DALARNA UNIVERSITY

**Working papers in transport, tourism, information technology and microdata analysis**

# Optimal retail location and CO2 emissions

**Författare 1: Kenneth Carling**
**Författare 2: Johan Håkansson**
**Författare 3: Niklas Rudholm**
**Editor: Hasan Fleyeh**

**Nr: 2012:05**

Working papers in transport, tourism, information technology and microdata analysis
ISSN: 1650-5581

# Optimal retail location and CO2 emissions

**Kenneth Carling**[♦], **Johan Håkansson**[♦,♣], **Niklas Rudholm**[♦]

**Abstract:** In this paper, the *p*-median model is used to find the location of retail stores that minimizes CO2 emissions from consumer travel. The optimal location is then compared with the existing retail location, and the excess CO2 emissions compared with the optimal solution is calculated. The results show that by using the environmentally optimal location, CO2 emissions from consumer travel could be reduced by approximately 25 percent.

**Keywords:** Firm location, spatial distribution of firms, *p*-median model, emission reduction.

**JEL codes:** D22, L13, L81, R12

♦ Kenneth Carling is a professor in Statistics, Johan Håkansson is a professor in Human Geography,and Niklas Rudholm is professor in Economics at the School of Technology and Business Studies, Dalarna university, SE-791 88 Falun, Sweden, and at HUI Research, Stockholm, Sweden.

♣ Corresponding author. E-mail: jhk@du.se. Phone: +46-23-778573.

# *1.* Introduction

The location choice of retail firms has been previously studied in Sweden (e.g. Daunfeldt et al., 2006; Daunfeldt et al., 2010; Daunfeldt et. al., 2012; Håkansson et al., 2012) and internationally (Benoit and Clarke, 1997; Cheng et al., 2007; Yu et al., 2007). The Swedish studies are based on the assumption that firms are maximizing profits, and that entry at a specific location occur as long as the properly discounted flow of future profits and losses is positive, while the international studies often uses Geographic Information Systems (GIS) assuming that retailers instead want to chose optimal locations with respect to travel time and accessibility for the consumer.

However, none of these studies addresses the question of how the location of retail stores affects the environment through CO2 emissions due to consumer travel to the stores. A first attempt at this is done in Määttä-Juntunen et al. (2011), who use GIS to investigate where retail units should be located in the Oulu region in Finland in order to minimize CO2 emissions. Their results show that the optimal location is near the city centre, while urban edge stores located about 10 kilometers from the city centre of Oulu have about 15 percent higher CO2 emissions.

Our study takes a somewhat different approach. Using detailed data over the residence of the population in the region, the location of all retailers in three distinct retail industries in the region, and the road network in the Dalecarlia region, a *p*-median model is set up to find the location that minimizes the CO2 emissions from consumer travel to the retail store. The total emissions from this optimal situation are then compared with the ones resulting from the actual location of the retail stores in the three different retail industries. The results show that using the optimal locations would reduce CO2 emissions with approximately 25 percent.

# 2. Empirical analysis

Our empirical strategy exploits the fact that we can derive the environmentally optimal retail locations and compare them with the actual ones. The thought experiment is as follows. Suppose there are two identical retail stores, one in the location that minimizes CO2 emissions from consumer travel and one located elsewhere. The experiment uses the optimal location as the benchmark, and then calculates the additional CO2 emissions caused by the actual store as compared to the hypothetical one located at the optimal point. The influence of the consumers’ travel pattern, on the CO2 emissions, is kept constant in the experiment by imposing that they consistently opt for the shortest route to the nearest retail store.

To implement this study design, we use the *p*-median model (e.g. Hakimi, 1964; Handler and Mirchandani, 1979 and Mirchandani 1990). Consider the problem of allocating *P* retail stores to a population geographically distributed in *Q* individual’s residences such that the population’s total CO2 emissions[1] of travelling to its nearest retail store is minimized.

The first thing we need to know to implement the *p*-median model and derive the optimal location of the retailers is the population of the Dalecarlia region and its geographical distribution. The population data comes from Statistics Sweden from the 2002 census (www.scb.se). The consumers’ residency is positioned with an error of at the most 175 meters.

