MEASURING COMPACTNESS OF A CITY WITH A FUNCTIONAL INDEX

Shamim Mahabubul Haque
Graduate School of Engineering, Hiroshima University
4-1, Kagamiyama 1 chome, Higashi-Hiroshima 739-8527, Japan

ABSTRACT

Traditionally, physical measures have been used to assess the compactness of cities. In this research we propose a functional index, based on the functional proximities among various land-uses of cities, to measure a city's compactness. Compactness of various land-use distributions of the study area, Higashi Hiroshima City of Japan, predicted under various experimental policy scenarios, has been compared based on the proposed functional index. Total development containment and development cost support had been the two experimental policy settings considered in this research.

Keywords: compactness, cities, physical compactness, functional compactness, land use distributions

COMPACTNESS OF THE CITIES

Historically, cities of the world began to emerge about 10,000 years ago within protective walls, constructed mainly for defense purposes, taking a compact physical form. With the emergence of modern warfare and new innovations in industrial manufacturing processes, wall-enclosed cities began to expand beyond their walls. Contemporary innovations in transportation and the availability of large amounts of useable land led to relocation of industries to city fringes. Cities began to grow, and an unprecedented process of urbanization set out and continued well into the 20th century. After the Second World War, automobile use became the most important single attribute for urban expansion. The fast growth of cities lead to congestion within older urban areas and a 'spill-over' occurred into the surrounding areas, but most importantly such 'spill-over' followed the main transportation access routes [1] this time. Widespread use of cars increased mobility dramatically, allowing rapid urban sprawl and the formation of suburbs and metropolitan villages [2] and edge cities [3]. Such outward proliferations resulted in the creation of new hubs of development within urban regions, and planners began to think about the effects of such developments within regions. Two important effects of such developments have been identified. One is the utilization of virgin land and the subsequent depletion of the world’s natural capital, and the other is development at the cost of atrophying older urban built-up lands. It has been argued, though, that such new development cannot be totally ignored given the fact that older urban limits might not have sufficient infrastructure to meet the standards being expected by young urbanites. In the backdrop of global concern about the sustainable use of natural resources, urban planners today, therefore, are urgently in need of devising suitable strategies for the spatial development of cities which will ensure both the efficient and equitable use of resources both for cities and for regions.

Recently such strategies have focused on historically-evolved notions of compactness and density of towns, factors that have enabled cities to thrive as living and built environments in the first place [4]. Historically, the very idea of ‘compactness’ evolved around the physical form of compactness, referring to increased spatial proximity of sparsely distributed built-up urban lands within a city. With the improvement of the transportation system, the mobility of both people and goods has substantially increased over last few decades, and functional proximity rather than physical proximity has now become important. Therefore, a city’s compactness now needs to be measured not in physical terms but in functional terms. The functional compactness of a city can be defined as functional proximity among different land uses within a city. Increased intensity of use, in other words, increased density, is generally the measure used for functional compactness. Traditionally in both cases —physical and functional— compactness is measured in reference to some local zones. Planning strategies to increase such local compactness, therefore, very often become unacceptable and undesirable by local inhabitants and politicians [5].

