Location of Distribution Facilities in an Urban System

-the Case of Sweden-

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1．Introduction
2．The Facility Location Problem
3．Choice of Solution Algorithm and Description of Data
4．Facility Location and Market Areas
5．Summary

1. Introduction[1)]

Facility location has an important role for any business, but especially for companies whose profits depends on efficient logistic operations. In this paper, we present a discrete uncapacitated facility location problem, where preferable locations for one or more distribution facilities are determined. We also make some general comments regarding probable and expected locations and the properties related to the stability of those, when number of facilities to be located increase. We apply the model on data from Sweden, and to some extent from Finland, in order to identify optimal locations for facilities in the urban system. We also perform a sensitivity analysis in order to find thresholds where cities become stable spots for a facility to locate in, independent on the number of facilities located in the urban system. Hence, a municipality leader who want to increase the attractiveness of the municipality as a site for new facilities may also find this study interesting. Finally, as an evaluation of the outcome of our purified model, we compare our results with the localisation made by IKEA of their warehouses in Sweden.

The more precise purpose of the paper thus is to model the facility location problem in a

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purified network by only considering transport costs on the links and the distribution of demand over nodes. We assume the network is autonomous. Hence, external links through land-based connections, bridges, sea- and airports or other terminals, are in the paper assumed away. The limits of such an autonomous network thus only change through a split of the network into two or more autonomous networks, or a merger with other networks. The analysis here is static, demand in municipalities are given. In a dynamic setting, one would allow the markets in the network to change by a relative adjustment of the size of the population, and thus of demand, between nodes, or by investments in infrastructure and transport capacities, as well as by various institutional and regulatory changes that would have an impact on transport costs on links.

When we have identified the optimal location of facilities, we report isochrones delimiting zones of transport time for deliveries from each facility to customers in the municipalities as well. We assume the company owing the facilities to cover demand in the complete Swedish urban system when it choses locations for its facilities. Hence, the shape of accessibility on links in the autonomous network and the distribution of market potentials over nodes are the only two forces assumed to determine the favourable locations of facilities.

Computationally, such a multi-facility network problem rapidly becomes complex and hard to solve. We therefore apply a heuristic algorithm to find solutions, while ArcGIS is utilised to illustrate locations chosen, market shares and zones of service time to reach demand in municipalities.

The paper add an to the extensive number of case studies of logistical challenges for companies such as network and transportation decisions, logistic planning, facility location, and inventory decisions. While many previous papers have analysed such specific cases, we here highlight the more general pattern of locations of facilities within an urban system. This pattern is in our applied case nation specific and the choice of each location for a facility is in our study heavily influenced by the geographical shape of the economic area of a specific nation, its networks and the distribution of inhabitants, and thus the market, over municipalities.

Our identification of the overall pattern and the structural stability of favourable locations should be a point of departure more detailed and company specific investigations. This is not only of interest for a company that want to decide about preferable locations for its facilities, but also for investors in real estate focused on trade and logistics, as well as city developers and leaders interested in the development of their cities. We assume that the company has full information regarding the structure of the urban system when it consider the location of a facility. This need not be the case. In Ishikawa (2012) the more detailed steps in a search process for a location of a facility in a system of cities are discussed.

In the following, section two introduces our specification of the discrete uncapacitated facility location problem. Here we also make a priori comments on location patterns expected by facility location in an autonomous network. In section three, our dataset and the heuristic algorithm used to find a solution are described. We present our findings in section four, were we also report the outcome of our sensitivity tests. In the section, we also make an illustrative comparison with the establishment of IKEA warehouses in the Swedish urban system. Finally, we summarise our findings.

2. The Facility Location Problem

The optimal facility location problem consists of finding the optimal location of a facility within a given set of possible locations, while the total cost of transportation in order to reach consumers in a given set of locations is minimized. The set of potential locations and the set of demand points may as here, be the same set, but need not be so. Weber (1909) early formulated the facility location problem for one facility, as the problem to find a location for a production site on a continuous and isolated (autonomous) space. Then, total cost of transportation is minimized somewhere in between a location with a given market and two fixed locations for inputs, e.g. two raw materials. This resulted in “the Weber triangle”, within which the optimal location must be found. Generally, the optimal location is somewhere interior to the triangle, not at its edges.

This problem may be extended in many directions. Labour cost could e.g. vary over space. An optimal cost minimizing location that includes cost of labour would take care of this. Agglomeration effects may give positive externalities and reduce costs faced by facilities located adjacent to each other. This would strengthen the attractiveness of already occupied locations. In such a case, where many companies, public bodies, and households are attracted to the same place as their optimal choice, this may increase land rents in the location, a fact that instead would be repellent on actors with smaller budgets or those with a demand for land intensive locations. If we introduce land rents in the problem, the latter would in order to minimize costs, move to nearby or other places with lower rents. Eventually, this will result in a specialisation in land use as a response to the fall in the land rent gradient out from the place with largest attractiveness.

In his model of a linear market, i.e. a street or a beach, Hotelling (1929) studied the choice of location of facilities such a shops that market similar products. In the model, consumers are distributed evenly along the linear market. If customers take the cost of transport to a shop, a single shop may due to its monopoly position locate anywhere along the market. From a social point of view, when time and other costs for transportation are minimized, a location in the middle of the linear market instead would be optimal. In the case of a public facility, which not may charge customers different prices but has to bear the cost of transportation to all customers, a location in the middle of the market would also be cost effective.

