

Adolphson, Marcus; Snickars, Folke

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## On Analysing Changes in Urban Form - Some Theoretical and Methodological Issues

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## ON ANALYSING CHANGES IN URBAN FORM – SOME THEORETICAL AND METHODOLOGICAL ISSUES

Marcus Adolphson and Folke Snickars

Department of Infrastructure

Royal Institute of Technology

S-10044 Stockholm

Email: Marcusa@infra.kth.se

### Abstract

Urban form is a result of social processes in an ecological context. The political systems put attention to the interaction between urban forms and social and ecological systems. This attention is expressed on different political levels where compactness, integration and accessibility are emphasised. The aim in this investigation is to assess if the development of urban form since 1992 to 2000 correspond to the political guidelines regarding the concept of “compact city”, mixed urban functions (“integrated city”) and proximity to transport nodes in the municipality of Strängnäs, west of Stockholm, Sweden. This investigation use non-aggregated geographical data on micro level with a high spatial resolution in an area effected by high speed commuting train. The evaluation of the urban form is here accomplished by development of a Compact city index – floor space per hectare, a Integrated city index – normalized ration of the distances to residential and commercial settlements, a Transport city index –proximity to national transport nodes from residential and commercial settlements and a regression analysis of spatial location factors.

The urban form develops in the direction of a decreased degree of compactness, decreased degree of functional integration and an increased degree of dispersed settlement regarding proximity to national transport nodes. The attractiveness regarding new residential settlements depends to a great extent on the proximity to already existing residential settlements, to some extent to proximity to water areas and to some extent on remoteness of national road nodes. The location factors taken in to account do not yet predict the probabilities in a sufficient degree. Thus, the urban development seems to be governed by other forces than the expressed political.

Further research could cover a number of areas of interest. It would be interesting to use this material to explore more exhaustive how to depict urban form and the spatial causalities effecting the urban development.

## INTRODUCTION

### PROBLEM TO BE STUDIED

The topic of the paper is the development of an empirical analysis some dynamic aspects of urban form, compact city, integrated city, transport city and probabilities regarding location of settlements. The topic is studied using data for three years during the period 1992- 2000 in the Swedish municipality of Strängnäs, 80 km west of Stockholm. The main questions to be answered in the analysis are: Does the development of urban form correspond to the guidelines of the political systems? Have changes in transport infrastructure systems in 1997 in the region affected the development of urban form? Urban form is here interpreted as the location of firms and residential areas in relation to fixed transport networks and other urban infrastructure amenities. The main attributes used to depict changes in urban form are building use, floor space composition, location attributes, and the year of construction.

### BACKGROUND

This paper is an initial part in a research project aiming to investigate the development of urban form and spatial location factors for residential areas. The idea is to increase the understanding of the actual location factors behind residential location, not only the ones stated in planning documents and given the foremost attention in aggregate analyses. The main thrust of the analysis of the paper is the very detailed map of land use, which forms the basis of the analysis. We aim to contribute to the research on urban land use in the context of the classical questions of the trade off between local density and overall accessibility, and the trade of between the optimum and the equilibrium city.

One can interpret urban form as an expression of forces of human nature, in which cities and citizens affect one another in a cyclic relationship. Urban form is a result of individual actions, which affects, and is affected by social, ecological and political circumstances. Different urban forms could be described in terms as the single nuclear city, the multi nuclear city, the edge city, the corridor city and the dispersed city. These forms have increasing negative impacts on the environment in the following order, the compact single nuclear city, the multi nuclear city, the edge city, and the corridor city. Last and foremost, the dispersed city has the most negative environmental impact with spatially separated functions.<sup>1</sup>

The political systems on different levels put attention to the urban form and its relationship to the ecological and social (including the economic) systems. This attention is expressed on the European level, for instance, in the ongoing work on the European spatial development perspective (ESDP) where control of the physical expansion of towns and cities, and mixture of functions and social groups are emphasized.<sup>2</sup> Spatial structures according to the compact city<sup>3</sup> and the polycentric urban system<sup>4</sup> are recommended. Similar political intentions could be found on the

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<sup>1</sup> Newton (1997, p9, p161).

<sup>2</sup> The European Commission (1999, p22)

<sup>3</sup> The European Commission (1999, p22)

<sup>4</sup> The European Commission (1999, p19)

national Swedish level in the Building and Planning Act,<sup>5</sup> the Environmental Protection Act,<sup>6</sup> in guidelines from the Swedish National Board of Housing, Building and Planning<sup>7</sup> and in other national governmental documents<sup>8</sup>. On the local level the political guidelines regarding land use, urban form and spatial development are expressed in the municipal comprehensive plans. For the municipality of Strängnäs such plans exist for 1984, 1992 and 2000.

## **THEORY**

Anderson et al (1996) depict urban features in the terms of urban form, urban interaction and urban spatial structure. The urban form refers to the relative location of residences, work places, shopping malls, and recreation areas. It is also interpreted in terms of their densities, and the location of transport infrastructure.<sup>9</sup> The urban interaction, in turn, refers to the flow of goods, people and information. Finally, the urban spatial structure refers to a set of organising principles that define the relationship between the urban form and the urban interaction.<sup>10</sup>

The above-sketched development of the urban form could, according to Anderson et al (1996), be described in three simple archetypal forms: the concentric city, the radial city and the multinuclear city, see also Figure 1. The characteristics of the concentric city are a central business district (CBD) that is constituted by maximum employment density, maximum rents and maximum trip ends as well as segregated land use located in concentric zones around the CBD. In the radial city intense land uses are extended out from the CBD along major transportation routes. The multinucleated city is constituted by a number of focal points with local maxima according to population and employment density, rents and trip ends.<sup>11</sup> Even if journey to work trips express a declining share of the total trips accomplished is the integrated land use of residents and work places emphasized as energy efficient<sup>12</sup> if the individuals take the opportunity regarding residential and mode choice together.<sup>13</sup>

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<sup>5</sup> The Swedish Parliament. (1987, p10)

<sup>6</sup> The Swedish Parliament (1998, p808)

<sup>7</sup> The Swedish National Board of Housing, Building and Planning (1999, p39)

<sup>8</sup> The Swedish Parliament (2000, p555, p586)

<sup>9</sup> Andersson, Kanaroglou and Miller (1996, p9)

<sup>10</sup> Bourne (1982)

<sup>11</sup> Anderson, Kanaroglou and Miller (1996, p9)

<sup>12</sup> Anderson et.al. (1996, p19, p23)

<sup>13</sup> Anderson et al. (1996, p14)

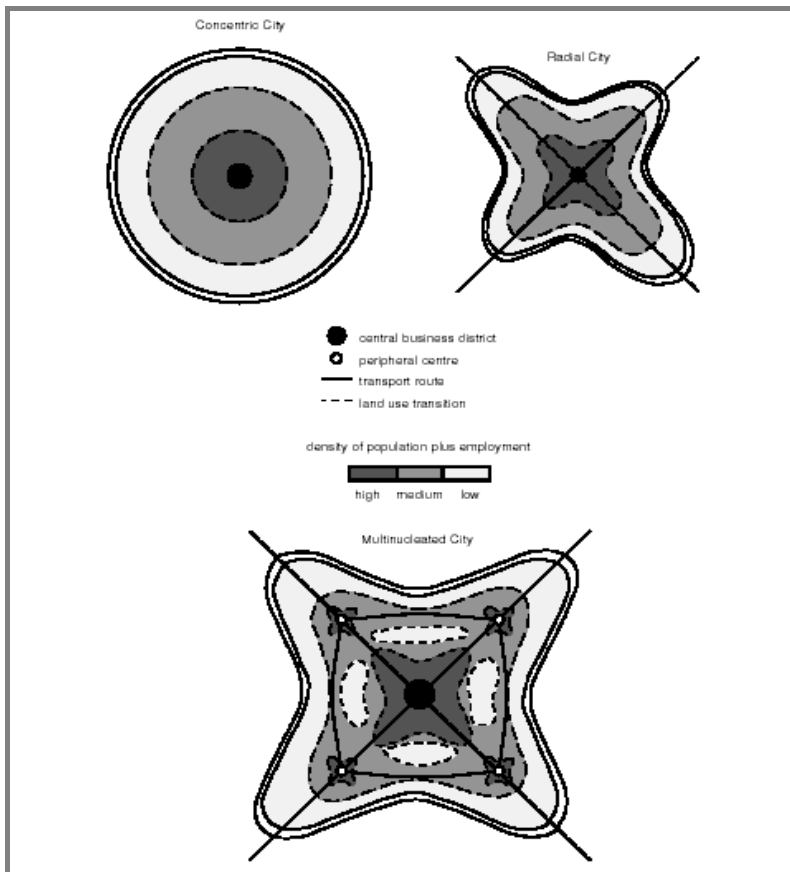


Figure 1: Some archetypal urban forms.<sup>14</sup>

The planning situation today is by Hall (1992) described as a complexity of planning in a mixed economy, where the private interests initiates a considerably degree of the development and where the public interest in a democracy is a composition of individuals and groups with opposite opinions about an appropriate development.<sup>15</sup>

