by rail

   One or a combination of the following criteria:
   - Distance to a station;
   - Distance to a railroad.

   For every grid cell, the distance from the centre of the cell to the closest station or the nearest railroad is used.
3. Location in relation to shopping centres, industrial sites and office locations

   NO suitable data are available on the potential customers (shops, industries and offices). Also, this criterion is closely linked to the unknown design of the network of the underground logistical system. The closer the Urban Logistic Park will be to the centre of the city, the lower the construction costs will be. Therefore, this criterion is measured as the distance to the centre of the city.
4. Availability of land

   The size of industrial sites in IBIS database is used. Suitable industrial sites can be selected based on a minimum size. The location profile of each individual site is given when the results of the search process are presented.
5. Position in relation to urban area

   Only zones within a distance of 1 kilometre from the built-up area are considered under the assumption that with a larger distance, the costs of building the underground logistical system are too high (infrastructure networks outside this area are included in the search process of the GIS-tool).

The method for searching sites most suitable to facilitate Urban Logistic Parks is as follows:

First, the search area is defined by selecting an area for a city up to one kilometre outside the built-up area (criterion 5). Next, for the industrial sites in those selected areas each of the accessibility criteria (1 and 2) and the position in relation to the city centre (criterion 3) has been calculated.

In the next step, the minima1 size of the industrial site to be able to facilitate the Urban Logistic Park in the selected city has to be set (criterion 4). Weighing factors can now be assigned to - a subset of - the criteria with which an accessibility map can be calculated (every grid cell of 500 meter by 500 meters receives a value which indicates how well the cell is accessible). Use is made of standardised criterion scores, a usual approach in multicriteria analysis (see for example Nijkamp et al., 1990). The best accessible grid cell receives a score of 100 and the scores of all other cells are related to the score of this best accessible cell. Consequently, these values can be compared with the values of other cells in the area. In this way, attractive located industrial sites can be identified (given the relative accessibility of the grid cell they are located in). The weighing factors may be interactively adjusted to see for example what the impact on the attractiveness of industrial sites would be, for instance, of assigning a higher value to the presence of a railway station.

Next, the industrial sites that meet the minimum required size in an urban region are presented on the suitability map. In this way, the best industrial site for the Urban Logistic Park can be visually determined for the conceming city (see Figure 1).