When two facilities should be located in such a linear market, the public facility would divide the line into two segments and locate a facility in the middle of each. Two competing shops, with customers paying for the cost of transport, would instead establish them self "back to back" in the middle of the line. Thus dividing the market into two, and establish a duopoly. The total cost of transportation for society would thus be larger in the private duopoly solution compared with a public solution or in a regulated duopoly.

The facility location problem is also closely related with both land rent theory and the location theory developed already in 1826 by von Thünen. Von Thünen deals with an isolated circular space where demand is concentrated to a market in its core. Given transport costs to the market and the yield of various agricultural products, such as extensive field crops, vegetables, timber, firewood, ranching etc., the problem is to find the optimal choice of land use, i.e. production, at given distances from the centre. The optimal choice of location of a facility for the production of a specific product as it was formulated by Weber, and the optimal choice of production at a given location as formulated by von Thünen, may, when integrated into a unified model framework, result in a common land use.

The optimal facility location problem thus is a generalised Weber problem, with a network in discrete space. The solution to the facility location problem is a set of located facilities in nodes that minimize total transport cost from each point of demand in the network to its nearest facility. The number of facilities located may be one, two or more. The larger the set of facilities introduced, the more nonlinear the problem becomes, and there may not be another way to find the optimal set of locations, than to calculate and compare total transport cost for each possible set of locations.

The above "core" facility location problem may be developed further e.g. by adding opening and construction costs for each facility or a more dense network with properties that are occupied or not occupied, that may be bought, renovated or teared down. In this case, land rent theory as discussed above in relation to von Thünen, could become part of the formulation. Extensions may also take care of transport of inputs and cost of labour as well as introduction of nodes that are specific import or export harbours, bridges or airports. In the case considered here, we instead want to simplify, streamline and focus on the spatial structure of the autonomous network considered. The accessibility inherent in the network for distribution and the allocation of demand over nodes are in focus. We have thus formulated our discrete uncapacitated facility location problem (DUFLP) for $i = 1, \ldots\ldots n; j = 1, \ldots\ldots m$ nodes as follows.

(1) DUFLP: $$\min T = \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} z_{ij} d_j$$

(2) s.t. $$\sum_{i=1}^{n} z_{ij} = 1 \ \textit{for all } j$$

(3) $\sum_{i=1}^{n} x_i = F$

(4) $z_{ij} \leq x_i$ *for all i*

(5) $x_i = \{0,1\}$ *for all i*

(6) $z_{ij} = \{0,1\}$ *for all i, j*

(7) $d_j, c_{ij} \geq 0$ *for all i,j*

The problem DUFLP, is an integer-programming problem; a facility x_i may as given by (5) only be located, or not located, in one of n possible nodes, in our case the set of municipalities in the urban system. The problem is uncapacitated since we not have capacity constraints on the size of a facility. Hence, when only one facility is located in the network, it serves total demand over all nodes. This illustrate how we focus on the location problem, completely separated from e.g. establishment and construction costs for a facility.

Demand in each of the n municipalities is given by; d_j, $j = 1, \ldots\ldots, m$. In the following, we assume $n = m$ so the set of nodes possible to locate a facility in, equals the set of demand nodes in the network. To simplify further, we assume the population in each municipality to have the same properties as the average Swedish population. In an application for a specific commodity, we could obviously adjust this to take care of income, age, and preference distributions as well as impacts of tourism, commuting, etc.

The problem is to find the set of locations for facilities where $x_i = 1$, that minimize the total cost of transport time from a facility to each node and its demand. Hence, the problem formulation implies that the company responsible for the facilities bears the transport cost to reach each customer in the set of nodes. Each customer thus meet the same price for the product distributed by the company all over the network.

The network consists of links with a transport cost, measured as travel time, given by c_{ij} between each of the nodes in the network. Hence, the objective (1) is to minimize the weighted sum of total transport costs on all links to the nodes where a facility may be located. Demand in nodes are then weights.

In a municipality not chosen as the localisation of a factory, $x_i = 0$, otherwise $x_i = 1$. From (4) and (6) this implies that the discrete interaction term z_{ij}, from municipality i without a facility to all other municipalities j also is zero. Hence, the objective function minimizes the total transport time from each of the chosen locations, i, where x_i is positive, to demand in all municipalities within its market area. This implies that $z_{ij} = 1$ for those relations, while $z_{ij} = 0$ holds for nodes outside the market area. By (2), we secure that only one factory serves demand in each municipality, while F in (3) constrains the number of facilities to be located in the network.

We may already here note some characteristics of problem DUFLP. The largest number of facilities is $F = n$. In this case, a factory will be located in each municipality, serving demand in this municipality. For each value F, the shadow (scarcity) price given by constraint (3), indicates how much T in objective (1) may be reduced if another factory is located in the network.

The problem DUFLP minimizes the overall transport time, but it is also contains in it the problem where the market area of each facility is maximized, given transport time and demand. This aspect of the problem thus reflects a competition for or a division of demand, i.e. customers, between located factories. The spatial distribution of demand over municipalities will obviously be important for the location of facilities.