Different theories regarding the development of urban form and urban functions have been elaborated in economic- geographic groups.<sup>16</sup> Alfred Weber (1909) describes in the cost-minimizing theory, how the industry searches location where the costs regarding employment, transports and so called agglomerations costs are minimized. Lösch (1940) develops a location model where income, instead of the cost, is maximized. In this point of view the productions are concentrated to a location with connection to a maximized market and thereby a maximized income. However, changes in infrastructure results in a differentiation in the spatial productive landscape and hence affects the economic prerequisites for labour and firms in the region concerned.<sup>17</sup>

Infrastructure investment could have impacts on regional development in different aspects: ecological, economical and social,<sup>18</sup> but also influence the actual residential and commercial spatial structures.<sup>19</sup> Infrastructure investments do in direct user benefits

<sup>14</sup> Anderson W et al. (1996, p11)

<sup>15</sup> Hall (1992, p61)

<sup>16</sup> Westlund (1998:pp21-30)

<sup>17</sup> Rietveld and Bruinsma (1998, p302)

<sup>18</sup> OECD (2002, pp9-10)

<sup>19</sup> Rietveld and Wagtendonk (2000, p1)

effect travel time, vehicle operating costs and safety<sup>20</sup> wider effects could be described in terms of accessibility, employment, private capital and labour productivity, social structure and environment.<sup>21</sup> In present time with the formation of the common market in the European union, together with other changes according to international obstacles for business, labour and goods, the development of urban infrastructure is one of the last opportunities for national governments to advance their cities in the international competition.<sup>22</sup>

In “Integrated land use and transport modelling: Decision chains and hierarchies” de la Barra (1989) gives account for quantitative approaches to describe the development of land use. The spatial locations of activities were in the most basic models, according to Barra, based on micro economic theory. A central element in the analysis is the individual rational action and the main central variables taken into account are the costs regarding the production of goods, land rents and transports.<sup>23</sup> This theory could be used regarding firms - exchange values, as well as residents – use values. Location models were, among others, developed by Thünen (1826), Wingo (1961) and Alonso (1960).

Spatial interaction models operate, according to Barra,<sup>24</sup> in spatial zones where activities are aggregated into categories as for instance in the members’ socio-economic characteristics. These theories are based on gravity models where the locations of residential areas are a function of proximity to workplaces.<sup>25</sup> The central elements in the interactions models are the activities within the zones and the abstract flow of activities generated in one zone and located in an other zone.<sup>26</sup> The magnitude of the flow depends on the activities in the zones and the infrastructure friction (distance, costs, time).<sup>27</sup> Echenique (1968)<sup>28</sup> introduced location of floor space instead of location of activities in the interaction model.

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<sup>20</sup> OECD (2002, p8)

<sup>21</sup> OECD (2002, pp9-10)

<sup>22</sup> Rietveld and Bruinsma (1998, p115)

<sup>23</sup> de la Barra (1989, p48)

<sup>24</sup> de la Barra (1989, p48)

<sup>25</sup> Hansen (1959), de la Barra (1989, p49)

<sup>26</sup> de la Barra (1989, p50)

<sup>27</sup> de la Barra (1989, p49)

<sup>28</sup> de la Barra (1989, p58)

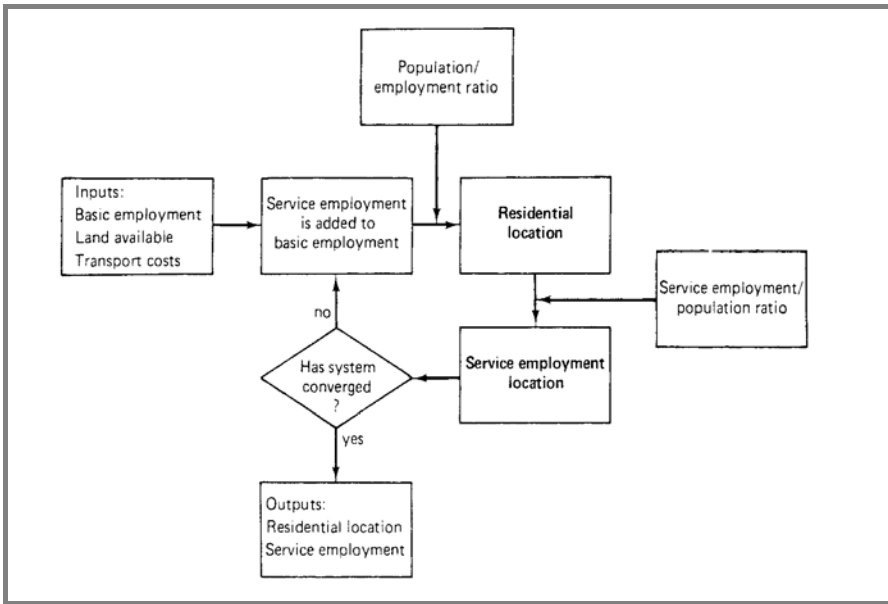


Figure 2: Lowry's (1964) interaction model.<sup>29</sup>

An increase in infrastructure leads to a shift in productivity for the region concerned.<sup>30</sup> This relationship could also be described in a conceptual model that illustrates the influence of transport infrastructure on economic activities.

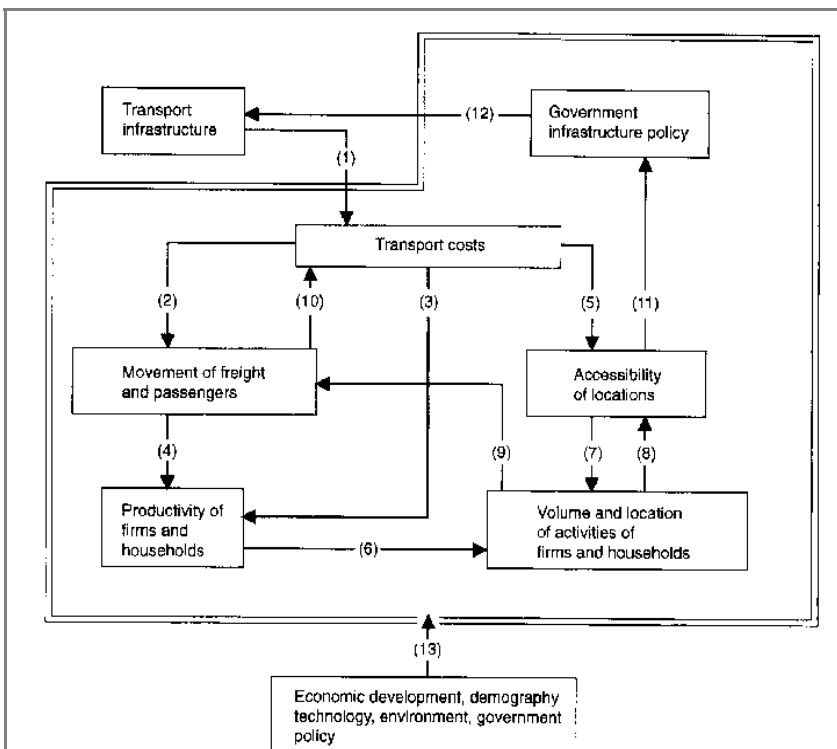


Figure 3: Conceptual model on the relation between transport infrastructure and the spatial pattern of economic activities.<sup>31</sup>

