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Analysis of Spatial Organization and Transportation Demand in an Expanding Urban Area: Sendai, Japan, 1972–92

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The enormous expansion of global urbanization and the emergence of huge agglomerations in the latter half of the 20th century are expected to continue, especially in developing countries (Jones 1992). As urbanization has taken place, it has brought about numerous problems such as urban sprawl, water shortages, and industrial air pollution. However, cities are also the driving force behind economic growth, and as globalization has progressed, competition among cities to attract both foreign and domestic investment has become more serious. Therefore, accommodating suitable living and business environments by developing urban infrastructure is essential.

As localization has taken place in many countries of the world, the role of local governments in urban infrastructure provision has increased significantly. In this regard, establishing a legal and institutional framework of city planning and infrastructure financing within which the local government can initiate implementation of planning activities is important. Improving interjurisdictional coordination between local and central governments and strengthening partnerships with the private sector and civil societies, such as nongovernmental organizations, are also crucial issues.

Facilitating safe, clean, efficient, and well-planned urban transportation while securing financial resources is critical for urban development, because it has not only accommodated a vast increase in demand, which causes congestion, air pollution, and traffic accidents, but has also interacted with urban space and contributed to shaping cities. However, recent literature suggests that we still know little about how transportation demand increases as urban areas disperse over time or how transport facilities contribute to changing urban spatial organization (Kitamura 1996; Steiner 1994; Transportation Research Board 1995, pp. 3–4). We also need to analyze how effectively the local and central governments have dealt with urban spatial change and the increase in transportation demand in terms of policies and planning.

This study first investigates the crucial relationship between urban spatial distribution and transportation demand. The derived demand for intra-urban transportation is determined by the interaction of two distributions: the population distribution, which represents where people reside, and the activity distribution, which represents where they engage in activities. In this chapter we hypothesize that, as these two distributions disperse, people travel greater distances to engage in activities. As a result, assuming a constant trip rate per person, total transportation demand, in terms of accumulated trip distance, increases more than proportionally to population growth.

This study also analyzes how local governments in Japan provide transportation infrastructure within the framework established by the central government and how a city can begin to deal with globalization and the localization trend. The role of city planning and interjurisdictional coordination is also discussed. Following these two sets of analyses, several policy recommendations relevant to cities in developing countries are presented.

The area studied was the city of Sendai in Miyagi Prefecture, Japan. Sendai is the largest city in the Tohoku district and is its economic growth center. Sendai was chosen because it is a typical regional center city in Japan, is a manageable size, and has data available for three points in time.

Analysis of Spatial Organization and Transportation Demand in the City of Sendai

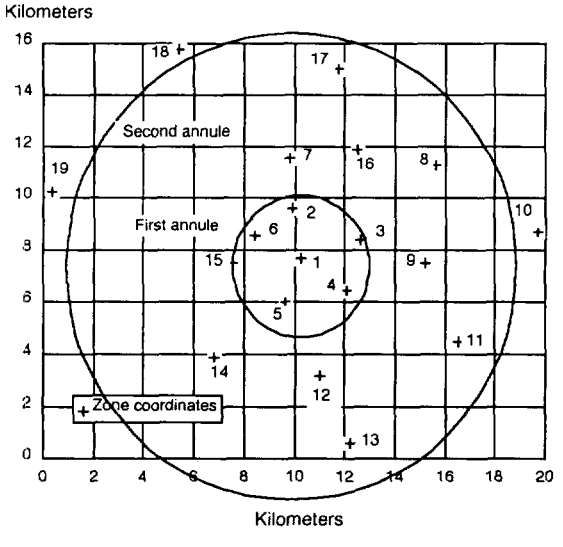
To investigate the relationship between urban spatial distribution and transportation demand and to test the hypothesis, this study extensively employed spatial descriptive statistical methods, such as density gradient analyses and centrographic methods. For a brief description of spatial statistical methods, see appendix 14.1.

Data

Repeated person trip survey data by zone in the Sendai Metropolitan Area for 1972, 1982, and 1992 were obtained from the Sendai Metropolitan Area Comprehensive Urban Transportation Planning Council. The Sendai Metropolitan Area, which consists of 5 cities, 14 towns, and 1 village, had a population of 1.4 million in 1992. The city of Sendai is the predominant urban area; 65 percent of the total area's population lives there, and the city generates about 70 percent of total trip destinations in the metropolitan area. For ease of analysis, this study focused primarily on movement within the city. Therefore, the cities, towns, and village outside the city of Sendai were excluded. The trip data were subsequently disaggregated by trip purpose, and trip-interchange matrices were constructed.

To capture general trends in changes in spatial organization, the city area was divided into 19 zones and 2 annules.[1] The first annule is the area within a 3-kilometer circumference extending from the city center that covers zones 1–6. The second annule basically covers the area between 3 kilometers and 10 kilometers, includes any boundaries of the city of Sendai that lie more than 10 kilometers from the center, and covers zones 7–19. The schematic representation of zone coordinates and the location of annules are presented in figure 14.1.

Figure 14.1. *Zone Coordinates, City of Sendai*



Source: Author.

[1] Zone 20 was not included in the study area because it is farther from the center of the city than the other zones and has only a small population (5,000 in 1992).

Change in Population Distribution

Sendai has experienced rapid development since the 1950s. To capture the relationship between population growth, urban space, and transportation demand, the change in population distribution was first analyzed. Table 14.1 shows the population change by zone in the city of Sendai. The total population increased by 30 percent from 1972 to 1982, but the percentage change declined to 15 percent from 1982 to 1992. The population in the first annule, zones 1–6, increased slightly from 1972 to 1982, then declined from 1982 to 1992. The population in zone 1, the city center, declined by 20 percent in the first period, then continued to decline from 1982 to 1992. The population in all zones in the second annule increased in both periods. In addition, the percentage of the total population in the study area within the first annule declined from 51 percent in 1972 to 33 percent in 1992, while the percentage in the second annule increased.