A third aspect of DUFLP, is to view it as policy problem for an actor located in one of the nodes. This could be a city or municipality leader that actively want to attract facilities, e.g. in order to increase local employment and its tax base. In DUFLP, a node will be more attractive as a location of a facility, the larger demand it may offer to the facility. Thus, ceteris paribus, we may conclude that within constrains given by DUFLP;

- A municipality will always gain from increased population.

Moreover, if we define a cluster of municipalities as a set of municipalities with relatively low internal transport times. Then we may observe that;

- A cluster with large common demand will have a higher probability to attract a facility to one of the municipalities in the cluster, than a smaller cluster.

- On the other hand, a municipality with low demand in the periphery of a cluster, may although attract a facility, when this implies that the market area of the facility may be enlarged into other clusters, on the expense of alternative facilities, while it not will lose market shares more central to its market area.

Locating two, instead of one facility, into a static autonomous DUFLP, implies a major change in the spatial structure of the optimal location of facilities. Moving from one to two facilities also makes the problem substantially more nonlinear and difficult to solve. Moving from one market area to two market areas is a large distortion to the pattern of location compared with when the number of facilities are increased from two to three and further. This is in accordance with the result Hotelling (1929) obtained in his line market with evenly distributed customers.

Networks are graphs with different configurations and thus properties. We characterise a *general network* as an autonomous network where customers may be distributed unevenly over nodes. Links between the nodes may also have uneven interaction costs, e.g. costs of transportation. There are in such a network moreover no constraints on the number of links connected by a node. This is in contrast with a discrete version of the Hotelling linear market, where a node only is connected with two other nodes by one link each of equal distance and with evenly distributed customers over the nodes. Such a graph of a linear market is a special case of the general network. We make the following observations in relation to the location of facilities in a general network.

- The optimal location of a single facility in a general network will most probably be in the interior of the network.
- When, in a general network, a second facility is introduced, we would expect the optimal single market location in the interior to lose its advantage.
- Instead, an optimum with two locations would be characterised as locations with some distance from each other, in order to minimize total cost of transportation.
- However, the Hotelling solution, with two facilities located in the centre of the network is possible in the case the network is symmetric with demand concentrated into the centre of the network.

In a non-autonomous network, e.g. with ports, for some commodities this may motivate a localisation of a facility adjacent to the harbour. This is also a common situation. In such a case, the cost advantage of a port location easily could be introduced explicitly in the model. In a non-autonomous network, the optimal location of one facility thus may be at the edge of the network.

Beside demand in nodes, the cost of interaction c_{ij} between municipalities, determines the location of facilities. Facilities will in a solution with one company which bears the distribution cost, be located where, ceteris paribus, the cost of interaction to all municipalities is as low as possible. It is here of interest to consider the impact on localisation of a marginal change in the cost of interaction at a random link in a general network. In relation to this, we make the following observation.

- A marginal change in the cost of interaction on a random link will always increase the possibility of a change in the location of at least one facility.

The conclusion is important and in line with other results within location theory. It means that from the point of view of a municipality leader, priority should be to strengthen the municipality. To increase its population and support its property market, its public facilities and its land use planning. After this, it should focus on the links in its network towards other municipalities. The conclusion should although not be interpreted as a suggestion that external links could be neglected, but those should not gain priority on the expense of the attractiveness of the municipality. We conclude that;

- While increased demand always has an attractive force on facilities, the impact of a reduced cost of interaction on a link in a general network is indeterminate.

Before a company makes a decision based on a solution of DUFLP, it should be evaluated against other factors of importance for a localisation. We have here assumed that opening and construction costs for a facility is the same independent on municipality chosen. We have neither taken into consideration the property value of the localities of a facility in case it should be sold, due to a relocation of the facility. The theory of valuation of properties in a market for real estate may thus also be part of the input to a decision.

Taking care of a wider set of aspects may result in a final location of a facility in a municipality nearby the one given by a solution of DUFLP. Moreover, our solution is unconstrained with respect to the size of facilities. The size should depend on the growth and distribution of demand, i.e. the dynamics of markets and costs of interaction. Hence, questions related to the choice of capacity of facilities as well as the order and tempo in the development of the logistic system in between and around the facilities should be concretized before a decision is made.

3. Choice of Solution Algorithm and Description of Data

The facility location problem DUFLP is a combinatorial optimization problem where the number of possible solutions quickly will increase with the size of the network and the set of facilities to locate. The problem may also be given other, and modified, formulations, towards more archetypical gravity formulations, or mixed integer and bi-level programming formulations. In this paper, we have used the minimum impedance formulation provided by the Network Analyst extension in ArcGIS.

As mentioned, an increase in the size of the problem anyhow makes it challenging to solve due to its NP-hard structure, Manzini, Gamberi & Regatierri (2006); Wang, Yao & Huang (2007); Zhou, Peng & Wang (2013). Therefore, exhaustive search techniques are unfeasible in order to reach the optimum solution within a rational search time. Various heuristic algorithms have thus been developed for this class of problems.

The algorithm in the Network Analyst extension of ArcGIS creates an origin-destination matrix of shortest-path cost between a possible facility location and all nodes of demand. A modified version of the matrix is then created by a process called Hillsman editing, Hillsman (1984). Given this, a set of semi-randomized solutions are identified, and a vertex substitution heuristic is used to refine solutions by generating a set of good solutions. A metaheuristic then merges these groups of solutions to create improved solutions. The metaheuristic approach returns the best solution when no further improvement is possible. The combination of these approaches provide an as near-optimal result as possible, given time settings.