Relation 1 in the figure above describes the construction of transport infrastructure costs

<sup>29</sup> Lowry (1964), de la Barra (1989, p57)

<sup>30</sup> Rietveld et al. (1998, p37)

<sup>31</sup> Bruinsma, Rienstra and Rietveld (1996, p393)

by means of reduction of distance and/or a higher average speed. Relation 5 describes the increase in accessibility. Relations 7 (and 6) describes that the increase in accessibility in a certain zone may result in an expansion of the population (and economic activity) within the zone. Relation 11 and 12 describes the interaction between the intra political system and urban form. Relation 13, at last, describes the influences from the extra societal systems on traffic flows and spatial patterns of economic activities.<sup>32</sup> These spatial relations are also illustrated by Wegener M. (1996) in “The land use transport feedback cycle”.<sup>33</sup>

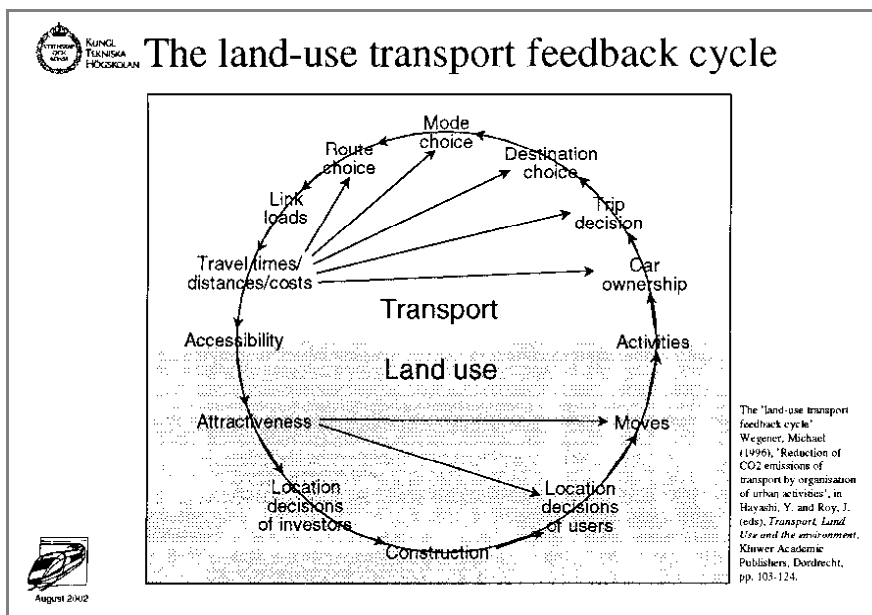


Figure 4: The relation between accessibility and attractiveness.<sup>34</sup>

## RESULTS FROM EARLIER RESEARCH

The relation concerning urban form and the societal systems have been investigated by Anderson et al (1996), Srinivasan (2002), Think, Arlt, Heber, Hennersdorf and Lehmann (2002), Rietveld et al (2000) among others.

In their paper on urban form, energy and the environment including a review of issues, evidence and policy, Anderson et al (1996) evaluate the state of knowledge according to the area given by the title. The urban form is here described in terms of spatial pattern of land uses and their densities, population density and the integration of residents, work places, recreation areas and shopping.<sup>35</sup> It is emphasized that adjustment of urban form gives the opportunity for individuals to change residential and mode choices, but the reduction in energy consumption is dependent on the individual behaviour.<sup>36</sup> One result of the investigation is thus that “trends in urban form cannot be addressed in isolation from other social and economic trends”.<sup>37</sup>

Think (2002) describes the relation between compactness and ecological and

<sup>32</sup> Bruinsma et al. (1996, p392)

<sup>33</sup> Wegener (1996)

<sup>34</sup> Wegener (1996)

<sup>35</sup> Anderson et al. (1996, p9)

<sup>36</sup> Anderson et al. (1996, p14).

<sup>37</sup> Anderson et al. (1996, p25)



economical potential. The physical compactness is here defined as the attraction between areas depending on the degree of sealed land and the distance.<sup>38</sup> By cluster analysis of 116 German cities with the variables: degree of sealing and land price was the sustainable balance between ecological and economical potential assessed.

Srinivasan (2002), in turn, investigates the linkage between land use and transports in Boston, USA and describes the spatial characteristics in terms of entropy, homogeneity and contrast. To measure land use diversity and balance, statistical Haralick measures were used. Entropy (E) indicates the “edginess” of the texture and expresses the mixture of land use in an area. Homogeneity (H) indicates the domination of one form of land use. The contrast (C) is defined as the degree of coarseness in the texture.<sup>39</sup> All measures are dependent on the classification of land use in terms of residential, commercial, industrial, recreational and open space. Two measures regarding accessibility are used.<sup>40</sup> A “Hansen type” is used for accessibility of recreation and shopping. This measurement is dependent of the number of relevant opportunities in an area and travel time. For accessibility of work places are the number of workers, the employment opportunities, transport mode and a travel impedance function taken into account. The neighbourhood characteristics are combined with a survey regarding residents’ activities. Srinivasan concludes that spatial characteristics is significant in predicting mode choice”.<sup>41</sup>

Rietveld and Wagtendonk (2000)<sup>42</sup> investigated the main factors for residential locations in the Netherlands during the period 1980 – 1995. The aim was to examine the weight of political forces regarding “compact city”, zoning, new towns versus market forces. By using logistic regression analysis were the dependent variable was the number of new dwellings in a pixel of 500\*500 meters and independent variables was a number of spatial features as: proximity to existing residential areas, proximity to employment, distance to transport nodes and so forth. The investigation states that important location factors for new residential areas during the period are proximity to already existing residential areas and infrastructure access points – with an emphasis of rail way stations. The importance of proximity to nature conservation areas is small. A conclusion is that physical planning might have influenced housing developments.

## **MATERIAL AND METHODS**

The aim, as mention above, is to assess if the development of urban form since 1992 to 2000 correspond to the political guidelines regarding the concept of “compact city”, mixed urban functions (“integrated city”) and proximity to transport nodes in improved transport systems in 1996. This implies a comprehensive spatial investigation of changes in urban form during the period. The focus is thus to describe the general change in urban form and not to investigate the individual built up units.

The process could be described in a dynamic model on macro level. The change in urban form ( $\Delta$  Urban form<sub>t1-t2</sub>) is a spatial result according to existing spatial urban forms (Urban form<sub>t1</sub>) and existing social processes in an ecological context. The urban

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<sup>38</sup> Thinn et al. (2002, p480)

<sup>39</sup> Srinivasan (2002, p2010)

<sup>40</sup> Srinivasan (2002, p2014)

<sup>41</sup> Srinivasan (2002, p2026)

<sup>42</sup> Rietveld and Wagtendonk (2000)

forms investigated are in 1992,  $\Delta$  1993 – 1996, -1996,  $\Delta$  1997 – 2000 and 2000.

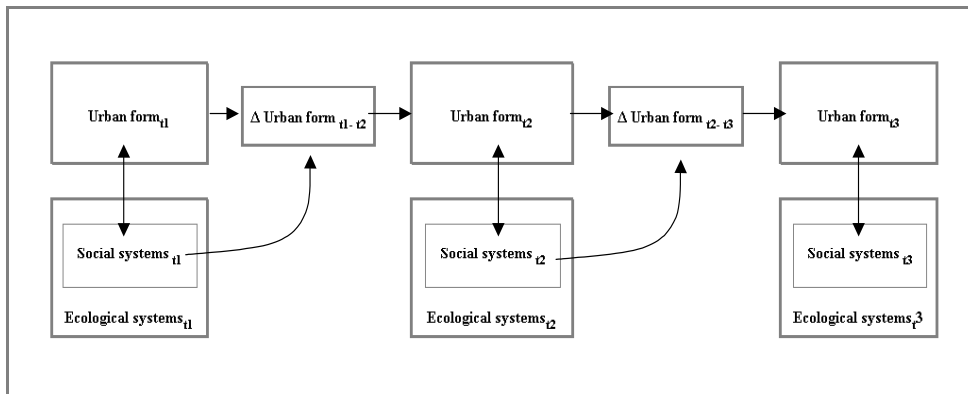


Figure 5: A comprehensive dynamic model of change in urban form.