EXISTING POLICIES AND INSTRUMENTS FOR ATTAINING COMPACTNESS

Virtually all urban spatial development and redevelopment policies adopted across the globe in recent years, such as defining urban growth boundaries, re-development of brown fields and derelict urban land, densification, promoting the mixture of land uses at lot or zone levels, and downtown revitalization projects embody the aim of enhancing the compactness of cities [6] [7] [8] [9]. As far as policies directly related to transportation are concerned, the use of personal automobiles has been discouraged due to its close relationship with urban sprawl. Instead, the building of new public transit systems and locating developments close to key transportation nodes and along transportation corridors have been encouraged to attain city’s compactness. Therefore, transit oriented development (TOD) has been observed to be the key policy focus in many cities [10]. Emphasis has also been given to promoting growth in areas where sufficient infrastructure exists [11]. Land use control through zoning (urban growth boundaries) and the issuance of building permits are traditionally used as legal instruments to control urban sprawl and thereby achieve compact city objectives. But, if applied piecemeal, effectiveness of such instruments at metropolitan regional levels is not clear [12] as developers might shift the location of their intended developments outside the designated growth boundaries. Development impact fees are often imposed as a fiscal instrument by which local governments can control urban expansion. But such instruments seem to be effective only when city economies are in good shape and vibrant construction sprees are well under way in cities. At times of economic slowdown, these instruments might not deliver the desired compactness of the cities. Developers may not find already built-up urban cores or derelict urban lands suitable for development matching the infrastructure standards expected by new generations of urbanites. Besides, *brown field* sites are more costly to develop than *green field* ones, and therefore financial assistance may often be required to develop inner urban sites [13]. Developers are particularly in favor of tax breaks to bring smaller sites into use, but grant aid of some sort is also required for many larger sites [14].

EXISTING MEASURES TO ASSESS COMPACTNESS

Until recently, physical compactness of cities has been the focus of urban researchers. The very idea of “compactness” is found to be very closely linked to concepts and definitions of ‘urban growth boundaries’, ‘urban brown field areas’ or ‘urban infill areas’ —which themselves are very subjective in nature. Therefore, it has been observed [15] that the definitions of the term "compactness" have, for the most part, been blurred or merely qualitative. The percentages of sealing [4], or the percentages of built up areas within urban growth boundaries, are widely used quantitative indices used to measure urban physical compactness. Nevertheless, such quantitative measures of compactness have the considerable drawback of not recording spatial distances between individual settlement areas, and hence of not being able to mirror the varying degrees of dispersion in urban structures [16]. The lacunarity index, which measures the ‘gappiness’ of a geometric structure, has also been used to measure the physical compactness of various landscape features [17]. But the lacunarity index is a scale-dependent measure of compactness and, therefore, might turn out to be misleading if applied to the context of cities.

PROPOSED INDEX

We assume in this research that a city’s compactness can be defined by the functional proximities of residential land uses to three other fundamental land use types viz., industrial, commercial, and vacant lands, generating three fundamental activity types viz., work, shopping, and leisure, respectively. Such functional proximities can be defined as the minimum distances required for making trips from residential lots to the other three types of land lots. We used summation of averages of shortest distances from all residential lots to the nearest industrial, commercial, and vacant land lots to define our proposed functional compactness index.

RESULTS AND DISCUSSION

In this research, land use simulation was carried out for four categories viz., industrial, residential, commercial, and vacant. We used 100 m mesh data of the study area. Cost support was considered for built-up land use types only. No supporting mechanism was considered for the vacant meshes to remain vacant. Three scenarios were considered: viz., without any support (Scenario 1), with flat rate support of average construction cost (4,713 yen / m^2) of all three uses (Scenario 2), and with flat rate support of the estimated construction cost of each category (Scenario 3). To assess the effects of development containment policies, we compared the simulation results of the above-mentioned scenarios under no containment policy and under a development containment policy. In the case of the development containment policy, we did not consider spatial containment; rather, we considered total development containment. Therefore, in the case of no containment policy, any number of meshes of any of the above-mentioned categories had been allowed to be developed. While in the case of development containment, development of land uses for all the above-mentioned categories was restricted to year 2000 level. **Table 1** and **Table 2** show average minimum distances from residential meshes to the three other types of meshes under 'development containment' and 'no development containment' policy settings.

Table 1 Average minimum distances from residential meshes to three other types of uses under the development containment policy.

Cases	Avg. Min.Distance:Industrial	Avg. Min.Distance:Commercial	Avg. Min.Distance:Vacant	Compactness index
Scenario 1	659.46	401.43	196.22	1257.11
Scenario 2	659.46	401.43	196.22	1257.11
Scenario 3	645.32	352.90	202.14	1200.37

Table 2 Average minimum distances from residential meshes to three other types of uses under no development containment policy.