When the algorithm have selected the optimal location of facilities, those are used to create zones of common travel time, i.e. common service quality, from each facility to all municipalities within the market area of the facilities. The zones are generated by Dijkstra's algorithm. The algorithm retrieve a subgroup of linked edges given by the time cut off for each distribution time. As part of the result, time zones delimited by isochrones within the market areas thus also are reported. A one-hour service area for distribution from a facility thus includes all customers that may be reached within this hour. Lines are also created that connect the location of a facility, i.e. a distribution centre, with the municipalities whose demand is part of the market area of this facility.

Data are from open data sources. We obtain demand from the spatial distribution of the Swedish population over municipalities. Population figures are collected for the year 2016 from Statistics Sweden. Hence, the set of demand nodes, as well as the set of possible locations, are the 290 municipalities in Sweden. The network between municipalities is based on the distance in travel time by road between community centres of each municipality. Travel times were obtained from OSM, OpenStreetMap. In our last sensitivity analysis, the model is extended to include municipalities and the road network of Finland. Data for those have been obtained from Statistics Finland and OSM as well. In order to integrate the networks of the two countries into a single network, sea routes between the countries are included in the common network of links and nodes.

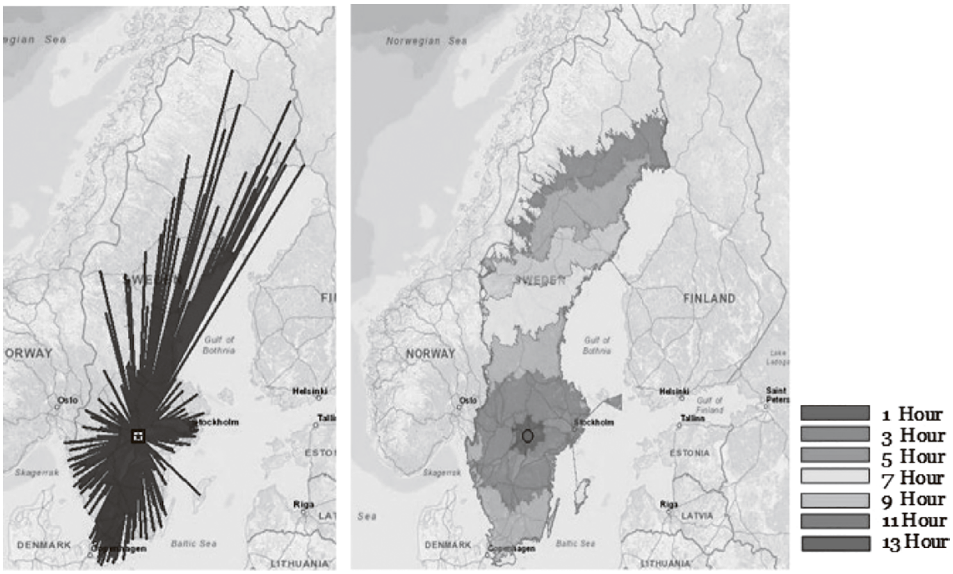
4. Facility Location and Market Areas

In this section, we will present our results as two maps with the location and information on the size of market areas for each facility. In one map, lines connect each factory with the municipalities within its market area. In the other, service time to municipalities within market areas are shown as isochrones. In Figure 1 below, the solution when one facility is located in the Swedish urban system is shown. The municipality chosen as the optimal location is Kumla. Kumla is a small municipality with 21 000 inhabitants in the Örebro-region. By assumption, the facility should cover demand from the total Swedish population, i.e. 9,995 million people.

In line with our general observation previously, the single facility location is interior to the Swedish urban system when we consider Sweden as an autonomous network. Obviously, the service time needed to reach the market in the most distance northern parts of Sweden becomes around twelve hours. This is in principle possible for next day deliveries, but will due to time limits set on individual drivers, be costly. However, the facility in Kumla covers the large urban areas of central and southern Sweden within five hours.

This solution validates the fact that the municipality Örebro, with its surrounding region, since long has been a centre for distribution services in Sweden. Örebro is one of

Figure 1 The optimal location of a single distribution facility in the Swedish urban system. Data from the year 2016.



the larger medium sized municipalities in Sweden with 153 000 inhabitants. As was discussed earlier, the suggested optimal location in Kumla, slightly to the south of Örebro, should be considered as an approximate location. After a more detailed analysis in the vicinity, the most suitable land for the precise location of a facility could be identified.

As expected, when we locate two distribution centres in the network, this changes, as shown in Figure 2, the optimal pattern rather drastically. The Örebro area loses its advantage. This location is not structural stable when we move from one to two facilities. With two facilities, the service time is substantially reduced to the two major urban areas around Mälaren-Stockholm on one hand, and Malmö-Gothenburg on the other. A smaller municipality, Sollentuna slightly to the north west of Stockholm, will be the location that covers the larger lake Mälaren area as well as northern Sweden.

The Sollentuna facility will cover 5.7 million people, or 57 per cent of the Swedish population. The city Halmstad with 100 000 inhabitants in between Malmö and Gothenburg becomes the localisation of the distribution centre for southern Sweden. It thus covers the remaining 43 per cent of the Swedish population.