*The material:* The material used is the national real estate tax register and digital maps from the Swedish survey organisation (Lantmäteriet). The real estate tax register contains information about the use of buildings, the year of construction, floor space, location among other things. The smallest unit in the register are the so called “value unit” representing the use of a part of a building. The residential units consist of eight sub classes, for instance: permanent dwellings for 1-2 families, recreation houses and multi family houses. The firms consist also of eight subclasses: “commercial space” (offices and services), industry among others. The digital maps depict the overall land use e.g. infrastructure, water areas and so forth.

*The method:* The value units were geocoded, divided into the time periods mentioned above and aggregated into 50\*50 pixels in IDRISI (raster GIS) with attributes as floor space and number of units for residential and commercial purposes. According to the intention to express changes in urban form a compact city index (CC) and an integrated city index (IC) were developed.

*Compact city index (CC):* Compactness used to be described in terms of residential density<sup>43</sup>, degree of sealed land combined with distance,<sup>44</sup> number of dwellings or floor space within a defined area.<sup>45</sup> The assumption here is that compactness is constituted by floor space and distance. An area around one or a number of buildings could be classified as “build up area” containing a build up density. According to the Swedish national statistical organisation a dense built up area is comprised by at least 200 inhabitants and at most a distance of 200 meters between the houses.<sup>46</sup>

The compact city index (CC) is developed according to following reasoning: If several built up areas, one by one, with low built up density are located close to each other - then should the compactness increase. Buildings with a low amount of floor space e.g. single-family houses should contribute with low density and buildings with high amount of floor space e.g. multi family houses should contribute with higher density. According to this reasoning could the compactness not be a decaying function of the distance to the building as buildings with a considerable amount of floor space then would produce

<sup>43</sup> Anderson et al. (1996, p9)

<sup>44</sup> Thinn et al. (2002, p480)

<sup>45</sup> Rietveld and Wagtendonk (2000)

<sup>46</sup>SCB (2003)

pixels with the same compactness as small recreation houses and thus making it impossible to investigate the change in compactness in the municipality. The opposite situation is however preferable: close settled building with, one by one, low amount of floor space could produce a quite high degree of compactness.

The compact city index exhibits the average density of floor space in an area (250\*250 meters) used for residential *and* commercial purposes. The areas were created by using an image-processing filter in IDRISI producing a mean value of the density floor space from the original pixel in a radius of approximately 100 meters (5\*5 pixels). The built up density unit was set to square meter floor space per hectare land (m<sup>2</sup>/ ha). If two built up areas overlapping (that is with a distance less than 200 meters between the build up pixels (or 150-250 meters between the build up objects) then are the built up density values added forming Compact City indexes, indicating that a certain amount of floor space could be reach within a distance of two pixels (100-140 meters) from the effected pixel. Thus a high amount of overlapping pixels (dense urban form) results in a high number of pixels with a higher value of Compact city index.

Thus, all pixels within a radius of 100 meters from a built up pixel forming a built up area:

$$\text{Built up density}_{x,y} = \frac{\Sigma \text{Floor space}_{x,y} (\text{m}^2)}{(250 * 250) (\text{m}^2)} * 10\,000 (\text{m}) \quad (\text{m}^2/\text{ha}) \quad (1)$$

And:

$$\text{CC}_{x,y} = \Sigma \text{Built up density}_{x,y} \quad (\text{m}^2/\text{ha}) \quad (2)$$

*Integrated city index (IC):* Anderson et.al. (1996) discuss urban integration in terms of the spatial pattern of land use<sup>47</sup> and segregation of residential land use from other land use.<sup>48</sup> Thinn N. X et. al. (2002) interprets functional compactness as “the density and daily activity”.<sup>49</sup> Urban form is defined as “a frame work of spatial relations between lands with different uses and hence are also expressions of a spatial configuration of functions”.<sup>50</sup> Ewing (1994) used jobs- housing ratio in a disaggregated analysis of exploring the relation urban form and travel behaviour.<sup>51</sup>

Integrated urban form is here assumed to consider the integration of firms and residents according to a normalized ratio of the distance of the nearest pixel containing a firm or a residential building.

Thus:

$$\text{IC}_{x,y} = \frac{\text{Distance to nearest firm} - \text{Distance to nearest residents}}{\text{Distance to nearest firm} + \text{Distance to nearest residents}} \quad (3)$$

With this definition will segregated residential areas express IC-values close to +1,

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<sup>47</sup> Anderson et.al. (1996, p9)

<sup>48</sup> Anderson et.al. (1996, p12)

<sup>49</sup> Thinn et al. (2002, p477)

<sup>50</sup>Thinn et al. (2002, p478)

<sup>51</sup> Ewing (1994) and Handy (1996, p158)

segregated workplace areas express IC-values close to -1 and integrated areas will express values close to 0. Thus, if a pixel is situated 100 meters from nearest residential pixel and 500 meters from nearest pixel containing a firm, then will the pixel obtain an IC-value of 0.7.

*Transportation city index (TC):* A number of definitions regarding the accessibility concept are given into account by Rietveld, Bruinsma (1998).<sup>52</sup> A general definition of accessibility is “the potential of opportunities for interaction”.<sup>53</sup> Here is, however, the distance from built up areas to the nearest node on national transport networks measured as the value of proximity.

*Importance of location factors and probabilities for residential settlements:* Importance of location factors and probabilities (P) regarding new urban settlements were accomplished by logistic regression analysis. The dependent variables were the construction of new residential buildings (R<sub>ix</sub>\_N1) and commercial buildings (F<sub>ix</sub>\_DN1) in 1993-1996 and 1996-2000. The value “0” indicates no new settlement and the value “1” indicates a new settlement. The predictor variables were: the distance in km to residential buildings (R<sub>t1</sub>\_D), firms (F<sub>t1</sub>\_D), public buildings (SB\_D), railway stations (STN\_D), national road nodes (TRN\_D) and water areas (WA\_D) in the previous period. Water areas are however excluded. The purpose of this analysis is to predict the value of the dependent variable according to the values of the predictor variables. 310951 cases were investigated in each period. In the period 1993-1996 were 122 pixels modified by residential settlements and 9 pixels modified by commercial settlements. In the subsequent period 1996-2000 were 92 pixels modified by residential settlements and 8 pixels modified by commercial settlements.

Thus:

$$\ln \left( \frac{P}{1 - P} \right) = \beta_0 + \beta_1 * r_{t1\_d} + \beta_2 * f_{t1\_d} + \beta_3 * sb\_d + \beta_4 * stn\_d + \beta_5 * trn\_d + \beta_6 * wa\_d. \quad (4)$$

And:

$$P = \frac{\exp(\beta_0 + \beta_1 * r_{t1\_d} + \beta_2 * f_{t1\_d} + \beta_3 * sb\_d + \beta_4 * stn\_d + \beta_5 * trn\_d + \beta_6 * wa\_d)}{1 + \exp(\beta_0 + \beta_1 * r_{t1\_d} + \beta_2 * f_{t1\_d} + \beta_3 * sb\_d + \beta_4 * stn\_d + \beta_5 * trn\_d + \beta_6 * wa\_d)} \quad (5)$$

The probability values will according to this definition exhibit values in the range of 0 – 1.