Table 14.1. *Population Changes, Sendai, Selected Years*

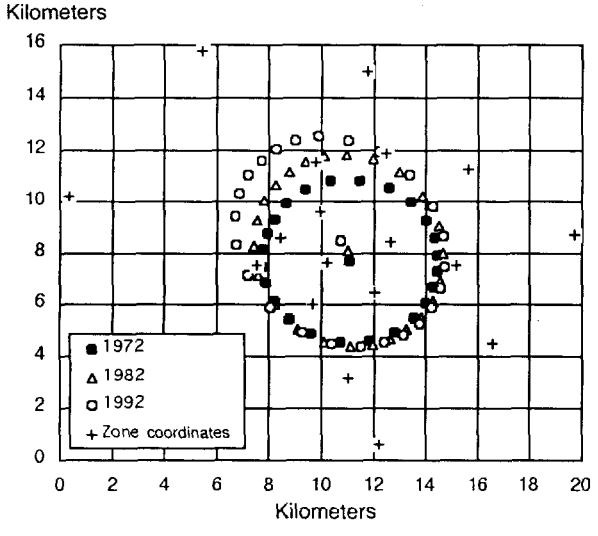
	Population (thousands)			*Change (percent)*		
Zone	*1972*	*1982*	*1992*	*1972–82*	*1982–92*	*1972–92*
1	19.3	15.5	13.1	–20	–15	–32
2	66.0	66.9	65.3	1	–2	–1
3	76.2	77.2	75.1	1	–3	–1
4	79.8	80.0	79.6	0	–1	0
5	44.2	48.7	47.1	10	–3	7
6	32.4	31.3	29.0	–3	–7	–10
1–6	317.9	319.6	309.3	1	–3	–3
Percentage of total	51	39	33			
7	33.8	56.0	57.7	66	3	71
8	34.3	46.9	49.0	37	5	43
9	11.5	16.4	20.6	43	26	79
10	18.5	27.6	37.9	49	37	105
11	25.6	43.0	46.3	68	8	81
12	47.4	51.0	61.8	8	21	30
13	20.1	33.4	41.1	66	23	104
14	44.1	71.4	81.2	62	14	84
15	12.5	15.2	17.4	22	14	39
16	20.0	33.3	37.2	67	12	86
17	15.8	49.7	65.0	215	31	311
18	8.8	26.2	68.9	198	163	683
19	16.9	25.6	42.9	51	68	154
7–19	309.0	495.8	627.1	60	26	103
Percentage of total	49	61	67			
Total	627	815.3	936.4	30	15	49

Note: Figures may not add due to rounding.
Source: Author.

To look at these demographic changes graphically, a centrographic analysis was applied. Figure 14.2 shows the change in the population density ellipse, which represents the direction and dispersion of the distribution over the period. Recognizable changes took place in centrographic measures. First, the

location of the center of population moved to the northwest in both periods: 0.4 kilometers west and 0.8 kilometers north. This is attributable to the rapid population increase in the northwestern part of the city, where large-scale residential development took place in the last two decades, such as in zones 17 and 18. As a result, the population in those zones increased significantly. Second, the standard radius and average radius increased significantly, showing substantial dispersion. Third, the coefficient of circularity became less circular and more elliptical toward the northwest. These results show clearly that, as the population increased in the city of Sendai in 1972–92, suburbanization and spatial dispersion took place. The results also imply that the distribution of residential building areas also dispersed over the period.

Figure 14.2. *Change in Population Density Ellipse, Sendai, Selected Years*



Source: Author calculations.

Change in Employment Distribution

Next, we examined employment distribution. Employment constitutes a major portion of activities in the city. Table 14.2 shows employment change by zone in Sendai between 1972 and 1992. Total employment, which includes the work of both people who live and work in the city and those who work in the city but live outside it, increased by 48 percent in the first period and by 22 percent in the second period. Unlike the population in the first annule, employment continued to grow, but some zones lost employment in the second period. In the second annule, employment increased even more rapidly than in the first annule. As a result, the share of employment in the first annule declined from 69 percent in 1972 to 56 percent in 1992. Employment in zone 9, where wholesale centers are located, increased dramatically, from 26,400 people in 1972 to 59,000 in 1982. As a result, it became the second largest employment center in the city.

Figure 14.3 shows changes in the ellipse of employment density over the period. The center of employment moved 0.3 kilometers east and 0.4 kilometers north. Compared with the shift in the center of population, the direction is somewhat skewed to the east, especially in the first period. As noted already, the rapid increase in employment in the eastern part of the city, such as in zone 9, contributed to this change in the spatial distribution of employment. Although the standard radius and average radius for the employment distribution increased over the period, they remained smaller than those of the

population distribution. These results imply that employment was more densely distributed than was population over the period.

Table 14.2. Employment Changes, Sendai, Selected Years

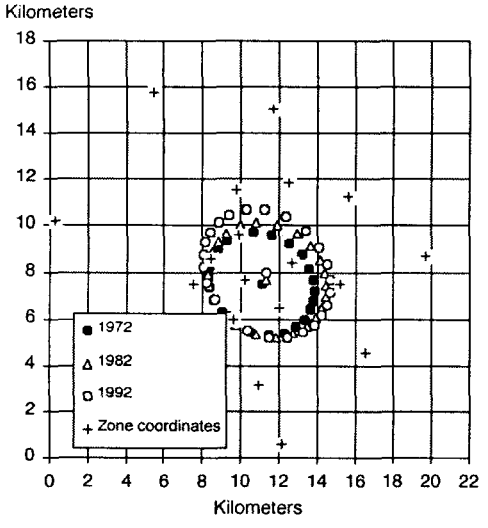
	Employment (thousands)			Change (percent)		
Zone	1972	1982	1992	1972–82	1982–92	1972–92
1	87.3	117.8	152.1	35	29	74
2	22.3	28.9	30.6	30	6	37
3	27.0	31.2	28.6	16	–8	6
4	27.4	32.9	36.5	20	11	33
5	19.1	23.5	22.7	23	–3	19
6	15.1	19.3	17.1	28	–11	13
1-6	198.1	253.7	287.6	28	13	45
Percentage of total	69	60	56			
7	3.0	5.8	8.2	93	41	173
8	3.8	7.5	9.3	97	24	145
9	26.4	59.0	72.3	123	23	174
10	4.7	11.4	18.1	143	59	285
11	6.5	11.1	14.7	71	32	126
12	16.9	19.9	24.5	18	23	45
13	4.1	7.8	8.5	90	9	107
14	5.9	10.7	12.9	81	21	119
15	4.0	7.6	6.0	90	–22	50
16	2.6	5.2	7.5	100	46	188
17	3.0	9.3	17.5	210	88	483
18	2.7	6.4	16.7	137	161	519
19	5.0	7.6	11.3	52	49	129
7–19	88.6	169.4	227.5	91	34	157
Percentage of total	31	40	44			
Total	286.7	423.1	515.1	48	22	80

Note: Figures may not add due to rounding.
Source: Author.