As of December 2010, the Dalecarlia population numbers 277,000 residents. About 65% of the population lives in towns and villages with between 1,000 and 40,000 residents. Figure 1 shows the distribution of the residents in the region. It indicates that the population is non-symmetrically distributed. The majority of residents live in the southeast corner, while the remaining residents are primarily located along the two rivers and around Lake Siljan in the middle of the region. Overall, the region is not only non-symmetrical, but it is also sparsely populated with an average of nine residents per square kilometer (the average for Sweden overall is 21).

The second thing we need to know is the road network in the Dalecarlia region. The Swedish road system is divided into national roads, local streets and private roads. The local streets are managed by the municipalities. The national roads are public, funded by a state tax, and administered by a government agency called the Swedish Transport Administration. The data for the road network comes from Sweden’s Mapping, Cadastral and Land Registration Authority (www.lantmateriet.se). The road network data describes the situation as of 2001.

The national road system in the region totals 5,437 kilometers; and the computer model there off divided them into

[1] The road distance serves as a proxy for the CO2 emissions. Määttä-Juntunen et al (2011) elaborate on more refined proxies for the CO2 emissions derived from the road distance. Primarily, these are based on highway and urban roads with two different average speeds. Since this study is conducted in a rural area with a national road network, there is little variation in road types and thus average speed. Hence, we have not attempted to refine the measure of CO2 emissions further.

1,977 digitally stored road segments. The road segments vary in length and range from a few meters (typically at intersections) to 52 kilometers, although the typical road segment is a couple of kilometers.[2]

There are many possible routes to travel between any two points. However, we impose that consumers opt for the shortest route to their retailer and that the retailers are located at nodes in the road network. Following Carling et al (2012) we created a distance matrix to represent the shortest network distance between all node-pairs. The creation of the distance-matrix was conducted according to the Dijkstra algorithm (Dijkstra, 1959) and implemented in the program-package *R* (see www.r-project.org).

Finally, we need to decide which retail industries to study. In this paper we have chosen to study the location and CO2 emissions of consumers visiting 1) consumer electronic stores, 2) locksmiths, and 3) pet shops in the Dalecarlia region. These industries are chosen since the goods and services sold are fairly homogenous, and price and other potential differences between the retailers should be inconsequential. These features make it more likely that the consumers chose the nearest retailer.

Using the data described above, the $p$-median objective function is $\sum_{q\in N} w_q \min_{p\in P}\{d_{qp}\}$, where $N$ is the number of nodes, $q$ and $p$ indexes the individual residence and the retail store respectively, $w_q$ the number of consumers at node $q$, and $d_{qp}$ the shortest distance between the nodes $q$ and $p$. A thorough description of the optimization technique used to derive the retail store location that minimizes the CO2 emissions of consumer travel to the retail stores can be found in Carling et al. (2012). The geographical distribution of the population in the Dalecarlia region, the road network, and the optimal and actual locations of the retail stores are presented in Figure 1 a-d.

[2] Han et al. (2012) have compared the network used here with a very refined network of the region consisting of some 1,500,000 nodes. The refined network gives the same location when the number of facilities to locate is modest as in this study.