<sup>52</sup> Rietveld and Bruinsma (1998, p34)

<sup>53</sup> Rietveld and Bruinsma (1998, p33)

## ANALYSIS

### THE REGION INVESTIGATED

The municipality of Strängnäs is situated 80 km west of Stockholm. In the municipality lives (in the year of 2000) about 30 000 persons (in 1992 about 28 000) and about 2 700 workplaces are situated here. There are six small “towns” with 500 to 11 000 inhabitants situated in the area. About 35 % of the employees work in the sector of public service and about 65% in commercial firms, mainly manufacturing (18%).<sup>54</sup>

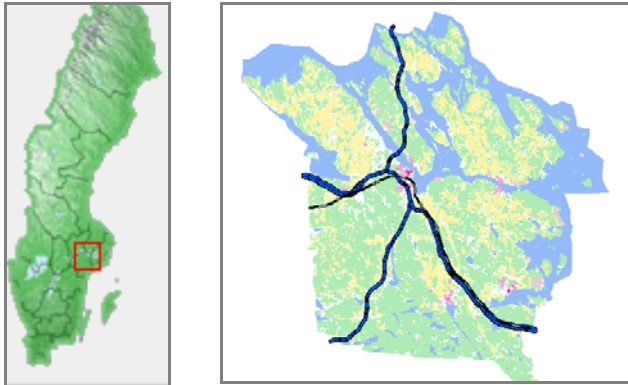


Figure 6: The geographical location of the municipality of Strängnäs, directions of the national transportations systems and land use.<sup>55</sup>

In 1997 the rail way was improved and high-speed trains were introduced to the Stockholm region. In the same year was a high way, connecting the national road system in the municipality with the high way system in the Stockholm region, constructed. The high way and the national road have approximately the same direction as the high-speed railway.

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<sup>54</sup> The Municipality of Strängnäs (2003)

<sup>55</sup> Lantmäteriet (2003)

## COMPACT CITY INDEX (CC)

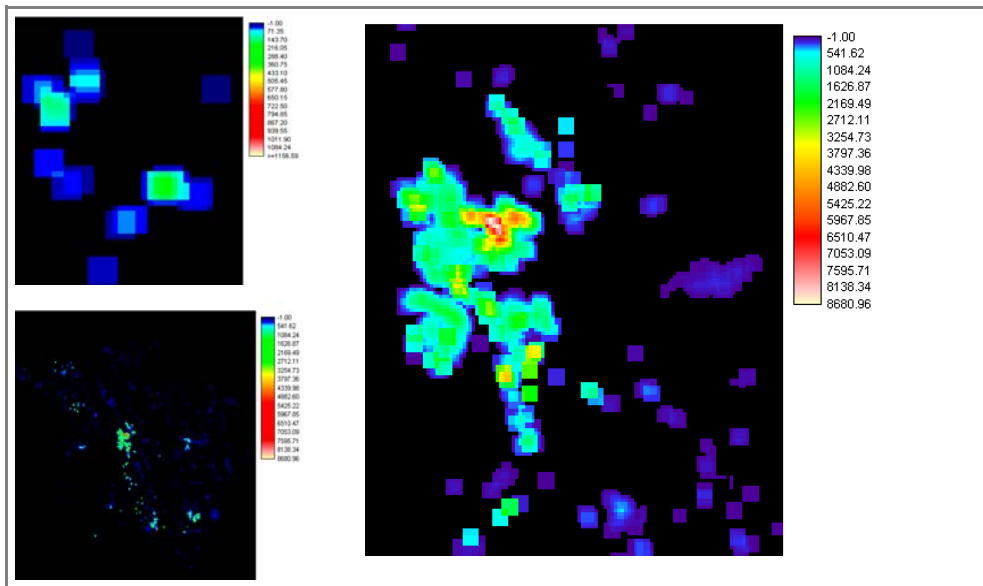


Figure 7: The images express the compact city index for all built up areas in the municipality of Strängnäs.

The upper left image presents how the individual values of compactness are added in overlapping built up areas. The right image and the lower left image show the urban form of Strängnäs town and municipality according to compactness in the year 2000. Dispersed built up areas for recreation purposes presents a mean CC-index of approximately  $80 \text{ m}^2/\text{ha}$  and the dense built up areas in central Strängnäs presents a mean CC-index of approximately  $3000 \text{ m}^2/\text{ha}$ . The overall impression is that the municipality express rather low compactness except the central part of the town Strängnäs.

## INTEGRATED CITY INDEX (IC):

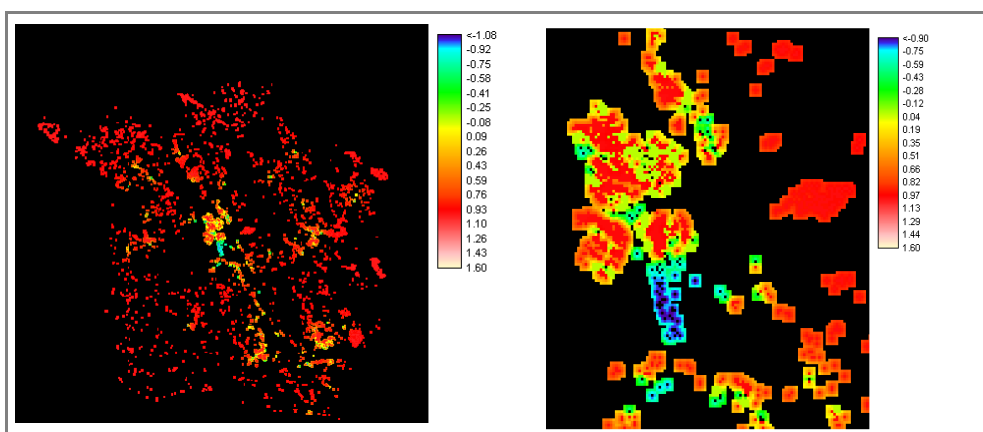


Figure 8: The images express the integrated city index for all built up areas in the municipality of Strängnäs.

Most of the areas are homogenous residential areas except some integrated areas situated in the towns. Dispersed built up areas for recreation purposes presents a mean IC-index of approximately 0.9 and the dense built up areas in central Strängnäs presents a mean IC-index of approximately 0.4. Some areas in the fringe of the towns depict a

homogenous settlement of firms (IC-index of approximately  $-0.7$ ).

**TRANSPORT CITY INDEX (TC)**

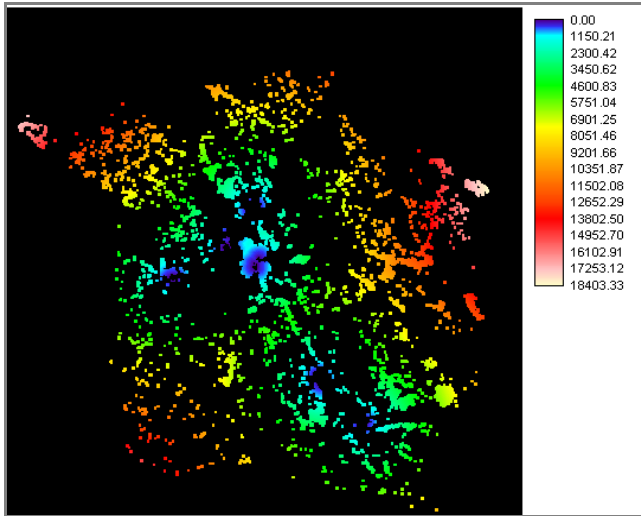


Figure 9: The image expresses the distance from a pixel containing resident or firms to nearest transport node on the national railway or road net work.

**INFLUENCE OF LOCATION FACTORS**

The  $\beta$ -coefficients in equation (5) are accomplished by logistic regression analysis. Reliable values could not be achieved regarding commercial settlements depending on the low amount of cases.

**Residential settlements in 1993-1996.**

Variables in equation (4):

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1	R92_D	-14.239	1.247	130.310	1	.000	.000
	F92_D	.011	.060	.033	1	.856	1.011
	SB_D	.085	.067	1.597	1	.206	1.088
	STN_D	-.037	.059	.392	1	.531	.963
	TRN_D	.094	.055	2.902	1	.088	1.098
	WA_D	-.591	.171	11.944	1	.001	.554
	Constant	-5.495	.261	442.866	1	.000	.004

a Variable(s) entered on step 1: R92\_D, F92\_D, SB\_D, STN\_D, TRN\_D, WA\_D.

Table 1: The distance to residential settlements in 1992, national road nodes and water areas have, to some extent, a statistical significance (within the 90% confidence interval) as location factors for residential buildings in the period 1993-1996. The attractiveness is decreasing with the distance to residential buildings and water areas and increasing with the distance to national road nodes.