Change in Activity Distribution

Since people travel not only for work, but also for other purposes, such as school and shopping, capturing the distribution of all these activities is important. For this reason, the return-to-home trip was identified as a useful category. Return-to-home trips are journeys that are made by people who reside in a destination zone and engage in activities in an origin zone. The accumulated trip origin distributions of return-to-home trips over all zones can be close to the activity distribution for the entire area of the city. Furthermore, the number of return-to-home trips terminated at each destination zone is determined by the zone population; thus, the number of return-to-home trip destinations can represent the zone population. In this respect, the return-to-home trip can bridge both the population and activity place distributions. A shortcoming of using this type of trip is that only the last activity of the day will be taken into account. However, to a large extent, the trip origin distribution for return-to-home trips can represent the locations of activity fairly well.

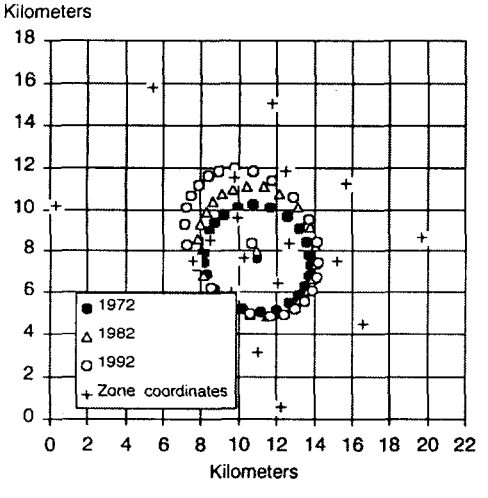
Figure 14.3. Change in Employment Density Ellipse, Sendai, Selected Years



Source: Author.

The pattern of change in the ellipse of density for the trip origin distribution of return-to-home trips shown in figure 14.4 is similar to that of the population distribution shown in figure 14.2, although the shape in figure 14.4 is slightly smaller. These results suggest that the distribution of cumulative activity is relatively close to that of population distribution.

Figure 14.4. Change in Return-to-Home Trip Density Ellipse, Sendai, Selected Years



Source: Author.

General Trends in Transportation Demand Growth

Next, general trends of changes in transportation demand in the city of Sendai were examined. The return-to-home trips represent the total trips taken in this case. Several indicators of return-to-home trips are listed in table 14.3. The total number of trips generated and terminated in the city increased proportionally to the population, by 55 percent from 1972 to 1992. The average number of trips per person, which is around 0.9, has not significantly changed in 20 years. Total trip distance, which was calculated using the distance matrix, increased by more than 100 percent, a greater increase than that seen for the population. The average distance per trip increased by about 30 percent.

Table 14.3. *Average Trip Distance and Centrographic Measures: Return-to-Home Trip, Sendai, Selected Years*

	Year			Change (percent)		
Category	*1972*	*1982*	*1992*	*1972–82*	*1982–92*	*1972–92*
Population (thousands)	627.0	815.3	936.4	30	15	49
Number of trips (thousands)	539.4	720.4	838.6	34	16	55
Trip rate[a]	0.86	0.88	0.90	3	1	4
Total trip distance (km thousands)	1,562	2,332	3,185	49	37	104
Average trip distance (km)	2.9	3.2	3.8	10	19	31
Standard radius (km)	4.6	5.2	5.7	13	10	24
Average radius (km)	3.9	4.5	5.0	15	11	28

a. The trip rate was calculated by dividing the number of trips by population.
Source: Author.

Thus, it can be said that as the population increased, the total number of trips increased linearly, and the total trip distance increased faster than the population. Because total trip distance is a measure of total transportation demand in an urban area, this is evidence to support the hypothesis that as the population increases, demand for urban transportation increases at an even greater rate.

Furthermore, the average trip distance was compared with the changes in the standard radius and average radius. Table 14.3 demonstrates that the percentage change in the standard radius between 1972 and 1992 was 24 percent, while that in the average radius was 28 percent. Both are close to the percentage change in the average trip distance, 31 percent. These results imply that as the population disperses and these centrographic measures increase, the average trip distance increases accordingly.

Because the data in table 14.3 are highly aggregated, in the next step, the average trip distances for return-to-home trips, which represent activity distribution, were calculated zone by zone. The average trip distance in the second annule was significantly greater than that in the first annule over the period. This is shown in table 14.4. These results mean that people in the second annule traveled a greater distance than people in the first annule did. Furthermore, the percentage increase in average distance for the city overall was significantly higher than that for each zone. This is attributable to the rapid increase in population of the second annule, and to this population's longer average travel distances.

Table 14.4. Average Trip Distance of Return-to-Home Trips by Destination Zone, Sendai, Selected Years

	Average trip distance (km)			Change in population (percent)		
Zone	1972	1982	1992	1972–82	1982–92	1972–92
1–6	1.9	2.1	2.3	11	10	21
7–19	3.9	4.0	4.6	3	15	18
Average	2.9	3.2	3.8	10	19	31

Note: Figures are weighted averages of respective zones.
Source: Author.

Disaggregated Data Analysis by Transportation Mode

To look at the travel patterns on a more disaggregated level, the data for return-to-home trips were broken down by transportation mode, specifically are railway, bus, car, and walking-bicycling-motorcycling. Tables 14.5 and 14.6 show the number and total trip distances of return-to-home trips by mode. Trips by car and railway contributed to the increase in the total number of trips.