Cases	Avg. Min.Distance:Industrial	Avg. Min.Distance:Commercial	Avg. Min.Distance:Vacant	Compactness index
Scenario 1	703.94	498.50	196.85	1399.30
Scenario 2	740.11	559.42	220.30	1519.82
Scenario 3	694.32	451.27	205.86	1351.45

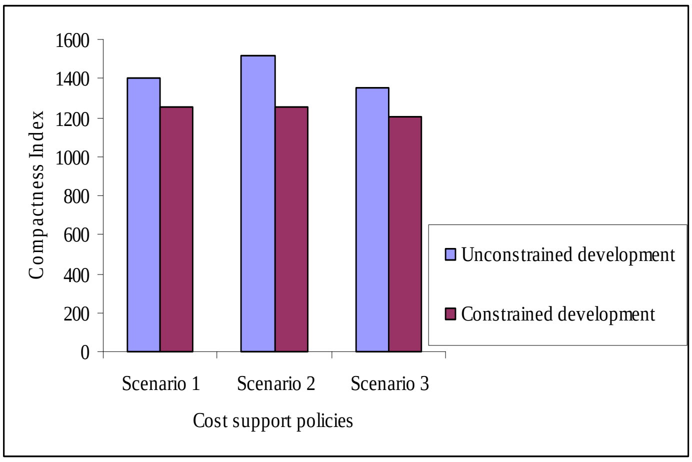

Fig. 1 Comparison of compactness indices.

Fig. 1 shows the comparison of compactness indices across three cost support scenarios under two development containment policy settings. Larger compactness index values indicate sparse distribution of land uses and therefore less accessibility of different land uses from residential use, and subsequently a less compacted urban form. It can be observed from **Fig. 1** that a development containment policy provides better functional compactness than no development containment policy in all of the three above-mentioned scenarios. However, no effect of cost support can be observed if support is provided at a flat average rate without considering land use types in the meshes under development containment policies. But if the unevenness of construction costs for different land use types (Scenario 3) is considered, and support is provided according to different estimated construction costs for different land use types, a better compactness can be achieved. The reason for this mainly involves the fact that some commercial meshes leave their remote locations and get relocated close to residential meshes. **Table 1** shows that there are no appreciable differences among Scenarios 1, 2, and 3 in cases of residential to industrial and residential to vacant mesh distances, which further clarifies the point.

As far as cost support policy is concerned, a similar trend of compactness index can be observed in the case of no development containment policy, too. But in this case, average flat rate cost support without considering land use types of the meshes (Scenario 2) increased industrial and residential development from the base case (Scenario 1), but commercial development remained the same. Therefore, the average shortest distances from all residential to both industrial and commercial cells increased, making the compactness index higher than that of the base case. But in the case of Scenario 3 where cost support was related to land use types, due to higher estimated construction cost and consequently higher support for commercial meshes, there were increases in commercial development and decreases in residential and industrial developments compared to the previous case (Scenario 2). In addition, newly developed commercial meshes were located close to major residential concentrations. As a result, average minimum distances from all residential to both industrial and commercial meshes decreased, as can be observed from **Table 2**, resulting in a lower compactness index value.

CONCLUSION

The questions as to what degree and what form of compactness are conducive to sustainable urban development both locally and regionally have yet to be answered. Actually, there is no universally accepted standard for it. In this research we emphasized functional proximities among different urban land uses. However, use of minimum distance from residence to industries relies on the assumption that people always work close to their residence, which is not always reasonable. But if we consider the fact that living near work is the most desirable option, it can be acceptable. Another lacuna of this research is that, though we have discussed functional compactness, we weighted all functional activities with similar weight. But in the real world these weights vary not only across activities but also across the heterogeneity within a particular activity type and also across the heterogeneity of the people performing those activities.

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