## Residential settlements in 1997-2000.

Variables in equation (4):

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1	R96_D	-16.096	1.576	104.245	1	.000	.000
	F96_D	.051	.074	.477	1	.490	1.053
	SB_D	.060	.081	.562	1	.454	1.062
	STN_D	-.073	.066	1.226	1	.268	.929
	TRN_D	.063	.063	1.019	1	.313	1.065
	WA_D	-.470	.187	6.307	1	.012	.625
	Constant	-5.202	.270	372.298	1	.000	.006

a Variable(s) entered on step 1: R96\_D, F96\_D, SB\_D, STN\_D, TRN\_D, WA\_D.

Table 2: The distance to residential settlements in 1996 and water areas have a statistical significance (within the 95% confidence interval) as location factors for residential buildings in the period 1997-2000. The attractiveness is decreasing with the distance to residential buildings and water areas.

## CHANGES IN URBAN FORM

The changes in urban form are here depicted in three dimensions expressing the state values and the delta values.

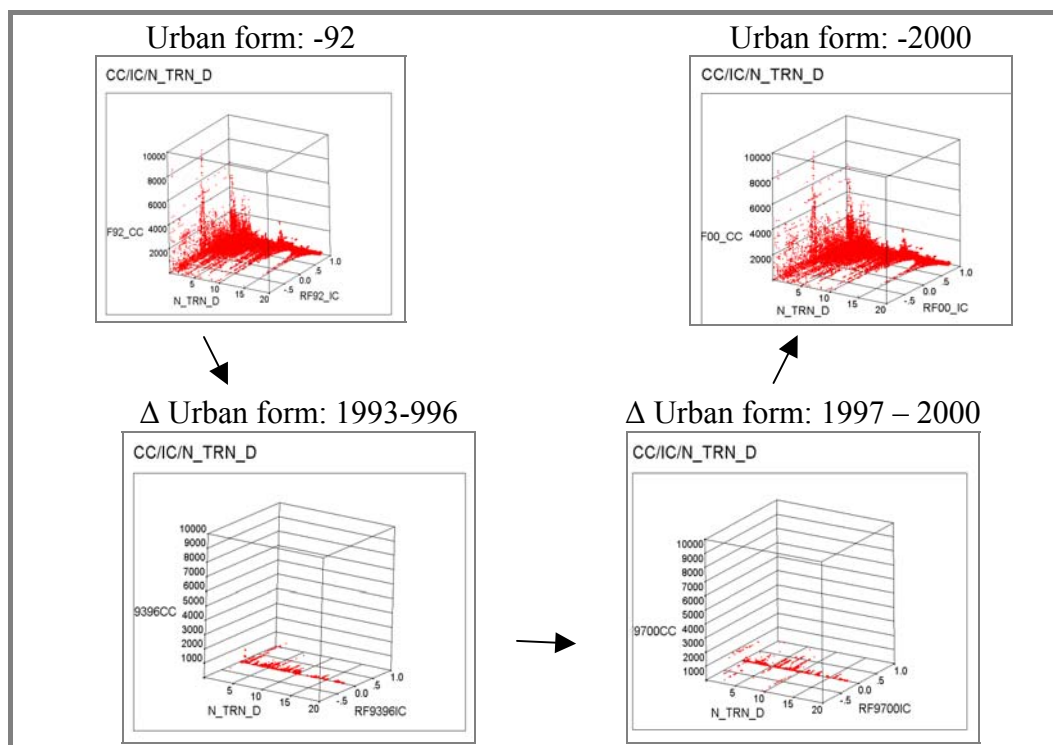


Figure 10: The 3-d diagrams presents the values of urban form: Compact city index (CC), Integrated City index (IC) and proximity to transport nodes for all pixels in the municipality in the state of 1992 and 2000 and delta values in the time periods of 1993-1996 and 1997 – 2000.

The upper diagrams, presenting the state of urban form in 1992 and 2000, express a



situation where the majority of the pixels have low values of compactness, integration values close to 1 and have decreasing values according the distance to national transport nodes. The lower diagrams presents those pixels were a change has occurred in the periods of 1993-1996 and 1997-2000.

In the first period the pixels express a modest change regarding CC-index though increasing, the IC-index are increasing and the change in urban form are almost evenly distributed regarding proximity national transport nodes. In the second period, however, some of the pixels express a change towards considerable higher values regarding the CC-index and spread containing negative values regarding the IC-index.

**Probabilities regarding residential settlements in 1993-1996 and 1997-2000**

The probability regarding new residential settlements (P(R)) in a pixel (x, y) in a period (t) is here assumed to correspond P-value in the logistic regression equation (5) in the considered period. These probabilities were calculated for each pixel with new residential settlements in the municipality in the period of 1993-1996 and 1997-2000.

Thus, in period 1993-1996:

$$P(R_{9396})_{x,y} = \frac{\exp(-5.495 - 14.239*r_{92\_d_{x,y}} + 0.094*trn\_d_{x,y} - 0.591*wa\_d_{x,y})}{1 + \exp(-5.495 - 14.239*r_{92\_d_{x,y}} + 0.094*trn\_d_{x,y} - 0.591*wa\_d_{x,y})} \quad (6)$$

And in period 1997-2000:

$$P(R_{9700})_{x,y} = \frac{\exp(-5.202 - 16.096*r_{96\_d_{x,y}} - 0.470*wa\_d_{x,y})}{1 + \exp(-5.202 - 16.096*r_{96\_d_{x,y}} - 0.470*wa\_d_{x,y})} \quad (7)$$

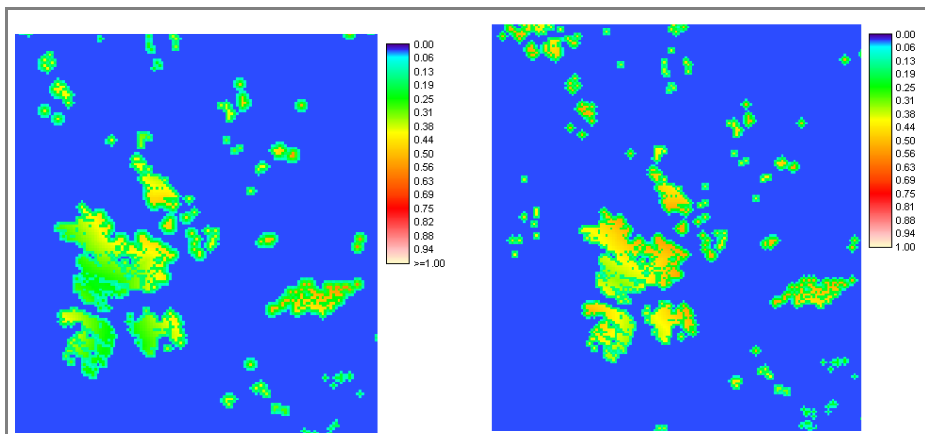


Figure 11: The left image express the spatial probabilities for residential settlements according to the development in period 1993-1996, and the right image express the spatial probabilities according to the development in period 1997-2000.

Pixels close to already existing residential settlements and water areas express high probably values in comparative terms. The probabilities in the period 1993-1996 are in a range of 0 – 1.5% regarding those pixels that have been taken into account for new residential settlements. The probabilities in the period 1997 - 2000 are in a range of 0 –

0.8% regarding those pixels that have been taken into account for new residential settlements.

**State of urban form in 1992, 1996 and 2000: Number of pixels**

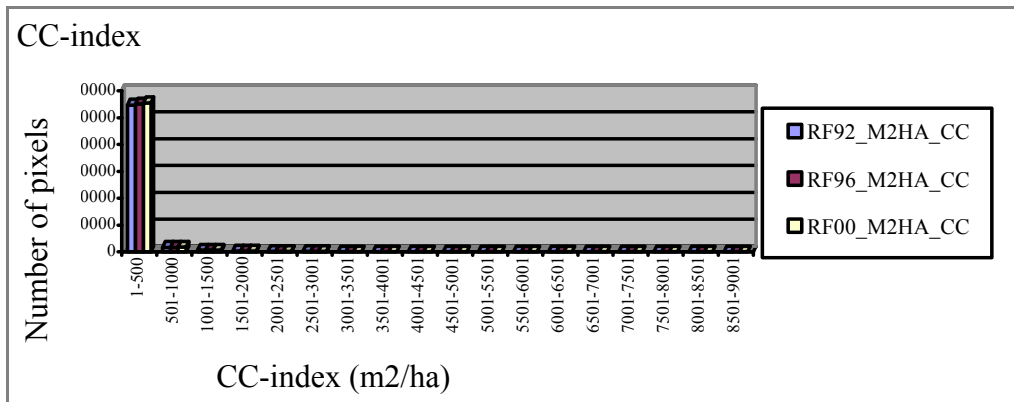


Figure 12: CC-Index in 1992 (RF92), 1996 (RF96) and 2000 (RF00). Number of pixels in intervals of 500 m<sup>2</sup>/ha. A majority of the built up pixels express a very low CC-value less than 500 m<sup>2</sup>/ha.