Table 14.5. Number of Return-to-Home Trips by Mode, Sendai, Selected Years

Category	Total	Rail	Bus	Auto	WBM
Number of trips (thousands)					
1972	539.4	9.3	122.5	112.7	294.3
Percentage of total	100	2	23	21	55
1982	720.4	11.1	113.7	190.5	405.1
Percentage of total	100	2	16	26	56
1992	838.6	73.2	75.5	301.7	388.1
Percentage of total	100	9	9	36	46
Percent change					
1972–82	34	19	–7	69	38
1982–92	16	562	–34	58	–4
1972–92	55	686	–38	168	32
Percent change in share					
1972–82	—	0	–7	6	2
1982–92	—	7	–7	10	–10
1972–92	—	7	–14	15	–8

WBM Walking-Bicycling-Motorcycling.
Source: Author.

Car ownership in the Sendai Metropolitan Area more than doubled, from 0.18 per capita in 1972 to 0.48 per capita in 1992. This implies that the increase in automobile ownership was much greater than the increase in population. This trend brought about a significant increase in the number of trips by automobiles, up from 21 percent of the total number of trips in 1972 to 36 percent in 1992, and also in the total trip distance, up from 28 to 46 percent of the total trip distance.

Table 14.6. Total Trip Distance of Return-to-Home Trips by Mode, Sendai, Selected Years

Category	Total	Rail	Bus	Auto	WBM
Total trip distance (thousands)					
1972	1,562	60	493	444	563
Percent of total	100	4	32	28	36
1982	2,332	80	501	860	891
Percent of total	100	3	21	37	38
1992	3,185	457	325	1,452	951
Percent of total	100	14	10	46	30
Percent change					
1972–82	49	33	2	94	58
1982–92	37	471	–35	69	7
1972–92	104	661	–34	227	69
Percent change in share					
1972–82		0	–10	8	2
1982–92		11	–11	9	–8
1972–92		11	–21	17	–6

WBM Walking-Bicycling-Motorcycling.
Source: Author.

Special attention was given to the number of trips by rail, which increased more than five times between 1982 and 1992. The introduction of the subway system in 1987, which connects the northern and southern parts of the city through the city center, has contributed to this significant increase. In contrast, the number of trips by bus and walking-bicycling-motorcycling declined by 14 and 8 percent from 1972 to 1992, respectively.[2] The percentage share of these two modes also declined significantly both in the number of trips and in trip distance. These figures imply that the introduction of subway transport may not contribute to reducing car trips. In fact, one recent urban transportation problem in Sendai concerns the high population growth that has been seen in areas isolated from public transport stations. This trend has caused society to become even more dependent upon automobiles. In addition, traffic congestion at peak hours is still an obstacle of the city that is partly due to the untimely construction of road networks.

Policy Issues in City Planning and Urban Transportation Infrastructure Provision

As described in the previous section, the city of Sendai has grown significantly in the last two decades. The population increased and dispersed toward the periphery of the city. In the same period, employment and activity distributions also increased and dispersed toward the periphery of the city. As the population and number of activities increased and dispersed, the number of trips increased linearly with the population, and the average trip distance increased significantly. As a result, the total demand for urban transportation has increased more rapidly than the population has. Increases in car ownership and expansion of urbanized areas have contributed to this increase.

This section describes how the city of Sendai has provided urban transportation infrastructure to deal with the rapidly increasing transportation demand. Focal points are relevant national and local policies

[2] A trip rate might consist of several transportation modes and the mode of the trip is determined based on a priority list. Because subways are superior to buses, trips that are designated subway trips may include a considerable number of walk-bus-subway type trips.

and institutional systems, such as city planning laws and budgetary systems. The impact of globalization and localization are also described.

Urban Development History

After the Meiji Revolution, the new government established a highly centralized administrative system such that the central government controls administrative authority and revenue sources. Reflecting this characteristic of the state, city planning in Japan can be described as city planning by the state. (Watanabe 1998) This trend continued even in the 1990s.

EARLY STAGES OF DEVELOPMENT. To deal with the rapidly expanding urban sprawl in large cities such as Kyoto, Osaka, and Tokyo in the course of early industrial and urban development, the Old City Planning Law was established in 1919 as the first city planning law in Japan. The Old City Planning Law was equipped with several innovative techniques, such as land readjustment, and was implemented by the Home Ministry, the most powerful ministry in that period. The city of Sendai, which was designated a city in 1889, spontaneously prepared to be covered under this law.[3] Finally, the central government did apply it to Sendai in 1923. As a result, an urban planning area of 52.8 square kilometers, which contained 38 major urban roads, was established in 1925. However, it was never fully implemented because Japan subsequently entered a period of war.

POSTWAR PERIOD. During World War II, as a result of U.S. bombing, many Japanese cities lost their built-up areas. After the war, in 1946, the Special City Planning Law was enacted. This law was applied to more than 120 cities with an aggregate damaged area of 630 square kilometers by a special administrative office in the central government. In actual figures, 102 cities with 280 square kilometers were rebuilt under the law. In the case of Sendai, which lost 5 square kilometers of built-up area, the municipal government widened major avenues and built new parks based on the law. In addition, the city center was transformed from an old castle town into a modern central business district.

PERIOD OF RAPID ECONOMIC GROWTH. In the late 1950s and 1960s, the major agenda of Japan was rapid economic growth through industrial development. The Income Doubling Plan was formulated in the 1950s, and based on that, the First Integrated National Physical Development Plan 1960–70 was set up and approved in 1962. Within this framework, the 1962 Law for the Promotion of the Construction of New Industrial Cities was introduced. Under this law, the central government designated new industrial city districts and indicated basic construction guidelines. Prefectural governments prepared basic construction plans, and the central government approved them. Financial treatment was also legislated.

In the first plan, decentralizing the industrial bases was one of the major targets, and Sendai was recognized as a district core center in the Tohoku district. Furthermore, Sendai Bay, which includes the city of Sendai, was officially designated a new industrial city in 1964. A new port was constructed in Sendai under the five-year national port development plan, begun in 1961, and eastern industrial zones were developed.