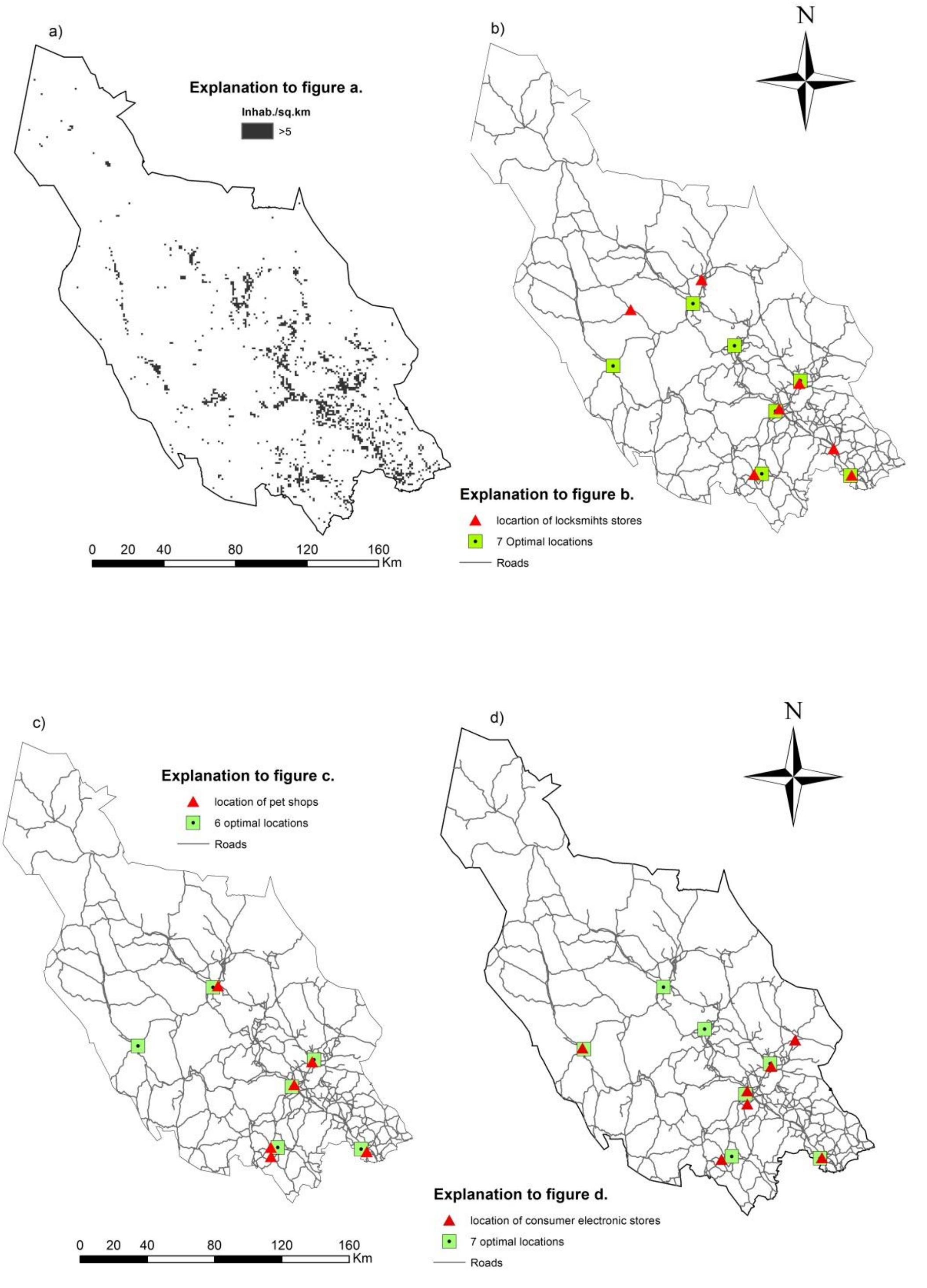


**Figure 1:** Distribution of the population in Dalecarlia (a). Current and *p*-median optimal location of retail stores and the road network in the region (b-d).

Table 1 gives the consumers' average distance to the nearest retailer as of today as well as for optimally located stores. Currently there are six pet shops, seven locksmiths and seven consumer electronic stores to which consumers on average have some 25 km. A *p*-median optimal location would reduce the average road distance by some 5 km to the retailers.

Table 1: The consumers' shortest road distance to the nearest retailer. Standard deviation in parenthesis

| | Average distance to nearest retailer (km) | | Decrease in |
|---|---|---|---|
| Retailer | Current location | Optimal location | average distance |
| Locksmiths | 20.5 (22.1) | 17.2 (19.2) | 16 % |
| Pet shops | 22.6 (25.3) | 19.5 (20.5) | 14 % |
| Consumer electronics | 26.5 (29.2) | 17.2 (19.2) | 35 % |

Turning to our main question of interest in this paper, there is a potential for decreasing CO2 emissions with, on average, 25 per cent in the studied retail industries. The potential for reduction is largest for consumer electronics (35 per cent) and smallest for pet shops (14 per cent).