When we locate three facilities in the urban system, as shown below in Figure 3, the locations in the south remains relatively stable. Instead, the new facility in the north reduces the cost of interaction and service times in this area. Umeå with around 125 000 inhabitants is the municipality chosen in the north. Due to the lack of larger agglomerations in the north, this facility only serves 9 percent of the Swedish market.

Figure 2 Optimal location of two distribution centres in the Swedish urban system. Data from the year 2016.

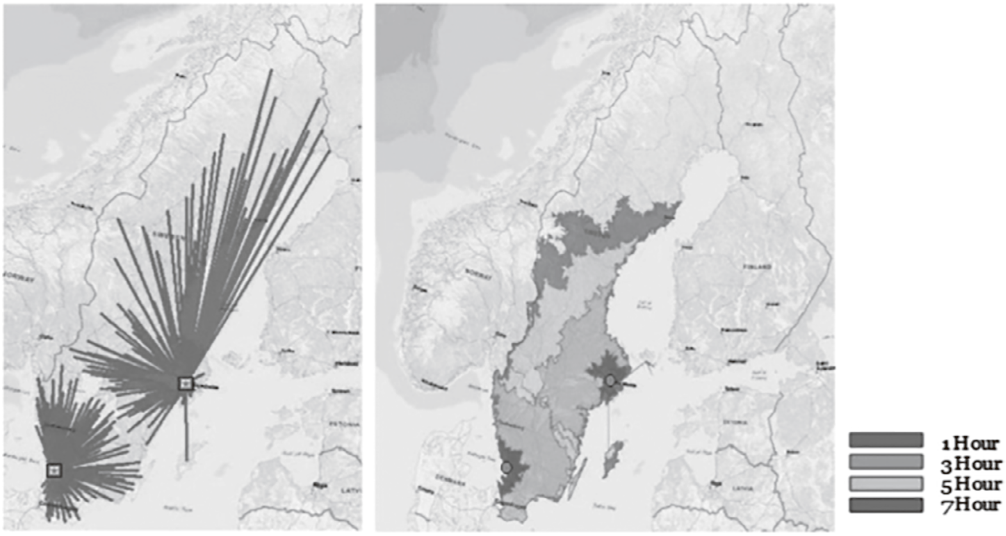
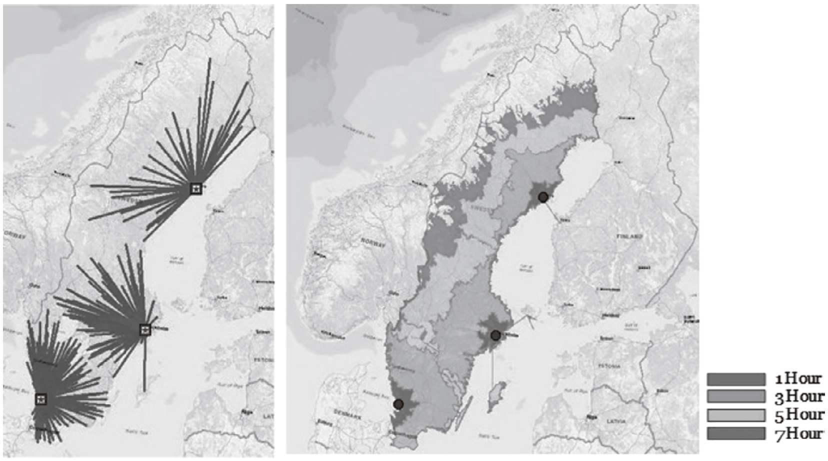


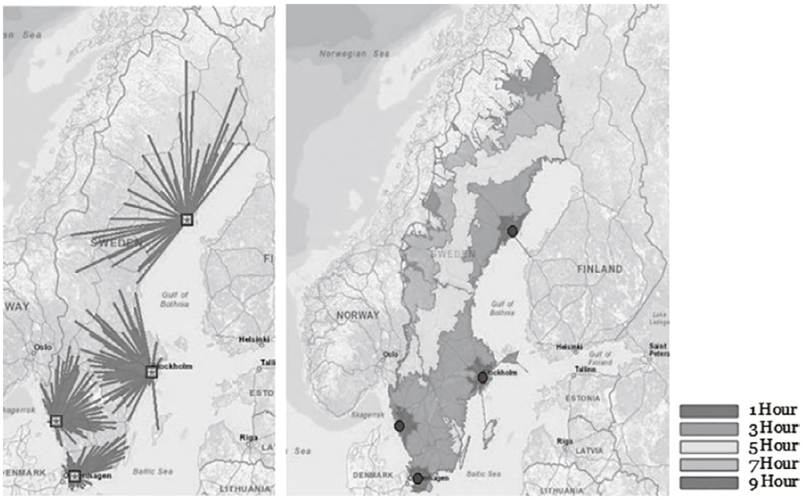
Figure 3 Optimal location of three distribution centres in the Swedish urban system. Data from the year 2016.



This reduce the market share for the facility in the Mälaren area to 48 per cent. Moreover, the optimal location of this facility is moved slightly to the southeast, from Sollentuna, to the Stockholm municipality. In the south, Halmstad remains as the optimal location, with 43 per cent of the market. The new facility in Umeå thus only reduces the market for the Mälaren-Stockholm facility.