Japan accomplished significant economic growth, but experienced a number of urban problems, such as urban sprawl, congestion, and pollution. To deal with these problems, the Ministry of Construction drafted the New City Planning Law, which was put into effect in 1969. To prevent urban sprawl and to facilitate urban infrastructure, the new law has introduced a number of planning techniques, such as the designation of urbanization promotion areas and urbanization control areas and the introduction of the land development permission system.

Based on this law, Sendai established a new city planning area, including surrounding administrative areas, of 804 square kilometers in 1970. By that time, many of the central ministries and private firms had

[3] In 1889, Sendai had a population of approximately 86,000 and 17.6 square kilometers of urbanized area.

established their bases in the Tohoku district in Sendai, and their presence contributed to a high percentage of tertiary industries. During this period, the population increased from 0.4 million in 1955 to 0.6 million in 1970.

During the 1970s and 1980s, Sendai continued to play its role as the regional center of the Tohoku region, as stated in subsequent integrated national physical development plans. Economic growth of the city continued, and the urban area expanded to the periphery of the city. The bullet train and the Tohoku expressway, which connect to the Tokyo Metropolitan Area, were opened in 1982 and 1986, respectively, reinforcing the link with Tokyo. As the population continued to increase rapidly, both the public and private sectors significantly increased their involvement in real estate development, and several new residential areas, such as Izumi Park Town, located in zone 18, emerged. However, because road construction could not catch up with the rapid increase in both population and the number of automobiles, traffic congestion continued to be the major problem of the city. Incoherent urban development with respect to transportation planning was also observed.

To deal with urban problems in large cities such as Kyoto, Nagoya, and Osaka, the central government introduced the ordinance designated city system in 1956. An ordinance-designated city is a city with a population of roughly 1 million that the Diet has given special status. This status includes functions the prefectures normally perform, such as part of city planning approval and establishment of wards within the city government. This system does not fully satisfy municipal governments, because autonomy from the prefectural governments remains limited, but it still attracts candidate cities in Japan.

The target of the city government of Sendai in the 1980s was to become an ordinance-designated city. To achieve the relevant conditions, in 1987 and 1988 the city annexed the surrounding towns and a city, and its administrative area grew to 788 square kilometers. As a result, the population of the city increased by 172,000 people to approximately 0.9 million in 1988. In 1989, the city of Sendai became the 11th ordinance designated city in Japan[4].

Sendai's city planning and related policies were implemented within the framework set by the national government. The national government identified the role of the city and also prepared implementation schemes. Japan can be said to have implemented centrally controlled national urban policies, which contributed to the development of regional center cities. Policies promoting decentralization were also observed under the guidance of the central government such as the ordinance designated city system, but this trend was still limited until recently.

Transportation Infrastructure Provision and Financing

As described previously, transportation demand increased rapidly during the high economic growth period in Sendai. To deal with this increase in demand, the city government has taken a series of measures within the framework of city planning. Like the city planning practice, transportation infrastructure planning and financing also take place based on the central governmental system.

COMPREHENSIVE URBAN TRANSPORTATION PLANNING. In Japan, person trip surveys have been conducted in major cities every 10 years. This work has been done by the local Comprehensive Urban Transportation Planning Council under the guidance of the Ministry of Construction since the 1970s. Based on these surveys, metropolitan area comprehensive urban transportation plans are formulated and individual urban transportation projects are identified and prioritized. These plans are eventually designated city planning projects within the framework of the city master plans through the city planning authorization process.

[4] The 12 ordinance designated cities are Chiba, Fukuoka, Hiroshima, Kawasaki, Kitakyushu, Kobe, Kyoto, Nagoya, Osaka, Sapporo, Sendai, and Yokohama. At least four more cities and regions are seeking to become ordinance designated cities.

The first person trip survey for the Sendai Metropolitan Area was conducted in 1972–74 for a comprehensive urban transportation plan. Based on the survey, Sendai's metropolitan area comprehensive urban transportation plan was formulated. Ten years later, in 1982–84, a second person trip study was conducted, partly to aid in subway construction planning. The third person trip survey was conducted in 1992–94. Based on that study, a new metropolitan area comprehensive urban transportation plan was announced to the public in 1996. The target of this plan is to realize a multinuclear metropolitan area type in which several urban centers are interconnected by transportation networks. To reduce automobile dependency, reinforcement of public transportation and introduction of transportation demand management are parts of the plan. One of the difficulties of implementing this plan is that land use controls are not strict enough to restrict residential development in areas isolated from public transport stations.

URBAN ROAD DEVELOPMENT. Road infrastructure is key to facilitating smooth urban transportation. Road development is included in the city master plan. Major road networks are designated urban facilities within the city planning framework. The first designation of a city planning road network in Sendai took place in 1927. Since then, the road network plan has been revised as the city developed. A major revision was made in 1966, which encompassed 76 planned road projects covering 284 kilometers, of which 11.5 percent was completed. By 1996, the city's planned roads had expanded to 504 kilometers with 140 lines, of which 53 percent (267 kilometers) were completed.

For financing, a national standard applies to Japanese cities. Roads are classified as national and local roads, and both central and local governments use the road development special account and general account for road development. The revenues come from the earmarked gasoline tax, oil and gas taxes, national auto-weight tax, local road transfer tax, oil and gas transfer taxes, light gas transaction tax, and automobile sales tax.

In Sendai, the road-related budget increased from ¥ 10 billion in 1980 to ¥ 60 billion in 1993, then decreased slightly to ¥ 54.6 billion in 1998. This trend reflects the rapid increase in transportation demand, especially in automobile transportation, in Sendai. As in cities of other regions, one of the main problems of urban road construction is the difficulty and high cost of land acquisition. Once the built environment is established, persuading residents along the roads to resettle is difficult, especially those who have commercial activities such as shops. This problem was attributable to the untimely provision of roads in Sendai described previously.

PUBLIC TRANSPORTATION. To mitigate urban congestion and improve the urban environment, introducing a public transportation system is essential. The major issue here is the enormously high construction cost, especially for urban rails.