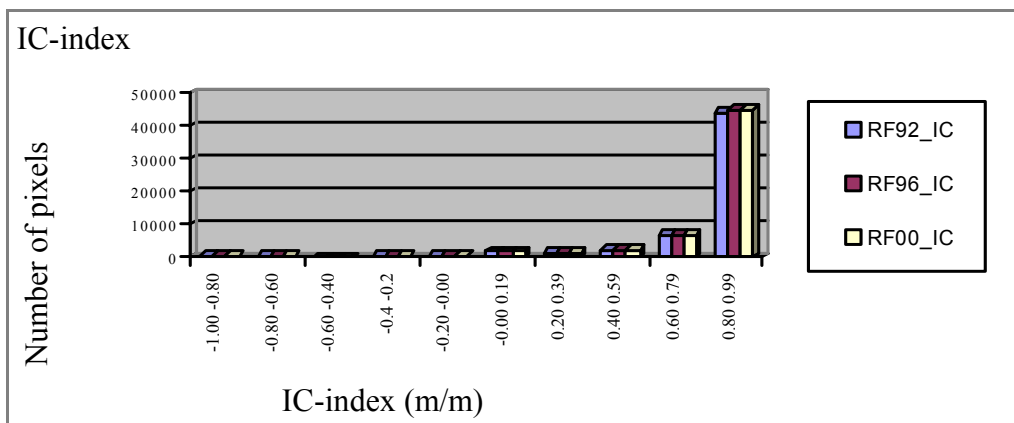


Figure 13: IC-Index in 1992 (RF92), 1996 (RF96) and 2000 (RF00). Number of pixels in intervals of 0.2 m/m. A majority of the built up pixels express an IC-value close to one indicating segregated residential areas.

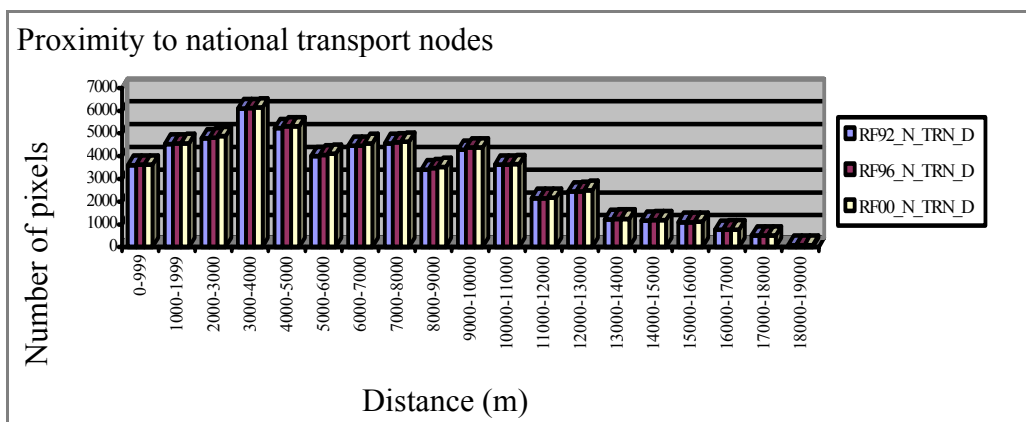


Figure 14: Proximity to national transport nodes in 1992 (RF92), 1996 (RF96) and 2000 (RF00). The number of pixels in interval of 1000 meters. The built up pixels are quite evenly distributed according to the distance to national transport nodes

## Change of urban form in 1993-1996 and 1997-2000: Number of pixels

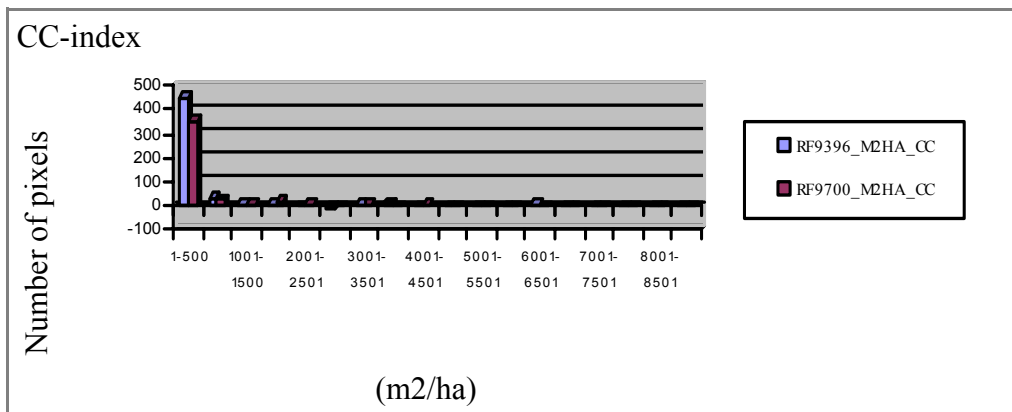


Figure 15: CC-Index in 1993-1996 (RF9396) and 1997-2000 (RF9700). In both periods the urban form has expanded with approximately 400 pixels with low compactness - less than 500 m<sup>2</sup>/ha.

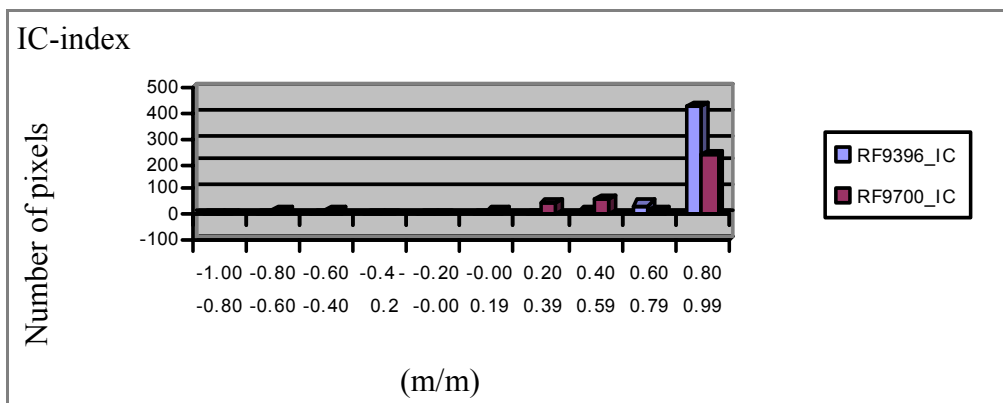


Figure 16: IC-Index in 1993-1996 (RF9396) and 1997-2000 (RF9700). In both periods the urban form has expanded with approximately 200 - 400 pixels with IC-value close to +1 - indicating segregated residential areas. In the last period have, to some extent, the amount of pixels with negative values increased, indicating segregated workplace areas.