When four centres for distribution share the Swedish market, as shown in Figure 4 below, the structure in the south is changed. Halmstad lost its position as an “in between”

Figure 4 Optimal location of four distribution centres in the Swedish urban system. Data from the year 2016.



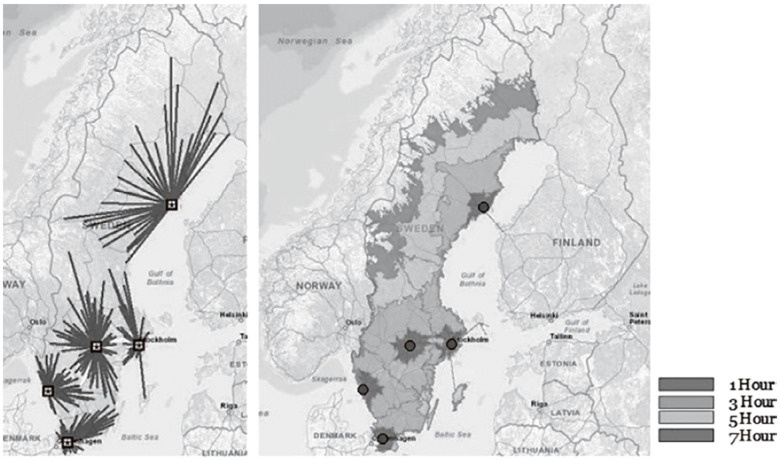
localisation for the two larger agglomerations in the south. Instead, the two larger urban areas Gotenburg and Malmö receive one facility each. Umeå and Stockholm remain, although the market share for the facility in Stockholm now is reduced to 46 per cent of total Swedish demand. In the Malmö area, it actually is the smaller municipality Eslöv, 40 km to the north of Malmö, which becomes the optimal location. Eslöv thus covers 20 per cent of the Swedish market. Since there is no alternative facility south of Malmö, it is competitive to locate a facility north of the city in order to reduce the total overall service time for the company.

The solution with four facilities seems to be basic for a company that want to cover the Swedish market with a relatively high degree of service. The three major agglomerations are covered while the facility in the north reduces service time in this area characterised by its dispersed distribution of population.

Interestingly enough, when five facilities for distribution are located in the Swedish market, Örebro returns as one of the optimal locations. This facility gains a 20 per cent market share, especially from the facilities in Stockholm and Gothenburg, while the facilities in Umeå and Eslöv near Malmö, not are affected so much. The Stockholm facility now has 30 per cent of the market.

When we allow for six facilities, the pattern is quit stable. The new facility is located in Växjö, in between Malmö and Stockholm, at the east side of southern Sweden. However, when seven facilites are located, the pattern in the north goes through a change. Umeå loses its position in favour of Sundsvall to the south and Skellefteå to the north of the city. Hence, although Umeå is the largest municipality in the north, it does not have scale enough, or the strong surrounding urban area, to establish itself as a strucutral dominant

Figure 5 Optimal location of five distribution centres in the Swedish urban system. Data from 2016.



node, such as Malmö, Göteborg and Stockholm.

As a sensitivity analysis, we therefore increase the population in Umeå to around 300 000 inhabitants, more than twice its current size, and well above the current population goal for the city, 200 000 inhabitants. With this population, northern Sweden would have a city comparable with Malmö in size. It would thus establish a forth larger urban northern alternative within the Swedish urban system. Obviously, this makes Umeå a stable location for a facility in the north.

However, instead of illustrating this, we will here broaden our approach to include the Finnish market in our facility location problem. There are reasons for some companies to consider the Swedish and Finninsh markets as a common market for distribution; history, migration, languages, and common border are some of those. By tradition, the city of Umeå moreover has had strong connections with the city of Vaasa in the Western part of Finland. The relatively short distance between the cities over the sea, as crow flies, makes Vaasa the nearest city to Umeå. When Sweden and Finland before 1809 was one country, exchange was realtively intensive, those contacts have remained through a history of major changes, even when Vaasa was part of Russia.

In a illustrative simulation with DUFLP, we have identified the optimal locations in the common Swedish and Finnish markets with five distribution facilites and with a population in Umeå of 300 000 inhabitants. In this case we have, as mentioned previously, introduced landbased border passages and sea routes to establish connections between the Swedish and Finnish road networks. Hence, facilities located in Sweden may include parts of Finland in their market areas, and vice versa for facilities located in Finland.

The result is presented in Figure 6. Three facilities will be located in Sweden and two in Finland. To some extent this represents the relative share of the total population in

Figure 6 Optimal location of five distribution centres in the common Swedish and Finnish urban system if Umeå has 300 000 inhabitants. Data from 2016.

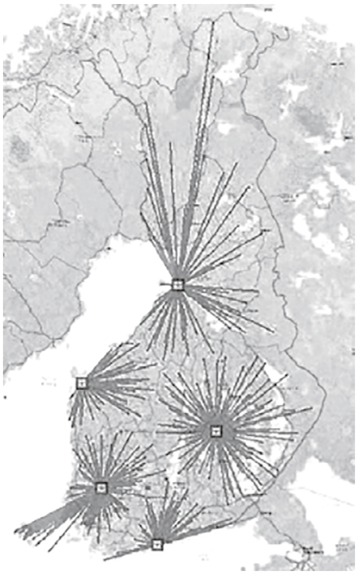
the two countries. In Sweden, the optimal pattern of localisation is not changed, compared with the case presented in Figure 3 with three facilities.