In Japan, railway operators are largely responsible for funding their own improvement costs. However, because revenues from railways are seldom sufficient to fully cover the high initial costs of major railway infrastructure investments, some additional financial resources are often necessary. These include public subsidies, value capture from nonrailway user beneficiaries, and cross-subsidization of railway operators with revenues from nonrailway services. In addition to these financial resources, the central government provides public subsidies in the form of the subsidy for construction of a public subway, the subsidy for construction of a public new town railway, the subsidy for construction of a railway constructed by the Japan Railway Construction public corporations, low-interest loans from the Japan Development Bank, and other subsidy systems (Overseas Economic Cooperation Fund 1998).

The subsidy for construction of a public subway was first introduced in 1962. Several revisions have been made to increase its level of support, because the construction cost of a subway is extremely high (¥ 20 billion to ¥ 30 billion per kilometer). The current scheme is to subsidize 35 percent of the construction cost (not the entire project cost) through the central government and another 35 percent through the local government's general budget. Equity financing by the local government covers another 20 percent. The

local government can also provide financing by issuing municipality bonds with the approval of the Ministry of Home Affairs.

In Sendai, the city government introduced streetcars in 1926 to facilitate public transportation. The demand for streetcars reached a peak in the early 1950s. With the rapid increase in the number of automobiles, streetcars were finally abandoned in 1976. Bus transportation substituted for streetcars, but ridership of the public bus system has continued to decline. To accommodate the rapid increase in urban transportation demand, the construction of a new 13.6-kilometer south-north subway line was approved in 1981 and completed in 1987. In 1992, the subway was extended to 14.8 kilometers.

The construction cost of the subway was ¥ 235 billion (about US$2 billion) for the first stage alone, and additional spending was required for the subsequent expansion. The subsidy for construction of a public subway was also applied in this case. In addition, based on local decrees, the city government established the rapid rail transit construction fund in 1980. It was established based on the previous experience of Fukuoka and Kitakyushu. In this scheme, the fund's resources comprise half the excess tax from the corporation tax and half the business establishment tax. The local allocation tax from the central government subsidizes 60 percent of the interest payments and repayment of local government bonds for equity financing, while the rapid rail transit construction fund finances the remaining 40 percent.

Despite such a subsidy system, the subway has operated at a deficit every year, although the number of passengers increased from 50.8 million in fiscal year 1990 to 60.0 million in fiscal year 1996. Annual expenditure is around ¥ 23 billion to ¥ 24 billion, while profit was around ¥ 12 billion to ¥ 13 billion in fiscal years 1991-1996. The deficit is about the same amount of the profit every year. The debt was approximately ¥ 145 billion in the public enterprise account and ¥ 35 billion in the ordinary account at the end of fiscal year 1996. Apparently, the subway is a big financial burden for the city.

As described here, infrastructure financing is also part of the national framework. This system has significantly contributed to transportation infrastructure development in Sendai. However, the local government has less flexibility in such financial arrangements. For example, the subsidy for subway construction only applies to public entities, not to private ones that provide subway construction and services. Given the fact that urban public transportation still needs support from outside, the financing scheme must be more innovative and flexible.

Recent Trend: Impact of Globalization and Localization on Urban Transportation

In the 1990s, Japan transformed its social and economic systems in accordance with globalization and localization. In national urban policy, the New City Planning Law was revised in 1992 to promote more participation by the people. Based on the 1992 revision, a city master plan is required for all municipalities, and public participation and involvement processes are also required in the approval process.

The city of Sendai formulated a comprehensive city plan, the Sendai 21 Plan, in 1998. The plan targets the year 2010 and consists of many policy goals concerning social welfare, environment, education, and urban development, which includes transportation. Interestingly, the city recognizes the globalization and localization trend and identifies itself as not only as the center of the Tohoku region in collaboration with other prefectures and cities, but also as the gateway of the region. The latter vision goes far beyond the historical role of the city, in which it acts as the central branch of the Tohoku region for the central government or the Tokyo Metropolitan Region.

Urban infrastructure plays an important role in supporting the gateway function of the city. The port continues to expand its capacities and Sendai International Airport has also been expanded. Both facilities were designated foreign access zones under the Law on Extraordinary Measures for the Promotion of Imports and Facilitation of Foreign Direct Investment, enacted in 1992. Several facilities, for example a trade center, have been constructed under this scheme. However, this kind of central

government–initiated project seems to not be as effective any more. As yet, no foreign enterprises have planned to locate in the foreign access zone in Sendai.

To improve access to these interurban transportation facilities, several urban transportation projects, such as access roads to the port and access railways, were planned and are partly under construction. In this case, one of the main issues is cost sharing of the projects. For example, the 7.5-kilometer access railway costs approximately ¥38 billion and will be constructed and operated by a third sector company consisting of the Miyagi Prefecture; the cities of Iwanuma, Natori, and Sendai; and the East Japan Railway Company. After intense negotiations, these parties finally agreed to share the financial burden.

Despite these plans and efforts for Sendai, Kidokoro (1998) rightly pointed out that most foreign--affiliated companies are located in the Tokyo Metropolitan Area. Most likely, those companies establish their branch offices in Sendai to cover the Tohoku district, but overall few foreign direct investments were introduced in Sendai. On these terms, the impact of globalization has not been significant to date in Sendai; the situation remains basically the same as 10 years ago. However, as the case of Sendai shows, Japan's local governments recognize the importance of the trends of globalization and localization. For example, Hiroshima's municipal government has made an effort to promote foreign direct investment in Hiroshima's industrial estate.

Regarding localization, several interesting trends have been observed. The comprehensive city plan targets public transportation development together with traffic demand management. The city of Sendai's municipal government announced a proposed new public transportation system, a 14-kilometer east-west line, in 1998. This line would connect the eastern area of the city to the western area, where academic and cultural facilities such as Tohoku University and the zoo are located. The city's municipal government has also considered an underground, linear, motorcar system, but a citizens' group proposed introduction of a light rail transit system so that the line could connect directly with other railway lines in the future. The group has advocated its idea using the Internet. In fact, a dialogue has been ongoing between the city government and the citizens' group. Some financing issues exist. The city purports that, together with land readjustment projects in the eastern area, the line could feasibly be constructed. Based on experience from the north-south line, the new line is not likely to be profitable and would need subsidies from the city. The outcome is a matter of the values of the people of Sendai, and whether they are willing to pay for public transportation or will continue to rely on automobiles.