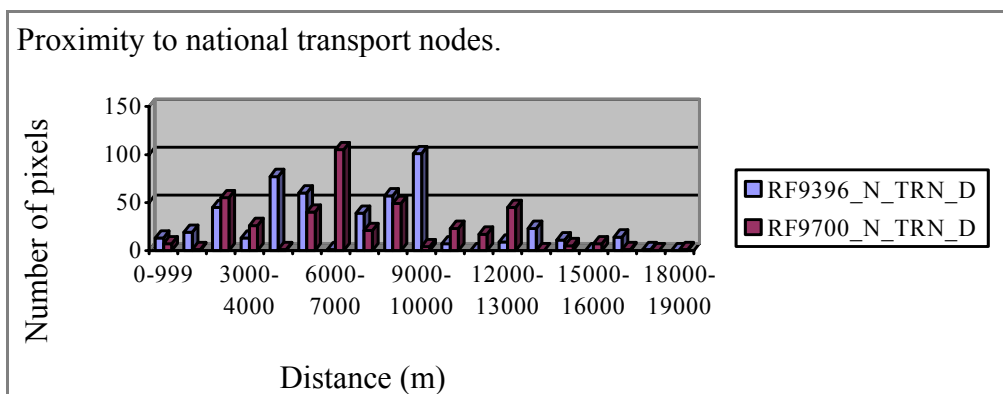


Figure 17: Proximity to transport nodes in 1993-1996 (RF9396) and 1997-2000 (RF9700). Most built up pixels in the two periods express a proximity values in the range of 1 km to 10 km distance to national transport nodes.

## RESULTS

### The change in urban form 1992-2000

The built up areas, with the definition used here, have expanded with 225 hectares (898 pixels) since 1992 (from 14 520 hectares (58083 pixels) to 14 745 hectares (58981 pixels)). 200 hectares or 88% (803 pixels) of the new built up areas express a built up density (CC-index) less than 500 m<sup>2</sup>/ha. 82 hectares or 36% (327 pixels) of the new built up areas express a built up density (CC-index) less than 60 m<sup>2</sup>/ha. 166 hectares or 74% (665 pixels) of the new built up areas express a Integrated city index in the range 0.8 – 1.0 which denotes pixels with less than 100 meters to the nearest residential pixels and with more than 500 meters to the nearest firm settlement. 214 hectares or 95% (858 pixels) of the new built up areas were located more than 2 km from nearest national transport node. The logistic regression analysis give some information within the 90% confidence interval about the location of residential settlements, but not regarding the location of commercial settlements. In both periods depends the location of residential settlement on proximity to already existing residential settlements and water areas. In the period 1993-1996 do the location, to some extent, depend on the remoteness to national road nodes. The overall most important location factor is proximity to already existing residential settlements. The probability regarding new residential settlements in a pixel with the preferable location features are, however, exceptionally low, in the range of 0-1.5% in the period 1993-1996 and 1 – 0.8% in the period 1997-2000.

### Urban form in the year 2000

The built up areas in the year 2000 covered 14 745 hectares (58981 pixels) or 27% of the area (406998 pixels) in the municipality (water areas included). 13 666 hectare (55466 pixels) or 94% of the built up area express a CC-value less than 500 m<sup>2</sup>/ha. This could be compared with residential single house areas for permanently living, which exhibit a CC-value of 1000 m<sup>2</sup>/ha, or a single dispersed house with 100-m<sup>2</sup> floor space, which set off a CC-value of 16 m<sup>2</sup>/ha. 11 234 hectare (44938 pixels) or 76% of the built up area express an IC-value more than 0.8. This could be compared with the inner part of the town Strängnäs where the pixels exhibits a mean IC-value of 0.3 which denotes 50-100 meters to the nearest residential pixel and 100 – 200 meters to the nearest pixel with commercial activities. 12 696 hectares (50787 pixels) or 86% of the built up area express a distance to national transport nodes more than 2 km.

## DISCUSSION

The changes in urban form, since 1992 to 2000 in the municipality of Strängnäs do not, according to this investigation, correspond to the political guidelines regarding compactness, integration or theories regarding attraction of location with high proximity to national transport nodes. The attractiveness regarding new residential settlements depends to a great extent on the proximity to already existing residential settlements, to some extent to proximity to water areas and to some extent on remoteness of national road nodes. The urban form develops in the direction of a decreased degree of compactness, decreased degree of functional integration and a dispersed settlement regarding proximity to national transport nodes. The development of urban form could be illuminated by the distribution of pixel values in the period:

- 94% of the modified pixels express a CC-value less than 500 m<sup>2</sup>/ha.

- 76% of the modified pixels express an IC-value more than 0.8.
- 86% of the modified pixels express a distance to national transport nodes more than 2 km.

These figures indicate a change in urban form in the direction of further dispersed and segregated low density built up areas quite far from national transport nodes. However, the urban development in the preceding period 1997-2000 express an increasing degree of compactness, integration and proximity to transport nodes compared to the former period 1993-1996.

The material used in the study does just include residential building units and commercial building units – not building units used by public organisation as schools, health care organisations, political administration and so forth. As mention above approximately 35 % of the employees are connected to these organisations in the municipality. Thus, this investigation just includes a part of the buildings that give rise to the urban form. Some other building units assumed not function as work place, for instance electric power stations, are also excluded. The results from the logistic regression analysis regarding importance of location factors concerning residential and commercial settlements are calculated from a quite low amount of cases. As mentioned above: in the period 1993-1996 were 122 pixels modified by residential settlements and 9 pixels modified by commercial settlements. In the subsequent period 1996-2000 were 92 pixels modified by residential settlements and 8 pixels modified by commercial settlements. The residential settlements do comprise a number of subclasses. The cases investigated here consist of approximately 50 % recreation houses where possibly other location preferences are significant than the location of houses for permanent use.

One could consider if the Compact City-index and the Integrated City-index measurements are informative regarding urban compactness and functional integration? The CC-index concerns the amounts of built up area, and to some extent – within 200 meters – the distance between buildings. Overlapping built up areas – where there are no buildings - obtains higher CC-values than in the actual location of the building. The integrated city index, in turn, is based on normalized ratio of simply the distance to nearest pixel with a firm or a residential building from any pixel classified as built up area. It could be preferable that an index regarding integration of firms and residential locations would include the area used for each purpose together with the distance. Some problems occur with this index in its current shape. Pixels containing, for instance a firm, get an IC-value of “-1” indicating segregation even if it is located next to a pixel with a residential building. When the IC-value is 0, then it declare that this built up area are situated at the same distance to a commercial building as well as a residential building. It does not give any information regarding the ratio of floor space used for each purpose. In the regressions analysis in both periods exhibits the location factors: distance to already existing residential settlements and water areas significance within the 90% confidence interval. In the first period also remoteness to national road nodes. Distance to railway stations and commercial settlements could not be taken into account. None of the location factors regarding commercial settlement could be achieved within the statistical 90% confidence interval. An other deficiency is the low amount of location factors investigated affecting the probability values.

However, these measures are quite easy to understand and gives actually information about urban form from a general point of view: If the built up areas contain a

considerable amount floor-space then will the image consequently present pixels with high CC-values, and even higher CC-values if the buildings are settled in a dense pattern. If an urban area is evenly scattered by firms and residential buildings, then will the image present a considerable number of pixels with IC-values in the range of  $-0.5$  to  $+0.5$ , indicating a high degree of integration. The IC-index gives information about the nearest opposite function even in cases with extensive remoteness. Lastly, the coefficients regarding location factors for new residential settlements give some information regarding the importance of the individual factor in the periods. The exceptional low value according to probabilities indicates though that these location factors investigated here do not give sufficient information regarding the cause for a settlement in a specific location. These results correspond partly to the investigation performed by Rietveld et al (2000) regarding the proximity to already existing residential settlements and water areas, but not according to the remoteness of national road nodes, where the investigation in the Netherlands exhibits a decreasing attractiveness with the remoteness. The investigation in the Netherlands covered, in contrast, geographically the entire country and a twenty-year period.

This analysis might give some information about the urban form in the municipality of Strängnäs. It is here obvious that the change in urban form does not correspond to the comprehensive political guidelines. The development seems to be governed by other forces than the expressed political. As mentioned in the introduction there are, naturally, a number of other social and ecological factors influencing the development of settlement. Further research could cover a number of areas of interest. It would be interesting to use this material to explore more exhaustive how to depict urban form both according to the features mentioned here: compactness and integration, but also to extend the analysis to cover further aspects of the urban form, for instance recreation areas, shopping, public service and so forth. Future surveys could include an extended analysis of the specific locations factors and their importance for settlement of certain urban units, for instance subclasses of firms and residents. Since the urban form could be regarded as an expression of the social system in an ecological context, it is naturally also interesting to go into these subjects according to the definition of urban interaction and urban spatial structures.

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