In Finland, with 5.2 million inhabitants, one facility is located north of Helsinki. It deals with distribution to southern Finland, and almost 70 per cent of the population in Finland. In the northern part of the country, the population is relatively disperse with one larger city, Oulu, near the coast. The second facility thus must be to the south of this city, but also more centrally located into the interior of the country, in order to reach municipalities along the Russian border.

The most interesting result is that the market of Umeå, if the city has a size of 300 000 inhabitants and the ferry connection remins or is improved, would be extended into the western part of Finland, to the surroundings of Vaasa. This may be interpreted as the establishment of a common urban area for the Umeå-Vaasa region over the national border. In this respect it may be compared with the ongoing integration in the south of Sweden, between Mamö and Copenhagen in Denmark. Still, the total market for a facility in Umeå would only be around 1.4 million people or 9 per cent of the common Swedish and Finnish market. It is also of interest to note that the facility in Stockholm would be the centre of distribution to the archipelago of Åland, in between Sweden and Finland.

Approximately, the Vaasa urban area has 100 000 inhabitants. If Umeå has 300 000 inhabitants it would thus be the natural location for a common facility. With 100 000 inhabitants and a location at the coast, Vaasa has not enough of attractiviness to be the location for one of five facilities in Finland, as Umeå did in the cases with three to six facilities in Sweden. An obvious question then is what population goal Vaasa should set

Figure 7 Optimal location of three distribution centres in the urban system of Finland if Vaasa has 190 000 inhabitants. Data from the year 2016.



in order to become one of five locations for a facility in Finland? A sensitivity analysis shows that with around 190 000 inhabitants, Vaasa would be one of five facilities in the market of Finland. The pattern of localisation in this case is shown in Figure 7.

Compared with the pattern with two facilites in Finland in the joint market with Sweden in Figure 6, the three new facilites in Finland are located in between the two first. Vaasa now becomes one of them. The southernmost faility is moved slightly to the south, into the largest muncipality of Finland, Helsinki with 645 000 inhabitants. The northernmost facility instead is moved slightly to the nortwest into the largest municipality in the north, the city of Oulu.

A new, what we previously has denoted “in between” facility is located to the southwest in between the larger cities Åbo/Turku and Tammerfors/Tampere. In the east, a municipality in between the three cities Jyväskylä, Kuopio and Mikkeli also becomes the location of the third facility. This indicates that in this middle part of Finland there is not one or two cities that naturally dominate the area to such an extent that they would be natural locations for two facilities. Instead two localisations in the small municipalities in between medium sized cities are suggested as optimal locations.

Finally, and as a reference to a real case of location of facilities by a company, we compare our solutions given by our strongly simplified UDFLP, with the pattern of localisation of warehouses made by IKEA in Sweden. IKEA has established warehouses over around sixty years, with phases of inactivity, and not in one static simultaneous solution as by UDFLP. One may although imagine that once it became clear for the IKEA establishment, that they could expand their business over the country, some sort of localisation analysis and plan for establishment of warehouses was made. IKEA probably has adjusted this “plan” over time, due to changes in the relative distribution of the Swedish population over municipalities, as well as by changes in the possibilities for IKEA to establish an efficient system for logistics. Anyhow, Table 1 shows the sites for the IKEA warehouses and their year of construction. In some of the cities, IKEA has established more than one warehouse. We here only consider the year IKEA makes its debut in a city.

The table clearly identifies the four phases in the development of the IKEA distribution system of warehouses in Sweden. IKEA established its first warehouse in Älmhult, in the south east of Sweden, where the owner Kamprad lived. Hence, the IKEA case already here diverges from our assumptions above, were there was no a priori reason to choose a specific location for a facility. Given the facility in Älmhult, the most important market in Sweden became Stockholm. In 1965, a facility was located into Stockholm. However, its second facility, IKEA actually built in Oslo, in Norway. The Stockholm facility was the third facility, but the start of the expansion into the core markets of Sweden. It is interesting to observe that those locations relatively well follow the pattern in Figure 5 above for five facilities in the Swedish urban system. Stockholm, Malmö, and Gothenburg are recognised. IKEA thus directly established its warehouse in the two larger agglomerations Malmö and Gothenburg, instead of starting with an “in between” solution in Halmstad, as suggested by our model. The explanation may be that for a warehouse, it is even more important to be near customers compared with a distribution facility with wholesale. However, instead of Örebro as suggested by our simulations, a facility instead was located to Köping, a typical “in between” localisation, between Örebro and Västerås, two regional centres. This warehouse although was moved to Västerås in 1984, while Örebro got its own IKEA seven year later, in 1991. IKEA has made other adjustments in the localisation of its warehouses, but those has been smaller movements within the same region as the initial localisations.

In the north of Sweden, Sundsvall was as early as 1966 chosen as the site for a facility. This choice was made instead of Umeå, as our model suggested, for the third warehouse by IKEA. Clearly, this was rational in 1966, but our model solution also illustrates the relative change that has occurred in the urban system in northern Sweden since 1966. At that time, the region around Sundsvall clearly had a substantially larger population compared with the smaller city of Umeå. Stockholm was an obvious location and the capital was an accessible destination for people living in the southern part of North Sweden. From a strategic point of view, it was then preferable for IKEA to locate in the southern part of the remaining North Sweden market area. Customers north of Sundsvall would not have any competing alternatives, than to visit IKEA in Sundsvall, e.g. when travelling to the south on holidays etc.