Conclusion and Policy Implications

This study's results provide strong evidence that urban transportation demand increases more rapidly than the population growth. In addition, this study shows that transportation demand is greater in the periphery of a city than it is in the center area in terms of average trip distance. These findings suggest that in growing cities in developing countries, especially in their urban peripheries, enormously rapid increases in urban transportation demand can be expected as the urban population increases. In cities with rapid economic growth, the overall trends are likely to follow the pattern of Sendai (Kidokoro and Hanh 1993). These expectations have strong policy implications for large cities in developing countries, including large funding requirements, effective and comprehensive planning, and interjurisdictional coordination in the building of urban infrastructure. In the 21st century, however, local governments also need to deal with the impacts of globalization and localization on the spatial organization of cities and urban transportation demand.

Timely Provision of Transportation Infrastructure

As seen in this study, urban spatial distribution continues to disperse. As a result, the average trip distance of people who reside in the city periphery is longer than that of people in the central area. To reduce transportation demand, gasoline consumption, and vehicle emissions, some researchers advocate

creating a high-density city by reurbanizing an existing city or developing multicenter cities (see Steiner 1994 for more detail). However, as the case of Sendai has demonstrated, a policy is unlikely to reverse the dispersion of urban space nor are people who reside in the subcenters likely to travel less than those who reside in the center of the city. Thus, as demand for transportation increases rapidly in cities in developing countries such as Hanoi and Ho Chi Minh City in Vietnam, facilitating road or rail infrastructure to connect the outer link with the center city or link roads in advance is important. The key is to guide urbanization, rather than reverse the trend.

Establishing Effective, Integrated Land Use Transportation Planning

The case of Sendai shows that transportation infrastructure provision such as roads and subways have been unable to keep up with the rapid increase in traffic demand since the 1950s. In central business districts, the road system is well developed as a result of reconstruction. However, bottlenecks exist between the outer link of the city and the city center. These conditions imply that the land use plan and transportation plan were not well coordinated. Actually, land and housing development, mainly by the private sector in the outer link, came first, and road development came later after a long time lag. Sendai's experience demonstrates that during the rapid development of cities, implementing a sound and integrated urban transportation plan is essential, especially when incorporating the urban land use plan with the outer link of the cities or future suburban areas.

The necessity of this type of planning has been recognized for a long time, but has not yet been practiced broadly. Researchers have identified a number of difficulties in developing countries, such as the lack of legislation on land use planning and the pervasiveness of weak and reluctant agencies (Miyamoto and Udomsri 1994). With this in mind, strengthening the planning institutions and the legal framework must also occur. In addition, noting that the effectiveness of such plans depends heavily on the economic and demographic focus is important. If a city has a strong intention to expand, all these factors could affect the economic and demographic focus. Thus, having realistic figures for the near future is essential for appropriate planning.

Securing Financial Resources

Securing financial resources for urban transportation infrastructure provision is essential (World Bank 1994, 1996). Introduction of a pay for use principle, such as that of Japan's Road Development Special Account, might be appropriate for large cities in developing countries. Establishing an urban transit construction fund may also be a way to even the financial burden. Recent research on urban transportation improvement measures in Vietnam shows that Hanoi and Ho Chi Minh City need to make large transportation investments in the next few decades to catch up with rapid motorization. The major issues are insufficient budgets for road development at both the national and city levels, inadequate charges to road users for recovering the cost of road development, and imbalance in the financial assignment of the road budget between the central and city governments. Some of Japan's innovations in this area, such as establishing a national special account for road development, broadening the tax base to include an automobile weight tax for both national and city governments, introducing a city-level development fund, and using an effective intergovernmental transfer system, might also be appropriate for these other cities. In addition, financial arrangements must be flexible and subsidies for private operators considered, so that limiting the operators to public enterprises is not necessary.

National Urban and Regional Policy

Japan has been implementing centrally controlled national urban policies, which have contributed to the development of regional center cities such as Sendai. Local governments have implemented city planning

and related policies within the framework set by the national government. However, the autonomy of local governments is relatively limited in terms of planning and financial systems. During rapid economic development, such a model might be appropriate for developing countries to expand their regional growth centers, so that more concentration in primary cities could be avoided (Jones and Koné 1996). With respect to national urban and regional policies, Japan's integrated national physical development plans provide valuable examples.

Toward Globalization and Localization

In the rapid economic growth period, the central government initiated economic development of Sendai as the regional center of the Tohoku region, which was heavily dependent on the central government or Tokyo Metropolitan Region. The situation today is basically the same. However, as Sendai shows, Japan's local governments now recognize the importance of the trends established in that period. Globalization and localization have taken place simultaneously, and both capital cities and regional centers need to deal with their implications. So far, the actual impact of globalization on Sendai has been small compared with the effects on Tokyo, but in the long run, such regional center cities, even those in the developing countries, will be affected. The role of the central government might be to support local governments to respond spontaneously to these trends.

Appendix 14.1. Spatial Statistical Methods

Some basic literature concerning spatial statistical methods and their applications to urban transportation demand analyses are reviewed here.

Density Gradient Analyses

Clark (1951) examined the current and historical population density patterns of several major cities in different countries. He found that (a) the negative exponential function fits the urban density patterns in those cities quite well, and (b) the slopes of the functions tend to decline over time, while the expected densities at the center of the cities either increase or decrease over time. Clark's negative exponential density gradient function is expressed as:

$$D(u) = A\, e^{-bu}$$

where u is the distance from the center of the city, $D(u)$ is the density of the residential population, b is the rate of decline of density (which could be called the density gradient parameter), and A is the density at the center (which could be called the central density parameter). A is hypothetical because the center of the city is occupied by business activities and has a less dense residential population, but it is still useful for approximating the population density of inner cities. Figure A14.1 shows the schematic graph of density gradients.