# 3. Discussion

The results from this study shows that CO2 emissions from consumer travel to consumer electronics stores, locksmiths, and pet shops in the Dalecarlia region could be reduced by some 25 percent if the actual stores would have been located at their, from a CO2 emissions standpoint, optimal location. The discrepancy is largest for the consumer electronics industry with a potential decrease in emissions of 35 per cent.

This potential for reducing CO2 emissions can be compared to another emission mitigation strategy such as Eco-driving. The strategy has been adopted by many countries and its main aim is to achieve some 10 per cent reduction in fuel consumption via educating drivers in efficient driving techniques. In a report (Vägverket, 2009) by the Swedish National Road Administration, giving an international perspective on Eco-driving, it is reported that about one per cent of the Swedish drivers in a 10-year period had been trained in eco-driving. Moreover, the Netherlands with the world's most ambitious eco-driving strategy, at the cost of 30 million euro, now have about 20 per cent drivers that have adopted eco-driving. The Dutch strategy has achieved a 2 per cent CO2 emissions reduction on consumers' retail trips, assuming that consumers in the Netherlands were equally affected by the strategy as the population over all.

It should, however, be noted that retail relocation as a method of reducing CO2 emissions would probably come at a prohibitive cost, but $CO_2$ emission optimal location choices could perhaps be used by environmentally friendly retailers when entering new markets.


## Acknowledgements

Financial support from the Swedish Retail and Wholesale Development Council is gratefully acknowledged.


## References


Benoit, D. and G.P. Clarke 1997. Assessing GIS for retail location planning. *Journal of Retailing and Consumer Services* 4, 239–258.

Carling, K., Han, M., and J. Håkansson 2012. Does Euclidian distance work well when the *p*-median model is applied in rural areas?, *Annals of Operations Research*, Online First September 2012.

Cheng, E.W.L., Li, H., and L. Yu 2007. A GIS approach to shopping mall location selection, *Building and Environment* 42, 884–892.

Daunfeldt, S-O., Rudholm, N., and F. Bergström 2006. Entry into Swedish retail- and wholesale trade markets, *Review of Industrial Organization* 29, 213–225.

Daunfeldt, S-O., Orth, M., and N. Rudholm 2010. Opening local retail food stores: A real-options approach, *Journal of Industry, Competition and Trade* 10, 373–387.

Daunfeldt, S-O., Elert, N., and N. Rudholm 2012. New Start-ups and Firm In-migration - Evidence from the Swedish Wholesale Trade Industry, *The Annals of Regional Science*, Online First October 2012.

Dijkstra, E. W. 1959. A note on two problems in connexion with graphs, *Numerische Mathematik* 1, 269-271.

Håkansson, J., Machucova, Z., and N. Rudholm 2012. Visualizing potential entry areas for Swedish wholesale firms, HUI Working Paper No (in press).

Hakimi, S.L. 1964. Optimum locations of switching centers and the absolute centers and medians of a graph, *Operations Research* 12, 450-459.

Han, M., Håkansson, J., and P. Rebreyend (2012). How does the use of different road networks effect the optimal location of facilities in rural areas?, Working papers in transport, tourism, information technology and microdata analysis, ISSN 1650-5581

Handler, G.Y, and P.B. Mirchandani 1979. Location on networks: Theorem and algorithms, MIT Press, Cambridge, MA.

Määttä-Juntunen, H., Antikainen, H., Kotavaara, O., and J. Rusanen 2011. Using GIS tools to estimate CO2 emissions related to the accessibility of large retail stores in the Oulu region, Finland, *Journal of Transport Geography* 19, 346-354.

Mirchandani, P.B. 1990. The *p*-median problem and generalizations, Discrete location theory, John Wiley & Sons, Inc., New York, pp 55-117.

Vägverket 2009. Sparsam körning i världen: En internationell utblick (Eco-driving – the international perspective), Rapport Vägverket 2009:133, Sweden.

Yu, B., Yang, Z, and C. Cheng 2007. Optimizing the distribution of shopping centers with parallel genetic algorithm, *Engineering Applications of Artificial Intelligence* 20, 215–223.