Table 1 Location and year of construction of IKEA warehouses in Sweden.

YEAR	CITY
1958	**Älmhult**
(1963)	(Oslo)
1965	**Stockholm**
1966	**Sundsvall**
1967	**Malmö**
1972	**Gothenburg**
1973	**Köping/Västerås** (1984)
1977	Linköping
1981	Gävle
1981	Jönköping
1986	Uppsala
1988	Helsingborg
1991	**Örebro**
2006	**Haparanda**
2006	Kalmar
2007	Karlstad
2013	Borlänge
2013	Uddevalla
2016	**Umeå**

Source: Wikipedia.

The localisation of a warehouse 2006 in Haparanda, near Finland in northern Sweden may seem to be an odd border location, given our previous results. However, IKEA has no warehouse in northern Finland. Haparanda thus could, besides covering the far upper north of Sweden also include Northern Finland, the Kola Peninsula and other parts of Northwest Russia into its market area. Given the existence of Sundsvall and Haparanda, the localisation in Umeå became interesting in 2016. The city had passed Sundsvall in number of inhabitants and the financial problem the ferry between Umeå and Vaasa in Finland had had since the late 1990, now were overcome. Umeå could thus as Haparanda, attract customers from Finland. This is in agreement with the results of our simulations reported in Figure 6.

Hence, the basic pattern in the localisation of IKEA warehouses resembles central properties in the pattern identified by our much stylised facility location model. The remaining nine locations in Table 1, not mentioned explicitly in this text, are of the type that they reduce accessibility to regional centres. It reflects an increased competence by IKEA to manage their logistic network, diversify its offer, and increase its reach out to customers via a denser set of warehouses.

A special note may also be made in relation to the year of establishment of IKEA warehouses reported in Table 1. The Swedish economy faces a major crisis in the beginning of 1990, with a considerable disturbance in the real estate markets. The Örebro facility thus mark the end of a long period of inaugurations. After a recovery the years before 2000, a new crisis hit Sweden, mainly related to the IT sector. After this, the economy and the property markets recover again. Hence, after 15 years of passivity, IKEA once again established new facilities in 2006–2007. However, a third but short period of turbulence related to the American property market, with Lehman Brothers as its symbol, happens in 2007. IKEA reacts directly to this uncertainty. It is not until the Swedish economy seems more stable again, that IKEA opens a new warehouse in 2013.

5. Summary

In the paper, we have specified a discrete uncapacitated facility location problem for our analysis of the optimal localisation of a set of distribution centres by a single company in an autonomous network. We applied this on the Swedish urban system and generated patterns of optimal localisation for up to seven facilities. We also applied our model to the case when the company considers localisation of facilities in an integrated Swedish-Finnish market.

By our simplified formulation of the localisation problem, we could focus and purify the problem. The cost of transportation at links and the structure of demand over nodes in the urban system were the only factors that determine the pattern in our solutions. This also gave us a possibility to make some general observations on the facility location problem, when municipality leaders want to attract facilities to their own municipality. A motive for this could be to attract direct employment and tax incomes from the facility as such, but also to attract indirect employment generated by the adjacency to a distribution centre.

With respect to this, we observe that the size of the municipality generally will increase the probability to attract a facility to the municipality. We also observe the major structural change in the pattern of localisation from a move from one to two facilities. While one facility generally will be located in the interior of the network, the most probable localisation of two facilities instead are on either side of, and with some distance from, the single facility location, but not in that same location.

Our simulations shows that in the case of the Swedish urban system, a rather stable pattern evolves when four and six facilities are located. With less and with more facilities some more apparent changes occur. Hence, the localisation pattern in Sweden is not structural stable with regard to the number of facilities introduced.

When we make sensitivity analysis with respect to the number of inhabitants in the municipalities Umeå in Sweden and Vaasa in Finland, we observe that if Umeå ceteris paribus would have 300 000 inhabitants it would fulfil the role as a stable centre in northern Sweden. A centre that with a transport capacity gained from an improved ferry connection to Vaasa in Finland, also would serve as a market area around the Vaasa region. Moreover, we also note that if the population of Vaasa municipality was increased to 190 000 inhabitants, Vaasa would be one of five locations for a distribution facility in Finland. This would also decrease the penetration by Umeå in the Vaasa region. Nevertheless, it would also have a possibility to create a stronger common market for the two cities.

In a final comparison of our simulations with the localisation of IKEA facilities in Sweden, we conclude that except for locations determined by personal preferences such as the birthplace of the founder, our model captures many aspects of such a real case localisation pattern. Obviously, number of inhabitants in municipalities strongly explain the localisation of IKEA warehouses. When the growth of population over municipalities is uneven, the set of optimal locations for a given set of facilities thus may change over time. Our model had a tendency to select “in between” localisations, i.e. small municipalities in between larger municipalities, when the larger cities were balancing each other. We found that IKEA early made such a localisation in Köping, but also that IKEA later replaced this by new facilities in the larger municipalities. Hence, one could for retail commodities, introduce some penalty in our model against a selection of too small local markets. However, for wholesale-related commodities, a location a little peripheral from the higher land rents in more congested areas, may instead be advantageous.

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