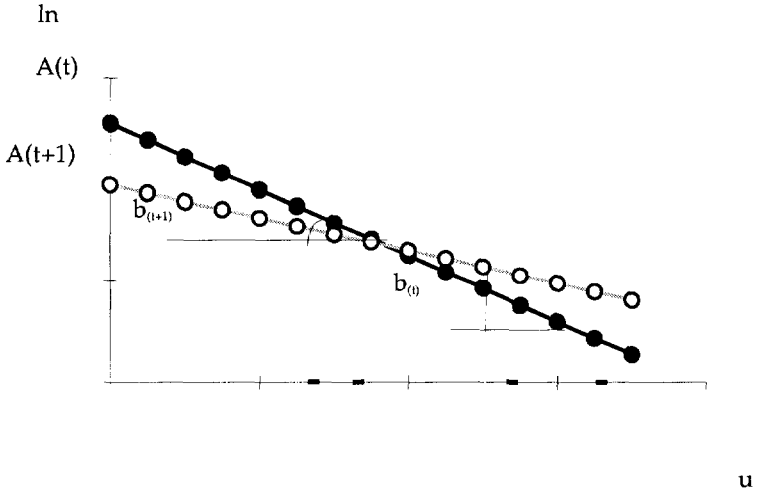
Using data for Wichita-Sedgwick County, Kansas, Jones and others (1987) and Patel (1991) discovered that the density gradients of both residential and nonresidential buildings, in terms of the number of buildings per square mile by annule and the density gradient of surface infrastructure, such as highways and roads, in terms of area per square mile by annule, are similar to that of the population density, both of which conform to the negative exponential function.

Akimoto, Harada, and Ohta (1990, 1992) applied a density gradient function to the commuting flow in the Tokyo Metropolitan Area. The authors created a commuting trip generation density gradient function. Given a commuting trip destination zone j, the commuting trip generation density gradient function is defined as follows:

$$D(u_{ij})=Ae^{-buij}$$

where u_{ij} is the straight distance from the commuting trip destination zone j to the respective origin zone i. $D(u_{ij})$ is the commuting trip generation density of zone i given the trip destination zone j; A is the central commuting trip density parameter; and b is the commuting trip density gradient parameter.

Figure A14.1. *Density Gradient Measures*



A(t) = density at city center at time t
A(t + 1) = density at city center at time t + 1
b(t) = density gradient parameter at time t
b(t + 1) = density gradient parameter at time t + 1
u = distance from city center
Source: Author.

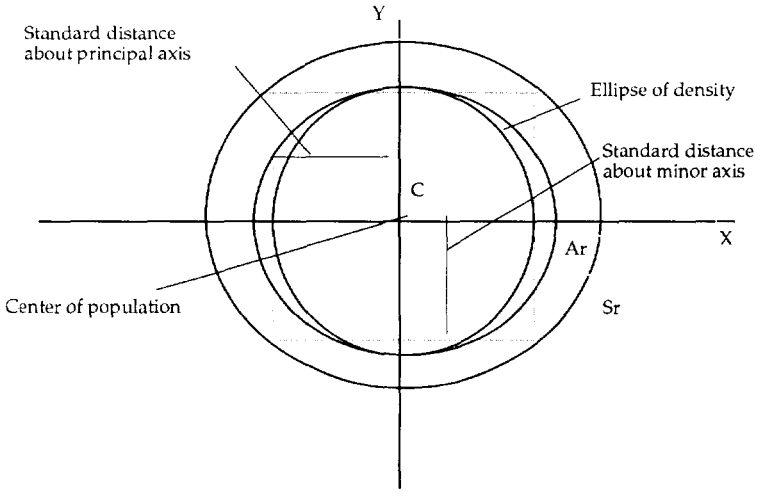
The commuting trip generation density for the origin zone i is obtained by dividing the number of commuting trips to the destination zone by the square kilometer of the origin zone. Akimoto, Harada, and Ohta (1990, 1992) made a number of findings: (a) Clark's density function generally provides a good fit for the commuting trip generation density for zones with a density of more than 500 people per square kilometer, (b) the density function generally explains the trend of where to live, and (c) time distance is statistically superior to straight distance.

Centrographic Methods

In the field of geography and planning, descriptive measures of space are commonly used to study spatial distributions. Among other concepts, centrographic methods, also known as spatial statistics or geostatistics, are extremely useful for observing changes in spatial distributions over time or comparing different distributions. The essential characteristics of spatial distributions—location, dispersion, and shape—can be coherently examined by these measures.

Centrographic measures are graphically shown in figure A14.2. Brief descriptions of each measure follow (Jones 1980).

Figure A14.2. Centrographic Measures



Ar Average distance of observations' distance from the center.
Sr Square root of the mean of the sum of squared distances of the observations
Source: Author.

To measure the location of the spatial distribution, the center of gravity, or center of population, is calculated. To measure concentration or dispersion of distribution, the concept of average radius and standard radius are introduced. Average radius, *Ar*, is the average distance of the observations from the center of population, while standard radius, *Sr*, is the square root of the mean of the sum of squared distances of the observations, which is equivalent to the radius of gyration of an area in mechanics.

To measure the shapes of spatial distributions, the concept the density ellipse is introduced. First, the principal axis is obtained in such a way that the root-mean-second-moment, or standard distance, of the distribution is minimized with respect to that axis. The cross axis through the center is called the minor axis. The ellipse with respect to these axes is obtained using the corresponding standard distances. The ellipse of density contains information about the direction and dispersion of the distribution. In addition, the ratio of the standard distances about the principal axis and the minor axis is called the coefficient of circularity. If the coefficient of circularity is equal to 1.0, the shape of the ellipse is circular.

Zahavi (1979) and Zahavi, Beckmann, and Golob (1981) developed the unified mechanism of travel approach as an alternative approach to modeling interactions between travel and urban structure. As part of the analysis, Zahavi introduced the centrographic methods to capture the travel destination distribution. He called it "the travel probability field" and defined it as the area that is covered by the ellipse of density with respect to the center of travel destination distribution. By applying this concept to Nuremberg and Washington, D.C., he found (a) the direction of travel probability fields tends toward the central business district; (b) the centroid distance, which is the distance between the household centroid and the activity site centroid, and the standard distance of destinations tend to increase as both the distance from the central business district and income increase; (c) automobile travel fields tend to be larger and more elongated than transit travel fields; and (d) the direction of the travel field is affected by the available system supply. To date, no other attempt has been made to apply centrographic methods to urban transportation demand analysis.

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