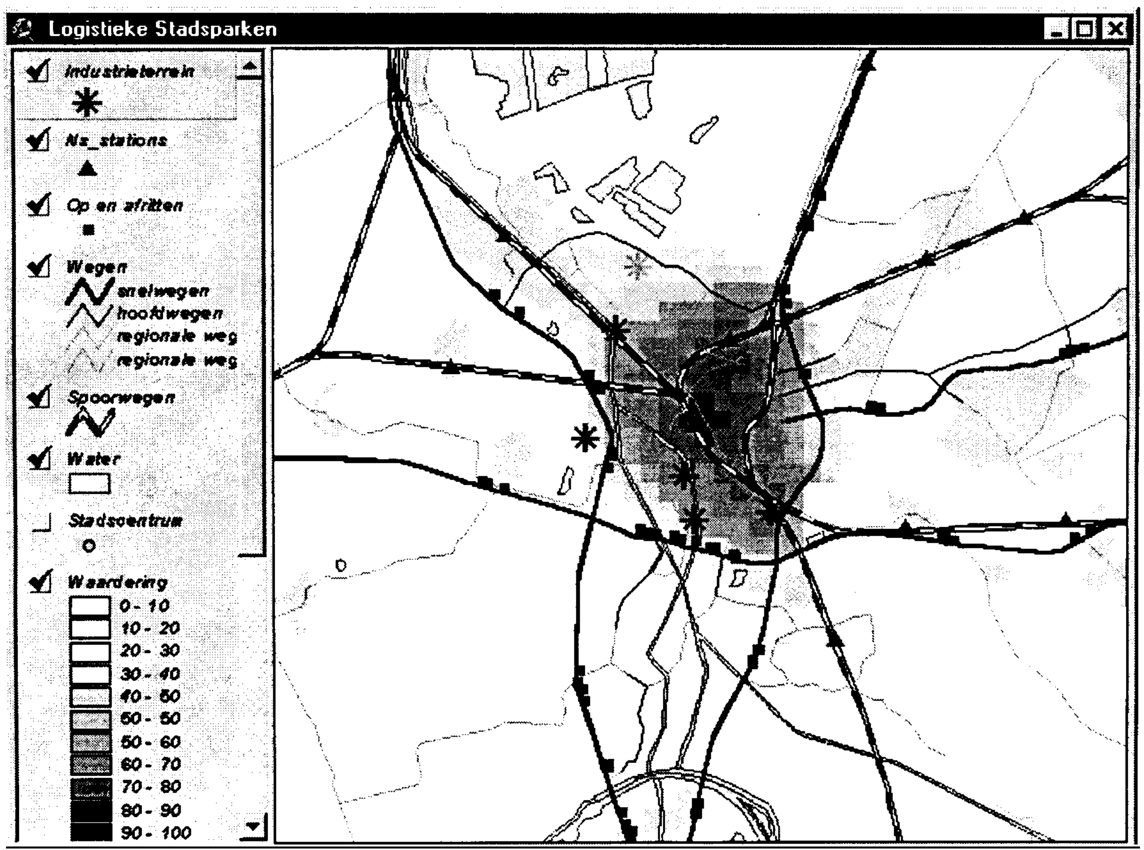

Figure 1: Example of the results of the analysis

It is now possible to request an overview in the table 'Industrial sites' on all suitable areas including their measures. As presented in Figure 1, it is also possible, by clicking the mouse on the required industrial site, to acquire the necessary data on attributes (location profile of the site, size etc.).

5.2 Some results

In the model, a weighing is made of the various accessibility indicators, which are the locational profiles of suitable industrial sites. Obviously, sites close to infrastructure networks and nodes appear to perform well. This holds true especially when rail and road are close. In many cases though, a reverse effect of distance to the city centre and railway stations (both centrally located in the city) on the one hand and distance to main roads and highways (located in the city surroundings) on the other hand arises.

If the criteria 'distance to railway station' and 'distance to entrance/exit' have value 1 and all other criteria are left out of consideration, this results in locations located nearby a highway as well as a railway station (this mainly concerns the suburban railway stations). If all criteria receive an equal weighing, with larger cities the results are somewhat unclear, but generally, the areas in the city centre or within the orbital motorway are preferable. For smal1 cities a clear preference exists for the centre: the entrances/exists and highways are not compensated for by the closeness to the centre and (central) railway station and the presence of roads in the centre.

According to the current data set, in most cases some industrial sites are located in the areas that score high according to the calculations. In the centre the number of sites is lower and, mainly in larger cities, the size of the centrally located sites is small.

6 Conclusions and further research

In this paper, the results of research on potential locations for Urban Logistic Parks in and nearby Dutch cities are presented. The aim of the research was to give some insight into the mechanisms behind industrial location on Urban Logistic Parks. These mechanisms are then operationalised by a quantitative estimate of the size of the spatial claims. Also, an inventory of suitable locations is given. Summarised, this means investigating the following issues: 'potential users', 'size' and 'location choice'.

After a short overview of different locations that can be connected by underground logistic systems (the inner-city shopping centre, shopping facilities outside the centre, industrial sites and office locations) potential locations for Urban Logistic Parks are described. Such a location should satisfy requirements such as fitting in existing urban structures and the accessibility both for supply by surface transport modalities and deliveries to customers (shops, industries and office). In addition, decisions have to be made on the density of the grid and the diameter of the underground transport system.

The issue 'potential users' has been investigated on the basis of a classification of the aim for which the underground logistic system will be used. A distinction has been made between companies that develop their own underground logistic system (specific companies) and companies that wish to be connected to an underground logistic system for public use. This last group is subdivided in tied and untied firms. Tied firms are warehouses and transport companies, in particular urban delivery services. Remarkable, however, is that a pilot study in Leiden shows that deliveries to industries make up a large share of the potential good flows to be transported by urban underground logistic systems.

The issue of 'size' has lead to an estimation of the space needed for handling and transhipment of goods in Urban Logistic Parks by relating the potential goods flows per city with space-volume parameters.

To investigate the issue of 'location choice', a GIS-tool (Geographical Information System) has been developed. The developed GIS-tool offers the user the possibility to select seven location factors and to give these factors weights with which the attractiveness of sites can be calculated.

Several directions for further research can be formulated.

First, the economic feasibility of underground logistical networks has to be assessed. This would call for a careful analysis of the market potential for underground networks in urban areas plus the costs involved. Especially it would be important to find out under what conditions underground logistic transport would be a serious competitor of surface transport systems. One may think of policies of local governments to allow trucks only very limited access to inner cities, or financial instruments to discourage surface freight transport in urban areas.

Second, the structure of the network (diameter, grid, length, number of interfaces with surface transport) deserves attention, both from a technological, an economic and a spatial planning point of view.

Third, part of such an analysis of underground logistical systems would be a further assessment of Urban Logistic Parks. Research would focus among other on:

- A detailed investigation of the size of the flows entering urban areas and suitable for underground transport in the city;
- A careful analysis of the land use implications of Urban Logistic Parks.

The fourth direction for research concerns the development of the GIS-tool:

- Extra factors that are relevant in calculating the valuation may be added, such as distance to waterways, quays and railway emplacements. Furthermore, it is possible to value roads not only on the basis of the type of road, but also, for example, on the basis of the congestion on the road. In this way, roads where problems like congestion occur, are valued less than roads without problems;
- The model can be improved by adding the spatial distribution of customers of the underground logistic system (shopping centres, industrial sites and office locations). In the present models only the city centre is taken into account;
- Besides existing industrial sites, it is also possible to include future and planned sites. Not only the total area issued now is relevant, also sites to be issued in the future can be interesting.

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